



**US Army Corps
of Engineers®**

Prepared for the U.S. Army Corps of Engineers, Seattle District,
under an Interagency Agreement with the U.S. Department of Energy
Contract DE-AC05-76RL01830

PNNL-19816

Acoustic Doppler Current Profiler Surveys of Velocity Downstream of Albeni Falls Dam

Final Report

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September 2010



Pacific Northwest
NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The U.S. Army Corps of Engineers (USACE), Seattle District, is studying the potential to locate fish bypass systems at Albeni Falls Dam. The USACE requested Pacific Northwest National Laboratory (PNNL) to survey velocity magnitude and direction in the dam tailrace. The empirical data collected will be used to support future numerical modeling, physical modeling, and evaluation of fish bypass system alternatives.

In May 2010, PNNL conducted velocity surveys of the Albeni Falls Dam using a boat-mounted acoustic Doppler current profiler. The surveys were conducted over three days (May 25 through 27). During the survey period, total river discharge at the dam varied between 30.2 and 31.0 kcfs. A small amount of spill discharge, 2 kcfs, was present on two days (May 26 and 27).

This report presents data plots showing measured velocity direction and magnitude averaged over the entire depth and over 5-ft depth increments from 5 to 30 ft.

Acknowledgments

The authors thank Pat Wheeler of the USACE Seattle District for valuable assistance in project planning and implementation. We also thank PNNL staff Lori Ortega for taking video during the survey, and Andrea Currie for editing this report.

Abbreviations

ADCP	acoustic Doppler current profiler
BRZ	boat-restricted zone
CFD	computational fluid dynamics
GPS	Global Positioning System
ft	foot, feet
ft/s	feet per second
kcfs	thousand cubic feet per second
kHz	kilohertz
m	meter(s)
min	minute(s)
PNNL	Pacific Northwest National Laboratory
s	second(s)
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

The U.S. Army Corps of Engineers (USACE), Seattle District, has been researching the feasibility of constructing a fish passage facility at Albeni Falls Dam to allow passage of threatened bull trout *Salvelinus confluentus*, species of concern westslope cutthroat trout *Oncorhynchus clarki lewisi*, and other native species to historically contiguous habitats (Bellgraph et al. 2010). Albeni Falls Dam is situated on the Pend Oreille River upstream of the town of Newport, Washington, inside the Idaho state border (Figure 1). This dam regulates the water surface elevation of Lake Oreille. Currently, no facilities enable bull trout and other species downstream of the dam to return upstream and reach potential natal streams such as the Priest River and its tributaries or Lake Pend Oreille and its tributaries. Bull trout hatch and spend one to three years as juveniles, within their natal streams, before traveling downstream to mature in larger bodies of water. When bull trout have reaching adulthood, they migrate back upstream to their original birth streams to spawn. For bull trout and many other migratory fish, their habitat has been fragmented by man-made obstructions that block fish migration.

In 2004, the USACE developed a program to evaluate fish passage alternatives for Albeni Falls Dam and has been investigating different options to construct a facility (GEI Consultants Inc. 2009). To properly select and position fish passage structures, a thorough understanding of water velocity patterns and fine-scale bathymetry is essential through collection of empirical data. The USACE has collected the fine scale bathymetry data thus, requested Pacific Northwest National Laboratory (PNNL) to measure the existing velocity conditions that could aid in the selection of locations and positioning of a fish passage facility.

1.1 Objective

The objective of this task was to measure river velocities across the river channel using a boat-deployed acoustic Doppler current profiler (ADCP) within the Albeni Falls Dam tailrace. The survey was conducted in late spring 2010. The collected data are intended to support the validation of future numerical simulations of the dam tailrace and the evaluation of fish passage alternatives.

1.2 Report Organization

Section 2 provides descriptions of the methods and equipment used to obtain water velocity measurements at each of the two survey sites. The results of each survey are described and discussed, and implications for fish passage presented in Section 3. For ease of viewing, all figures and the table are presented in Section 4. Sources cited in the text are listed in Section 5.

2.0 Methods

Water velocity magnitude and direction were measured by PNNL researchers using an ADCP (Workhorse Sentinel model [1200 kHz, 20 degrees], Teledyne RD Instruments, Poway, California). The ADCP was fastened to a mount fixed to the research vessel. The ADCP was connected directly to a

laptop computer that provided real-time readout of the data as well as saving the data for later analysis. All ADCP data were georeferenced using a portable Global Positioning System (GPS) receiver (Model GeoXT, Trimble Navigation Limited, Sunnyvale, California) with real-time differential correction by radio or by Wide Area Augmentation System satellite. The ADCP collected velocity information at depth and location with WinRiver software (Teledyne RD Instruments). A vertical resolution (bins) of 0.5 m was used. Each velocity measurement collected by the ADCP was composed of several individual acoustic pings, which were combined to form an ensemble average. Averaging the pings together over time decreases the standard deviation of the ensemble in this very turbulent natural system. In turbulent river systems, it is necessary to average the data to characterize the average flow velocity and direction rather than a just a “snapshot.” Two different ADCP instrument settings were used for the measurements at Albeni Falls Dam. The first configuration used eight water and eight river bottom pings to produce an ensemble every 5 s. This velocity collection configuration did not provide a great enough resolution; therefore, a second configuration used two water and two river bottom pings to produce an ensemble every 1 s.

Velocity surveys were conducted daily May 25–27, 2010. Each day, discharge was measured at the beginning and end of the survey by surveying cross-stream transects just below the confluence of the powerhouse and spillway channels. The transect was surveyed twice, and the two estimated discharges (computed by the WinRiver software) were averaged. The remainder of the day was spent surveying nearshore areas in the spillway and powerhouse channels. In addition, several points were surveyed over an extended period (10 to 15 min) while attempting to keep the boat in a single location. The first ADCP configuration (5-s ensembles) was used on May 25 and for discharge measurements on May 26 and 27. After the May 25 survey results were examined, it was determined that a more frequent recording was necessary; the second configuration (1-s ensembles) was used on May 26 and 27. For presentation, measured velocity direction and magnitude were averaged over the entire depth and over 5-ft depth increments from 5 to 30 ft.

3.0 Results, Discussion, and Implications

The operating conditions of Albeni Falls Dam and the measurements of flow depth and velocity collected from May 25 through May 27 were very similar because 2010 was a low-runoff year. The measured dam discharge for all three sampling days is shown in Table 1 along with the posted dam discharges for the survey periods (USACE-WMD 2010). On May 25, only the powerhouse was operating. On May 26, spillbays 9 and 10 were open to produce a total spill of 2.0 kcfs (spillway numbering is shown in Figure 2). Spillbays 1 and 2 were open on May 27, also producing a total spill of 2.0 kcfs (Figure 3). A map of the bathymetry around the dam shows the rapidly varying channel depths upstream and downstream of the dam, which has a strong effect on the velocity distribution (Figure 4).

The velocities and flow conditions for all three days are characterized in the following paragraphs. Depth-averaged velocities for May 25 are shown in Figure 5. A view centered on just the powerhouse channel is shown in Figure 6. Nearshore velocities were generally parallel to the shore and less than 1 ft/s. Higher velocities (3 to 5 ft/s) were present in the powerhouse channel and in the north side of the combined main channel just downstream of the boat-restricted zone (BRZ); the zone is shown in Figure 4. A counterclockwise, low-velocity gyre present in the spillway channel extended downstream into the

main channel past the BRZ. Another relatively large clockwise gyre was present along the north shore of the powerhouse channel upstream of the BRZ (Figure 7). The powerhouse and spillway channel velocities appear to be fully mixed within about one width of the main channel downstream of the BRZ. Velocities at depths of 5, 10, 20, and 30 ft are shown in Figure 8, Figure 9, Figure 10, and Figure 11, respectively. Velocities directly downstream of the powerhouse were very transient and spatially variable in the vertical and cross stream, as evidenced by the large-scale turbulent structures (boils) in Figure 12, Figure 13, and Figure 14.

The depth-averaged velocities measured on May 26 are shown in Figure 15, with a view of the powerhouse channel in Figure 16. Velocity magnitudes on May 26 were similar to those measured on May 25 (Figure 5). However, the addition of spill at the south end of the spillway caused the spillway channel gyre to reverse to a clockwise direction (Figure 17). This could indicate that relatively low spill discharges could be used to control this gyre and serve as attraction flow.

The depth-averaged velocities measured on May 27 are shown in Figure 18, with a view of the powerhouse channel in Figure 19. Velocities recorded on May 27 were similar to those of May 25, but flows are in the opposite direction in a counterclockwise fashion (Figure 20).

The empirical velocities measured in the Albeni Falls Dam tailrace are a first step toward building a computational fluid dynamics (CFD) model to assist in the design phase of a fish passage structure. Currently, the USACE is in the design phase of a prototype fish passage entrance that may be constructed at Albeni Falls Dam by spring 2011 or 2012. This prototype most likely will be located at the downstream left side (facing downstream) of the dam powerhouse because sufficient room exists in this area to build a structure. Further, behavioral data indicate that adult bull trout can access the left powerhouse area of the tailrace during the migration season (Bellgraph et al. 2010). Understanding the flow in and around this to-be-constructed prototype passage entrance and how it will affect flow velocities in the dam tailrace would be the key outputs and benefits of a CFD model. Further, CFD and physical model results could be used to assess variable flow conditions through a passage structure, and data could be used to predict how fish passage behavior may be affected. Empirical data collected during the current study will be critical to evaluating the functionality of a CFD model for the Albeni Falls Dam tailrace.

If the USACE decides to explore additional locations for a fish passage structure entrance (other than the left side of the powerhouse), such as the left or right sides of the spillway, hydraulic characteristics of the spillway tailrace should be considered. As measured on May 26 and 27, spill from bays 9 and 10 or bays 1 and 2 created a gyre that circumscribed the spillway tailrace and extended just downstream of the BRZ. Depending on the amount of flow through these bays, the gyre may increase or decrease in size and may influence fish movements through the spillway tailrace. For example, onset of a gyre created by spill at either side may guide passively migrating fish toward the spillway concrete and along the spillway face, which may increase the potential for fish to discover a passage entrance. Alternatively, spill from the left or right sides of the spillway may create attraction flows for upstream-migrating fish and guide them to the source of this flow.

If the USACE decides to move ahead with either a CFD or physical modeling investigation, PNNL would recommend collecting additional field data to

- Define tailrace bathymetry to approximately 2000–2500 ft downstream of the dam. These data could be collected using a single-beam fathometer and real-time kinematic GPS. This would allow for proper placement of the downstream boundary of the model sufficiently far from the dam.
- Measure velocities for a set of project operations with higher total discharge conditions and larger spill discharge. Model validation typically is done using at least two sets of field data for distinct flow conditions.
- Establish temporary tailwater elevation measurement locations (four to five locations) to provide water surface elevation data for model calibration validation.

4.0 Figures and Table

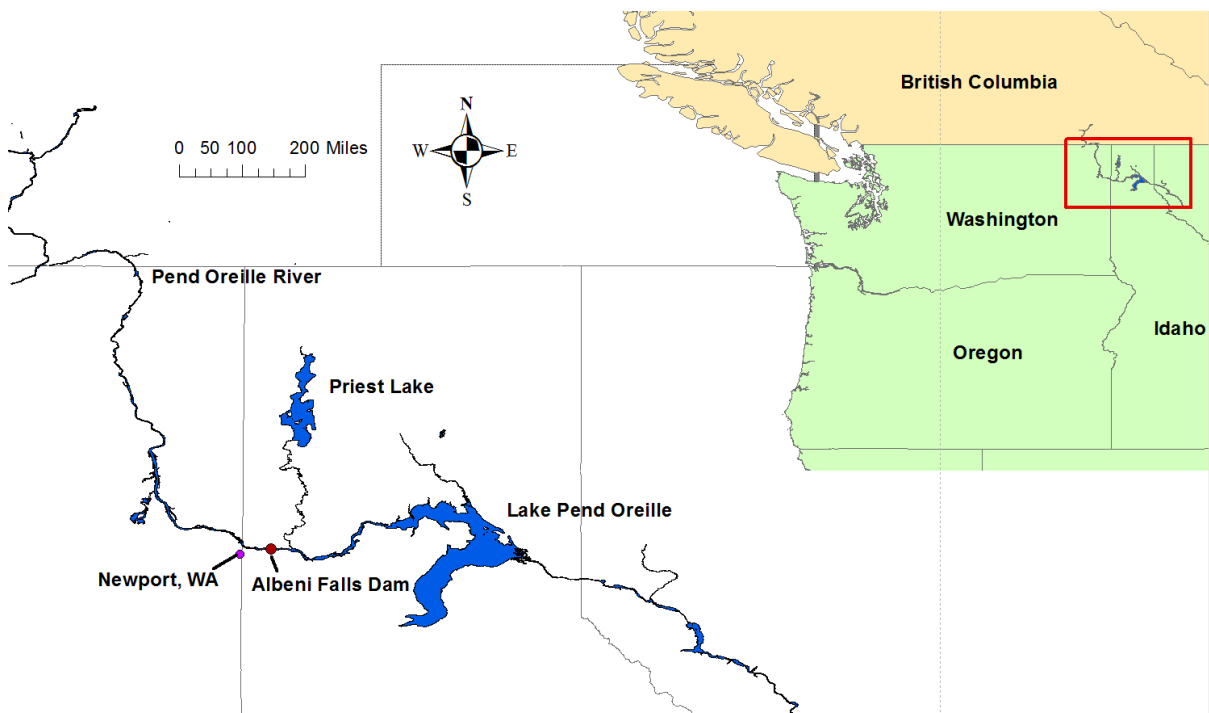
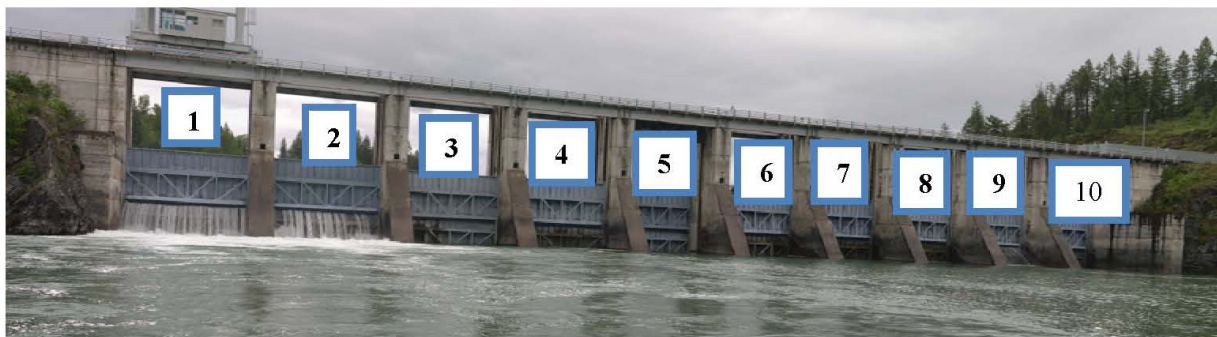


Figure 1. Site location of the Albeni Falls Dam on the Pend Oreille River in northern Washington and Idaho.

Table 1. Summary of river conditions during acoustic Doppler current profiler surveys at Albeni Falls Dam, 2010.

Transect/Survey Date	Total Average Dam Discharge ^(a) (kcfs)	Beginning of Survey Discharge (kcfs)	End of Survey Discharge (kcfs)	Spill Outflow (kcfs)
May 25, 2010	30.1	30.0	31.0	0.0 (No bays)
May 26, 2010	30.2	29.8	30.3	2.0 (Bays 9 & 10)
May 27, 2010	28.9	29.4	30.2	2.0 (Bays 1 & 2)

(a) Discharge data provided by U.S. Army Corps of Engineers, Water Management Division (USACE-WMD), Portland, Oregon.

**Figure 2.** Spillbays 9 and 10 open at Albeni Falls Dam Spillway on May 26, 2010. The PNNL survey boat is at the right side of the photograph.**Figure 3.** Spillbay numbering of Albeni Falls Dam from north (left side of photograph) to south (right side of photograph).

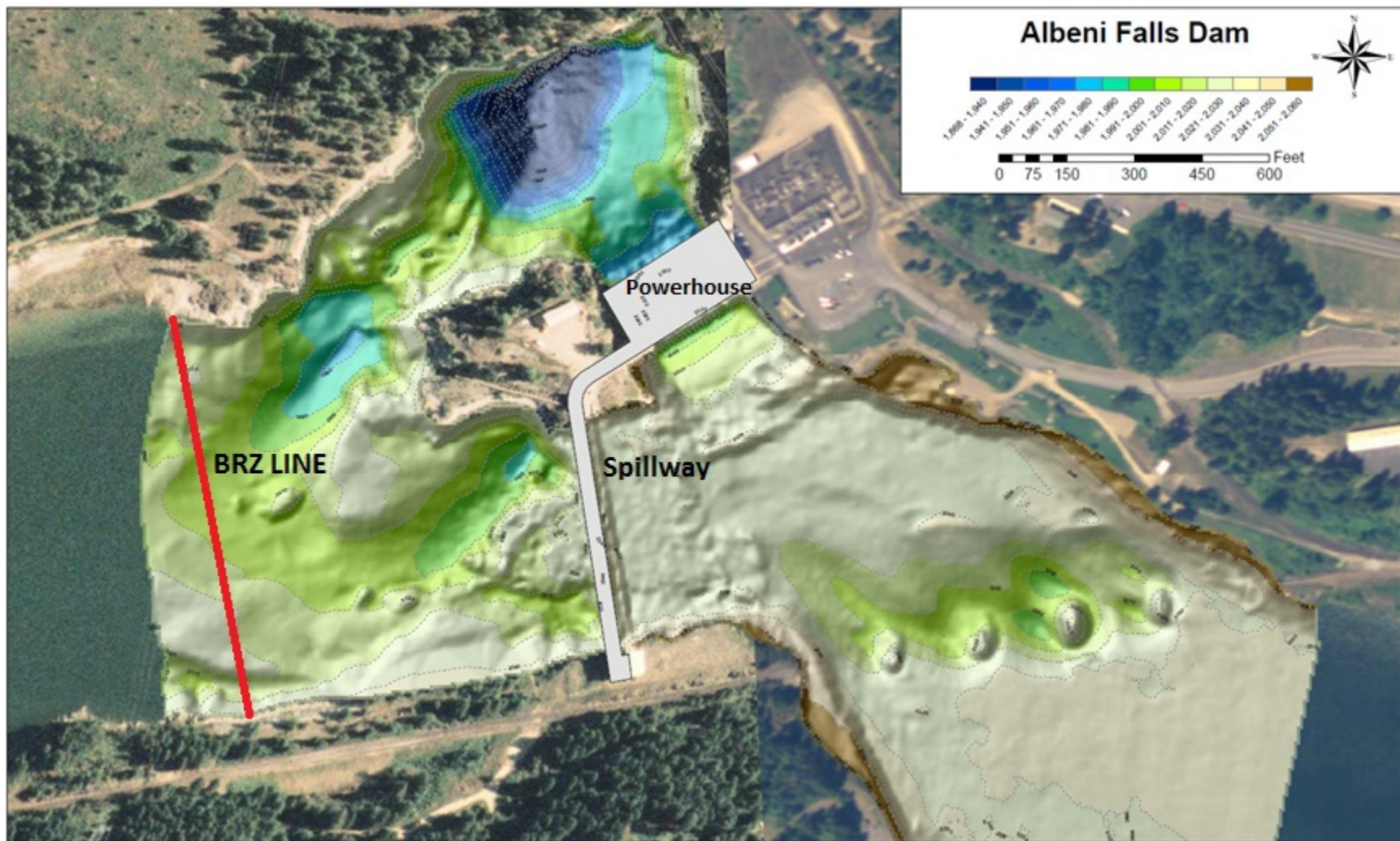


Figure 4. Bathymetry surrounding Albeni Falls Dam; flow from left to right. Source: USACE, Seattle District.

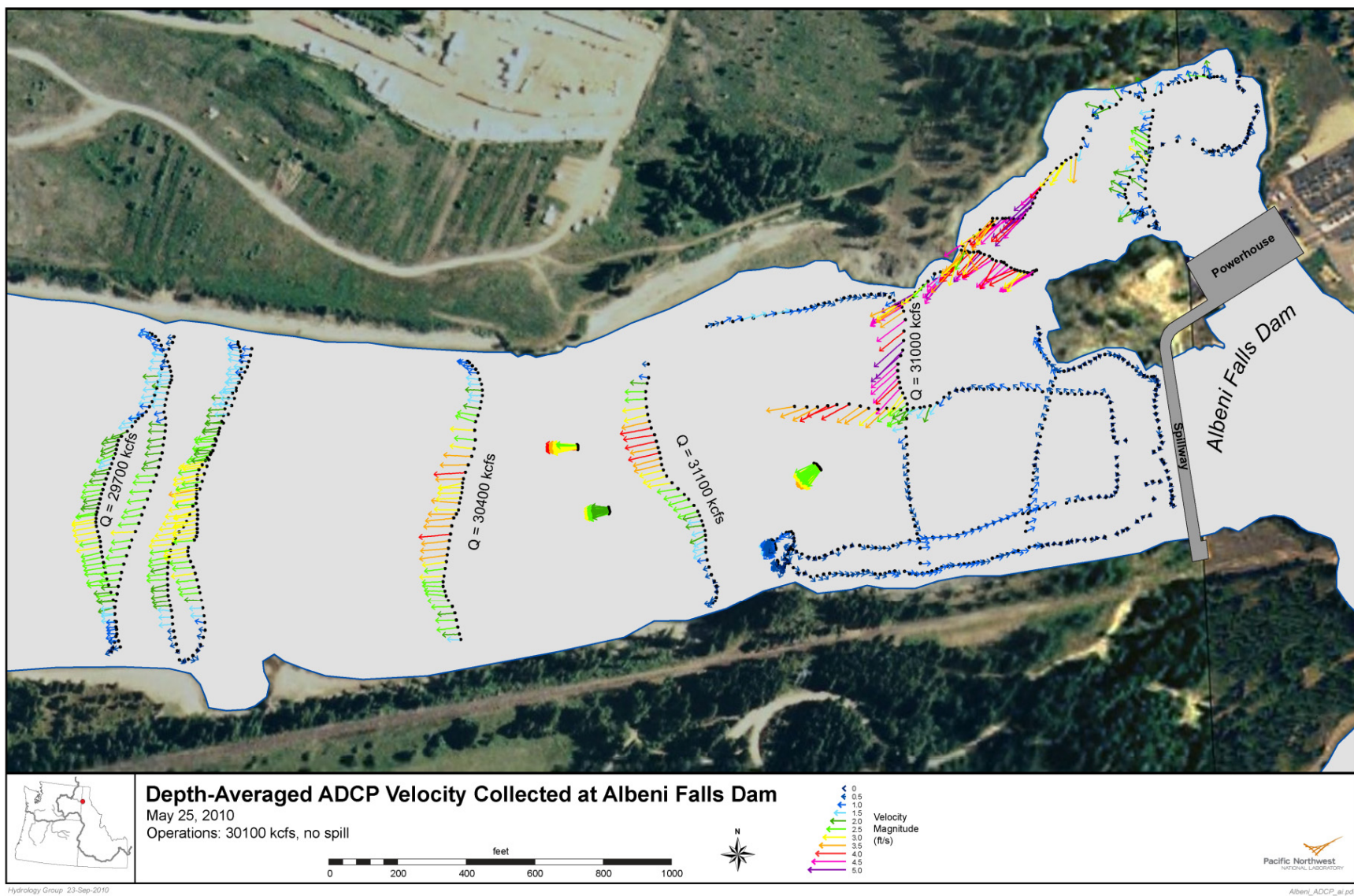


Figure 5. Albeni Falls Dam depth-averaged velocity measurements on May 25, 2010. Dam was operated at an average discharge for a 24-hr period at 30.1 kcfs on May 25, 2010. Measured discharges (Q) at transects also are shown.

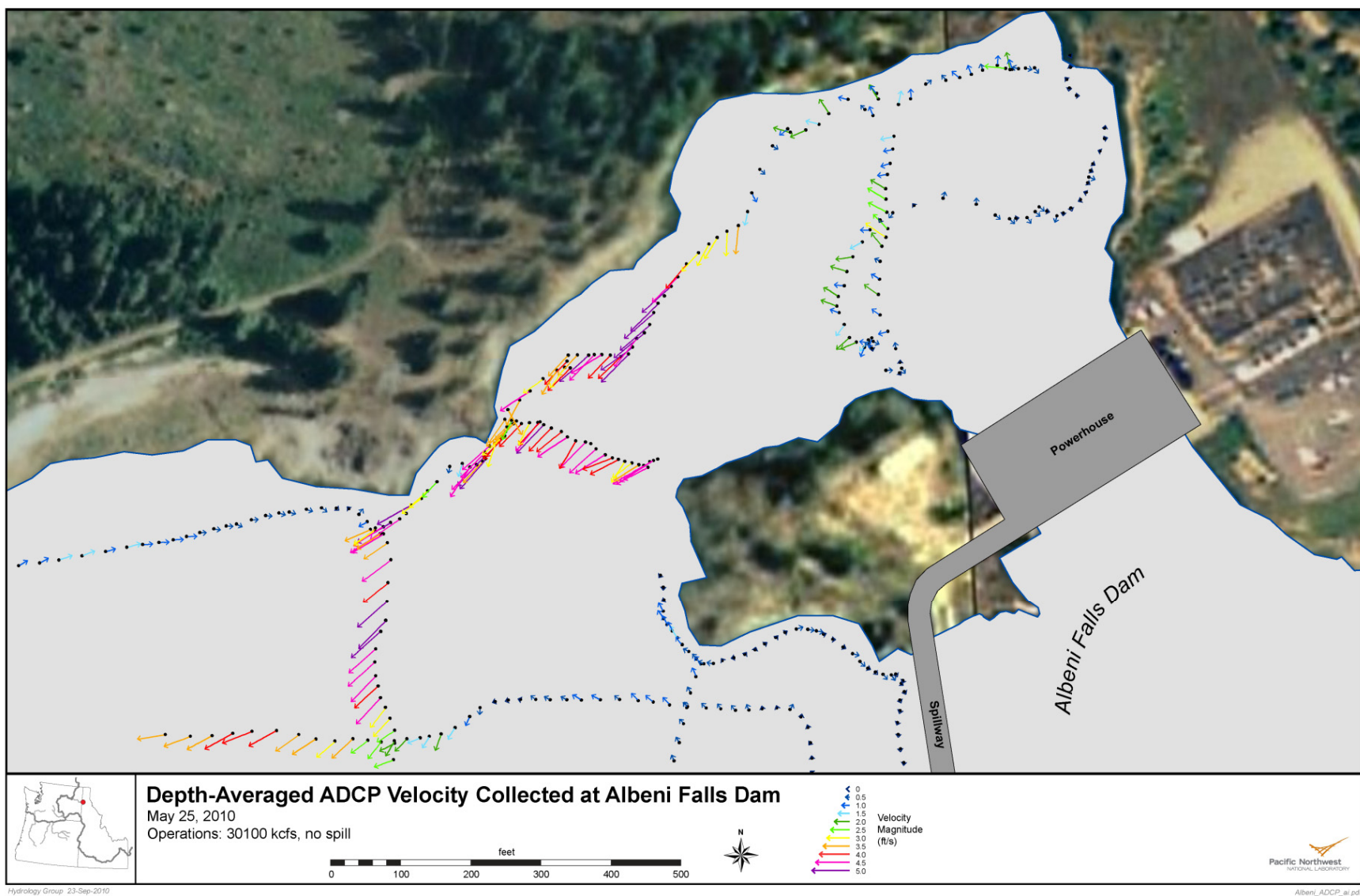


Figure 6. Albeni Falls Dam depth-averaged velocity measurements downstream of powerhouse on May 25, 2010. Dam was operated at an average discharge for a 24-hr period at 30.1 kcfs on May 25, 2010.



Figure 7. Eddy formation just upstream of the boat-restricted zone and along the northern shore of the powerhouse channel.

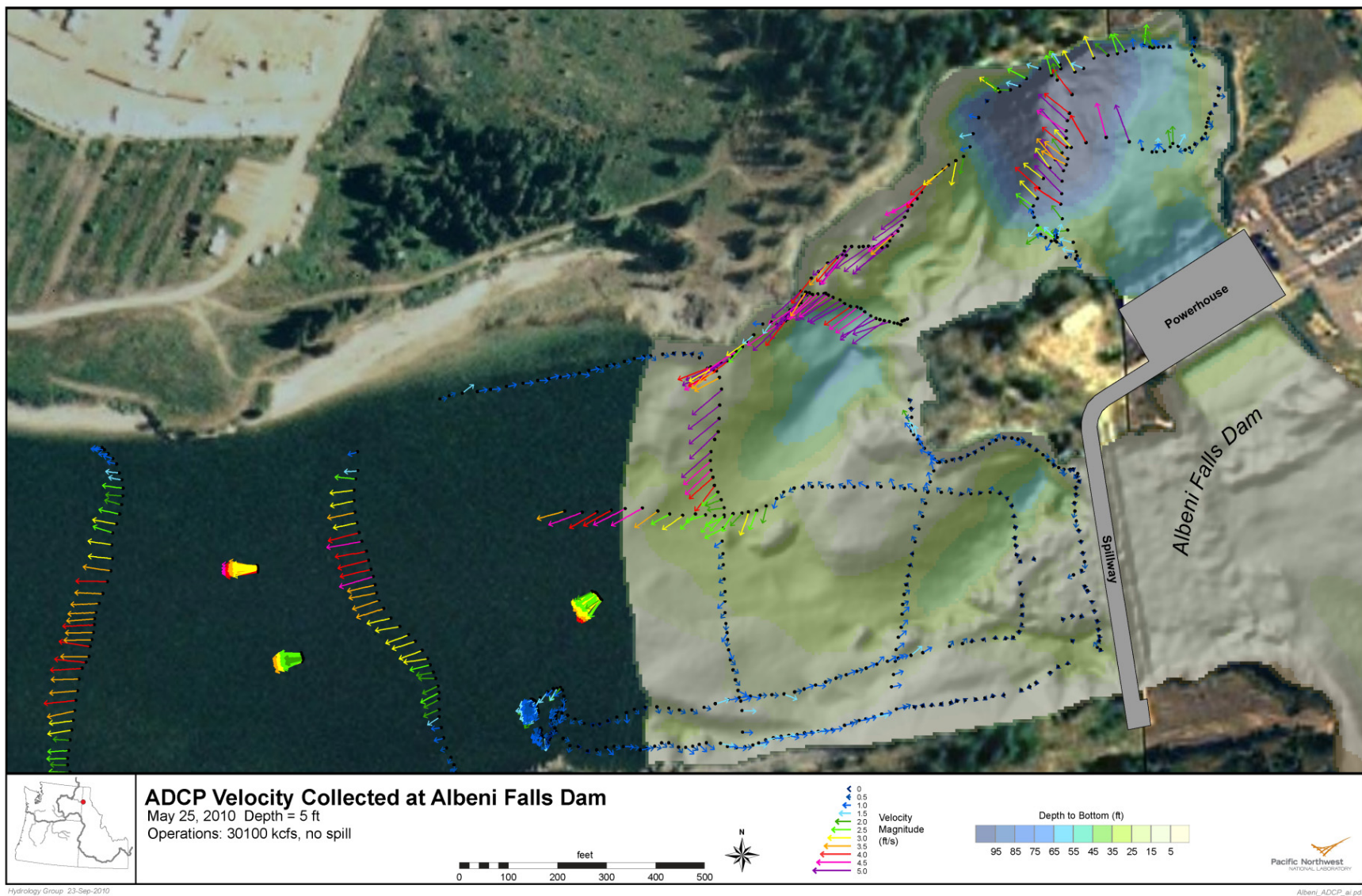


Figure 8. Albeni Falls Dam velocity measurements at 5-ft depth on May 25, 2010. Dam was operated at an average discharge for a 24-hr period at 30.1 kcfs on May 25, 2010.

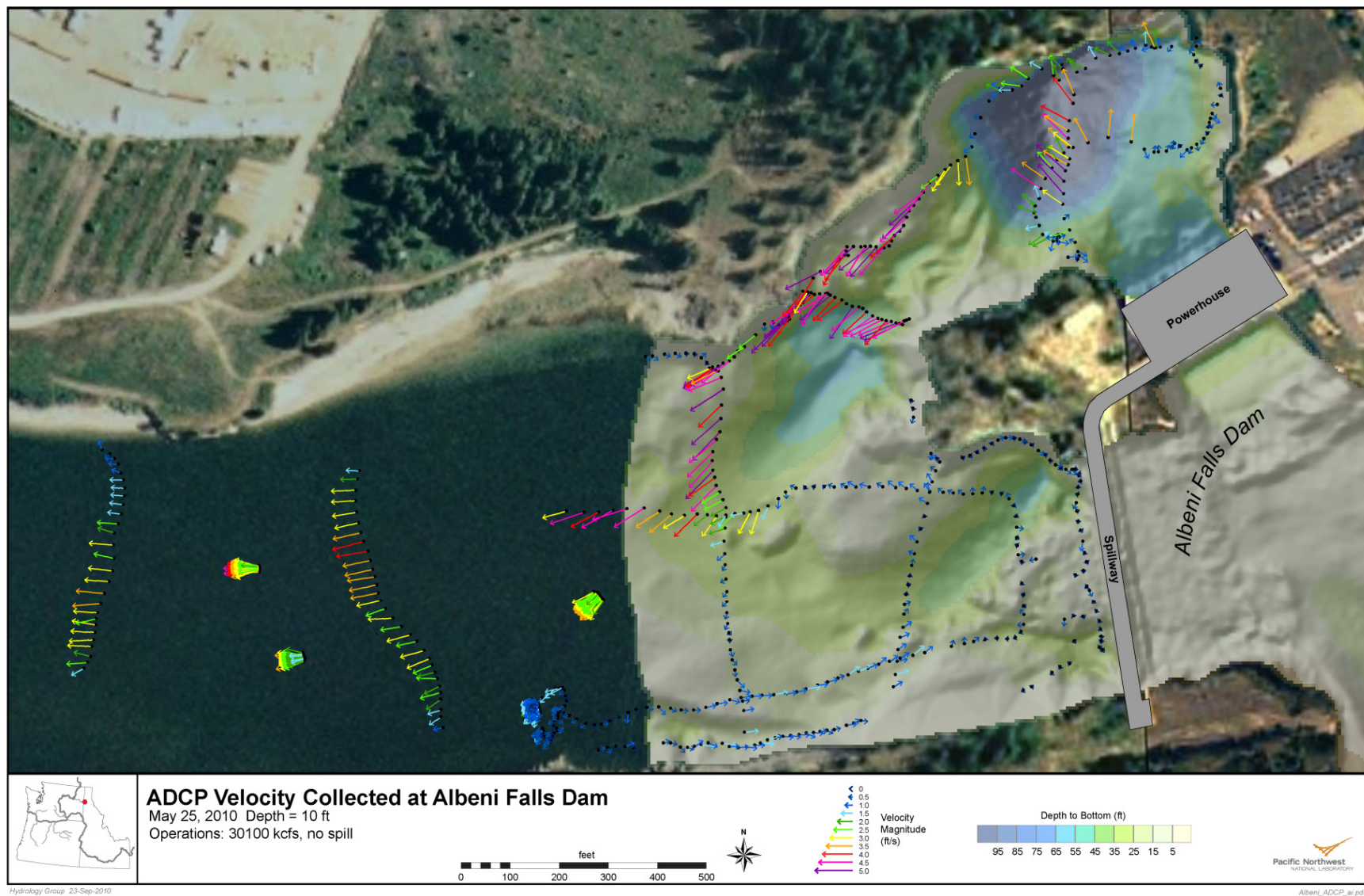


Figure 9. Albeni Falls Dam velocity measurements at 10-ft depth on May 25, 2010. Dam was operated at an average discharge for a 24-hr period at 30.1 kcfs on May 25, 2010.

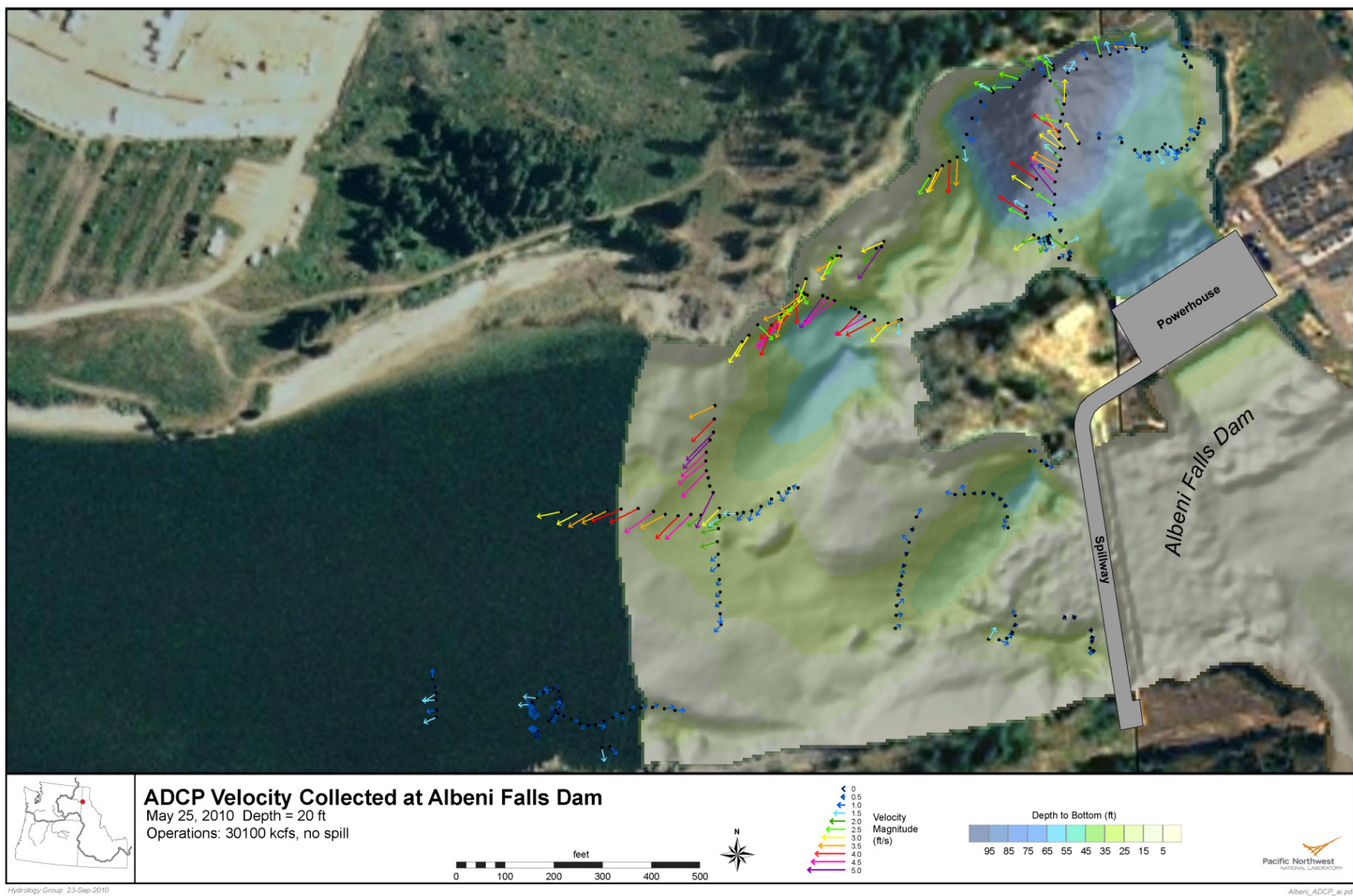


Figure 10. Albeni Falls Dam velocity measurements at 20-ft depth on May 25, 2010. Dam was operated at an average discharge for a 24-hr period at 30.1 kcfs on May 25, 2010.

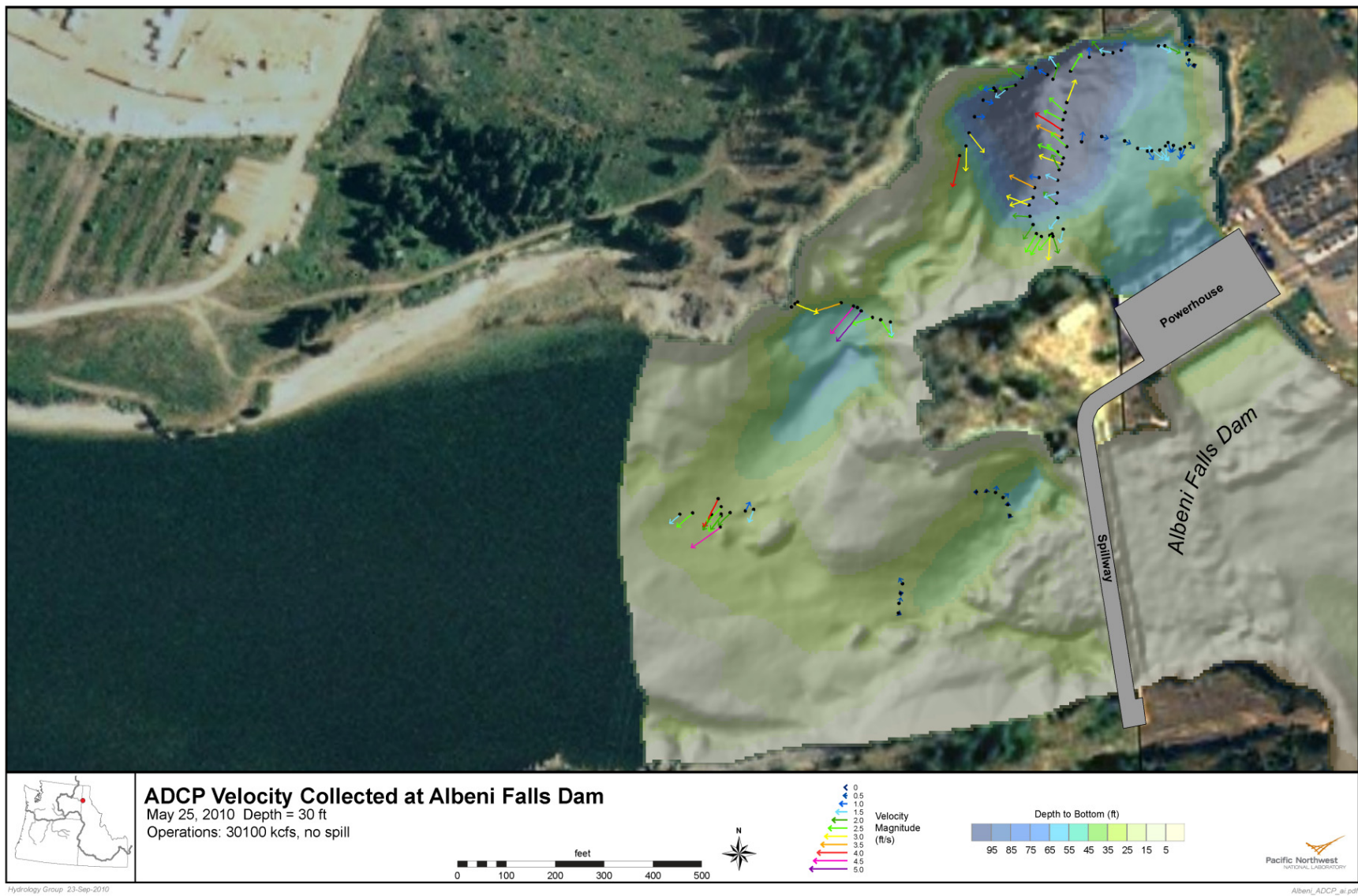


Figure 11. Albeni Falls Dam velocity measurements at 30-ft depth on May 25, 2010. Dam was operated at an average discharge for a 24-hr period at 30.1 kcfs on May 25, 2010.

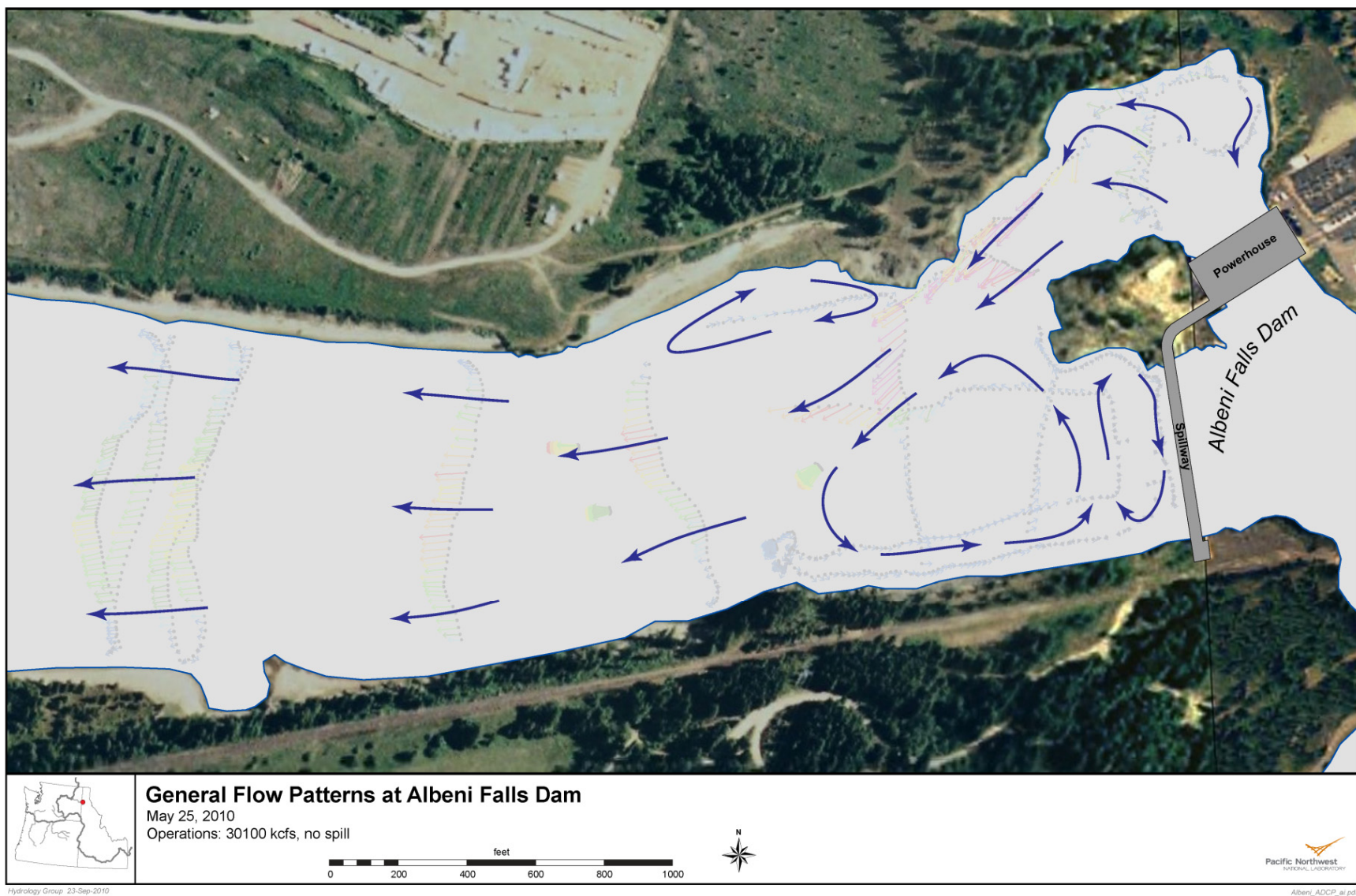


Figure 12. Flow pattern for dam operation at Albeni Falls Dam on May 25, 2010. Operations were at 30.1 kcfs and no spill. A clockwise gyre is present just below the spillway, as is a counterclockwise gyre farther downstream of the spillway.



Figure 13. Surface boils at outlet of Albeni Falls Dam powerhouse (looking downstream).



Figure 14. Surface boils at outlet of Albeni Falls Dam powerhouse (looking upstream).

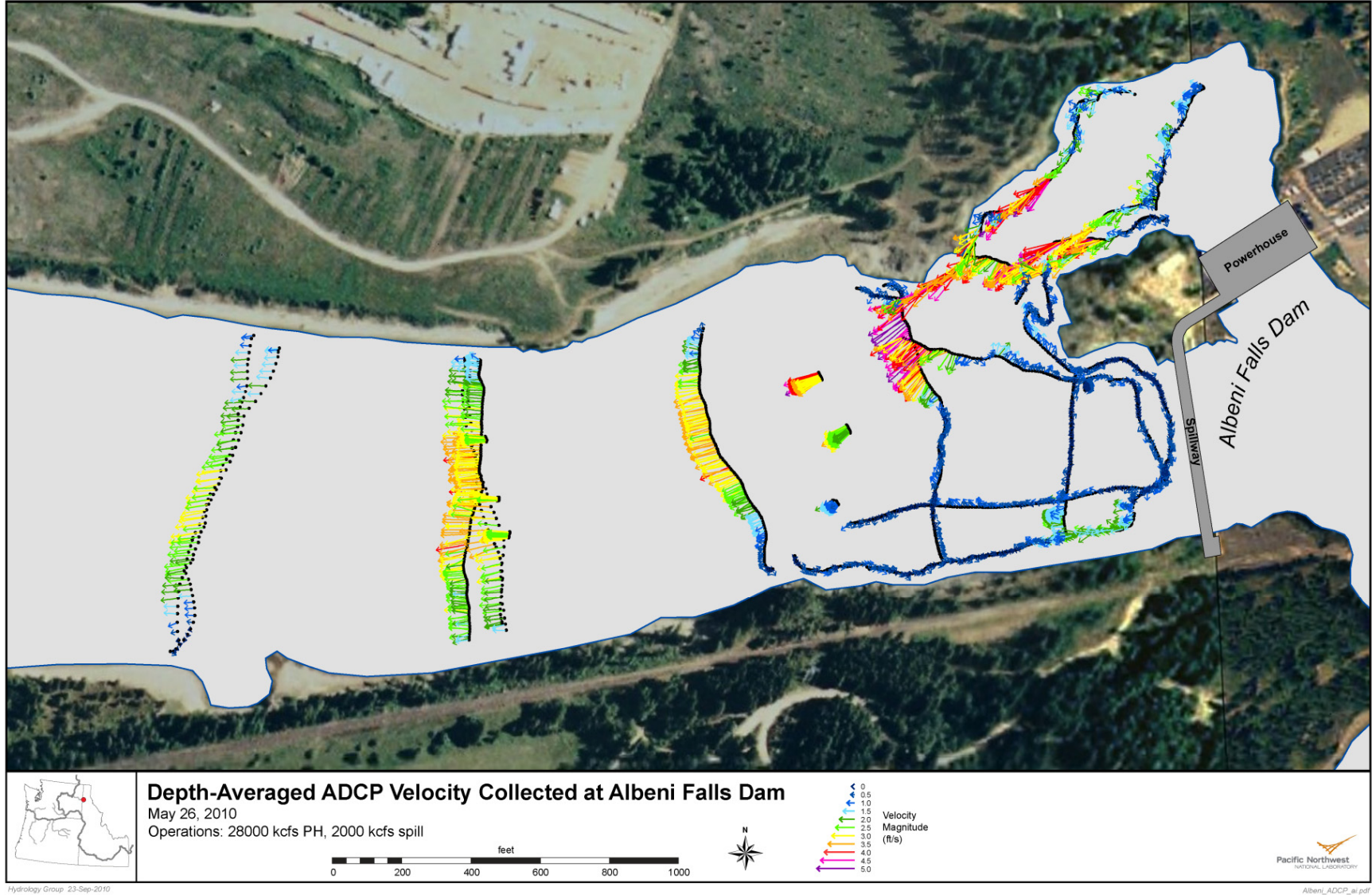


Figure 15. Albeni Falls Dam depth-averaged velocity measurements on May 26, 2010. Dam was operated at an average discharge for a 24-hr period at 28.0 kcfs on May 26, 2010.

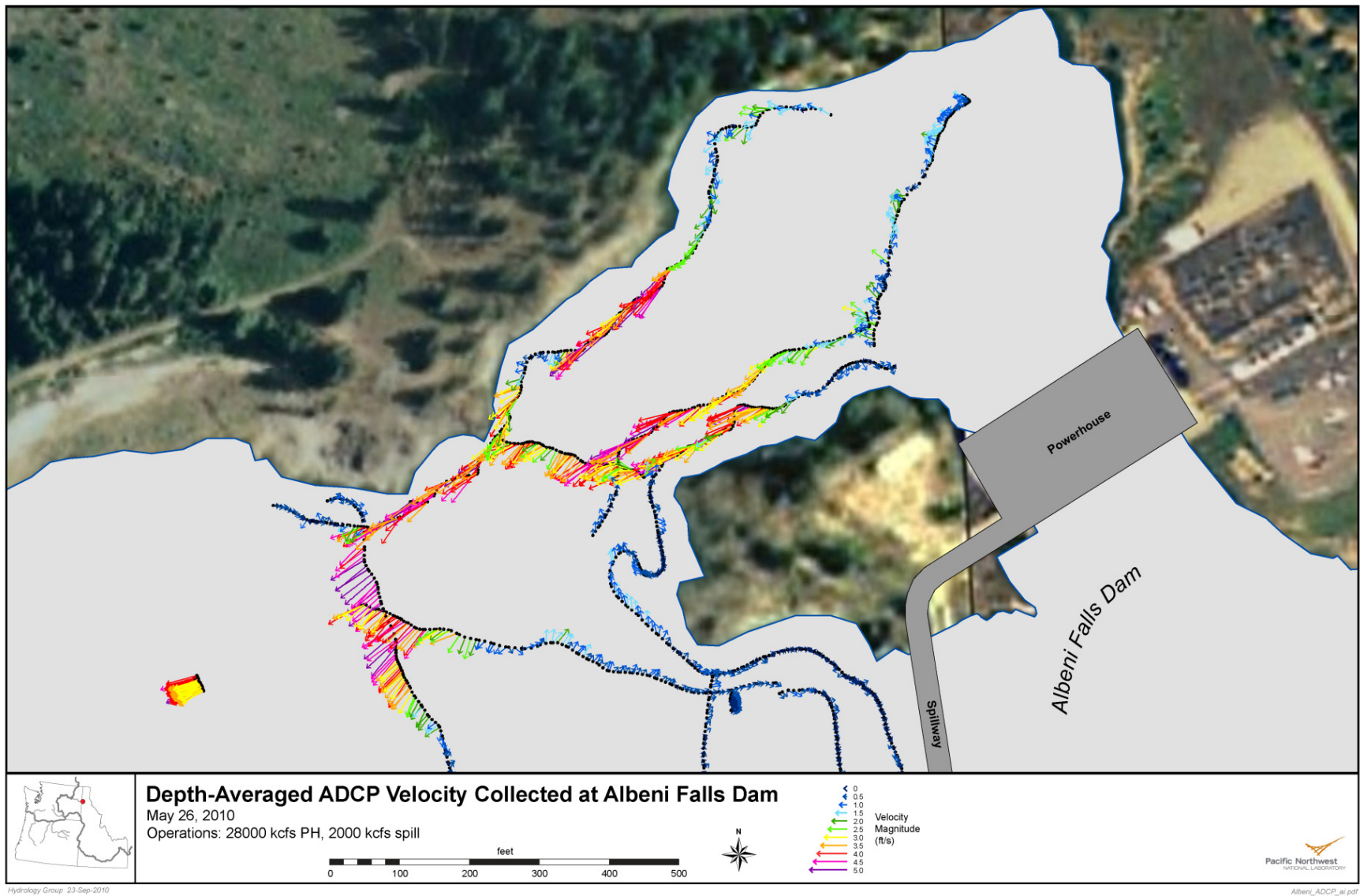


Figure 16. Albeni Falls Dam depth-averaged velocity measurements downstream of powerhouse on May 26, 2010. Dam was operated at an average discharge for a 24-hr period at 28.0 kcfs on May 26, 2010.

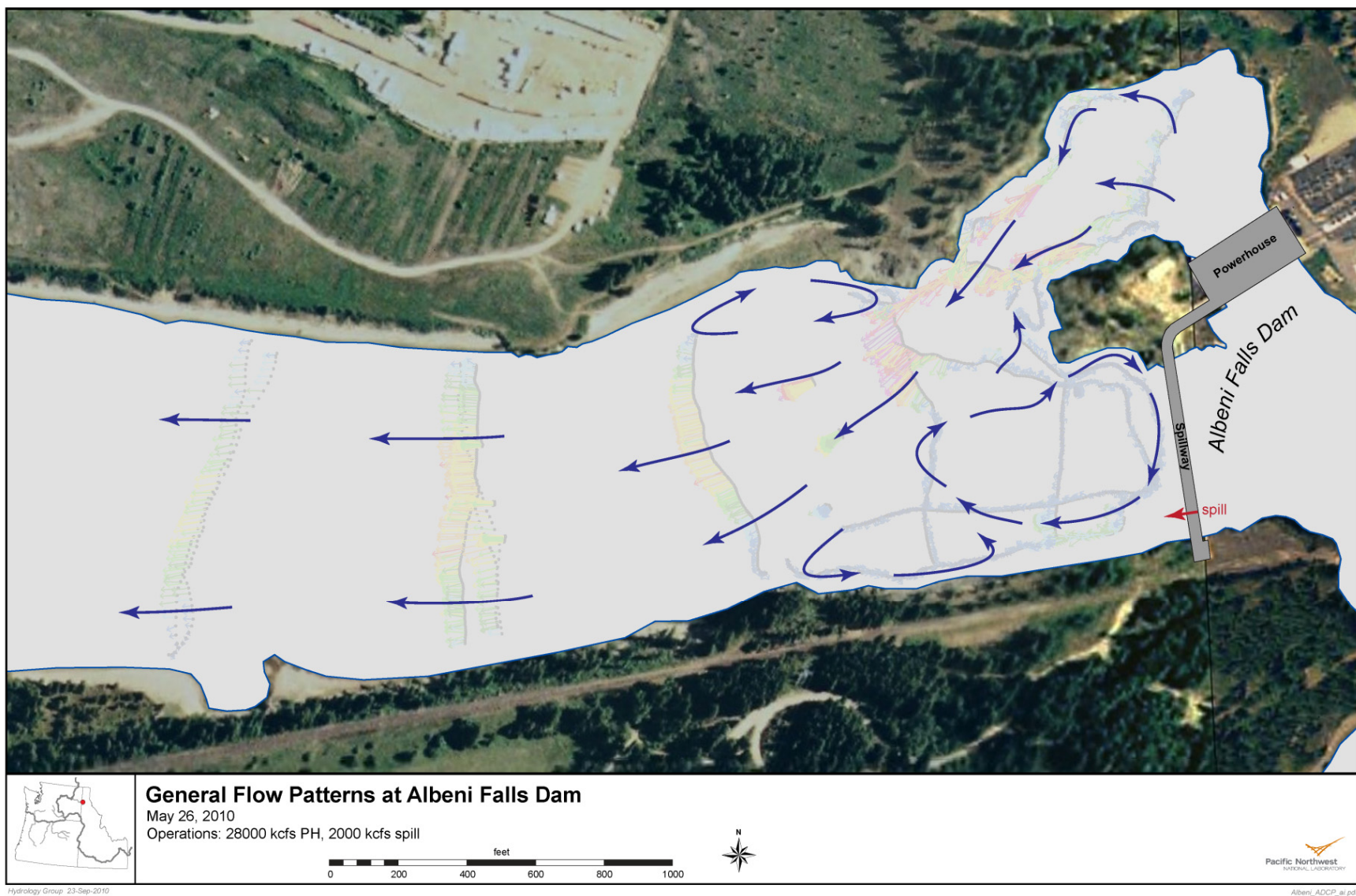


Figure 17. Flow pattern for dam operation at Albeni Falls Dam on May 26, 2010. Operations were at 28.0 kcfs and spill at gates 9 and 10. A large clockwise gyre is present just below the spillway.

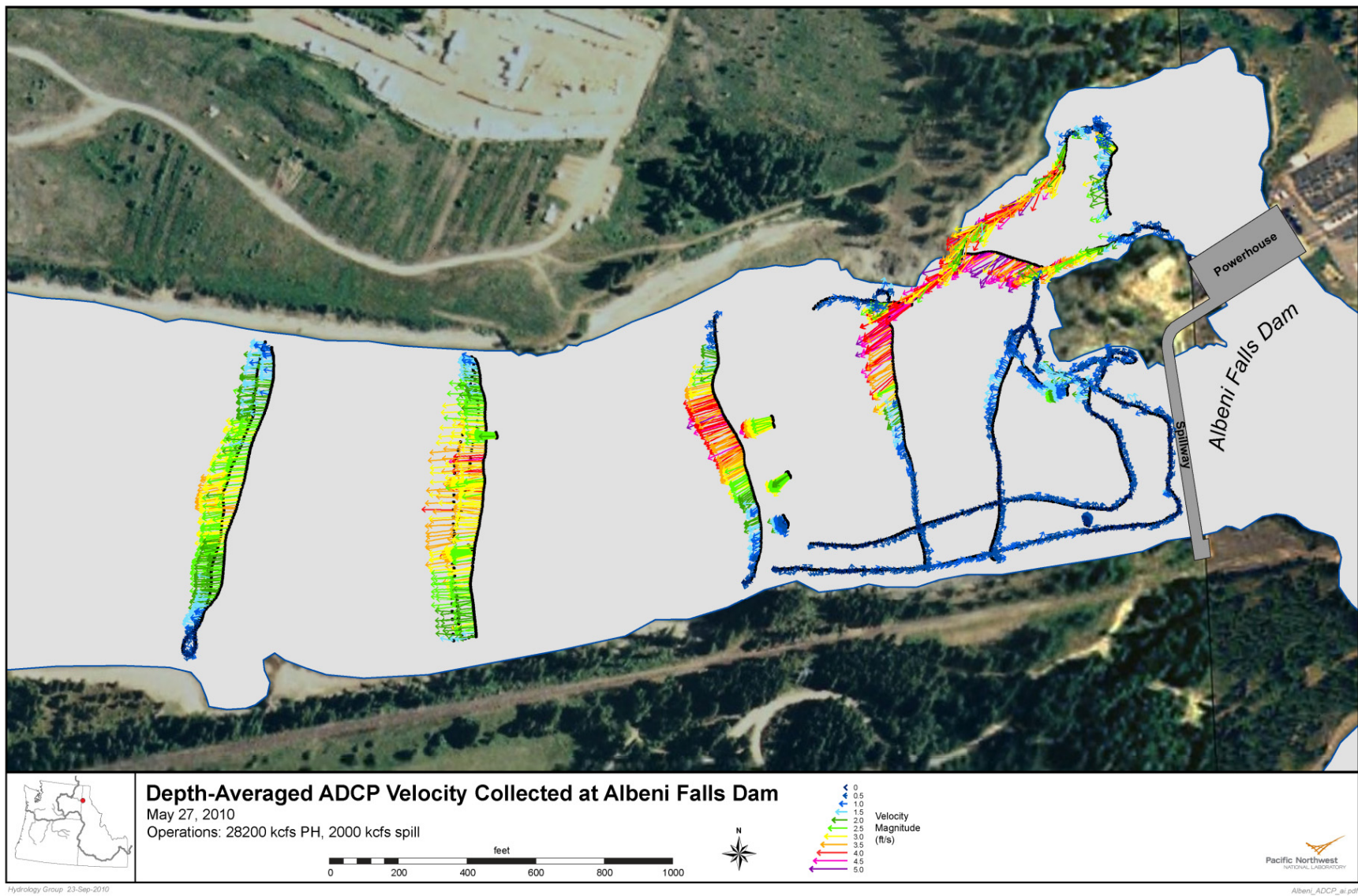


Figure 18. Albeni Falls Dam depth-averaged velocity measurements on May 27, 2010. Dam was operated at an average discharge for a 24-hr period at 28.2 kcfs on May 27, 2010.

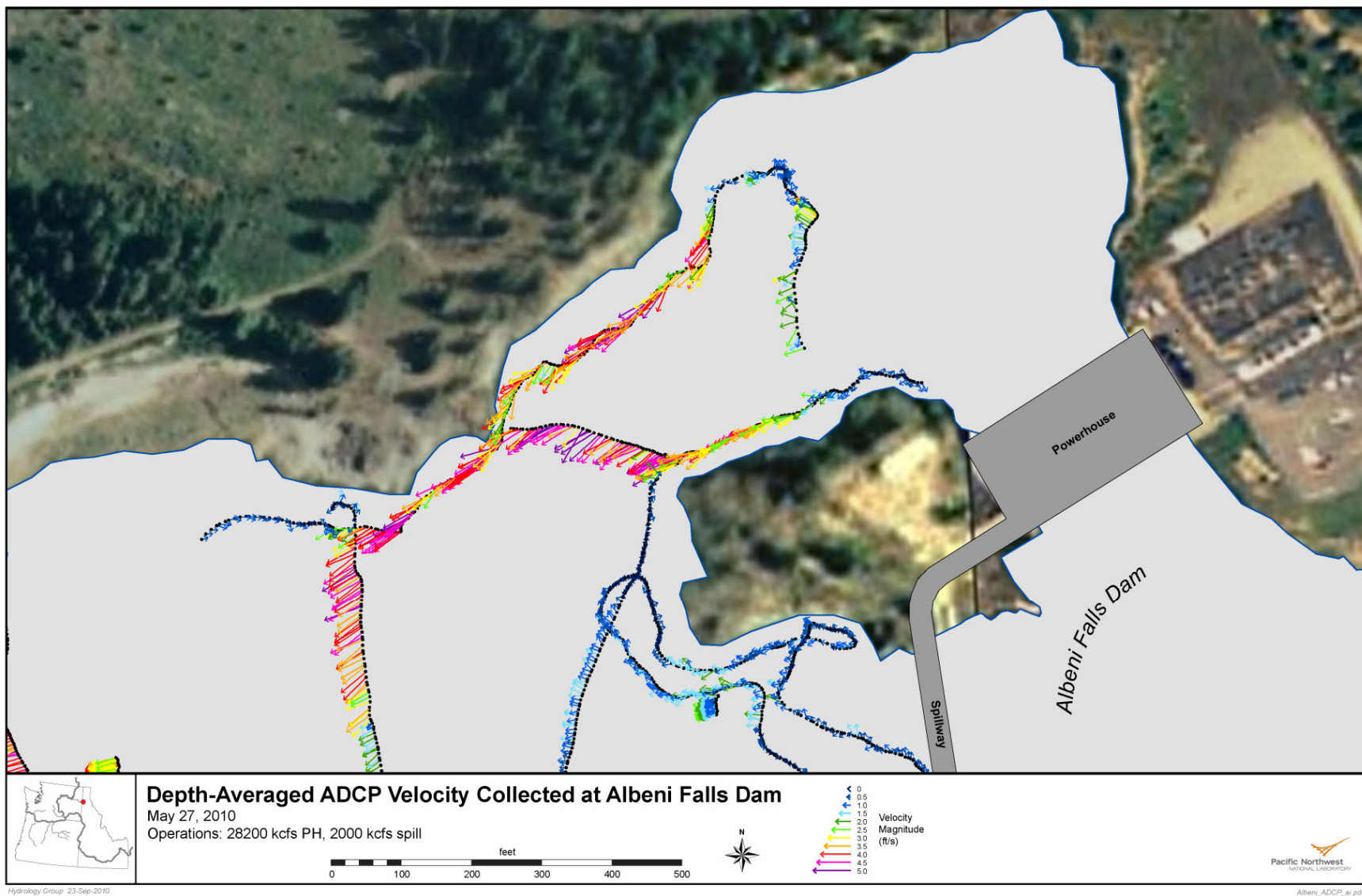


Figure 19. Albeni Falls Dam depth-averaged velocity measurements downstream of powerhouse on May 27, 2010. Dam was operated at an average discharge for a 24-hr period at 28.2 kcfs on May 27, 2010.

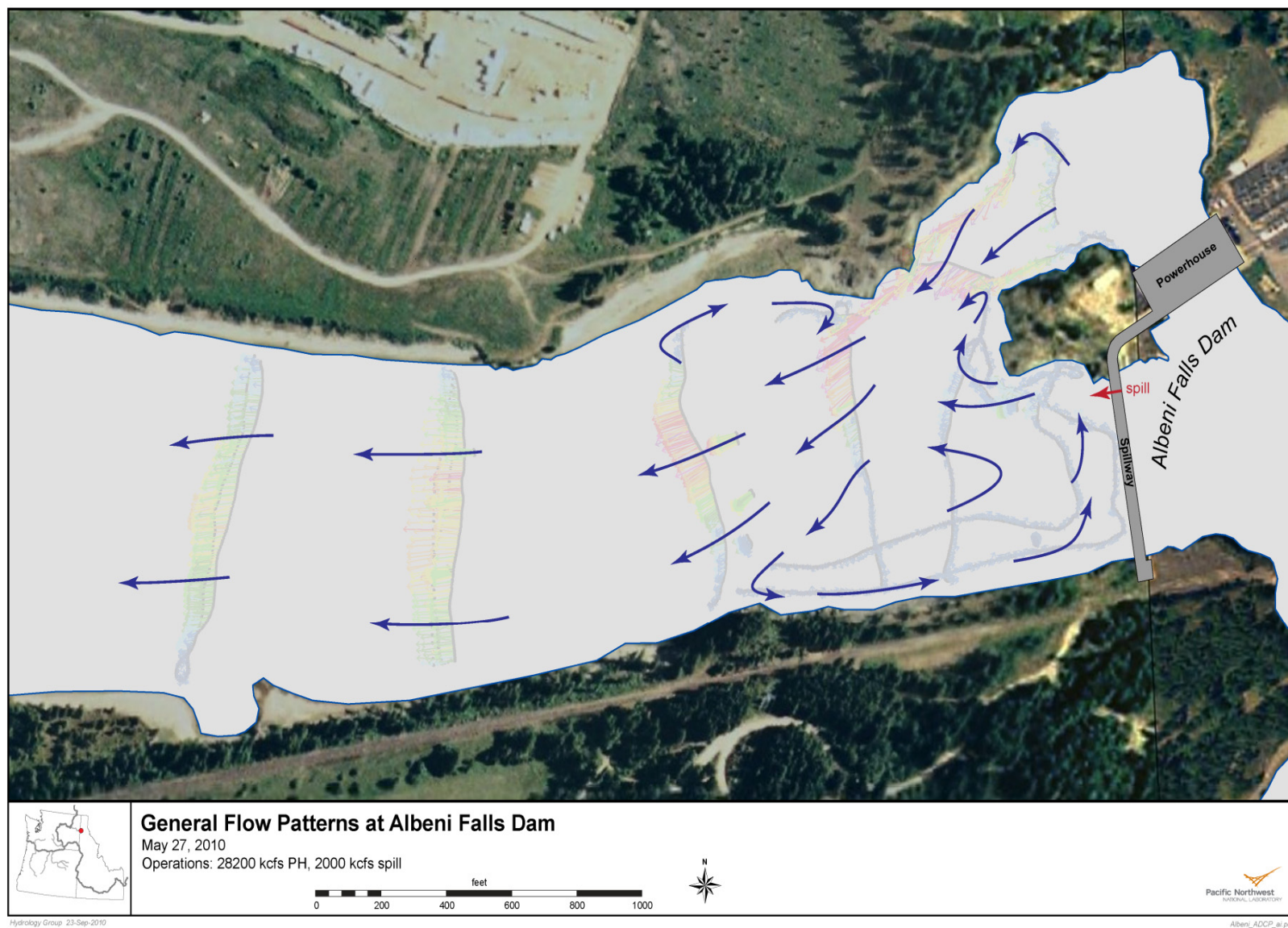


Figure 20. Flow pattern for dam operation at Albeni Falls Dam on May 27, 2010. Operations were at 28.2 kcfs and spill at gates 1 and 2. The clockwise gyre is reversed and directed toward the confluence of the powerhouse and the spillway.

5.0 References

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