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Ririe Dam Release Test Assessment

Steven F. Daly, Meredith Carr, Stephen Hall, and
Jeremy Giovando

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Ririe Dam Release Test Assessment

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Final Report

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Abstract

To potentially increase storage over the winter season, the US Army Corps of Engineers (Corps) Walla Walla District (NWW) is currently evaluating flood control operations at Ririe Reservoir. Because there is little experience with winter releases and a previous winter release resulted in minor flooding, it is important to understand the potential problems associated with releases in these conditions. Therefore, the Corps conducted a Release Test on 10–13 February 2013. Throughout the test, instruments took detailed measurements of the water temperature, stage, and discharge along the Willow Creek channel; and personnel observed the dynamic ice conditions.

The test included an initial release of 150 cfs for 28 hr; a rapid increase to 300 cfs, which was held for 14.5 hr; and another rapid increase to 500 cfs, which was held for 24 hr. The flow was then shut off. Neither the Initial Release Wave nor subsequent flow significantly removed, dislodged, or eroded snow in the channel; the snow melted only after a thermal melt-out front advanced downstream. No out-of-bank flooding occurred.

As a result of the information gathered from this Release Test and from one in 2011, this report presents a series of recommendations for future wintertime releases.

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Preface

This study was conducted for the Walla Walla District of the Corps of Engineers.

The work was performed by Dr. Steven F. Daly and Dr. Meredith Carr (Remote Sensing/GIS and Water Resources Branch, Timothy Pangburn, Chief), US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL); and Stephen Hall and Jeremy Giovando, Walla Walla District, US Army Corps of Engineers.

At the time of publication, Dr. Justin Berman was Chief of the Research and Engineering Division of ERDC-CRREL, the Deputy Director was Dr. Lance Hansen, and the Director was Dr. Robert Davis. COL Kevin J. Wilson was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Keith Brooks and Michael W. Beus of the Bureau of Reclamation, Peter Cooper of the Idaho Department of Water Resources, and USGS-Idaho Falls Field Office contributed to this study.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters

Executive Summary

A Release Test consisting of three days of outflows from Ririe Dam into Willow Creek was conducted 10–13 February 2013. The flow out of Ririe Dam prior to the Release Test was zero. The release schedule was an initial release of 150 cfs for 28 hr (10 February 2013 at 1450 until 11 February at 1920); a rapid increase to 300 cfs, which was held for 14.5 hr (11 February at 1920 until 12 February at 0950); and another rapid increase to 500 cfs, which was held for 24 hr (12 February at 0950 until 13 February at 1000). The flow was then shut off.

Prior to the Release Test, the temperature of Ririe Reservoir was measured; and the snow and ice conditions in Willow Creek were documented. Snow blocked less than 25% of the Outflow Channel cross section area at a stage height of 4.5 ft at any section surveyed.

Detailed measurements of the water temperature, stage, and discharge along the Willow Creek channel were made throughout the test. The dynamic ice conditions in the Willow Creek channel were observed.

The Initial Release Wave or subsequent flow did not significantly remove, dislodge, or erode snow in the channel prior to the release. This required the water to travel on top of the snow and around any snow drifts in place. The snow was melted out only after the thermal melt-out front had advanced downstream the length of the Willow Creek channel.

Floating slush ice was observed to collect at the Ferguson Bridge; at the check dam upstream of the Bifurcation; and to a lesser extent, at the Siphon.

A melt-out front advanced downstream as the relatively warm water in the outflow of Ririe Dam melted out the snow and ice in the channel. The melt-out front advanced to the downstream end of Willow Creek in 59 hr and 15 min. After this time, the entire Willow Creek channel was effectively ice free.

There was no out-of-bank flooding during the Release Test.

A series of recommendations for action during future releases was prepared based on these results and the results of a release in February 2011.

1 Introduction

The US Army Corps of Engineers (Corps) Walla Walla District (NWW) is currently evaluating flood control operations at Ririe Reservoir to allow increased storage over the winter season. This winter season carryover would replace some portion of the early winter season flood control space of the reservoir. This would require the option to conduct wintertime releases of retained water so as not to increase the downstream flood risk. At this time, there is little experience with winter releases into dry, snow filled channels. An experimental wintertime release from Ririe Dam in 2011 resulted in minor flooding that required active mechanical removal of snow and ice from the channel in response. Before wintertime releases can become an operational procedure at Ririe Dam, it is important to understand the potential problems and their solutions. To provide insight into the problems associated with wintertime releases, the Corps, in cooperation with the Bureau of Reclamation, the United States Geological Survey (USGS), the Idaho Department of Water Resources, and others, conducted a Release Test 10–13 February 2013. This test consisted of three days of outflows from Ririe Dam into Willow Creek. The flow out of Ririe Dam prior to the Release Test was zero. The release schedule was an initial release of 150 cfs for 28 hr (10 February 2013 at 1450 until 11 February at 1920); a rapid increase to 300 cfs, which was held for 14.5 hr (11 February at 1920 until 12 February at 0950); and another rapid increase to 500cfs, which was held for 24 hr (12 February at 0950 until 13 February at 1000). The flow was then shut off.

A team of observers from the Corps of Engineers, the Bureau of Reclamation, the United States Geological Survey, and the Idaho Department of Water Resources recorded the conditions in Willow Creek and in the Ririe Reservoir prior to and during the Release Test. Prior to the Release Test, they measured the temperature of Ririe Reservoir and documented the snow and ice conditions in Willow Creek. The team observed and documented the propagation of the Initial Release Wave (IRW) down the dry, partially snow-filled Willow Creek channel and made detailed measurements of the water temperature, stage, and discharge along the Willow Creek channel throughout the test. Additionally, they observed the dynamic ice conditions in the Willow Creek channel.

In general, the snow in the channel prior to the Release Test remained in place as the IRW propagated down the channel, requiring the water to travel on top of the snow and around any snow drifts in place. Slush ice, observed along most of the lower reach of Willow Creek, moved with the channel flow velocity but collected and built up at specific locations. The temperature of the water released from Ririe Dam was above 39°F (3.9°C) at the outlet of the dam throughout the test. As this warmer water propagated downstream, it melted the ice and snow in the channel, lowering the flow temperature to 32°F (0°C). The water temperature at any location increased above 32°F (0°C) when all the snow and ice upstream of that location had melted out. The melt-out phase of the test began at each channel location when water temperature rose above 32°F (0°C). By the end of the Release Test, all the snow and ice had melted throughout the entire Willow Creek channel, leaving the entire Willow Creek snow and ice free.

The objectives of this report are to document the conditions in Ririe Reservoir and Willow Creek prior to and during the Release Test, to compare the 2013 Release Test with the 2011 release, and to make recommendations regarding future wintertime releases from Ririe Dam and operation of Willow Creek.

2 Description of Ririe Reservoir and Outflow Channel

2.1 Ririe Dam

Constructed by the Corps from 1970 to 1977, the Ririe Dam and Reservoir project is approximately 17 miles northeast of the town of Idaho Falls, ID (Fig. 1). The dam is an earth and rockfill structure, 253-ft high and 1070-ft long (US Department of Interior 2013). The reservoir impounded by the dam has a total capacity of 100,500 acre-ft with an active storage of 90,500 acre-ft. This active storage includes 10,000 acre-ft of exclusive flood control and 80,541 acre-ft of joint use storage (irrigation and flood control). The Corps formally transferred the project to Reclamation through a memorandum of agreement effective 14 October 1976. The Corps continues to manage the flood control operations of the Ririe Project based on Section 7 of the Flood Control Act of 1944.

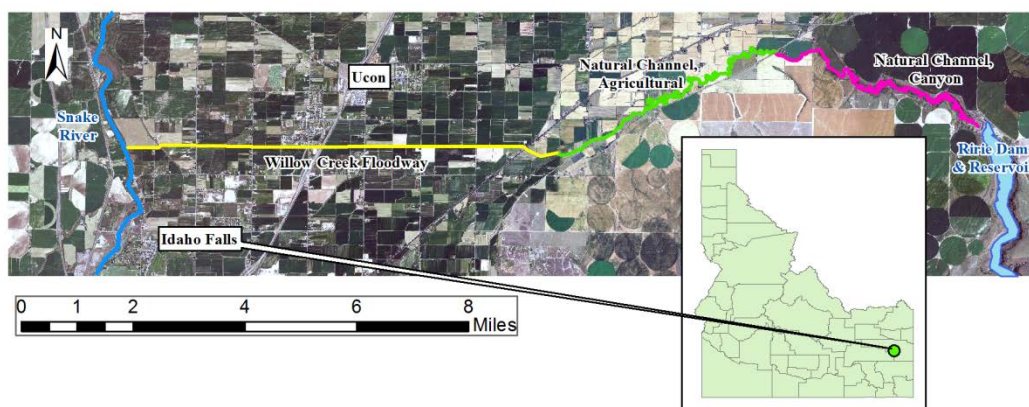


Figure 1. Overview map.

2.2 Willow Creek

2.2.1 Canyon section of the natural channel

The outlet of Ririe Dam enters immediately into Willow Creek. Willow Creek then meanders approximately 6.7 miles downstream through a canyon that provides no vehicular access to the creek (Fig. 2). In this report, this section of Willow Creek is referred to as “natural” although agricultural activity has modified some locations of the creek in this section, especially along the south bank. This canyon section of the natural channel ends at the 115th St. Bridge. This reach of Willow Creek can be accessed on-

ly at its upstream end at the Ririe Dam and its downstream end at the 115th St. Bridge.

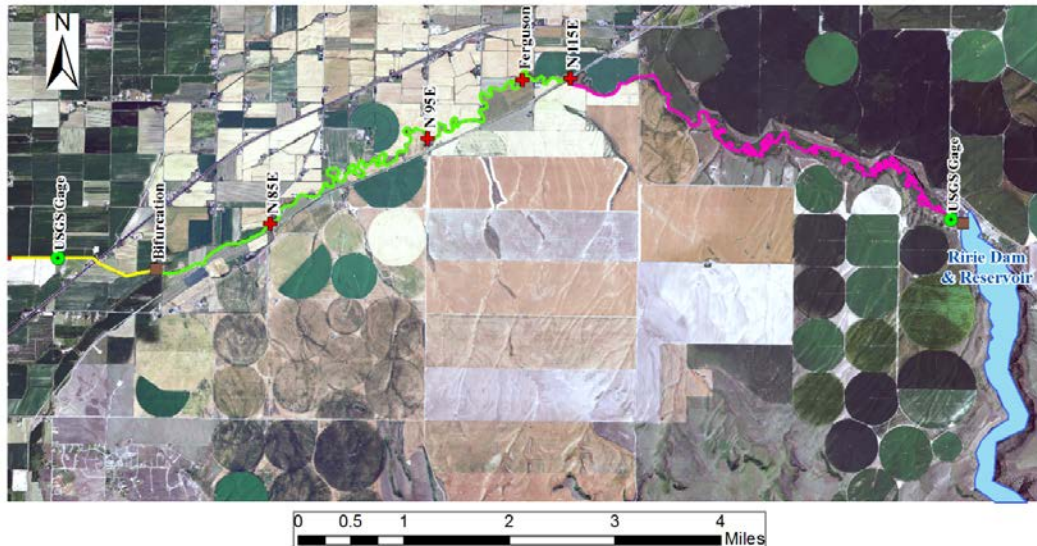


Figure 2. Upstream reaches.

2.2.2 Agricultural section of the natural channel

Downstream of the 115th St. Bridge, Willow Creek flows continuously through agricultural land (Fig. 2). The meandering of the creek through this section maintains a natural appearance, but agricultural activity has modified the channel banks over the years. This section extends downstream to the Bifurcation. The control gates located at the Bifurcation control the flow into the downstream reaches of Willow Creek and into Sand Creek. Five low-head weirs were identified in this reach based on satellite imagery. Only the weir farthest downstream was inspected during the course of the test. This weir is an uncontrolled rubble stone check dam that crosses Willow Creek approximately 0.4 miles upstream of the Bifurcation. The check dam has a drop of approximately 3 ft. This reach of Willow Creek can be accessed at its upstream end at the 115th St. Bridge, the Ferguson Road Bridge, the 95th St. Bridge, the 85th St. Bridge, and the Bifurcation.

2.2.3 Floodway Channel

The Floodway Channel is a constructed trapezoidal channel designed to divert flow from Willow Creek to reduce the flow through Idaho Falls and the area northeast of the city (Fig. 3). The Floodway Channel begins on Willow Creek just downstream from the point where Sand Creek branches

from Willow Creek. This location is referred to as the Bifurcation (US Department of the Interior 2013). The headworks of the Bifurcation allows water to be diverted to either the Floodway Channel or Sand Creek. The Floodway Channel extends directly west 7.8 miles and enters the larger natural channel of the Snake River 4.5 miles north of Idaho Falls. The Willow Creek Floodway Channel can be accessed at a number of locations listed in Table 1.

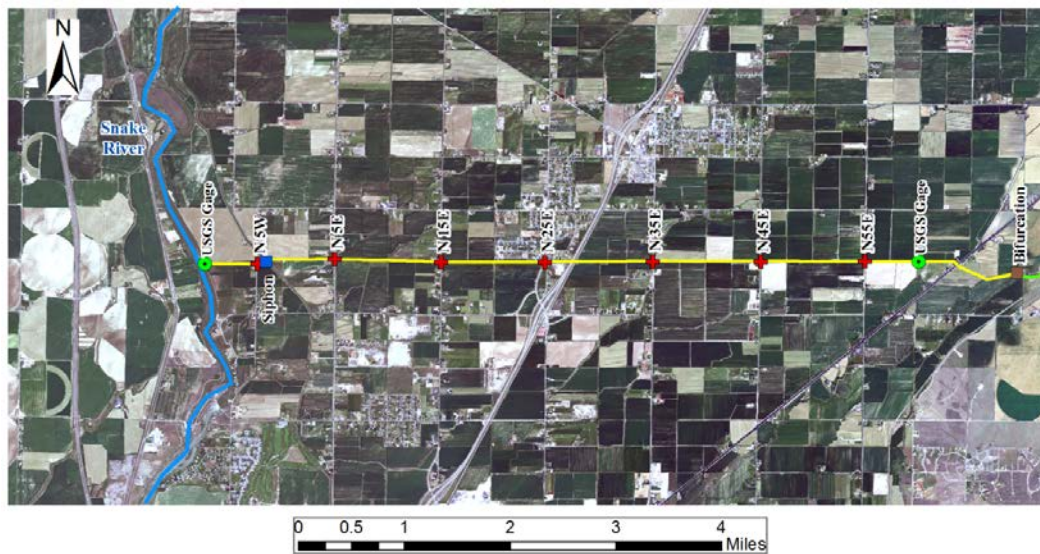


Figure 3. Downstream Floodway Channel.

3 2013 Pre-release conditions

3.1 Reservoir conditions

The Ririe Reservoir water level increased steadily throughout the winter of 2012–2013, as shown in Figure 4. The rate of increase was about 1 ft every 15 days. Recording sensors measured reservoir temperatures hourly from 24 November 2012 through 10 February 2013. They recorded the water temperatures at 15 ft intervals between 5000 and 5070 ft, and the data were downloaded after the sensors were removed from the reservoir. The temperature sensors were located on an instrumentation string that was suspended in the reservoir at the outlet structure of the dam. The Bureau of Reclamation removed the instrumentation string from the reservoir immediately before the Release Test was started. Given that the instrumentation string was frozen into the reservoir ice cover and that it was necessary to melt the ice surrounding the instrumentation string to remove the string, it is likely that the elevation of the temperature sensors changed over the course of the winter in response to the increase in the reservoir water level.

Figure 5 shows the recorded water temperatures. In November and through mid-December, the water temperatures decreased in response to heat loss from the reservoir surface to the atmosphere. The initial decrease in water temperature was very uniform throughout the depth of the reservoir. It is expected that the water temperature would be very uniform throughout the reservoir depth when the water temperature was at its density maximum of 39.2°F (4°C). As the reservoir continued to cool, the water temperatures throughout the depth reflected the balance between the stratification caused by the density differences of water because of temperature differences and the mixing from any wind stress applied at the water surface. Stratification is apparent by about 25 December with the warmest and most dense water near the bottom. This stratification increased as the surface layers continued to cool, and the water at depth remained more or less at a constant temperature. The reasons for some of the small scale variations in the water temperature after 1 January are not known. Certainly, movement of the instrumentation string by currents, the rise of the reservoir surface elevation lifting the string frozen into the surface ice cover, or other factors may have had an impact. In any case, it is apparent that at the start of the Release Test on 10 February 2013, there

was a large reserve of relatively warm water available in Ririe Reservoir. As a result of this reserve of warm water, the temperature of the outflow from Ririe Reservoir remained above 38.4°F (3.54°C) throughout the Release Test.

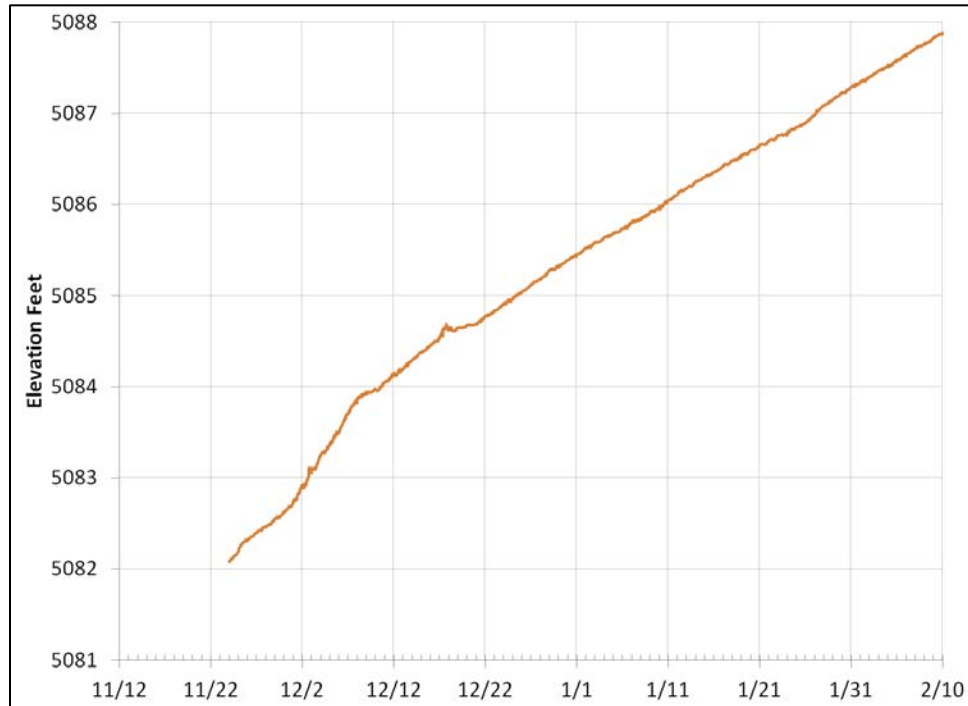


Figure 4. Ririe Dam reservoir water level over the winter.

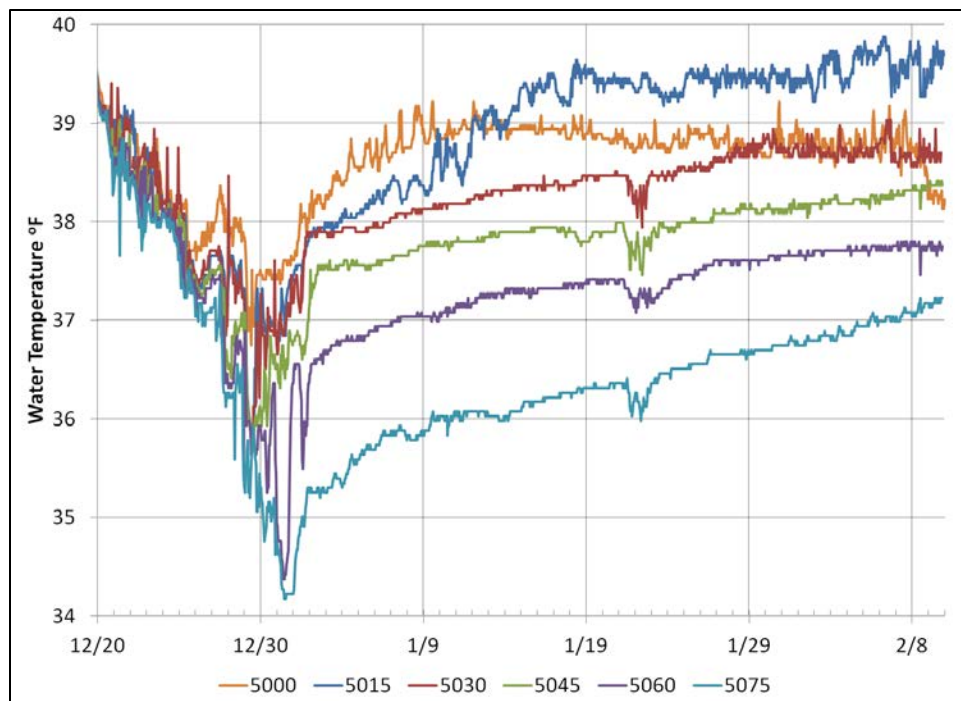


Figure 5. Ririe Dam reservoir water temperatures with depth.

3.2 Flow

Figure 6 shows the releases from Ririe Reservoir throughout the fall and winter of 2012–2013. The releases from the reservoir were stopped on 19 November 2012 and were not started again until the Release Test started on 10 February 2013. Observations made on 8–10 February 2013 in the Willow Creek channel prior to the arrival of the release flow determined that there was a small amount of flow in the canyon section of the natural channel. This flow probably originated partly from leakage around the Ririe Dam outflow gates and partly from ground water inflow. A small amount of leakage flow was observed at the Ririe Dam outlet prior to the Release Test. This flow allowed surface ice to form in this reach, as described in the next section. Some open areas upstream of the 115th St. Bridge indicated groundwater inflow into the system. There was no flow observed at the 115th St. Bridge. Prior to the Release Test, the channel was completely dry, although snow covered, downstream of the 115th St. Bridge to the Outlet works at the Snake River.

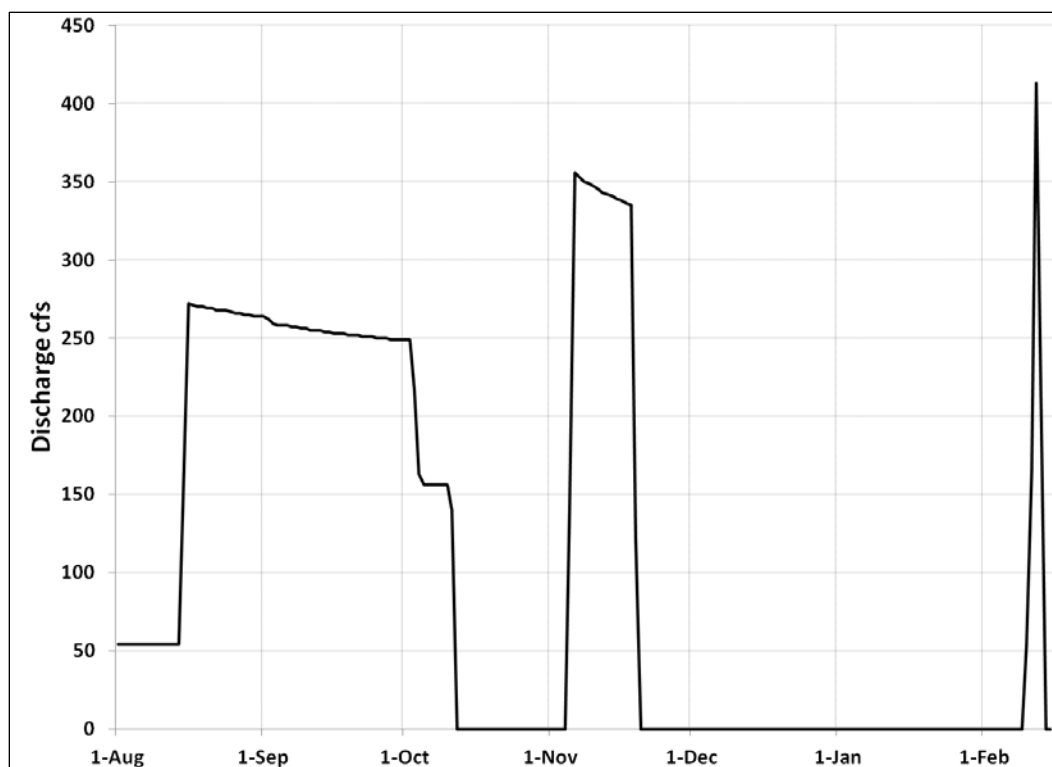


Figure 6. Ririe Dam discharges from 1 August 2012 until the end of the Release Test.

3.3 Snow and ice conditions

3.3.1 Ice

As a result of the flow in the canyon section of the Willow Creek natural channel, an ice cover was in place on Willow Creek starting about 0.25 miles upstream of the 115th St. Bridge and extending an unknown distance upstream. Holes drilled through the ice cover for ice fishing showed an ice thickness of 16 in. near the downstream end of the ice cover. A survey done on foot was conducted over a distance of approximately 1 mile upstream of the 115th St. Bridge (Fig. 7). Willow Creek ice covered over this entire 1-mile reach. Approximately 0.5 upstream of the 115th St. Bridge were the remains of a snow avalanche. The avalanche resulted from snow accumulation on a 50 to 75 ft bluff on the southern bank of Willow Creek. The avalanche appeared to have broken through the channel ice cover and filled approximately half the channel. The upstream extent of the ice cover was not determined, although an ice cover was observed approximately 0.25 miles downstream of Ririe Dam. No ice cover was observed downstream of the 115th St. Bridge.



Figure 7. Ice cover in place upstream of 115th St. Bridge prior to release.

3.3.2 Snow

Table 1 shows the snow density and snow distribution surveyed at a number of locations. The snow surface was crusty at most locations. The snow density was measured using a CRREL snow density tube (Ueda et al. 1975). The snow density tube has a volume of 500 cm³. At each location, the tube was driven into the snow cover until completely full. The end of the snow tube was cleaned flat using a beveled flat plate, and rubber caps were then placed on the end to hold the snow in the tube. The tube, snow, and rubber caps were then weighed using a gram scale. The tare weight of the tube and caps was subtracted from the total weight to determine the weight of the snow. The density was found as the ratio of the snow mass to the snow volume. Table 1 lists these results. The measured snow density ranged between 0.260 and 0.318 g cm⁻³.

Figures 8 through 27 show the snow distribution across the channel at each cross section. (Note: the plots of the snow distribution are shown left to right looking downstream.) The snow depth was measured at intervals across the channel. In addition to the snow depth, the elevation of the channel substrate was measured relative to the channel invert at the same intervals. In general, the snow distribution across the channel was very non-uniform with the greater mass of snow accumulated on the south bank of the channel. In some locations, a snow cornice had formed at the top of the south bank. The northern bank of the channel was more or less completely snow free, especially throughout the Willow Creek Floodway Channel. The non-uniform distribution of the snow was probably the result of drifting from the prevailing winds combined with snow ablation on the south-facing northern channel bank.

Table 1. Snow measurement summary.

8 February 2013				
Time	Reach	Location	Action	Snow Density (g cm ⁻³)
0800–1200	Floodway	5 th St. to Bifurcation	Inspection.	
1215–1245	Ririe Dam	Outlet	Installed temp. probes.	
1318	Agricultural	95 th St.	Section Survey.	0.272
1405	Agricultural	85 th St.	Section Survey.	0.280
1440	Floodway	Downstream (d/s) of Bifurcation	Section Survey.	0.264
1507	Floodway	Near gaging station	Section Survey.	
1525	Floodway	55 th St.	Section Survey. Installed temp. probes.	0.284 (Top left bank)
1610	Floodway	35 th St. (Yellowstone)	Section Survey. Installed temp. probes.	0.260
1650	Floodway	15 th St.	Section Survey. Installed temp. probes.	0.318 (Center channel)
1716	Floodway	5 th St. West	Section Survey. Installed temp. probes.	0.278 (Center channel)
9 February 2013				
Time	Reach	Location	Action	Snow Density
0935	Floodway	Outfall	Section Survey.	0.258
1010	Floodway	15 th St.	Installed water level probe.	0.280 (Center channel)
	Floodway	35 th St. (Yellowstone)	Installed water level probe.	0.284
1105	Floodway	55 th St.	Installed water level probe.	0.290 (Top left bank) 0.272 (Left bank) 0.268 (Center channel)
10 February 2013				
Time	Reach	Location	Action	Snow Density
1455	Canyon	115 th St.	Section Survey. Inspected upstream ice conditions for 1 mile. Ice thickness 16 in.	0.378 (Very crusty)

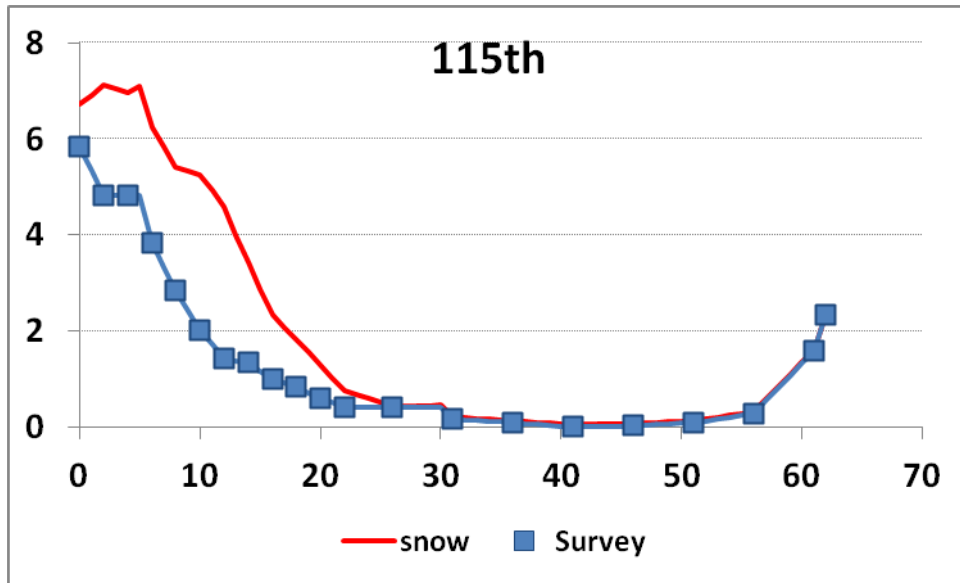


Figure 8. Snow depth and channel cross section (in feet) at the 115th St. Bridge.



Figure 9. Looking upstream from the 115th St. Bridge prior to release.

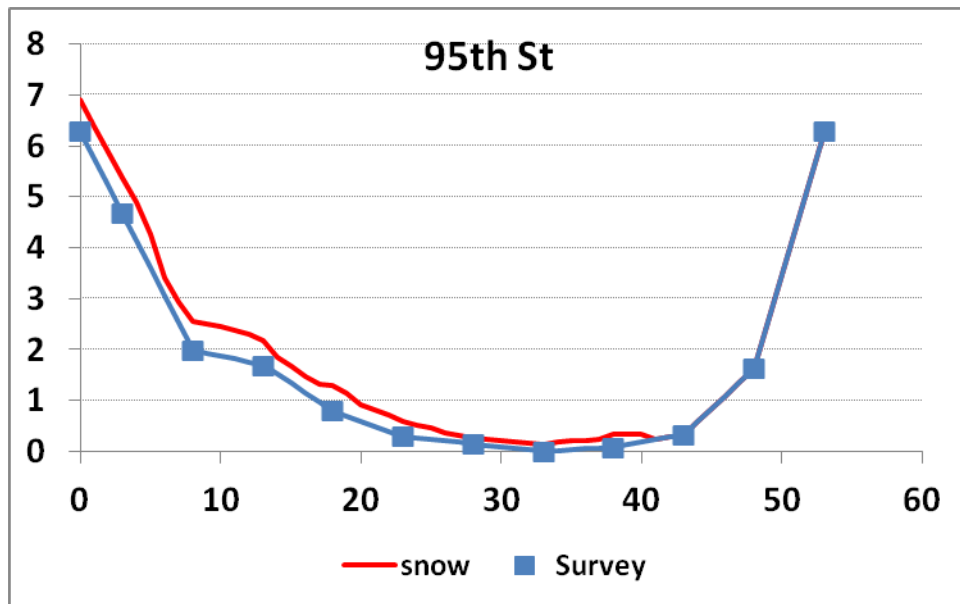


Figure 10. Snow depth and channel cross section (in feet) at the 95th St. Bridge.



Figure 11. Looking upstream from the 95th St. Bridge prior to release.

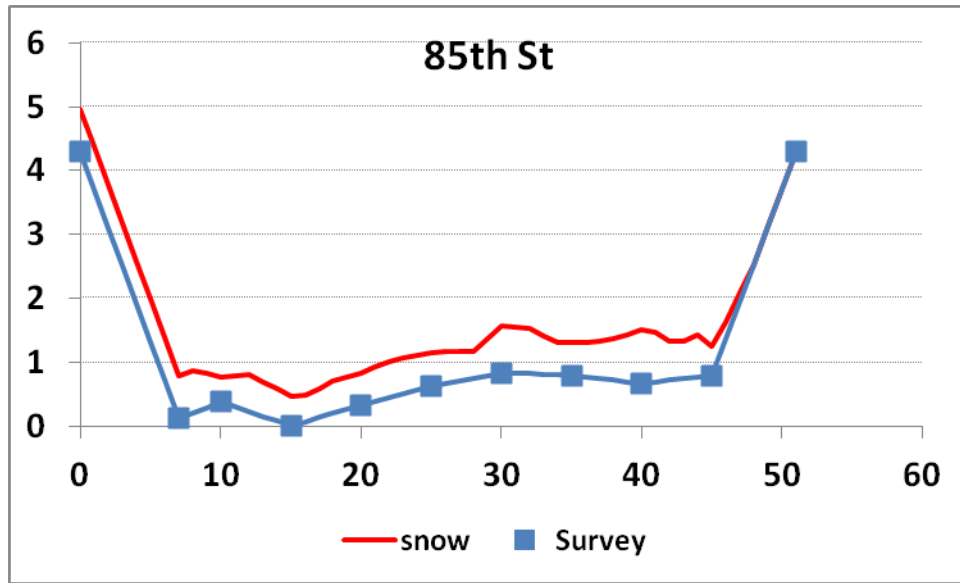


Figure 12. Snow depth and channel cross section (in feet) at the 85th St. Bridge.



Figure 13. Looking upstream from the 85th St. Bridge prior to release.

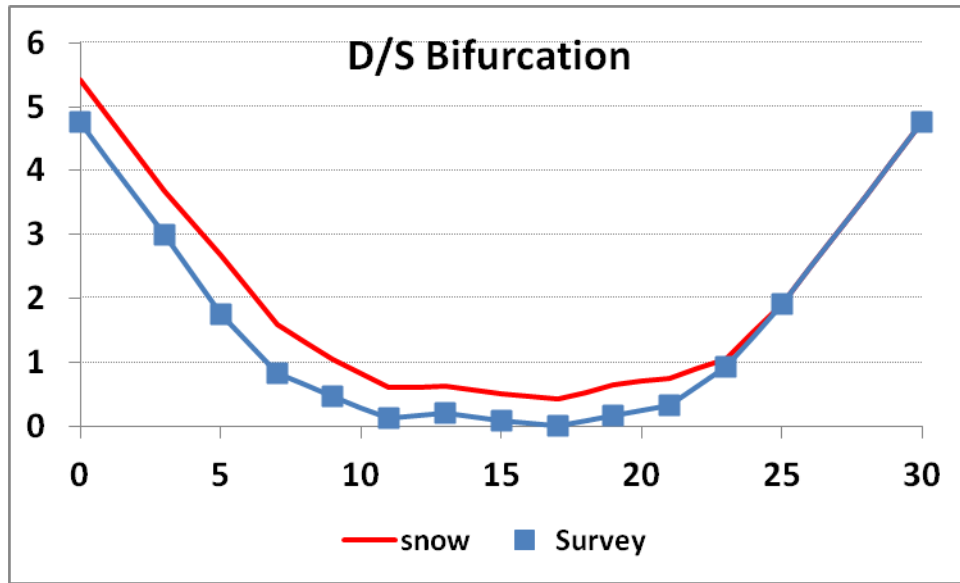


Figure 14. Snow depth and channel cross section (in feet) downstream of the Bifurcation.



Figure 15. Looking downstream from the Bifurcation Control Structure prior to release. (Image by P. Cooper.)

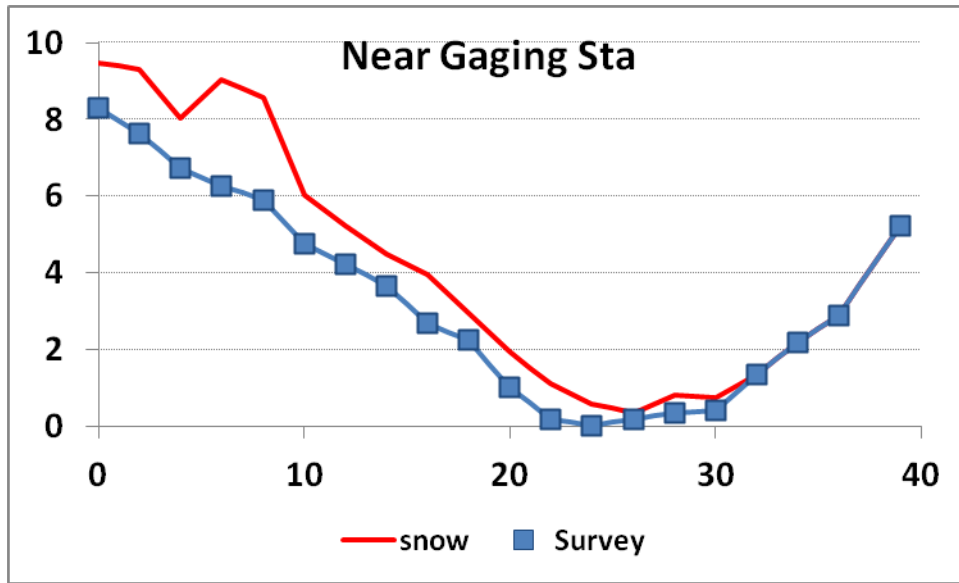


Figure 16. Snow depth and channel cross section (in feet) near the USGS Gaging Station.



Figure 17. Looking downstream from the Willow Creek Head Gates prior to release. USGS gage is visible. (Image by P. Cooper.)

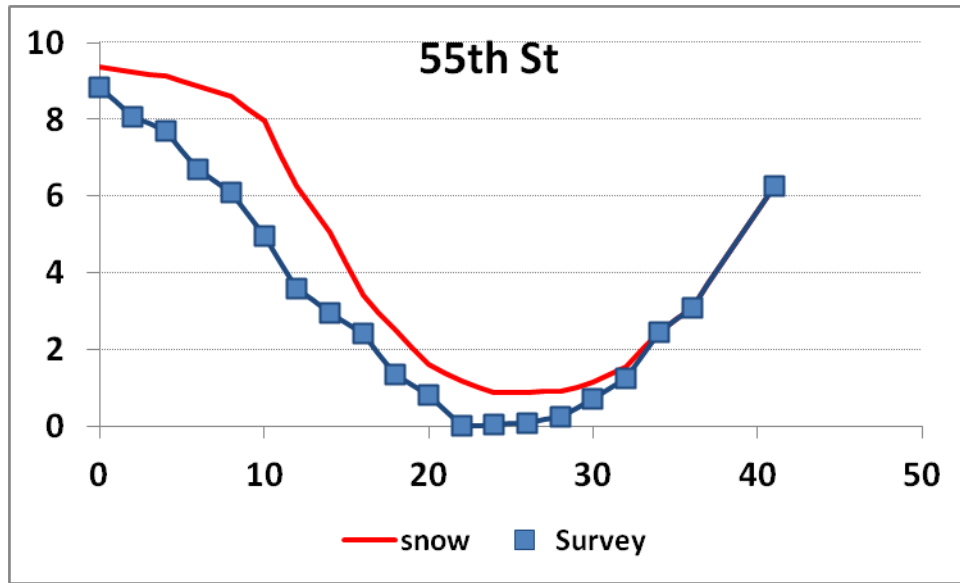


Figure 18. Snow depth and channel cross section (in feet) at the 55th St. Bridge.



Figure 19. Looking downstream from the 55th St. Bridge prior to release. (Image by P. Cooper.)

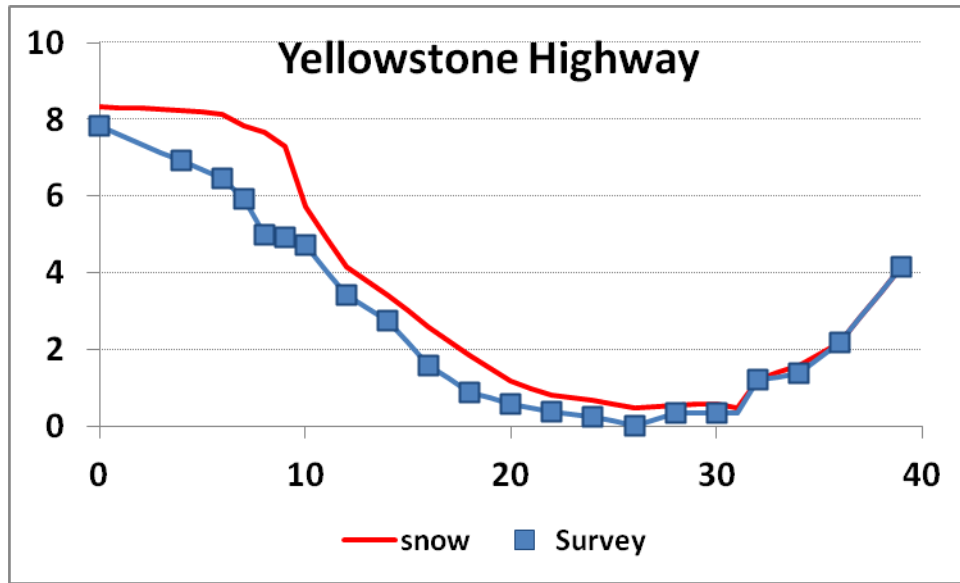


Figure 20. Snow depth and channel cross section (in feet) at the 35th St. Bridge (Yellowstone Highway).



Figure 21. Looking downstream from the 35th St. Bridge prior to release. (Image by P. Cooper.)

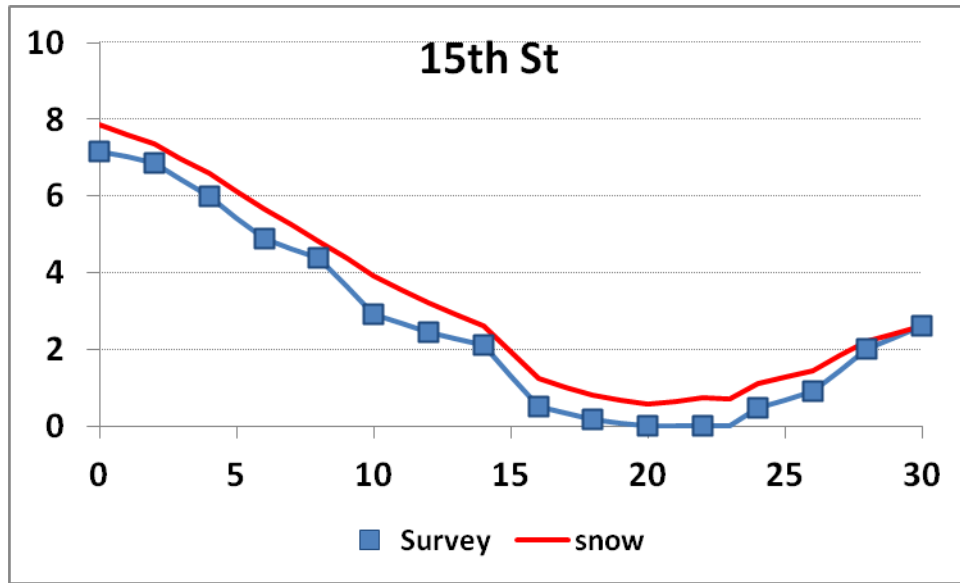


Figure 22. Snow depth and channel cross section (in feet) at the 15th St. Bridge.



Figure 23. Looking downstream from the 15th St. Bridge prior to release. (Image by P. Cooper.)

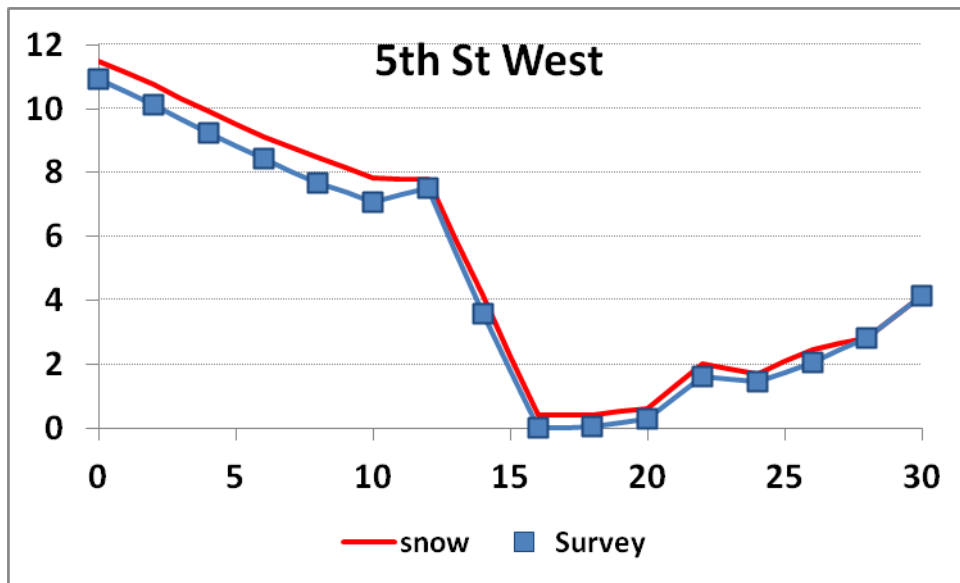


Figure 24. Snow depth and channel cross section (in feet) at the 5th St. Bridge.



Figure 25. Looking downstream from the 5th St. Bridge prior to release.

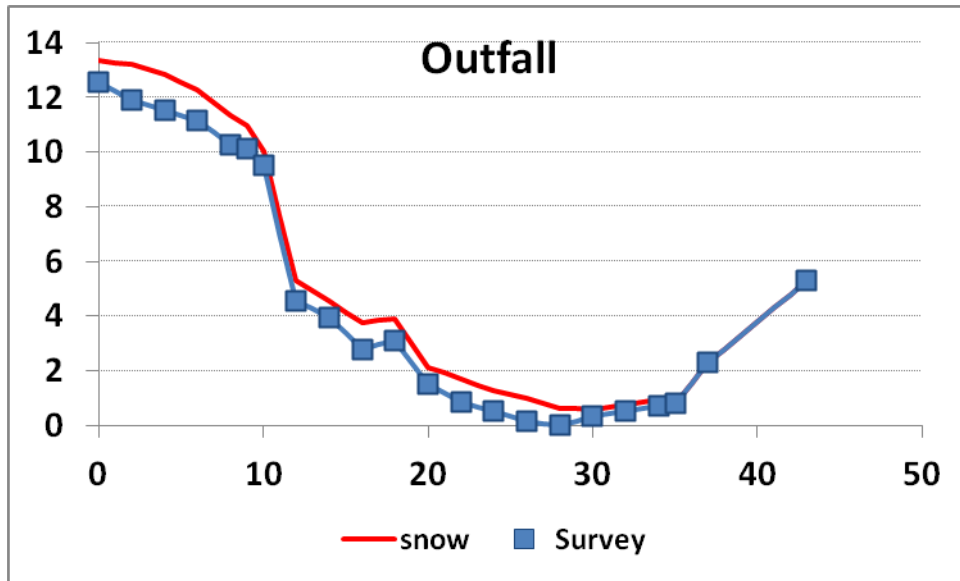


Figure 26. Snow depth and channel cross section (in feet) at the outfall.



Figure 27. Looking upstream from the mouth of the Floodway Channel during release.

4 2013 Release Test Observations

Three USGS gages, 12 temporary water temperature recorders, and three temporary stage recorders installed by the Corps of Engineers made measurements of the flow conditions in Willow Creek during the Release Test; and personnel of the Corps and Idaho Department of Water Resources made visual observations. The Bureau of Reclamation made hourly air temperature measurements at Ririe Dam, and the National Weather Service (NWS) also made them hourly at the Idaho Falls Municipal Airport. This data collection program allowed the following to be determined:

- The propagation of the IRW from Ririe Dam along the dry channel to the mouth of the Willow Creek Outflow Channel at the Snake River.
- The propagation along Willow Creek of the changes in the outflow discharge from Ririe Dam.
- The timing, location, and extent of the dynamic ice cover development along the length of the Willow Creek.
- The melt-out of ice and snow in Willow Creek as the relatively warm water released by Ririe Dam was convected downstream.

This section describes the measurements and then discusses each of the above.

4.1 Discharge

There are three USGS gages in place on Willow Creek. Table 2 lists these gages and Figures 2 and 3 show their location. These are permanent gage locations in place for many years. The gages recorded stage at all three locations and water temperature at two locations every 15 min throughout the Release Test.

The USGS estimated the discharge at their sites using rating curves developed from previous flow and stage measurements. The extent to which the ice and snow in the channel affected the accuracy of the discharge estimates during the Release Test is not known.

Figure 28 shows the discharge estimates, and the gage at the outlet of Ririe Dam (USGS Gage 13058000) shows clearly the three discharge steps of 150 cfs, 300 cfs, and 500 cfs. The two downstream gages (USGS Gages

13058520 and 13058529) show clearly the arrival of the IRW. A period of transient flow in which the apparent discharge at the two downstream gages varied above and below the 150 cfs outflow rate followed the arrival of the Initial Release Wave. The increase to 300 cfs followed before this transient settled out, and the start of the period of the 300 cfs flow was not clearly visible at the two downstream gages. Both downstream gages reached a period of near steady flow after the wave of the 500 cfs release reached their location. Tables 4 and 5 list the arrival times of the IRW, the 300 cfs flow, and the 500 cfs flow at each of the USGS gages. They list separately the leading edge of each increase, when the discharge was observed to increase, and the actual time when the outlet flow was reached.

It is interesting to note that the final steady flow during this period averaged 464 cfs at the mouth of the Willow Creek Outflow Channel (USGS Gage 13058520) and 480 cfs at the upstream gage near the Willow Creek headworks (USGS Gage 13058529). This suggests that some flow in the Willow Creek channel was lost to groundwater recharge, leakage through control gates, or other causes during the Release Test.

Table 2. USGS gages.

Distance from Mouth (ft)	Gage Number	Gage Name	Approximate Location	Data	Start Year
120,000	13058000	WILLOW CREEK NR RIRIE ID	0.25 miles below Ririe Dam	Temp., Flow	1903
36,000	13058520	WILLOW CREEK FLOODWAY CHANNEL NR UCON ID	300 ft below Willow Creek channel diversion structure	Flow	1978
80	13058529	WILLOW CR FLOODWAY CHANNEL AT MOUTH NR ID FALLS ID	80 ft upstream (u/s) of mouth	Temp., Flow	1987

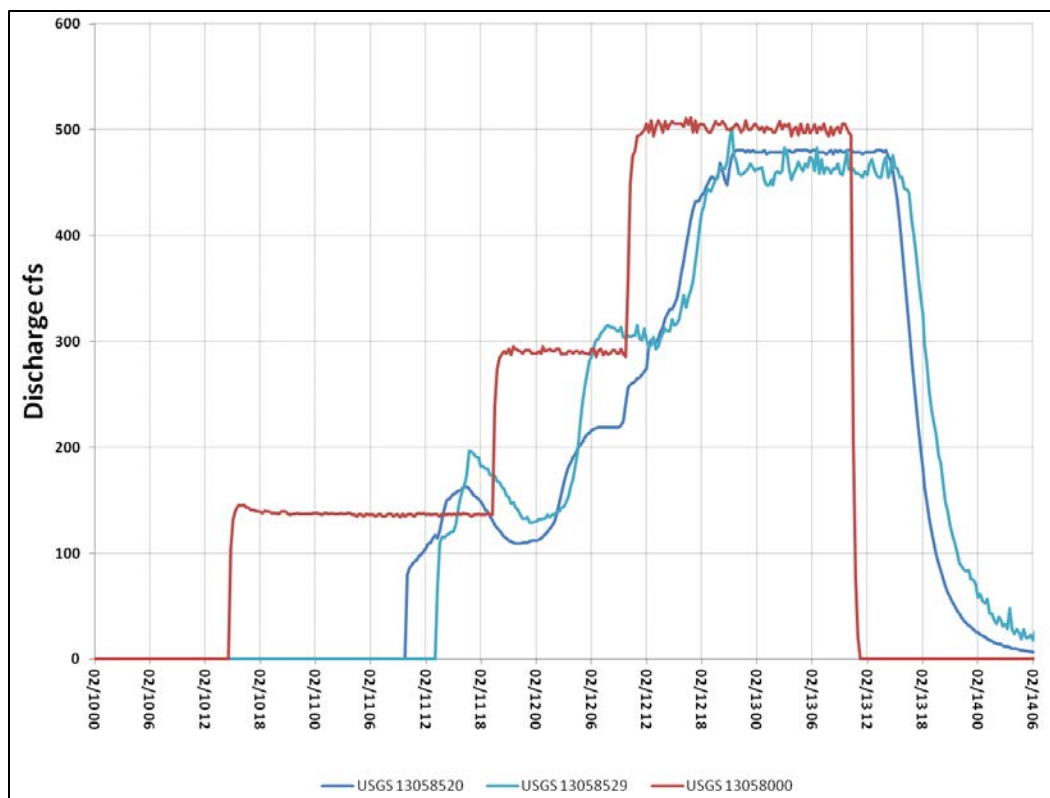


Figure 28. Observed discharge at the USGS gages during the Release Test.

4.2 Water temperature

The USGS made water temperature measurements at two of their gages (USGS Gages 13058000 and 13058529). Water temperature measurements were also made at six other locations using temporary water temperature sensors installed by the Corps (Table 3). The Corps installed two temperature sensors at the six locations providing a total of twelve time series of temperature. Each of these locations was immediately downstream of the bridge crossing listed in Table 3. The USGS data were recorded at 15-min intervals and the Corps data at 10-min intervals. In addition, at three locations, the Corps installed pressure sensors for stage measurement that also recorded water temperature (Table 3). These sensors recorded data every 30 s. In total, there were 17 time series of water temperature data recorded at seven different locations along Willow Creek. In every case, there was very little difference between the water temperature measurements made by different sensors at any one location.

The water temperature sensors installed at the outlet of Ririe Dam were underwater during the entire Release Test and recorded the outlet water temperature as shown in Figure 29. The outlet temperature held very

steady with only a slight decline from 3.8°C (38.8°F) to 3.5°C (38.3°F) over the course of the Release Test. The remaining temperature sensors were exposed to the air and recorded the air temperature prior to the arrival of the IRW. The air temperatures were relatively low in the hours leading up to the arrival of the IRW, with air temperatures dropping down to -15°C (5°F). The temperature sensors detected the arrival of the IRW at a specific location when the water temperature jumped abruptly to 0°C (32°F). Figure 29 clearly shows these jumps, and Table 3 lists the data and time of the IRW. After the arrival of the IRW, the water temperature remained at a constant value of 0°C (32°F) for a period. During this time, both ice and liquid water existed in the channel. Once the ice in the channel upstream of a specific location had effectively melted, the water temperature could rise towards the temperature of the water released from Ririe Dam. The actual temperature recorded at any site after the ice had melted resulted from the balance between the heat input from Ririe Dam and the heat loss/gain through the water surface to the atmosphere. As the air temperatures were generally below 0°C (32°F) for almost all of the Release Test, there was a heat loss from the water surface. This is also indicated by the slightly lower temperatures at each successive site moving downstream.

Table 3. Corps of Engineers water temperature data summary.

HOBO Water Temperature Pro v2 Data Logger—U22-001			
Serial Number	Location	Release Wave Arrival	Above 0°C
10120108	Ririe outfall (2)	2/10/2013 at 1440	2/10/2013 at 1440
9937334	Ririe outfall (1)		
9937335	95 th St. (2)	2/11/2013 at 0330	2/12/2013 at 1410
10120114	95 th St. (1)		
10120115	55 th St. (2)	2/11/2013 at 1010	2/12/2013 at 2120
10120111	55 th St. (1)		
9737377	35 th St. (2)	2/11/2013 at 1110	2/12/2013 at 2240
10120119	35 th St. (1)		
9937331	15 th St. (2)	2/11/2013 at 1200	2/12/2013 at 2350
10120116	15 th St. (2)		
10120112	5 th St. West (2)	2/13/2013 at 0130	2/13/2013 at 0130
10120113	5 th St. West (1)		
HOBO Pressure Sensors that also recorded water temperature			
Serial Number	Location	Release Wave Arrival	Above 0°C
2414446	55 th St.	2/11/2013	2/12/2013 at 2120
2414447	35 th St.	2/11/2013	2/12/2013 at 2231
2428956	15 th St.	2/11/2013	2/12/2013 at 2355

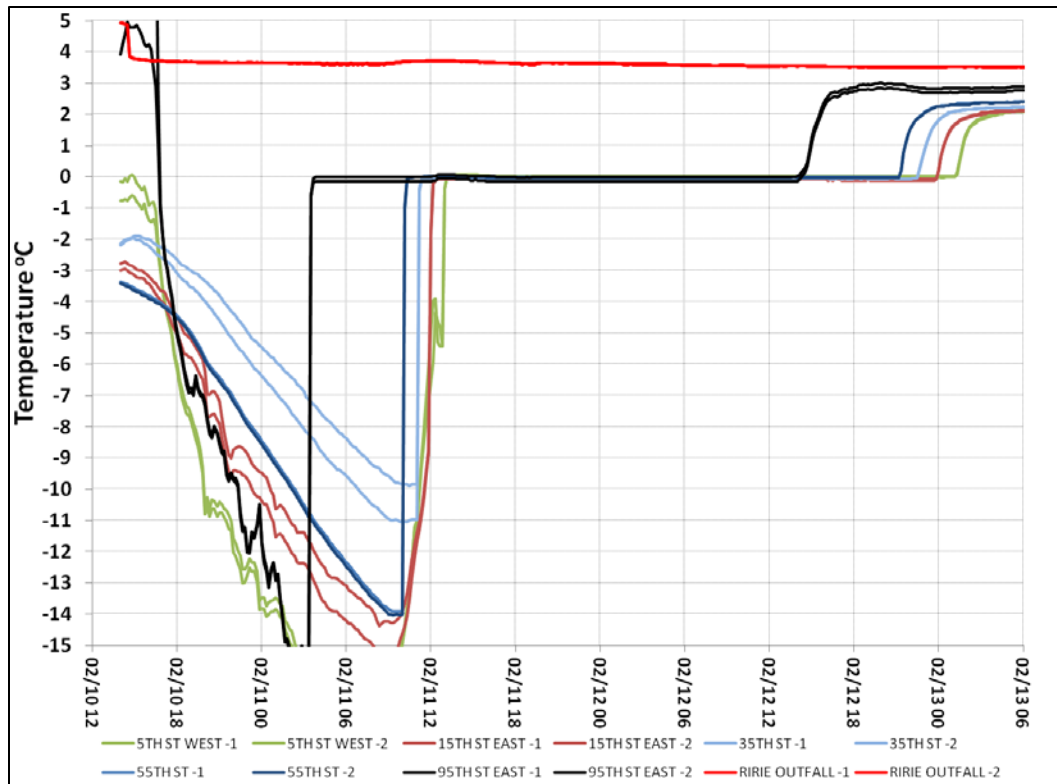


Figure 29. Observed water temperatures.

4.3 Air temperature

The Bureau of Reclamation made hourly air temperature measurements at the Ririe Dam, and the NWS made hourly measurements at the Idaho Falls Municipal Airport. Figure 30 shows the air temperature record over the course of the Release Test. The coldest air temperatures were recorded around 0700 on 11 February when the air temperature ranged between 5°F (−15°C) and 0°F (−17.8°C). Over the course of the Release Test, the air temperatures remained below 0°C (32°F) but were fairly moderate.

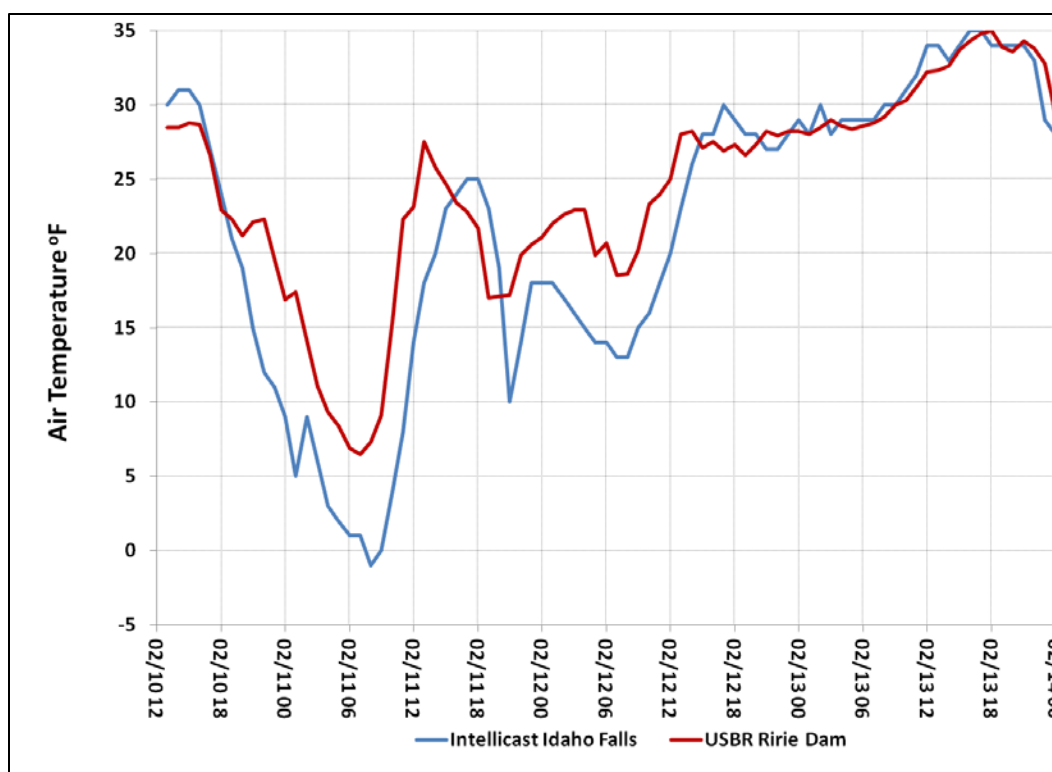


Figure 30. Observed air temperature.

4.4 Stage

Three temporary pressure gages installed by the Corps made stage measurements at the USGS gages. The Corps installed gages at the locations listed in Table 3. Figure 31 shows the measured stages. The stages at the USGS gages are shown relative to the stage immediately before the arrival of the IRW and not relative to the gage datum. The stage at the USGS gage immediately downstream of Ririe Dam is not shown. One can clearly see the arrival of the IRW at each of the locations and the transient flow that followed. Unfortunately, as Figure 31 shows, two of the Corps gages (labeled probes) apparently moved during the course of the Release Test. These gages probably provided an accurate measurement of the water stage prior to the time that the gages moved.

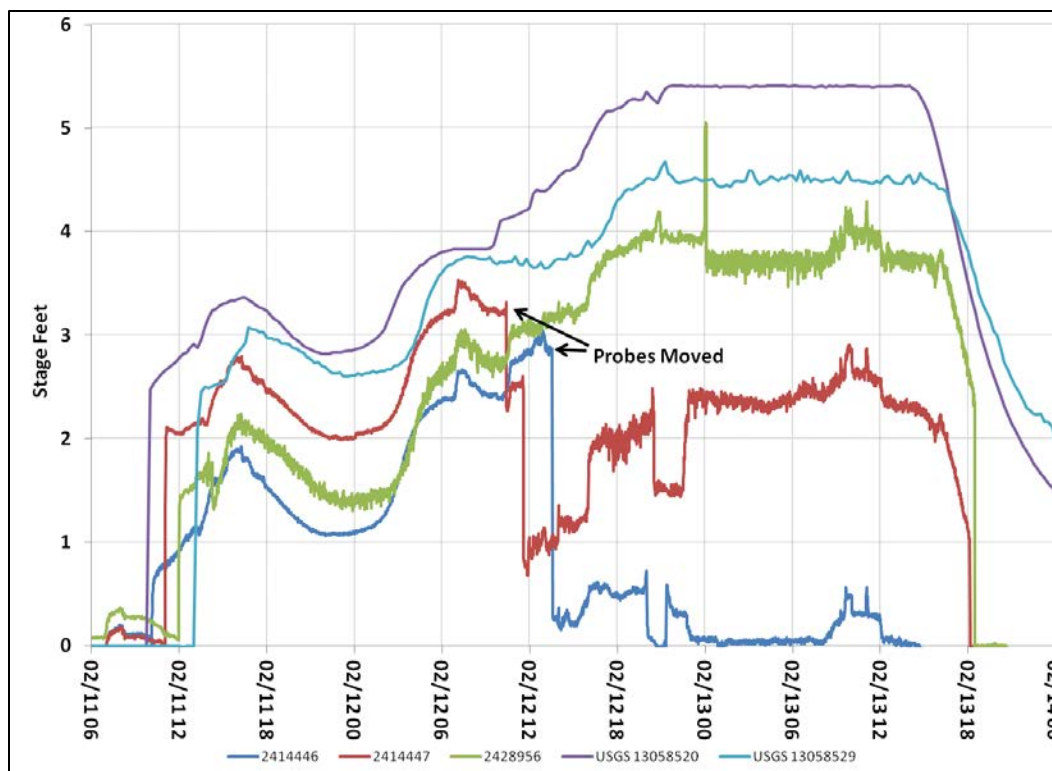


Figure 31. Observed stages.

4.5 Willow Creek hydraulic conditions

4.5.1 Initial Release Wave propagation

The IRW began at approximately 1420 on 10 February 2013 when the Bureau of Reclamation opened the gates of Ririe Dam to allow a flow of 150 cfs to pass. This release wave propagated downstream and arrived at the Snake River at 1315 on 11 February 2013, for a travel time of 22 hr and 55 min. The propagation of the IRW was tracked in three ways: by noting the arrival time at the USGS gages, by the abrupt change of temperature at the Corps water temperature sensors, and by on-site personnel's observations. Table 4 and Figure 32 show the IRW propagation results. The IRW traveled at an overall average velocity of 1.45 fps. It moved faster in the Floodway Channel than in the natural channel sections upstream. At every section observed, the snow in the channel remained in place during and after the IRW traveled through each section. The IRW did not significantly remove, dislodge, or erode away the snow that was in place prior to the Release Test. This required the IRW to travel on top of the snow and around any snow drifts in place and indicates that only part of the channel area was available for conveyance.

Table 4. Summary of the Initial Release Wave propagation. (Average velocity is the average propagation speed from Ririe Dam to that point.)

Distance (ft)	Location	Observation Type	Arrival Date Time	Total Travel Time	Average Velocity (fps)	Velocity (between sites)
119,880	Ririe Dam	Temp, Stage	2/10/2013 at 1420	0 hr		
84,480	115 th St. Bridge					
74,700	Ferguson Bridge	On-site obs.	2/11/2013 at 0030	10 hr 10 min	1.23	1.23
64,700	N 95 th E	Temp	2/11/2013 at 0330	13 hr 10 min	1.16	0.93
47,500	N 85 th E					
40,900	Bifurcation	On-site obs.	2/11/2013 at 0910	18 hr 50 min	1.16	1.17
37,700	26 th St. Highway Bridge	On-site obs.	2/11/2013 at 0935	19 hr 15 min	1.19	2.13
36,000	USGS gage	Stage	2/11/2013 at 1000	19 hr 42 min	1.18	1.13
33,020	55 th St. Bridge	On-site obs., Temp	2/11/2013 at 1002	19 hr 44 min	1.22	2.89
27,780	45 th St. Bridge	On-site obs.	2/11/2013 at 1033	20 hr 13 min	1.27	2.82
22,430	Highway 42 Bridge	On-site obs., Temp	2/11/2013 at 1103	20 hr 43 min	1.31	2.97
17,010	25 th St. Bridge	On-site obs.	2/11/2013 at 1125	21 hr 5 min	1.36	4.11
11,850	15 th St. Bridge	On-site obs., Temp	2/11/2013 at 1155	21 hr 35 min	1.39	2.87
6520	5 th St. East Bridge	On-site obs.	2/11/2013 at 1224	22 hr 4 min	1.43	3.06
3100	Siphon	On-site obs.	2/11/2013 at 1246	22 hr 26 min	1.45	2.59
	5 th St. West Bridge	On-site obs., Stage				
80	Mouth	Stage	2/11/2013 at 1315	22 hr 55 min	1.45	1.74

4.5.2 Propagation of discharge modifications made after the Initial Release Wave

The initial outlet discharge of 150 cfs was held constant for 29 hr and 10 min and then was increased rapidly to 300 cfs at 1930 on 11 February 2013. It is difficult to discern exactly the arrival of the 300 cfs discharge wave at the downstream USGS gages for two reasons. One, the transient set in motion following the propagation downstream of the IRW obscures the arrival of the step increase to 300 cfs. The second reason is that the sharp front of the step increase to 300 cfs tended to flatten out as it traveled downstream. Given these difficulties, the arrival of the step increase to 300 cfs was determined by two events: the arrival of the leading edge and the arrival of the flow increase itself. The leading edge was identified as the point where the discharge at the downstream gages began to in-

crease steadily above the low point of the transient. The wave arrival was identified by the point when the discharge at the gages reached approximately 300 cfs. The 300 cfs flow release propagated at a faster velocity than the IRW. The step increase to 300 cfs arrived at the mouth of Willow Creek at 0730 on 12 February 2013 after a travel time of 12 hr and an average wave celerity of 2.8 fps. Table 5 and Figure 32 (red lines) show the step increase to 300 cfs.

The 300 cfs outflow was held constant for 14 hr and 30 min and then was increased rapidly to 500 cfs at 1000 on 12 February 2013. The 500 cfs flow release propagated at a faster velocity than the IRW and at a slightly faster velocity than the step increase to 300 cfs. The step increase to 500 cfs arrived at the mouth of Willow Creek at 2115 on 12 February 2013 after a travel time of 11 hr and 15 min and an average wave celerity of 3.0 fps. Table 5 and Figure 32 (blue lines) show the step increase to 500 cfs.

The 500 cfs outflow was held constant for 24 hr and 30 min, and then the flow out of Ririe Dam was shut off at 1030 on 13 February 2013. The arrival of the shutoff at the downstream gages was determined as the time when the discharge began to drop below the approximately 500 cfs constant discharge recorded at the gages. The shutoff propagated at a faster velocity than the IRW and a faster velocity than either of the two previous step increases. The shutoff arrived at the mouth of Willow Creek at 1645 on 13 February 2013 after a travel time of 6 hr and 15 min and an average wave celerity of 5.3 fps. Table 5 and Figure 32 (black lines) also show the shutoff.

Table 5. Summary of propagation of discharge modifications made after the IRW.

300 cfs						
Distance (ft)	USGS Gage	Leading Edge Arrival	Wave Arrival	Total Travel Time	Average Velocity (fps)	Velocity (between gages)
120,000	13058000	2/11/2013 at 1930	2/11/2013 at 1930			
36,000	13058520	2/12/2013 at 0045	2/12/2013 at 0630	11 hr	2.1	2.1
80	13058529	2/12/2013 at 0330	2/12/2013 at 0730	12 hr	2.8	10.0
500 cfs						
Distance (ft)	USGS Gage	Leading Edge Arrival	Wave Arrival	Total Travel Time	Average Velocity (fps)	Velocity (between gages)
120,000	13058000	2/12/2013 at 1000	2/12/2013 at 1000			
36,000	13058520	2/12/2013 at 1300	2/12/2013 at 2000	10 hr	2.3	2.3
80	13058529	2/12/2013 at 1400	2/12/2013 at 2115	11.25 hr	3.0	8.0
Shutoff						
Distance (ft)	USGS Gage	Leading Edge Arrival	Total Travel Time	Average Velocity (fps)	Velocity (between gages)	
120,000	13058000	2/13/2013 at 1030				
36,000	13058520	2/13/2013 at 1445	4 hr 15 min	5.5	5.5	
80	13058529	2/13/2013 at 1645	6 hr 15 min	5.3	5.0	

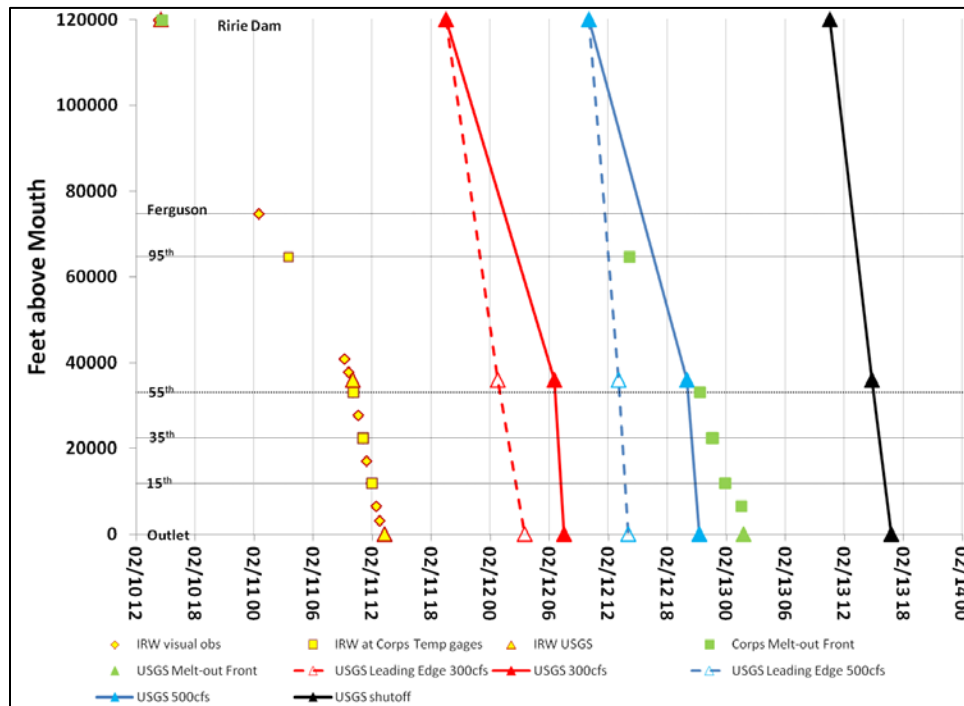


Figure 32. Observed Initial Release Wave, flow changes, and the advance of the melt-out front.

4.6 Ice conditions

The snow and ice conditions in Willow Creek during the Release Test can be divided into two phases: an ice and water phase, when ice and water co-existed, and a melt-out phase, when the warm water released from Ririe Dam had melted out the snow and ice in the channel. The ice and water phase followed passage of the IRW and continued while the water temperature remained at 32°F (0°C). During this phase, the ice and snow cover in place prior to the Release Test remained in place; slush ice traveled at the surface of the flowing water; heat transfer from the water surface to the atmosphere generated new ice; and floating ice collected at the Ferguson Road Bridge, the check dam upstream of the Bifurcation, and to a lesser extent, at the Siphon. It is during this phase that significant blockages to flow by snow and ice could occur.

The melt-out phase was occurring in all sub-reaches of the channel upstream of the 32°F (0°C) water temperature isotherm. As described above, the water temperature of the outflow from Ririe Dam was higher than 38.4°F (3.54°C) throughout the Release Test. However, contact with ice and snow in the channel lowered this water temperature to 32°F (0°C). As the ice and snow melted out, the leading edge of the warm water (the 32°F [0°C] isotherm) was convected further and further downstream. Upstream of the 32°F (0°C) isotherm, the snow and ice had melted out; and the channel was effectively ice free. Downstream of the 32°F (0°C) isotherm, snow and ice remained in the channel. The 32°F (0°C) isotherm reached the mouth of Willow Creek Floodway Channel at 0145 on 13 February 2013 after a travel time of 59 hr and 15 min. After this time, the entire Willow Creek flood control system was effectively ice free.

4.6.1 Ice and water phase

As noted above, the snow in the channel remained in place during and after the IRW traveled through each section. Neither the IRW nor the subsequent flow significantly removed, dislodged, or eroded away the snow that was in place prior to the Release Test. This required the IRW and all subsequent flow to travel on top of the snow and around any snow drifts in place. This condition remained at each section until the arrival of warm water, which melted out the snow at that location. It may be that some of the slush ice that floated on the water surface after the IRW had propagated through a section had originated from the snow that was in place prior to the Release Test. However, this floating slush ice could have also origi-

nated through ice formation resulting from heat transfer during the period of frigid air temperatures (Fig. 30).

The snow in the channel remained in place and did not change with time until the warm water arrived. This snow was a static obstruction to the flow. However, the floating ice conditions in the channel did change dynamically with time. Appendix B lists observations of the ice conditions. Figure 33 displays these observations and shows the percentage of the water surface covered by ice. All ice observations were of moving slush ice except upstream of the 115th St. Bridge (88,480 ft above the mouth), at the Ferguson Bridge (74,700 ft), and the check dam (42,200 ft). At these three locations, the ice was stationary, as described below.

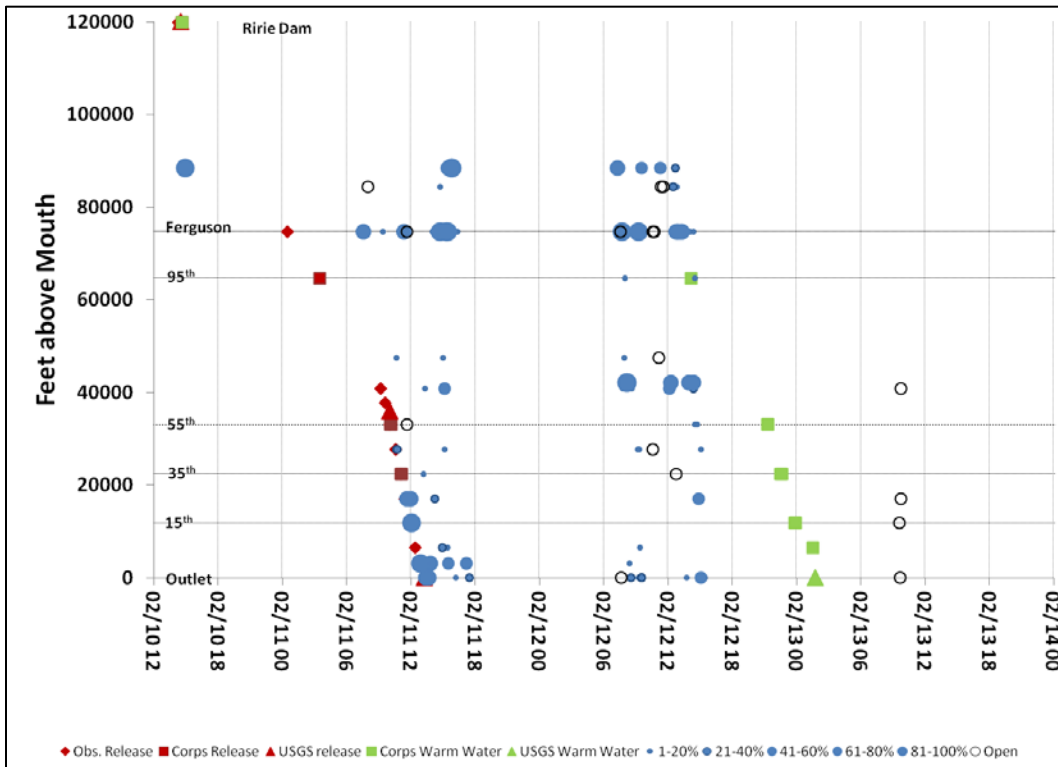


Figure 33. Ice observation summary.

4.6.1.1 Upstream of the 115th St. Bridge

As described above, an ice cover was in place in the canyon section of the Willow Creek natural channel prior to the Release Test. The reach is located downstream of Ririe Dam and upstream of the 115th St. Bridge. When the IRW passed through this section, it caused the ice cover to fracture as the ice along the channel centerline was lifted and the ice at the banks remained frozen in place. The portion of the ice cover nearest to the banks became submerged while the middle third remained above water (Fig. 34). In general, a single longitudinal crack that ran down the center of the channel ice cover fractured the ice cover. At wider locations, two longitudinal cracks were observed, each spaced about one quarter to one third of the channel width from the channel banks. When the melt-out front reached this ice, the ice generally melted in place, although the front transported some small percentage of the ice cover downstream.



Figure 34. Ice cover upstream of the 115th St. Bridge after passage of the IRW. Note portions near banks flooded and central longitudinal crack.

4.6.1.2 Immediately downstream of the Ferguson St. Bridge

A large depression covering the width of the Willow Creek channel and having strong downstream control existed in this location. This reduced the flow velocity in this reach and provided a location where slush ice could accumulate. A hanging dam-type ice formation formed and grew at this location. When the melt-out front reached this location, the hanging dam melted in place although the front transported a small percentage of the ice cover downstream. Figure 35 displays the steps in the evolution of the floating ice at this location. This ice cover did cause the upstream water levels to rise but did not produce any out of bank flooding.



Figure 35. Evolution of the hanging ice dam immediately downstream of the Ferguson Bridge.

4.6.1.3 The check dam

A rock check dam extends across the entire width of Willow Creek about 0.4 miles upstream of the Bifurcation. This check dam raises the upstream water level about 3 ft. Floating slush ice accumulated upstream of the check dam, and accumulation extended upstream about 0.25 miles (Fig. 36). This ice melted in place when the melt-out front reached this location.



Figure 36. Ice cover in place upstream of the check dam (looking upstream).

4.6.1.4 *The siphon*

Slush ice accumulated at the siphon when the IRW first inundated the siphon passage (Fig. 37). No ice was observed to exit the siphon for approximately 10 to 15 min after the IRW reached this location. After this time, slush ice appeared to transit the siphon without difficulty and not to accumulate further.



Figure 37. Ice upstream of the siphon.

4.6.1.5 *The mouth of Willow Creek at the Snake River*

Immediately after the arrival of the IRW, a large snow drift located immediately downstream of the weir crest located at the downstream end of Willow Creek impeded the passage of water out of the Willow Creek Out-flow Channel into the Snake River. This snow drift took almost an hour to erode away even though the flow dropped from the weir crest directly onto the drift at high velocity. It is likely that while the drift was in place, it increased upstream water levels.

At the time of the Release Test, a competent, intact, and level ice cover that extended from bank to bank and for a considerable distance upstream and downstream covered the Snake River. The flow from Willow Creek out onto the Snake River ice cover went through several stages. Initially, the water flowed out over the Snake River and inundated a wide area reaching past the center of the channel and for some distance up and downstream. The flow then apparently found (or created) several passages through the ice cover, and the inundated area was reduced in size. Eventually, the inundated area was reduced to an area located right at the mouth of the Out-flow Channel (Fig. 38). When the melt-out front reached the mouth, it melted out a relatively compact opening in the Snake River ice cover immediately at the mouth of Willow Creek. Following this, all the flow passed through this opening.



Figure 38. Willow Creek flow through Snake River ice cover, 12 February 2012 at 1630.

4.6.2 Melt-out phase

The melt-out phase began immediately downstream of Ririe Dam at the start of the Release Test. The melt-out phase describes all reaches of the channel upstream of the melt-out front defined by the 32°F (0°C) water temperature isotherm. The rate of advance of the melt-out front depended on the outflow rate, the outflow water temperature, the amount of snow and ice in the channel, and the rate of heat transfer to the air. The more snow and ice in the channel and the greater the heat loss to the atmosphere, the slower the melt-out front would advance downstream. It is possible that if the air temperatures were cold enough or the reservoir temperatures were cold enough, the melt-out front would stop advancing downstream and could even retreat.

Table 6 provides a summary of the data describing the advancement of the melt-out front down the channel and Figure 32 displays the melt-out front advancement. The melt-out front advanced slowly in the upstream canyon section of the natural channel sub-reach of Willow Creek where the rate of progress was roughly 0.32 fps. This slow rate probably reflected the balance between the heat released by Ririe Dam and heat either absorbed by

the melting ice cover (measured at 16 in. thick) or lost to the cold air above. Observations of the ice cover on 12 February in this section indicated that the ice cover was in fact melting out. When the 32°F (0°C) water temperature isotherm reached the Floodway Channel, its advance rate was generally faster. This reflected the fact that the snow cover in place represented less ice to melt, and the air temperatures were generally warmer during this period. Images taken of the Willow Creek channel after the completed Release Test confirm that the snow and ice in the channel had indeed melted out by the end of the Release Test (Fig. 39 and 40).

Table 6. Summary of melt-out front advance.

Distance (ft)	Location	Arrival Date Time	Total Travel Time	Average Velocity (fps)	Velocity (Between sites)
119,880	Ririe Dam	2/10/2013 at 1440	0 hr		
64,700	N 95 th E	2/12/2013 at 1410	47 hr 30 min	0.32	0.32
33,020	55 th St. Bridge	2/12/2013 at 2120	54 hr 40 min	0.44	1.23
22,430	Highway 42 Bridge	2/12/2013 at 2240	56 hr 00 min	0.48	2.21
11,850	15 th St. Bridge	2/12/2013 at 2350	57 hr 10 min	0.52	2.52
6520	5 th St. East Bridge	2/13/2013 at 0130	58 hr 50 min	0.54	0.89
80	Mouth	2/11/2013 at 0145	59 hr 15 min	0.56	0.32



Figure 39. Looking upstream from the 115th St. Bridge after the Release Test. (Image by P. Cooper.)



Figure 40. Looking upstream from the mouth of the Floodway Channel after the Release Test. (Image by P. Cooper.)

5 Comparison with the 2011 Release

In February 2011, there was an Operational Release from Ririe Dam to bring the reservoir contents back down below the winter flood control rule curve (Cooper 2013). This release occurred from approximately 07 February 2011 until 09 February 2011 (Swenk 2011). The test began at 2200 on 7 February 2011 with a step increase out of Ririe Dam of 150 cfs. This outflow was held constant until 1245 on 8 February 2011 when the outflow was increased to approximately 240 cfs. This flow was held constant until 1400 on 9 February 2011 when the outflow was shut off. The release flow was suspended because flooding occurred in Floodway Channel of the Willow Creek. It is interesting to compare the 2011 experience with the 2013 experience to gain insight into the possible causes of the flooding in 2011.

Not all of the data available in 2013 is available for the 2011 release. The water temperature in Ririe Reservoir was not measured prior to the release. In fact, the Ririe Reservoir temperature is not routinely measured in the winter; and the 2012–2013 winter measurements are unique. No record is available of the snow and ice conditions in Willow Creek before the 2011 release. The USGS gages did not record water temperature, and only daily discharges are available for the period of the release. The daily air temperature record from the Idaho Falls Municipal Airport for both years is available from the NWS. Figure 41 shows the air temperature record for each winter season. These records are very similar overall. Table 7 lists the daily maximum and minimum temperatures during the days of the tests. In 2011, the air temperature was quite low (-14.1°F [-25.6°C]) on the day the release flow was shut off (9 February 2011).

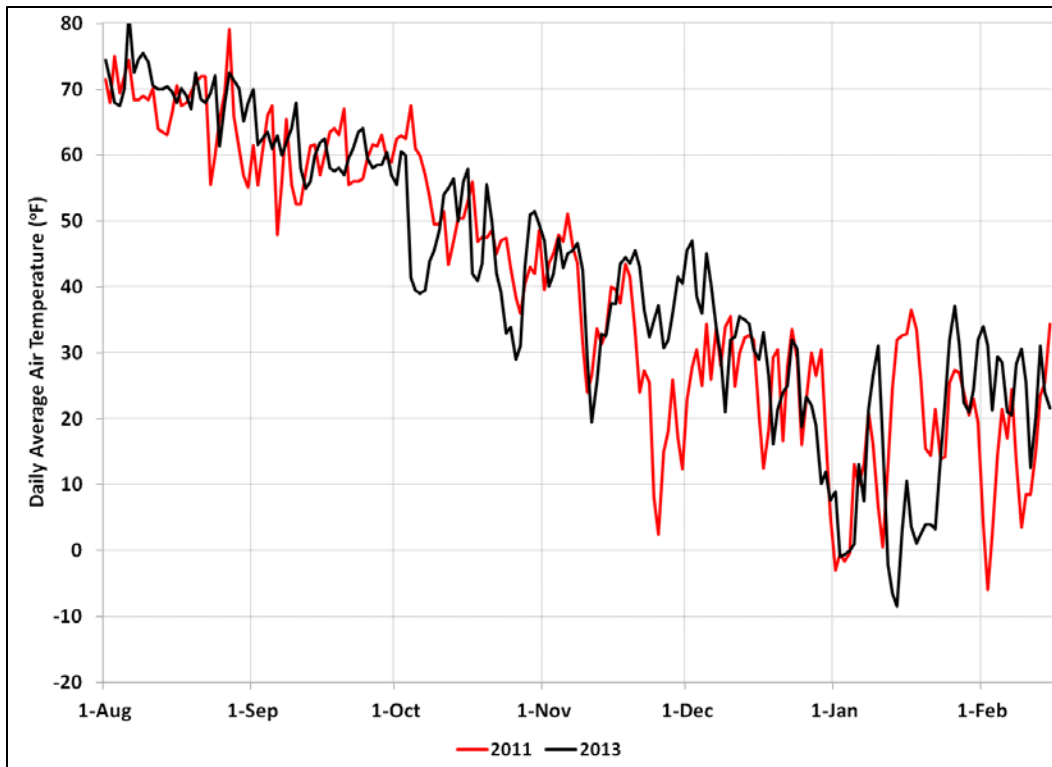


Figure 41. Daily average air temperatures leading up to the releases of 2011 and 2013.

Table 7. Comparison of daily maximum and minimum temperatures in 2011 and 2013.

Day of Release	Date 2013	Daily Max Temp. (°F)	Daily Min Temp. (°F)	Date 2011	Daily Max Temp. (°F)	Daily Min Temp. (°F)
-2	2/8/2013	35.6	21.0	2/5/2011	27.0	16.0
-1	2/9/2013	35.1	26.1	2/6/2011	25.0	9.0
1	2/10/2013	32.0	19.0	2/7/2011	30.9	18.0
2	2/11/2013	28.0	-2.9	2/8/2011	27.0	0.0
3	2/12/2013	30.0	10.4	2/9/2011 (Release shutoff)	21.0	-14.1
4	2/13/2013	35.6	26.6	2/10/2011	18.0	-0.9

Figure 42 shows the discharge records from Ririe Dam in 2011 and 2013. These discharge records are very similar in both years as there was no release from the dam after mid-November in either year.

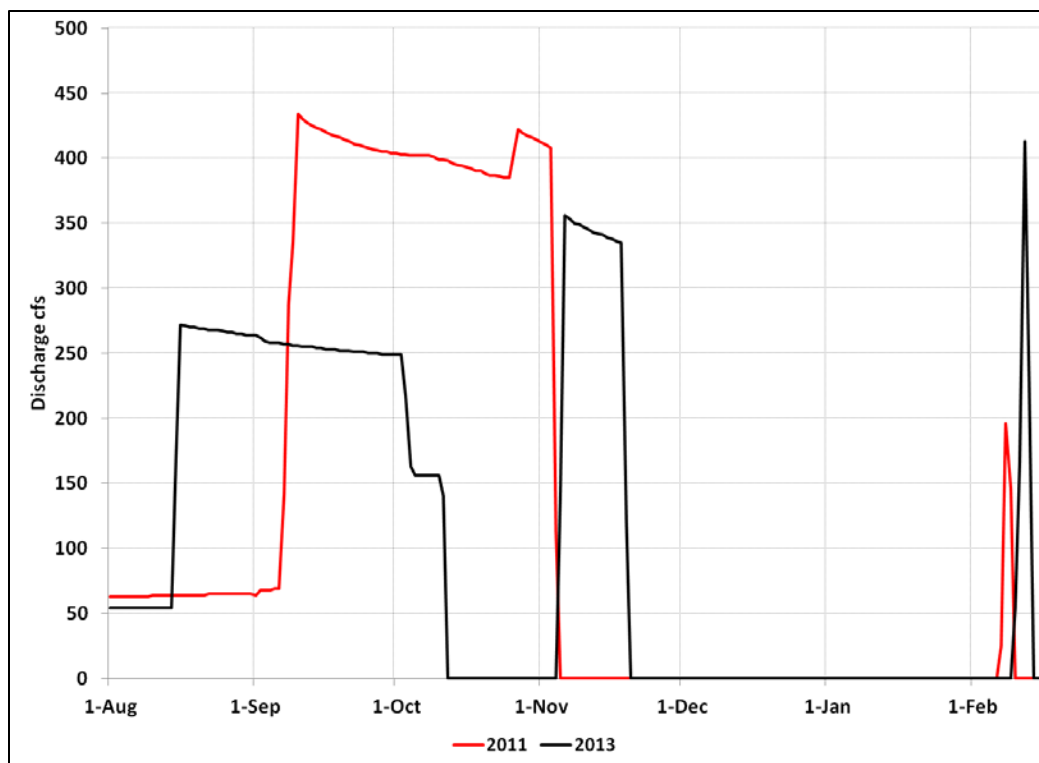


Figure 42. Daily discharge from Ririe Reservoir during the fall and winter of 2010–2011 and 2012–2013 leading up to the releases.

The IRW traveled at roughly the same speeds each year. The total travel time in 2013 was 22 hr and 55 min. In 2011 it is estimated to have taken between 23 hr and 26 hr (Table 8).

The major difference between 2011 and 2013 is probably the amount of snow in the channel prior to the releases. Unfortunately, there were no measurements of the snow conditions prior to the 2011 release. However, there are images of the snow remaining in the channel after the releases drained out in 2011 (Fig. 43) (Cooper 2013). These images show a relatively large blockage of snow following the release at the 25th St. Bridge.

Table 8. Comparison of Initial Release Wave propagation in 2011 and 2013.

Distance (ft)	Location	Arrival 2013 Date Time	Total Travel Time 2013	Arrival 2011 Date Time.	Total Travel Time 2011
119,880	Ririe Dam	2/10/2013 at 1420	0 hr	2/7/2011 at 2200	
84,480	115 th St. Bridge			2/8/2011 at 0600	8 hr
74,700	Ferguson Bridge	2/11/2013 at 0030	10 hr 10 min	2/8/2011 at 0910	11 hr 10 min
40,900	Bifurcation	2/11/2013 at 0910	18 hr 50 min	2/8/2011 at 1555	17 hr 55 min
80	Mouth	2/11/2013 at 1315	22 hr 55 min	2/8/2011 at 2100–2400 (estimated)	23–26 hr



Figure 43. Snow remaining in Floodway Channel at 25th St. Bridge following the release in 2011 (looking downstream). (Image by P. Cooper.)

6 Discussion of 2013 Results

6.1 Channel conveyance

The natural sections and the Floodway section of Willow Creek have adequate conveyance to pass the required flows during the open water season when snow and ice is not present. An important finding from the 2013 Release Test was that the snow in the channel prior to the Release Test was not significantly removed, dislodged, or eroded away by the IRW or subsequent flow. The snow was melted out only after the thermal melt-out front had advanced downstream the length of the Willow Creek channel. This front advanced relatively slowly—it took over 59 hr for the front to reach the mouth of Willow Creek. The snow in place prior to the thermal melt-out front arrival can significantly impact the channel conveyance. It can affect the conveyance by changing the channel effective roughness and by blocking a portion of the channel cross section. It is thought that the snow acted to reduce the effective hydraulic roughness of the channel during the Release Test, especially in the Floodway Channel, which is lined with stone riprap. The riprap was essentially buried in snow on the south side of the channel, and the snow presented a much smoother surface. In this Release Test, the area blocked by snow did not cause significant blockages. Table 9 lists the area blocked by snow in each surveyed cross section. The net effect of these blockage patterns was to raise the water level in the channel about 0.5 ft to 1.0 ft. The channel was not significantly blocked above these heights. At a height of about 4.5 ft, the approximate height at the maximum discharge of 500 cfs, less than 25% of the channel cross sectional area was blocked. Half of the surveyed sections had 15% or less of their cross sectional area blocked by snow at these stage heights. The net impact was to raise the stage and probably to increase the flow velocity.

Table 9. Percentage of each surveyed cross section area blocked by snow with height above the channel invert.

Distance (ft)	Location	% Blocked at Height above Channel Invert (ft)									
		.5	1.0	1.5	2.0	2.5	3	3.5	4.0	4.5	5.0
84,480	115 th St. Bridge	100	70	47	35	27	22	20	19	17	15
64,700	N 95 th E	41	22	16	13	13	10	9	8	7	6
47,500	N 85 th E	99	97	82	58	45	36	31	27	24	21
40,900	Bifurcation	97	58	39	29	23	19	17	15	13	12
36,000	USGS gage	93	62	43	32	26	22	20	18	17	16
33,020	55 th St. Bridge	100	93	66	50	40	33	29	26	24	23
22,430	Highway 42 Bridge	97	52	38	29	24	20	17	15	13	12
11,850	15 th St. Bridge	100	76	54	40	32	28	24	21	18	16
	5 th St. W Bridge	87	42	30	29	24	18	14	13	11	9
80	Mouth	100	70	47	35	27	22	20	19	17	15

A significant portion of the Outflow Channel cross section was apparently blocked by snow during the 2011 release (Fig. 43). The impact of this blockage would be to significantly increase the water stage and to significantly reduce the flow velocity in the reach immediately upstream of the blockage. This would allow the section with low velocity to collect slush ice that was carried downstream by the flow. In these slow-flowing reaches, the flow area could be blocked by slush, further increasing the upstream stages. Apparently this combination of snow blockage and ice buildup was sufficient to cause out-of-channel flooding in 2011.

6.2 Ice transport

Ice transport describes the ability of the channel flow to carry ice downstream. Slush ice was visible in Willow Creek during the 2013 release as soon as the IRW propagated down the channel. Changes in channel slope, sharp bends, bridge piers, islands, bars, and other obstacles to flow can significantly affect ice transport. There are few of these conditions in Willow Creek. The slush ice formed in the channel had little strength or cohesion and was easily transported downstream. However, the slush transport is sensitive to the flow velocity of the channel. As mentioned above, in 2013, the ice collected at three locations: the Ferguson Bridge; the check dam upstream of the Bifurcation; and to a lesser extent, at the Siphon. In the case of the Ferguson Bridge, a large, pre-existing depression in the channel caused a low velocity section where the slush collected. In the case of the check dam, the dam raised upstream water levels enough that the slush ice could collect in the reach immediately upstream of the dam. At

the siphon, the slush ice collected at the upstream face of the siphon until the head had risen sufficiently to transport the slush through the siphon. Any channel obstacle, such as snow filling the channel, that impacts the flow velocity has the potential of reducing ice transport and of causing the buildup of slush ice. The buildup of slush will adversely impact upstream stages.

7 Recommendations for Future Wintertime Releases

7.1 Pre-release

- Downstream of outfall structures, remove snow drifts that can increase upstream stages over and above the stage created by the outfall structure weir.
- Throughout the Floodway Channel, remove snow drifts that are substantially blocking the channel and could significantly increase upstream stages.
- Survey representative cross sections for snow distribution, depth, and density.
- Develop a plan for removing ice blockage from the siphon during the release. This may include pre-placement of ice clearing apparatus.
- Calibrate USGS temperature gages and install a water temperature gage at USGS gage 13058520 WILLOW CREEK FLOODWAY CHANNEL NR UCON ID.
- Determine reservoir temperature prior to release.

7.2 Wave propagation and ice and water flow

- Monitor release wave propagation.
- With set alarm levels, continuously monitor water level upstream of the siphon.
- Periodically monitor ice conditions at the check dam, Ferguson Bridge, Snake River, and other locations as required
- Note and record the location and time of all snow and ice blockages that significantly increase the upstream stage.

7.3 Ice melt-out and ice-free flow

- Monitor the advance of the ice melt-out front and the ice-free flow.
- Once the flow is ice free, discontinue monitoring unless the air temperature becomes frigid ($<0^{\circ}\text{F}$ [-17.8°C]).

7.4 Post-release

Submit report including the following information:

- Discharge record at USGS gages over the entire period of the release.
- Temperature record at USGS gages over the entire period of the release.
- Air temperatures over the entire period of test.
- Pre-release snow and ice conditions in the channel.
- Observations made during and after the release wave advance.
- Ririe Reservoir water temperature.
- Descriptions of the location and time of all snow and ice blockages that significantly increase the upstream stage. Include steps taken to counteract.
- Performance of the siphon under ice conditions

7.5 General recommendations

- Survey cross sections at representative locations of Outflow Channel, with particular attention to vertical control, to improve application of hydraulic models.
- Maintain long term record of Ririe Reservoir water temperatures.
- Investigate the impact of fall season recharge releases on the winter-time ice conditions in Willow Creek and in the Floodway Channel.

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Appendix A: Summary of Field Observations

Table A1. Observations made on 10 February 2013.

Time	Location Notes	HEC-RAS Location	Station (ft)	Observation	Notes
1420	Ririe Dam	Ririe Dam	119,880	Gates opened and initial release started.	
1455	115 th St. Bridge	N 115 th E	84,480	No flow. Ice in channel upstream of bridge.	
2220	115 th St. Bridge	N 115 th E	84,480	Flow reached bridge before this time.	16° F air temperature.

Table A2. Observations made on 11 February 2013.

Time	Location Notes	HEC-RAS Location	Station (ft)	Observation	Notes	Travel Time* (sec)	Vel.** (fps)
0030	Ferguson Bridge	Ferguson Rd	74,700	Release wave arrived			
0710	Bifurcation	Bifurcation	40,900	Dry channel			
0720	85 th St. Bridge	N 85 th E	47,500	Dry channel			
0730	95 th St. Bridge	N 95 th E	64,700	Steady flow			
0735	Ferguson Bridge	Ferguson Rd	74,700	Steady flow	Hanging dam immediately downstream of bridge. White "hump" forming as we watched. No slush visible leaving hanging dam. Slush arriving from upstream.		
0800	115 th St. Bridge	N 115 th E	84,480	Steady flow	No slush. Dendrites growing out from shore.		
0910	Bifurcation	Bifurcation	40,900	Release wave arrived			
0935	26 th St. Highway Bridge	26/20	37,700	Release wave arrived		34.32	2.91
1002	55 th St. Bridge	N 55 th E	33,020	Release wave arrived			
1033	45 th St. Bridge	N 45 th E	27,780	Release wave arrived			
1103	Highway 42 Bridge	YS/Rt 43	22,430	Release wave arrived			
1125	25 th St. Bridge	N 25 th E	17,010	Release wave arrived			
1155	15 th St. Bridge	N 15 th E	11,850	Release wave arrived		31.18	3.21

Time	Location Notes	HEC-RAS Location	Station (ft)	Observation	Notes	Travel Time* (sec)	Vel.** (fps)
1224	5 th St. East Bridge	N 5 th E	6520	Release wave arrived		35.94	2.78
1246	Siphon	Siphon	3100	Release wave arrived	Siphon filled with slush before slush was observed to pass through.		
?	Outfall structure	Outlet	2		Snow drift downstream of outfall raised water level.		
1500	45 th St. Bridge	N 45 th E	27,780	Steady flow	Slush on surface.		
1515	Ferguson Bridge	Ferguson Rd	74,700	Steady flow	Hanging dam and freeze up jam downstream of bridge.		
1530	115 th St. Bridge	N 115 th E	84,480	Steady flow	Upstream ice still in place. Single crack down center of channel with flooded edges along shore.		
1620	Bifurcation	Bifurcation	40,900	Steady flow.	Slush cover 10% to 15% of surface.		

*Time for object floating at surface to travel 100 ft.

**Estimated surface velocity.

Table A3. Observations made on 12 February 2013.

Time	Location Notes	HEC-RAS Location	Station (ft)	Observation	Notes	Travel Time* (sec)	Vel.** (fps)
0715	115 th St. Bridge	N 115 th E	84,480	Steady flow	Ice cover upstream still in place. Outer $\frac{1}{3}$ of ice cover flooded. Water turbid.		
0739	Ferguson Bridge	Ferguson Rd	74,700	Steady flow	Slush on surface. Hanging dam in place. Ice floes going under and out of hanging dam. Water turbid.		
0754	Bifurcation	Bifurcation	40,900	Steady flow	Some slush on surface. Water turbid.		
0806	Check dam u/s Bifurcation	Rock Check Dam	44,590	Ice cover in place upstream of check dam	Check dam located 0.4 miles upstream of bifurcation.		
0825	Control Structure	Willow Creek Structure	36,180	Steady flow	Small amount of slush. Water turbid.		
0838	45 th St. Bridge	N 45 th E	27,780	Steady flow	Small amount of slush. Water turbid.		

Time	Location Notes	HEC-RAS Location	Station (ft)	Observation	Notes	Travel Time* (sec)	Vel.** (fps)
0903	15 th St. Bridge	N 15 th E	11,850	Steady flow	Water turbid	12.89	7.76
0911	5 th St. East Bridge	N 5 th E	6520	Steady flow	Slush on surface.	16.97	5.89
0920	Siphon	Siphon	3100	Steady flow	Some slush on surface. Water turbid.	14.36	6.96
0930	Outfall structure	Outlet	2	Steady flow	Some slush on surface. Water turbid. Water has found route through Snake River ice cover. Snake River ice cover discolored downstream.		
1043	115 th St. Bridge	N 115 th E	84,480	Steady flow	No slush. 21° F air temperature.		
1135	115 th St. Bridge	N 115 th E	84,480	Steady flow	Melt-out of ice cover observed. All ice gone from about ½ mile upstream of bridge.		
1255	Ferguson Bridge	Ferguson Rd	74,700	Steady flow	Leading edge of hanging dam worn away. Upstream stage dropped 12-18 in. By 1345, hanging dam broken up and largely transported downstream.		
1347	95 th St. Bridge	N 95 th E	64,700	Steady flow	Ice from broken up hanging dam. 10% of surface covered by ice		
1402	85 th St. Bridge	N 85 th E	47,500	Steady flow	Moderate amount of ice coming downstream. Snow on right bank under water immediately downstream of bridge.		
1422	Check dam u/s Bifurcation	Rock Check Dam	44,590	Steady flow	Slush coming downstream. Ice jam remains in place. Slush passing through.		
1512	Outfall structure	Outlet	2	Steady flow	Flow going directly through Snake River ice cover.		

*Time for object floating at surface to travel 100 ft.

**Estimated surface velocity.

Appendix B: Summary of Ice Observations

115 th St. Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1530	u/s bend above cable bridge	80	Upstream ice still in place. Single crack down center of channel with flooded edges along shore.	Daly
2/11/2013	1549	u/s bend above cable bridge	85	Solid ice cover with crack along centerline. Some flow and melt-out along banks.	Carr
2/12/2013	715	u/s bend above cable bridge	60	Ice cover upstream still in place. Outer $\frac{1}{3}$ of ice cover flooded. Water turbid.	Daly
2/12/2013	916	u/s bend above cable bridge	60	Solid ice cover with crack along centerline. Thinning along banks. More flow and melt-out along banks.	Carr
2/12/2013	929	u/s bend above cable bridge	50	Ice along centerline with crack.	Cooper
2/12/2013	1117	u/s bend above cable bridge	50	Solid ice cover with one or two cracks along center. More transparent	Carr
2/12/2013	1121	u/s bend above cable bridge	0	Cover released in large floes. Moved downstream.	Carr
2/12/2013	1135	u/s bend above cable bridge	0	Melt-out of ice cover observed. All ice gone from about $\frac{1}{2}$ mile upstream of bridge.	Daly
2/11/2013	1543	u/s at ditch confluence	70	Solid ice along center of channel.	Carr
2/12/2013	716	u/s at ditch confluence	70	Solid ice along center of channel with streamwise crack. Flow along bank.	Carr
2/12/2013	1241	u/s at ditch confluence	35	Long free floes, paired along old central crack.	Carr
2/11/2013	1544	u/s at cable bridge	90	Solid ice cover with some flow along banks.	Carr
2/11/2013	1546	u/s at cable bridge	80	Cracked ice cover down center. Flow along banks.	Carr
2/10/2013	1455	u/s at cable bridge	100	Ice in channel upstream of bridge.	Daly
2/11/2013	800	u/s	0	No slush. Dendrites growing out from shore.	Daly
2/11/2013	1138	u/s	0	No slush.	Cooper
2/11/2013	1611	u/s	10	Little shore ice.	Carr

115 th St. Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/12/2013	733	u/s	0	Open water.	Carr
2/12/2013	1036	u/s	0	No slush.	Cooper
2/12/2013	1043	u/s	0	No slush. 21 ° F air temperature.	Daly
2/12/2013	1110	u/s	0	No slush.	Cooper
2/12/2013	1230	u/s	40	Large free floes, about stream width in long dimension.	Carr
2/13/2013	945	u/s	0	No slush.	Cooper
2/15/2013	2031	u/s	0	No ice/slush.	Cooper
2/11/2013	1138	d/s	0	No slush.	Cooper
2/12/2013	1036	d/s	0	No slush.	Cooper
2/12/2013	1236	d/s	5	Minor ice floes.	Cooper
2/12/2013	1245	d/s	0	No slush.	Cooper
2/13/2013	945	d/s	0	No slush.	Cooper
2/15/2013	2031	d/s	0	No ice/slush.	Cooper

Ferguson Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/10/2013	2225	u/s	5	Ice floes and water begin to arrive.	Carr
2/11/2013	1121	u/s	10	New shore ice.	Cooper
2/11/2013	1441	u/s	10	Shore ice.	Cooper
2/11/2013	1523	u/s	15	Shore ice on right bank, slush.	Carr
2/12/2013	744	u/s	20	Shore ice extended out from right bank around bend, slush.	Carr
2/12/2013	913	u/s	15	Shore ice, minor slush along thalweg.	Cooper
2/12/2013	1248	u/s	5	Almost no shore ice; almost no slush.	Cooper
2/13/2013	935	u/s	0	No ice.	Cooper
2/15/2013	2036	u/s	0	Shore ice, bits of slush.	Cooper
2/11/2013	735	d/s	80	Hanging dam immediately downstream of bridge. White "hump" forming as we watched. No slush visible leaving hanging dam. Slush arriving from upstream.	Daly
2/11/2013	1122	d/s	80	Hanging dam.	Cooper
2/11/2013	1442	d/s	85	Hanging dam.	Cooper
2/11/2013	1515	d/s	90	Hanging dam and freeze-up jam downstream of bridge.	Daly
2/11/2013	1523	d/s	90	Hanging dam, some flow around left bank, and open water just under bridge.	Carr
2/12/2013	739	d/s	0	Slush on surface. Hanging dam in place. Ice floes going under and out of hanging dam. Water turbid.	Daly
2/12/2013	743	d/s	100	Hanging dam.	Carr

Ferguson Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/12/2013	913	d/s	100	Hanging dam.	Cooper
2/12/2013	1245	d/s	75	Hanging dam, broken up at u/s end.	Cooper
2/12/2013	1255	d/s	75	Leading edge of hanging dam worn away (1245). Upstream stage dropped 12-18 in. By 1345, hanging dam broken up and largely transported downstream.	Daly
2/12/2013	1259	d/s	75	Hanging dam, broken up at u/s end.	Carr
2/12/2013	1313	d/s	70	Hanging dam, broken up at u/s end.	Cooper
2/12/2013	1320	d/s	65	Hanging dam, broken up at u/s end.	Cooper
2/12/2013	1327	d/s	60	Hanging dam, broken up at u/s end, flow around right bank.	Cooper
2/12/2013	1328	d/s	50	Hanging dam breaking up; solid circle visible.	Carr
2/12/2013	1332	d/s	60	Hanging dam, broken up at u/s end, flow around left bank, mid-size flows arriving from upstream, going under cover.	Cooper
2/12/2013	1342	d/s	20	Hanging dam broken up all but at toe of jam.	Cooper
2/13/2013	938	d/s	0	No ice.	Cooper

95 th St. Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1402	u/s	10	Shore ice, slush along thalweg.	Cooper
2/12/2013	1347	u/s	10	Ice from broken up hanging dam. 10% of surface covered by ice.	Daly

85 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	746	u/s	0	Flow arrives.	Carr
2/11/2013	1108	u/s	5	A small amount of slush moving d/s on right, submerged snowbank on left, eddy causing upstream flow upstream of snowbank.	Cooper
2/12/2013	1402	u/s	20	Some medium sized floes moving downstream along left bank.	Carr
2/12/2013	1402	u/s	20	Moderate amount of ice coming downstream. Snow on right bank under water immediately downstream of bridge.	Daly

Rock Check Dam above Bifurcation					
Date	Time	Location	% Ice Cover	Description	Source
2/12/2013	806	u/s	85	Ice cover in place upstream of check dam.	Daly
2/12/2013	810	u/s	85	Snow/ice/slush piled up upstream of dam.	Carr
2/12/2013	1214	u/s	80	Snow/ice/slush piled up upstream of dam.	Carr
2/12/2013	1356	u/s	80	Snow/ice/slush piled up upstream of dam.	Cooper
2/12/2013	1422	u/s	80	Slush coming downstream. Ice jam remains in place. Slush passing through.	Daly

Bifurcation					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	910	u/s	0	Release wave arrived.	Daly
2/11/2013	924	u/s	5	Very little slush.	Carr
2/11/2013	1507	u/s	45	Heavy slush.	Cooper
2/11/2013	1620	u/s	15	Slush cover 10% to 15% of surface.	Daly
2/12/2013	754	u/s	5	Some slush on surface. Water turbid.	Daly
2/12/2013	759	u/s	10	Shore ice on left bank, small amount of slush.	Carr
2/12/2013	1208	u/s	35	Shore ice on left bank, further into flow, small amount of slush.	Carr
2/12/2013	1420	u/s	30	Shore ice on left bank, slush.	Cooper
2/13/2013	926	u/s	0	No slush.	Cooper
2/12/2013	1208	d/s	50	Submerged snow, anchor ice.	Carr
2/12/2013	1420	d/s	15	Slush.	Cooper
2/13/2013	926	d/s	0	No slush.	Cooper

Willow Creek Control Structure					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1109	u/s	0	No slush, no flow.	Carr
2/12/2013	825	u/s	5	Small amount of slush. Water turbid.	Daly
2/12/2013	831	d/s	0	No slush.	Carr

55 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1002	u/s	0	Release wave arrived.	Daly
2/12/2013	1428	u/s	10	Small amounts of slush.	Cooper
2/12/2013	1427	d/s	5	Small amounts of slush.	Cooper

45 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1033	u/s	0	Release wave arrived.	Daly
2/11/2013	1038	u/s	20	Medium slush, eddy on right bank.	Carr
2/11/2013	1041	u/s	40	Heavy slush.	Cooper
2/11/2013	1500	u/s	20	Slush on surface.	Daly
2/12/2013	838	u/s	10	Small amount of slush. Water turbid.	Daly
2/12/2013	841	u/s	5	Almost no slush.	Carr
2/12/2013	1431	u/s	5	Minimal slush.	Cooper
2/11/2013	1040	u/s	30	Heavy slush, some small floes.	Carr
2/11/2013	1508	d/s	20	Rafted slush.	Carr

35 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1103	d/s	0	Release wave arrived.	Carr
2/12/2013	1441	d/s	10	Small submerged floes.	Cooper

25 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1125	u/s	0	Release wave arrived.	Daly
2/11/2013	1137	u/s	80	Heavy slush.	Carr
2/11/2013	1200	u/s	70	Heavy slush.	Cooper
2/12/2013	1449	u/s	50	Shore ice near bridge; medium size submerged floes.	Cooper
2/11/2013	1200	d/s	60	Heavy slush, smaller pieces than upstream.	Cooper
2/11/2013	1415	d/s	40	Smaller slush, shore ice at level slightly above water surface.	Cooper

15 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1155	u/s	0	Release wave arrived.	Daly
2/11/2013	1205	u/s	90	Heavy slush, building up in eddies on u/s side of bridge.	Cooper
2/12/2013	903	u/s	0	Water turbid.	Daly
2/11/2013	1201	d/s	70	Heavy slush.	Carr

5 th St Bridge					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1224	u/s	0	Release wave arrived.	Daly
2/11/2013	1456	u/s	30	Slush chunks.	Cooper
2/12/2013	911	u/s	10	Slush on surface.	Daly
2/12/2013	914	u/s	5	Almost no slush; still somewhat submerged snowbank on left.	Carr

Siphon					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1246	u/s	80	Siphon filled with slush before slush was observed to pass through.	Daly
2/11/2013	1252	u/s	80	Incoming large pieces of slush jamming.	Carr
2/11/2013	1255	u/s	85	Jammed slush.	Cooper
2/11/2013	1350	u/s	65	Shore ice/old jam coming in from both banks; slush moving through small channel.	Cooper
2/11/2013	1530	u/s	45	Old jam almost gone; large slush.	Cooper
2/11/2013	1709	u/s	50	Jammed slush, parts submerged, slug from upstream.	Carr
2/11/2013	1710	u/s	50	Upstream water level has dropped slightly.	Daly
2/12/2013	920	u/s	5	Some slush on surface. Water turbid.	Daly
2/12/2013	922	u/s	5	Little bits of submerged slush.	Carr
2/12/2013	1505	u/s	20	Large chunks of submerged slush.	Carr

Mouth of Outflow Channel					
Date	Time	Location	% Ice Cover	Description	Source
2/12/2013	931	u/s	25	Slush.	Carr
2/11/2013	1247	u/s	0	Flow arrival.	Carr
2/11/2013	1312	u/s	10	Small amount of slush.	Cooper

Mouth of Outflow Channel					
Date	Time	Location	% Ice Cover	Description	Source
2/11/2013	1318	u/s	15	Slush.	Carr
2/11/2013	1338	u/s	80	Heavy slush.	Cooper
2/12/2013	831	u/s	30	Slush, minor shore ice.	Cooper
2/12/2013	1503	u/s	50	Slush rafts.	Cooper
2/12/2013	1515	u/s	35	Slush.	Carr
2/13/2013	854	u/s	0	No slush.	Cooper
2/11/2013	1310	weir	0	Flow arrival.	Carr
2/11/2013	1316	weir	5	Small amount of slush.	Carr
2/11/2013	1323	weir	80	Heavy slush compacted together.	Carr
2/11/2013	1727	weir	30	Slush.	Carr
2/12/2013	930	weir	35	Some slush on surface. Water turbid. Water has found route through Snake River ice cover. Snake River ice cover discolored downstream.	Daly
2/12/2013	931	weir	35	Submerged slush.	Carr
2/12/2013	1512	weir	25	Flow going directly through Snake River ice cover.	Daly

REPORT DOCUMENTATION PAGE

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14. ABSTRACT To potentially increase storage over the winter season, the US Army Corps of Engineers (Corps) Walla Walla District (NWW) is currently evaluating flood control operations at Ririe Reservoir. Because there is little experience with winter releases and a previous winter release resulted in minor flooding, it is important to understand the potential problems associated with releases in these conditions. Therefore, the Corps conducted a Release Test on 10–13 February 2013. Throughout the test, instruments took detailed measurements of the water temperature, stage, and discharge along the Willow Creek channel; and personnel observed the dynamic ice conditions. The test included an initial release of 150 cfs for 28 hr; a rapid increase to 300 cfs, which was held for 14.5 hr; and another rapid increase to 500 cfs, which was held for 24 hr. The flow was then shut off. Neither the Initial Release Wave nor subsequent flow significantly removed, dislodged, or eroded snow in the channel; the snow melted only after a thermal melt-out front advanced downstream. No out-of-bank flooding occurred. As a result of the information gathered from this Release Test and from one in 2011, this report presents a series of recommendations for future wintertime releases.					
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