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Determining Columbia and Snake River Project Tailrace and Forebay Zones of Hydraulic Influence Using MASS2 Modeling

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2010

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Prepared for
U.S. Army Corps of Engineers
Portland District and Walla Walla District

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Fisheries biology studies are frequently performed at U.S. Army Corps of Engineers (USACE) projects along the Columbia and Snake Rivers, and the results are presented relative to the "forebay" and "tailrace" regions. At this time, each study may use somewhat arbitrary locations (e.g., the Boat Restriction Zone) to define the upstream and downstream limits of the study. The arbitrariness of the delineations could create inconsistencies between projects and make it difficult to draw conclusions involving multiple projects. To overcome this concern, USACE fisheries researchers are interested in establishing a consistent definition of project forebay and tailrace regions for the hydroelectric projects on the lower Columbia and Snake rivers.

The hydraulic extent of a project was defined by USACE CENWP[(a)] as follows: The river reach directly upstream (forebay) and downstream (tailrace) of a project that is influenced by the normal range of dam operations. Outside this reach, for a particular river discharge, changes in dam operations cannot be detected by hydraulic measurement.

In other words, the hydraulic extent is the zone where the flow direction or velocity can be influened by how the flow is distributed through the powerhouse and spillway bays at a project, i.e., the percent of spill flow, the spill pattern, and the turbines that are operational.

The purpose of this study was to develop and apply a consistent set of criteria for determining the hydraulic extent of each of the projects in the lower Columbia and Snake rivers. This was done in consultation with USACE and regional representatives,

A 2D depth-averaged river model, MASS2, was applied to the Snake and Columbia Rivers. New computational meshes were developed for most reaches, and the underlying bathymetric data were updated to include the most current survey data. These computational meshes were sufficient to resolve each spillway bay and turbine unit at each project, and they extended from the tailrace of one project to the forebay of the downstream project.

MASS2 was run for a range of total river flows and, for each total river flow, a range of project operations at each project. The modeled flow was analyzed to determine the range of velocity magnitude differences and the range of flow direction differences at each location in the computational mesh for each total river flow. Maps of the differences in flow direction and velocity magnitude were created.

After reviewing the preliminary results, USACE fishery biologists requested data analysis to determine the project hydraulic extent based on the following criteria:

- If mean water velocity is less than 4 ft/s, the differences in the magnitude water velocity between operations are not greater than 0.5 ft/s or the differences in water flow direction (azimuth) are not greater than 10°.

(a) Brad Eppard, USACE, CENWP in "Project Boundaries for Bonneville, The Dalles, and John Day Dams," April 2010.

- If mean water velocity is 4.0 ft/s or greater, the project hydraulic extent is determined using the differences in water flow direction (i.e., not greater than 10°).

Based on these criteria, and excluding areas with a mean velocity of less than 0.1 ft/s (within the error of the model), a final set of graphics was developed that included data from all flows and all operations.

Although each hydroelectric project has a different physical setting, there were some common results. The downstream hydraulic extent tended to be greater than the hydraulic extent in the forebay. The hydraulic extent of the projects tended to be larger at the mid-range flows. At higher flows, the channel geometry tends to reduce the impact of project operations. Table 1 summarizes the proposed upstream and downstream distances of the hydraulic extents of each project and its River Mile.

Table 1. Hydraulic Extents Summary

Project	**Forebay**		**Tailrace**	
	Distance (ft)	River Mile	Distance (ft)	River Mile
Columbia River				
Bonneville	5900	147.2	11,500	143.9
The Dalles	6300	192.9	5800	190.6
John Day	2800	216.2	7600	214.2
McNary	3700	292.7	7600	290.6
Snake River				
Ice Harbor	2200	10.3	2700	9.4
Lower Monumental	2400	42.1	6900	40.3
Little Goose	2200	70.7	5100	69.3
Lower Granite	1100	107.5	7300	105.9

Abbreviations and Acronyms

ABBREV	DEFINITION
2D	two dimensional
3D	three dimensional
ADCP	acoustic Doppler current profiler
BON	Bonneville Dam
BRZ	boat restricted zone
CENWP	U.S. Army Corps of Engineers, Portland District
CENWW	U.S. Army Corps of Engineers, Walla Walla District
DEM	digital elevation model
DGAS	Dissolved Gas Abatement Study
FPP	Fish Passage Plan
GIS	Geographic Information System
IHR	Ice Harbor Dam
JDA	John Day Dam
kcfs	Thousand cubic feet per second
LGO	Little Goose Dam
LGR	Lower Granite Dam
LMN	Lower Monumental Dam
MASS2	Modular Aquatic Simulation System in Two Dimensions
MCN	McNary Dam
NAD27	North American Datum of 1927
NAD83	North American Datum of 1983
NAVD29	North American Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
PNNL	Pacific Northwest National Laboratory
TDA	The Dalles Dam
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
vmag	Velocity magnitude

Acknowledgments

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1.0 Introduction

Although fisheries biology studies are frequently performed at U.S. Army Corps of Engineers (USACE) projects along the Columbia and Snake Rivers, currently there is no consistent definition of the “forebay” and “tailrace” regions for these studies. At this time, each study may use somewhat arbitrary lines (e.g., the Boat Restriction Zone) to define the upstream and downstream limits of the study, which may be significantly different at each project. Fisheries researchers are interested in establishing a consistent definition of project forebay and tailrace regions that define the hydraulic extent of a project. The hydraulic extent was defined by USACE (Brad Eppard, USACE Portland District (CENWP)) as follows: The river reach directly upstream (forebay) and downstream (tailrace) of a project that is influenced by the normal range of dam operations. Outside this reach, for a particular river discharge, changes in dam operations cannot be detected by hydraulic measurement.

The purpose of this project is to develop standard procedures to determine the operationally influenced extent of the forebay and tailrace regions in accordance with the following definitions:

- Forebay: The segment of river immediately upstream of a dam where operations at the dam are the primary contributing factor to velocity and direction of water flow. The upstream boundary defines the upstream limit where operational changes affect water velocity magnitude and direction.

- Tailrace: The segment of river immediately downstream of a dam where operations at the dam are the primary contributing factor to velocity and direction of water flow. The downstream boundary defines the downstream limit where operational changes affect water velocity magnitude and direction.

In 2008, Pacific Northwest National Laboratory (PNNL) used the John Day project as the test case to establish the modeling methodology and criteria to define areas affected by project operations at John Day in both the forebay and tailrace (Rakowski et al. 2008a). It was assumed that the forebay and tailrace definition could be adequately defined using a two-dimensional (2D) depth-averaged modeling approach instead of a true three-dimensional (3D) modeling effort. Using the 2D MASS2 model (Perkins and Richmond 2004b) saves significant computational time, especially given the large number of operational scenarios that must be simulated. Assessment criteria included the selection of river flows and hydraulic comparisons (velocity magnitude, direction, and/or tolerances).

In this study, the methodology and criteria established in Rakowski et al. (2008a) were applied to other projects on the Columbia and Snake Rivers (Figure 1.1) to define their respective forebay and tailrace regions for CENWP and USACE Walla Walla District (CENWW). Based on input from regional fisheries biologists, some of the criteria were modified for this work.

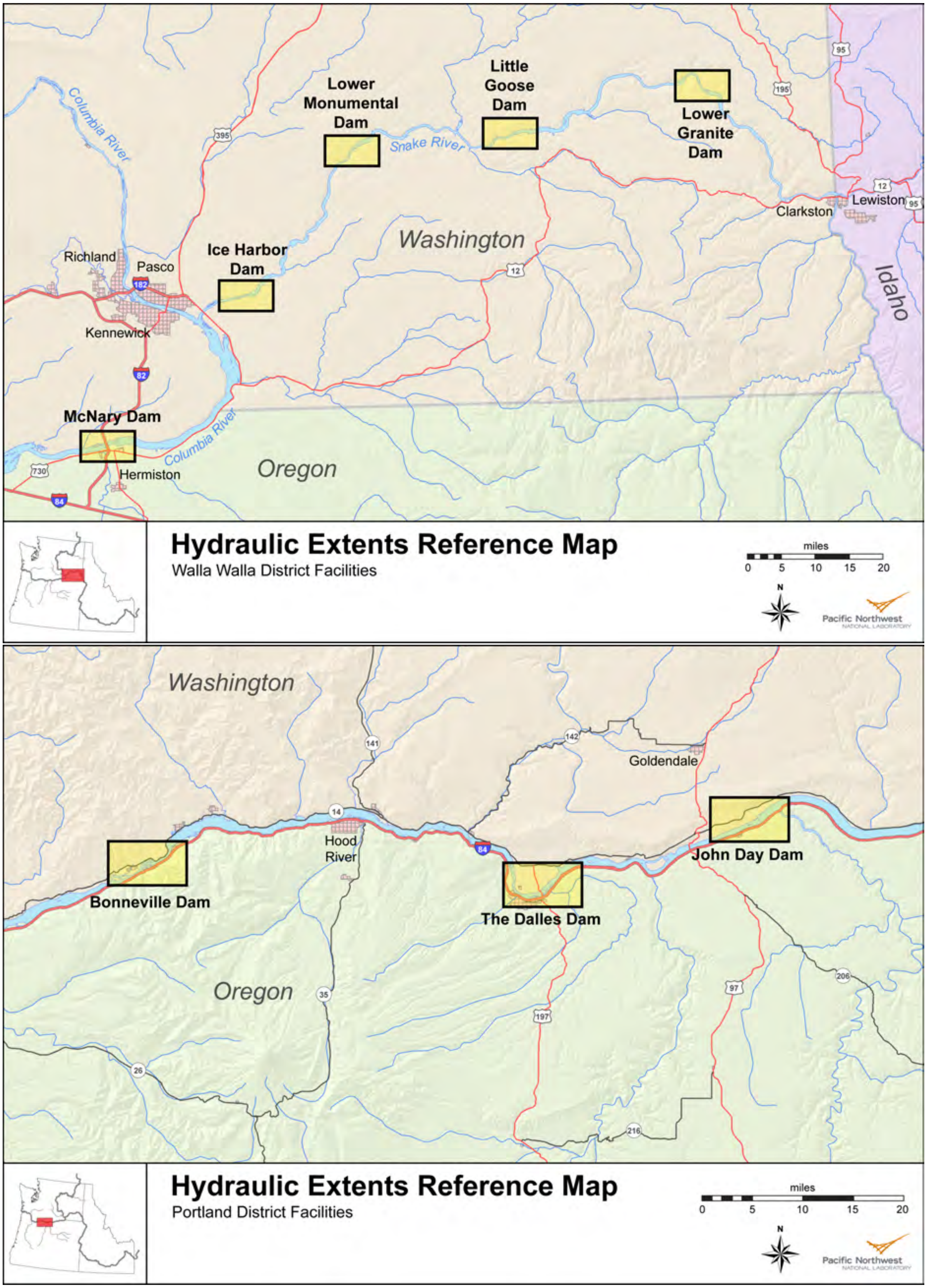

Figure 1.1. Location of the Walla Walla District Projects (top) and Portland District Projects (bottom)

2.0 Methods

This work used the approach described by Rakowski et al. (2008a). However, rather than relying on existing computational meshes, the meshes used in the present study had increased resolution near the hydro projects. The bathymetry was updated to incorporate the most current survey data available.

2.1 MASS2 Model—General Description

The Modular Aquatic Simulation System in 2 Dimensions (MASS2) was developed at PNNL (Perkins and Richmond 2004a,c) and has been successfully applied to a variety of river and estuarine flows (Richmond et al. 1999a, Rakowski and Richmond 2001, 2003, Rakowski et al. 2008b), water quality (Richmond et al. 1999b,c, 2000, Kincaid et al. 2001) and aquatic habitat (McMichael et al. 2003, Perkins et al. 2004, Hanrahan et al. 2007) problems.

MASS2 is formulated using the general finite-volume principles described by Patankar (1980). The model uses a structured multi-block scheme using a curvilinear computational mesh. Spasojevic and Holly (1990) give an example of a 2D model of this type. The momentum and mass conservation equations are coupled with a variation of the Patankar (1980) SIMPLE algorithm extended to shallow-water flows by Zhou (1995). In MASS2, Zhou's method has been applied to orthogonal curvilinear coordinates. In this method, the continuity equation is discretized and solved for a depth correction in lieu of the pressure correction in the original SIMPLE algorithm. The solution to the depth correction equation is used to correct the estimated velocity from the solution of the momentum equations. A portion of the depth correction is used to adjust depth. An in-depth description of the underlying theory for MASS2 is in Perkins and Richmond (2004a).

MASS2 is a depth-averaged river model. Although it works well and matches validation data in the river, the results in areas with highly 3D flows should be used with caution. The meshes of this study were designed for testing the upstream and downstream extents of impacts of project flow distributions rather than the details of flow very near the projects.

2.2 Bathymetry and Shorelines

Bathymetric surfaces were created with point and contour elevation data from a variety of sources. Datasets consisted primarily of point soundings from single- and multi-beam acoustic surveys provided by USACE. Where such surveys were unavailable, National Oceanic and Atmospheric Administration (NOAA) navigation charts filled in the gaps. The channel shorelines were manually digitized from high-resolution (0.5 m) aerial photography obtained from the U.S. Geological Survey (USGS) seamless server (http://seamless.usgs.gov), and assigned an elevation appropriate for the date of the imagery. That elevation was determined using the date of the photo, and then the elevation was estimated from the average of the DART forebay elevations measured during the month when the photo was taken. Typically, the elevations during July 2006 (when the photos were taken) fluctuated no more than about 1 ft. Thirty-meter digital elevation model (DEM) points, also from the USGS, provided near-shore topography data to produce a smoother transition between the shoreline and bathymetric datasets.

The elevation datasets were imported into ArcGIS^{TM} version 9.3.1 (ESRI, Inc.), a geographic information system (GIS), for storage, display, and processing. All datasets were projected into Washington State Plane South coordinates (in meters) using the North American Datum of 1983 (NAD83). Elevation data were generally received in the North American Vertical Datum of 1929 (NAVD29) and this was established as the standard. The point positions and elevations were examined for anomalies, and problem data were rejected. Where domains overlapped, both datasets were generally used, unless one of the datasets was considerably less reliable than the other, in which case it was excluded. The shoreline dataset defined the boundary between the topographic (DEM) and bathymetric data, and bathymetric points residing on the upland side of the shoreline were rejected.

Each bathymetric surface was produced with a script run in ArcGIS. The script gathered the appropriate datasets for the reach, interpolated the elevations onto a uniform raster grid, and projected the result into Oregon State Plane North coordinates (in feet) using the North American Datum of 1927 (NAD27). The raster grid cell size was set to 10 m, which is somewhat smaller than the smallest hydrodynamic model grid cell size.

Tables 2.1 to 2.9 summarize the source datasets used to create each of the bathymetric surfaces. Figures 2.1 to 2.8 show the bathymetric surfaces near each project. Note that in these figures, the overlying mesh is the MASS2 mesh, **not** the bathymetric surface mesh, and the contour intervals are different for each mesh.

Table 2.1. Datasets Used to Create Bathymetric Surface Downstream of Bonneville (BON) Dam

Dataset	Survey Year	Source	Approximate Resolution (ft)	Columbia River Mile from	Columbia River Mile to	Study
p_tidbath_cl	1999	CENWP	50–500	102.0	145.5	River transects at 500-ft spacing.
a_NOAA_Contours_er	1991–1992	NOAA	N/A	102.0	146.0	Depth contours from NOAA navigation charts 18526 and 18531.
p_cl_expts_cl	unknown	unknown	50–500	102.5	117.5	Surveys in secondary channels south of Hayden and Government Islands.
a_Shore	2006	PNNL	N/A	102.0	146.0	Digitized shoreline from July 2006, 0.5-m aerial photos.
p_USGS_Combined_cl	1999–2001	USGS in DOEBP-00004701-2	20–200	133.5	145.0	Combination of USACE, USGS, and USFWS surveys near Ives, Pierce, and Skamania Islands.
p_bon98_cl	1998	CENWP	5–250	144.5	146.0	Detailed survey of BON tailrace.

Table 2.2. Datasets Used to Create Bathymetric Surface for the BON Pool and The Dalles Dam (TDA) Tailrace

Dataset	Survey Year	Source	Approximate Resolution (ft)	Columbia River Mile from	Columbia River Mile to	Study
p_bon119_cl	unknown	unknown	100	147.0	147.5	Short section of channel not covered by other surveys.
p_bon98	1998	CENWP	5–250	146.0	147.0	Survey of BON forebay.
p_bonbath	unknown	CENWP	100–500	147.5	191.5	BON pool transects at 500-ft spacing and navigation channel at 100-ft spacing.
p_may2000	2000	CENWP	70–500	188.5	190.5	May 2000 survey of lower TDA tailrace.
p_outfall	2001	CENWP	25	192.0	192.0	Survey of plunge pool of TDA ice and trash sluiceway outfall.
p_sp06	2006	CENWP	1	191.5	191.5	February 2006 multibeam survey by David Evans and Associates of TDA tailrace behind first 11 spillbays.
p_sp99222	1999	CENWP	5–50	191.5	192.5	September 1999 survey by M&G of TDA tailrace.
a_JASCont	N/A	PNNL	N/A	188.5	190.5	Manually added contours for improving surface quality.
a_Control	N/A	PNNL	N/A	191.5	192.5	Manually added contours for controlling surface at dam interface.
a_Shore	N/A	PNNL	N/A	146.0	192.0	Digitized shoreline from July 2006, 0.5-m aerial photos.

Table 2.3. Datasets Used to Create Bathymetric Surface for the TDA Pool and the John Day Dam (JDA) Tailrace

Dataset	Survey Year	Source	Approximate Resolution (ft)	Columbia River Mile from	Columbia River Mile to	Study
p_Area1	1999	CENWP	10–300	213.0	214.0	TDA pool transects at 300-ft spacing.
p_Area4	1999	CENWP	5–30	215.5	215.5	Fills hole in p_mb06 survey in JDA navigation lock exit.
p_fb06	2006	unknown	3	192.0	192.5	Multibeam survey of TDA forebay.
p_fb99222	1999	CENWP	5–50	192.0	193.5	September 1999 survey by M&G of TDA forebay.
p_mb06	2006	David Evans and Associates	3	214.0	215.5	Multibeam survey of JDA tailrace.
p_sb06	2006	David Evans and Associates	5–50	214.5	215.0	Single beam survey of shoals and around islands in JDA tailrace.
p_tdabath_cl	1997	CENWP	50–500	193.5	213.5	TDA pool transects at 500-ft spacing.
a_Control	N/A	PNNL	N/A	215.5	215.5	Manually added contours to define JDA navigation lock exit.
a_Shore	N/A	PNNL	N/A	191.5	215.5	Digitized shoreline from July 2006, 0.5-m aerial photos.

Table 2.4. Datasets Used to Create Bathymetric Surface for JDA Pool and McNary Dam (MCN) Tailrace

Dataset	Survey Year	Source	Approximate Resolution (ft)	Columbia River Mile from	to	Study
p_NOAA_Depths_er	1984	NOAA	300–900	215.5	216.0	Spot depths from NOAA navigation chart 18535.
p_jda_xsectpt_er2	unknown	unknown	50–2500	216.0	290.0	JDA pool transects at 2500-ft spacing.
p_jdabath_er1	1997	CENWP	70–500	218.0	290.0	JDA pool transects at 500 ft spacing and 200 ft spacing for 10 miles up John Day River.
p_jdusxl1	unknown	CENWP	20–100	216.0	218.0	JDA pool transects at 100-ft spacing.
p_jdusxl2	unknown	CENWP	20–500	218.0	222.0	JDA pool transects at 500-ft spacing.
p_jdusxl3	unknown	CENWP	20–500	222.0	225.0	JDA pool transects at 500-ft spacing.
p_mcn_a	unknown	CENWP	5–30	291.0	292.0	Survey of MCN tailrace.
p_mcn_b	unknown	CENWP	5–100	290.0	291.0	MCN tailrace transects at 100-ft spacing.
a_NOAA_Contours_er	1984	NOAA	N/A	215.5	216.0	Depth contours from NOAA navigation chart 18535.
a_Shore	N/A	PNNL	N/A	215.5	292.0	Digitized shoreline from July 2006, 0.5-m aerial photos.

Table 2.5. Datasets Used to Create Bathymetric Surface for the MCN Pool and Ice Harbor Dam (IHR) Tailrace

Dataset	Survey Year	Source	Approximate Resolution (ft)	Snake River Mile from	Snake River Mile to	Study
p_mcn_fb	1997	CENWW	25	292.[a]	293.0[a]	Survey of MCN forebay.
p_hldsbsp	unknown	unknown	1–2	10.0	10.0	Survey of IHR stilling basin.
p_hldtrsp_cl1	unknown	unknown	3	9.5	10.0	Survey of IHR tailrace.
p_straw_is_95	1995	CENWW	10–25	2.5	3.0	Survey downstream of Strawberry Island.
p_area1edt_er1	1993	CENWW	2–20	9.0	10.0	Survey of IHR tailrace.
p_pnnl_05_er1	2005	PNNL	5–300	2.0	9.0	Snake River transects at 150- and 300-ft spacings.
p_navchan_02_cl	2002	unknown	10	0.5	10.0	Survey of Snake River navigation channel.
p_colbath_97_er1	1997	CENWW	5–500	294.0[a]	336.5[a]	MCN pool transects at 500-ft spacing.
p_snabath_97_er1	1997	CENWW	5–500	0.0	8.0	MCN pool transects at 500-ft spacing.
p_xsectselev_cl1	unknown	unknown	200–1500	292.5[a]	2.0	MCN pool btransects at 1500-ft spacing.
p_mcn_xsectpt_cl	unknown	unknown	50–3000	292.0[a]	2.0	MCN pool transects at 3000-ft spacing.
a_Control	N/A	PNNL	N/A	294.0[a]	336.5[a]9.5	Manually added contours for improving surface quality.
a_Shore	N/A	PNNL	N/A	292.0[a]	336.5[a]10.0	Digitized shoreline from July 2006, 0.5-m aerial photos.

(a) Columbia River mile (Snake River joins Columbia River at Columbia River mile 324).

Table 2.6. Datasets Used to Create Bathymetric Surface for the IHR Pool and Lower Monumental Dam (LMN) Tailrace.

Dataset	Survey Year	Source	Approximate Resolution (ft)	Snake River Mile from	Snake River Mile to	Study
p_bath_2006_er1	2006	PNNL	4–300	35.0	40.5	IHR pool transects at 300-ft spacing.
p_ihased_2003_er1	2003	CENWW	10–5000	11.0	40.5	Sediment range survey at 3000- to 5000-ft spacing.
p_NOAA_Depth_er2	unknown	NOAA	300–800	11.0	40.0	Spot depths from NOAA navigation chart 18545.
p_bath_2008_ed1	2008	PNNL	2–400	27.5	35.0	IHR pool transects at 300-ft spacing.
p_lomonobk	1992	CENWW	3–25	40.5	41.5	Survey of LMN tailrace.
p_area2edt	1993	CENWW	5–20	10.0	10.5	Survey of IHR forebay.
p_lmn_tail	1999	CENWW	3–25	40.5	41.5	Survey of LMN tailrace.
a_Control	N/A	PNNL	N/A	11.0	40.5	Manually added contours for improving surface quality.
a_Shore	N/A	PNNL	N/A	10.0	41.5	Digitized shoreline from July 2006, 0.5-m aerial photos.

Table 2.7. Datasets Used to Create Bathymetric Surface for the LMN and Little Goose Dam (LGO) Tailrace

Dataset	Survey Year	Source	Approximate Resolution (ft)	Snake River Mile from	Snake River Mile to	Study
p_NOAA_Depth_cl1	unknown	NOAA	500–1000	41.5	65.5	Spot depths from NOAA navigation chart 18546.
p_lgos	1992	CENWW	3–30	69.0	70.0	Survey of LGO tailrace.
p_lga_tail_navd	unknown	unknown	5–30	69.5	70.0	Survey of LGO tailrace.
p_bath_2006_ed1	2006	unknown	3–400	65.5	69.0	LMN pool transects at 400-ft spacing.
p_lmosed_2003_ed1	2003	unknown	10–8000	42.0	65.0	Sediment range survey at 2000- to 8000-ft spacing.
a_NOAA_Contours_cl1	unknown	NOAA	N/A	41.5	65.5	Depth contours from NOAA navigation chart 18546.
a_Control	N/A	PNNL	N/A	41.5	69.0	Manually added contours for improving surface quality.
a_Shore	N/A	PNNL	N/A	41.5	70.0	Digitized shoreline from July 2006, 0.5-m aerial photos.

Table 2.8. Datasets Used to Create Bathymetric Surface for the LGO Pool and Lower Granite (LGR) Tailrace

Dataset	Survey Year	Source	Approximate Resolution (ft)	Snake River Mile from	Snake River Mile to	Study
p_lgosed87	1987	CENWW	10–2000	102.0	107.0	Sediment range survey at 1000- to 2000-ft spacing.
p_pnnl05	2005	PNNL	3–400	100.0	106.0	LGO pool transects at 100-ft to 400-ft spacing.
p_sitec	unknown	unknown	5–30	106.0	107.5	Survey of LGR tailrace.
p_lgr_nav03	2003	unknown	4	106.0	107.0	Survey of navigation channel in LGR tailrace.
p_sitei_cl1	unknown	unknown	20	70.5	71.0	Survey of LGO forebay.
p_lgr_tail92	1992	CENWW	2–20	106.0	107.5	Survey of LGR tailrace.
p_NOAA_Depth_cl1	unknown	NOAA	500–1000	71.0	100.0	Spot depths from NOAA navigation chart 18547.
a_NOAA_Contours_cl1	unknown	NOAA	N/A	71.5	100.0	Depth contours from NOAA navigation chart 18547.
a_Control	N/A	PNNL	N/A	70.5	106.0	Manually added contours for improving surface quality.
a_Shore	N/A	PNNL	N/A	70.5	107.5	Digitized shoreline from July 2006, 0.5-m aerial photos.

Table 2.9. Datasets Used to Create Bathymetric Surface for the LGR Pool.

Dataset	Survey Year	Source	Approximate Resolution (ft)	Snake River Mile from	Snake River Mile to	Study
p_AndreBath_er3	1995 - 2007	PNNL	10	108.0	143–4.0[a]	Resampled bathymetry developed by PNNL
a_llacnt_er2	1995	PNNL	N/A	107.5	108.0	Contours developed by Gordon et al. (1995)
a_Control	N/A	PNNL	N/A	70.5	106.0	Manually added contours for improving surface quality.
a_Shore	N/A	PNNL	N/A	70.5	107.5	Digitized shoreline from July 2006, 0.5-m aerial photos.

(a) Clearwater River mile (Clearwater River joins the Snake River at Columbia River mile 139).

2.3 Computational Meshes

All meshes were created in Gridgen^{TM}(Pointwise, Inc 2003), and the extents were based on the shorelines discussed in Section 2.2. For some sections of the river far from the projects, shorelines from the Dissolved Gas Abatement Study (DGAS, Richmond et al. 2000) were used for areas for which no new bathymetry data were available. The areas of interest were near the projects; hence, the mesh resolution in these areas is much finer. Minimum cross-stream resolution included at least one cell per inflow/outflow location, i.e., at least one cell for each spill bay and turbine unit. Areas of increased cross-stream resolution were created for areas larger than the expected hydraulic extents.

The new meshes take advantage of the wetting and drying capabilities of the MASS2 (Perkins and Richmond 2004b) model. Multiple mesh blocks were used around some island features, although the shorelines were simplified and included some upland and island areas to improve mesh orthogonality. The wetting and drying feature of MASS2 creates “shorelines” in appropriate locations, thus accommodating changing water surface elevations.

2.3.1 Bonneville Tailrace and Tidal Reach

The tidal reach starts at Bonneville and has its downstream extent at Portland, OR, just upstream of the Willamette River confluence. The cross-stream resolution from the Ives Island complex is about double that found in the DGAS work (Figure 2.1). The purple lines in the bathymetry figures delineate the boat restriction zone (BRZ). The river through and to the north of the Ives Island complex was not included.

2.3.2 Bonneville Pool

The Bonneville Pool is from The Dalles to Bonneville Dam. At Bonneville (Figure 2.1), there are two cells per bay for the powerhouses, one per bay at the spillway. The increased cross-stream resolution extends from Cascade Locks down to the Bonneville Project. At TDA, the increased cross-stream resolution extends from the project to approximately 3.75 miles downstream. There are two cells per spill bay; however, the powerhouse is not resolved bay-by-bay. The powerhouse flow is specified as a single total value and the inflow boundary is located upstream of the flow constriction between the powerhouse and the spillway tailrace.

Below the TDA spillway (Figure 2.2), the bridge islands were included in the mesh to allow for large variations in water surface elevation. The new TDA spillwall was included in the mesh, although the navigation lock was not.

2.3.3 The Dalles Pool

In the TDA forebay (Figure 2.2), the spillbays had one cell per bay, the location of the navigation lock wall was included, and the powerhouse had two cells per turbine unit. The area of increased cross-stream resolution extends about 3.7 miles upstream.

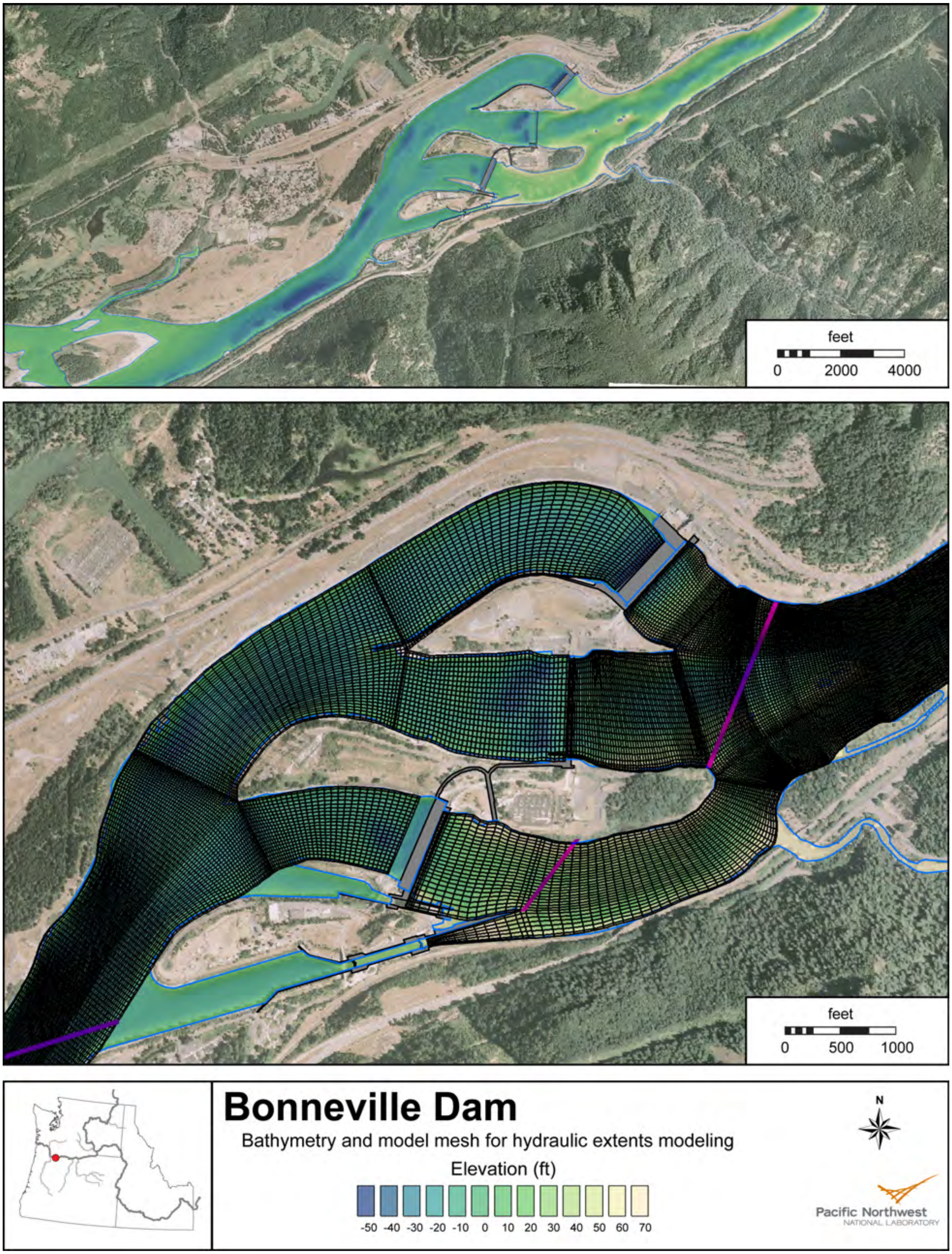

Figure 2.1. Bathymetry and Computational Mesh near the Bonneville Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry, computational mesh near the dam, and the BRZ (pink line).

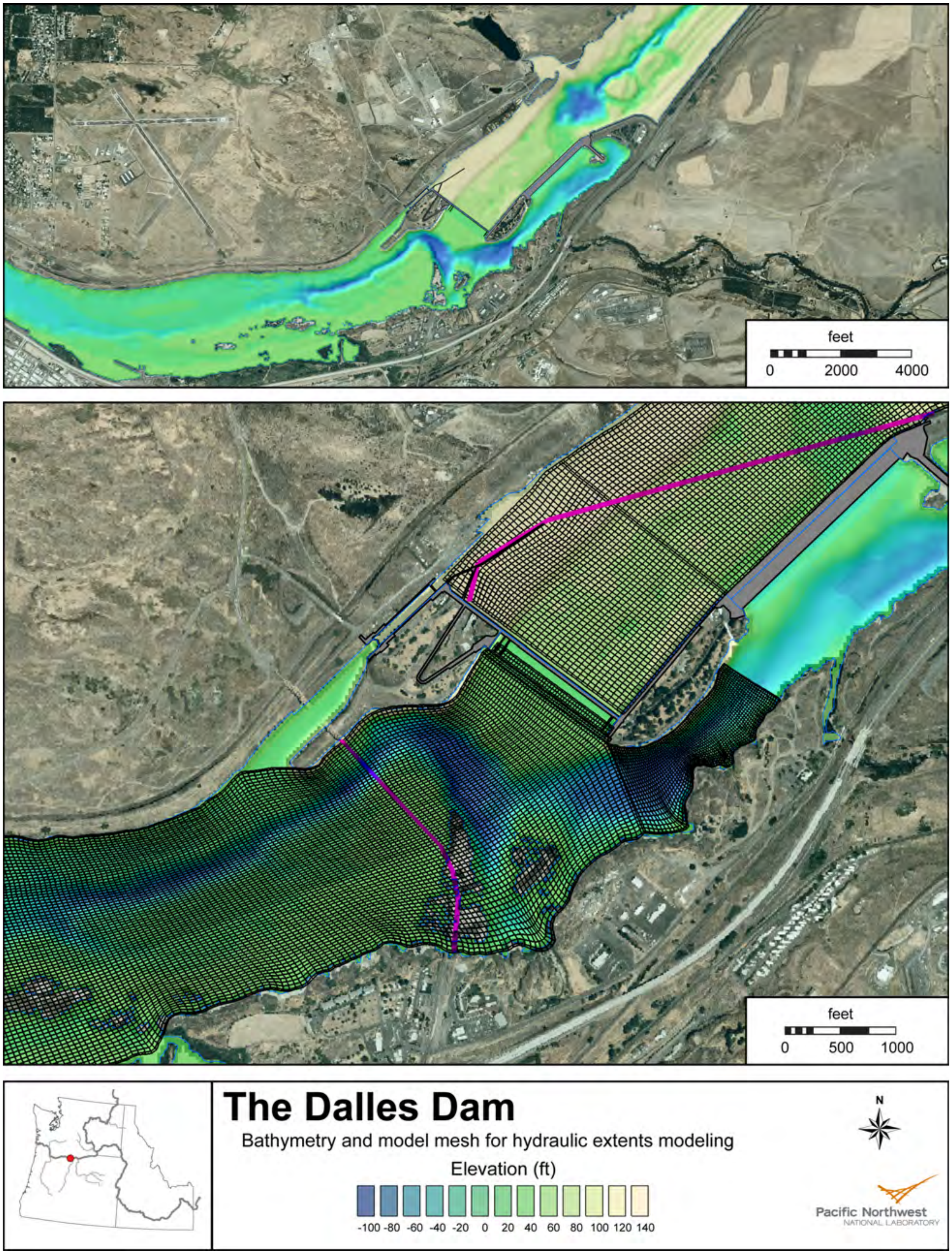

Figure 2.2. Bathymetry and Computational Mesh near The Dalles Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry, computational mesh near the dam, and the BRZ (pink line).

In the JDA tailrace (Figure 2.3), the mesh had one cell per spillbay, two per turbine unit. The island complex just downstream of the project was included in the mesh, allowing the modeling of the inundation of this complex. The area of increased cross-stream resolution extended 4.5 miles downstream.

2.3.4 John Day Pool

In the JDA forebay (Figure 2.3), the mesh has one cell per spillbay and per turbine unit. The area of increased cross-stream resolution extends 5.5 miles upstream.

At the MCN tailrace, the area of increased resolution extends only 2 miles downstream; however, a flow constriction makes the reduction in cross-stream cell numbers not as much of a change in cross-stream spatial resolution. At the dam, (Figure 2.4) there is one cell per spill bay, and two per turbine unit.)

2.3.5 McNary Pool up to Ice Harbor Dam

In the MCN forebay, the spillbays and turbine units have one cell each (Figure 2.4), and the area of increased cross-stream resolution extends 6 miles upstream. This mesh includes a short section of the Columbia upstream of its confluence with the Snake River and a well-resolved section of the Snake from Ice Harbor Dam to the Columbia River confluence.

At IHR, the mesh was taken from another study (Hanrahan et al. 2007). This well-resolved mesh has two cells per spillway bay and per turbine unit (Figure 2.5). This mesh has two locations, both near the confluence, where the mesh has 2:1 cross-stream matches across block boundaries to reduce the number of cells.

Above IHR, the river tends to have more convoluted shorelines. In many places, the mesh boundaries are outside the convolutions to increase mesh orthogonality while letting the wetting/drying capabilities determine the portions of the mesh that are within the flowing river. In the IHR forebay, there is one cell per bay and turbine unit (Figure 2.5), but more cells were added in upstream blocks to maintain cross stream resolution because the river and mesh are wider. In the LMN tailrace, there are two cells per turbine unit and spillbay (Figure 2.6).

2.3.6 Lower Monumental Pool

In the LMN forebay, there is one cell per turbine unit and spillbay (Figure 2.6). The shorelines for this pool extend outside much of the pool to include shoreline complexity and side channels while maintaining a sufficient number of cells in the main channel. In the Little Goose tailrace, there is one cell per spillbay, two per turbine unit (Figure 2.7).

In the LGO forebay, the computational mesh has one cell per turbine unit and spillbay (Figure 2.7). In the LGR tailrace, there are two cells per turbine unit and spillbay (Figure 2.8).

The mesh extends from LGR to 3.5 miles upstream of the Clearwater confluence and includes

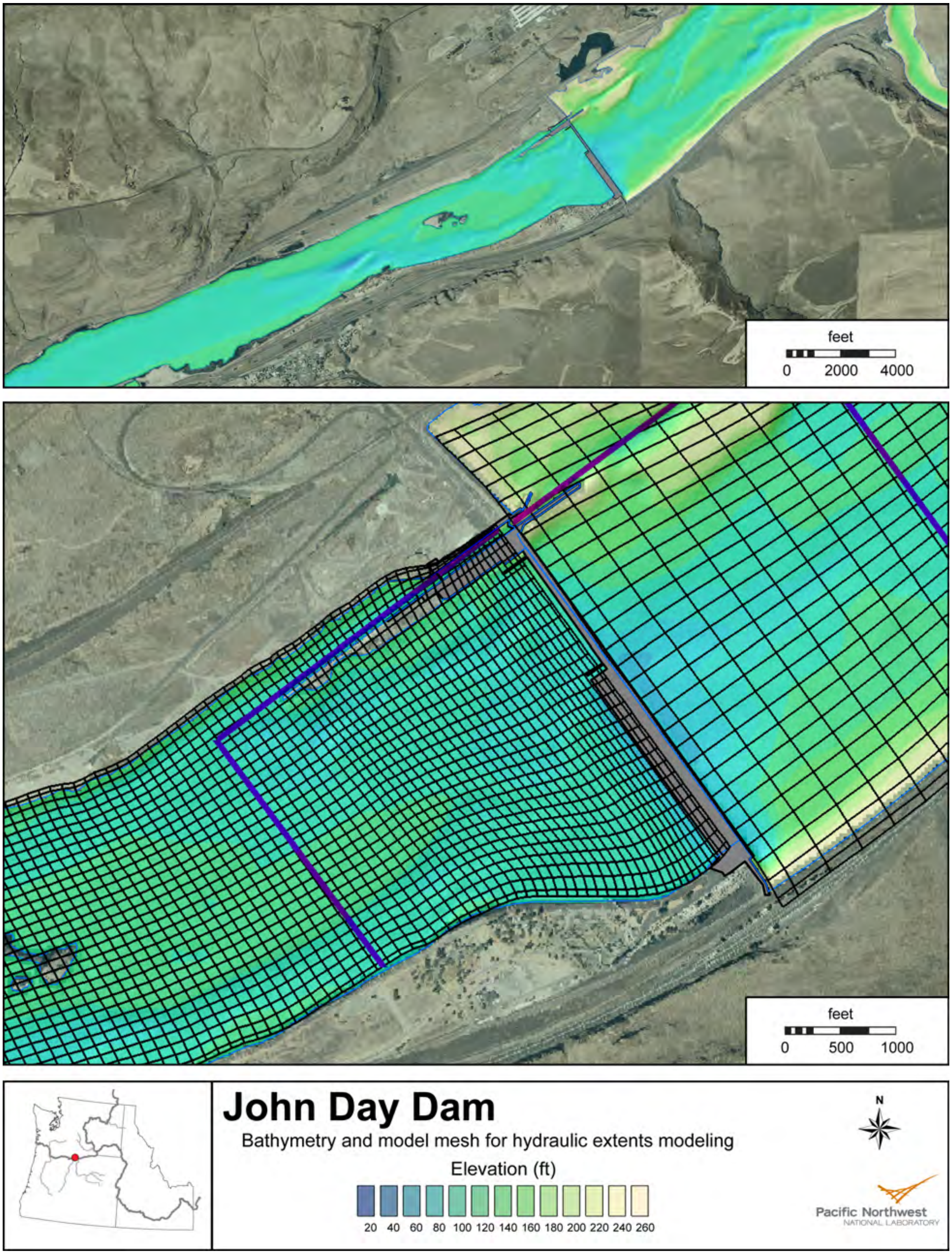

Figure 2.3. Bathymetry and Computational Mesh near the John Day Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry, computational mesh near the dam, and the BRZ (pink line).

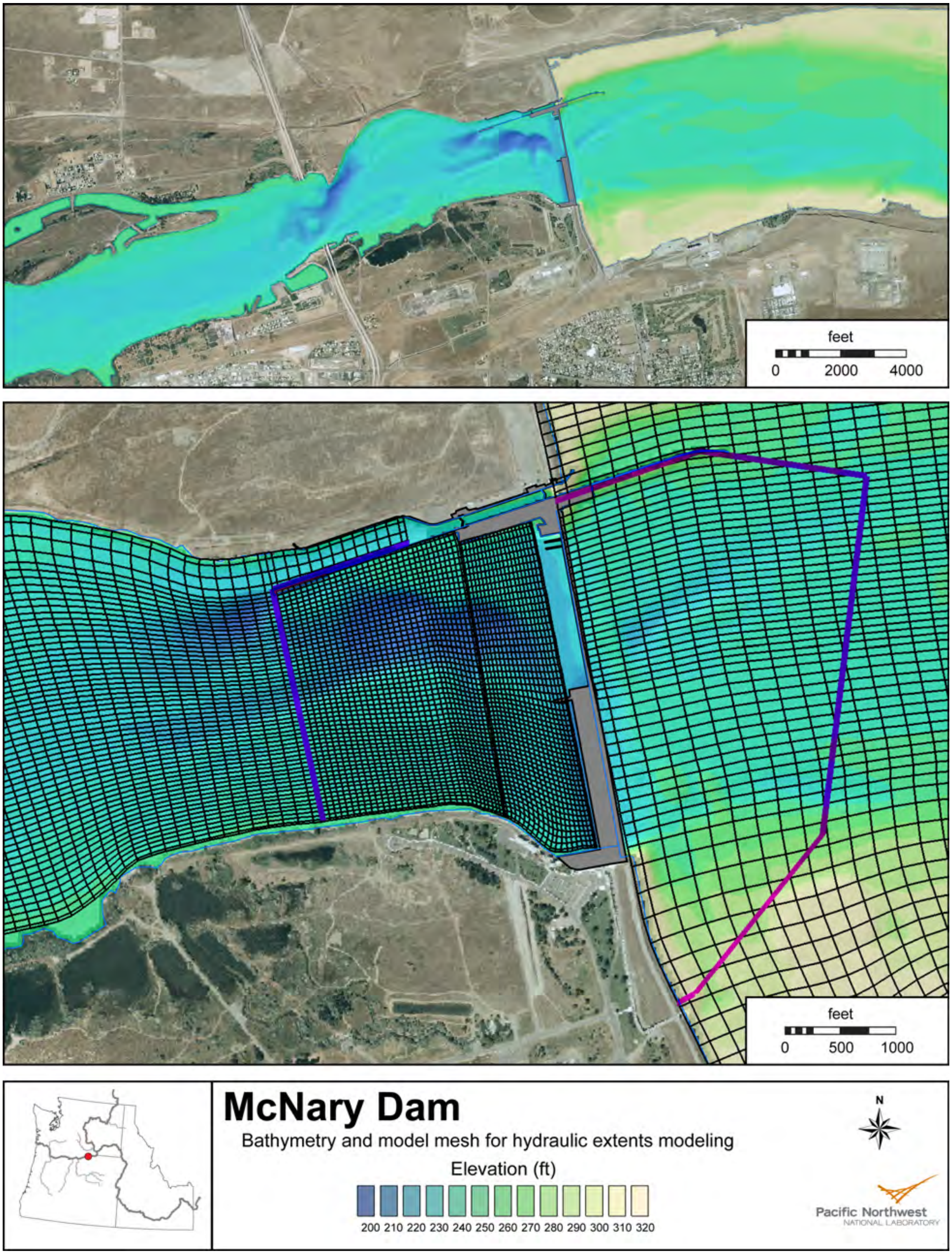

Figure 2.4. Bathymetry and Computational Mesh near the McNary Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry, computational mesh near the dam, and the BRZ (pink line).

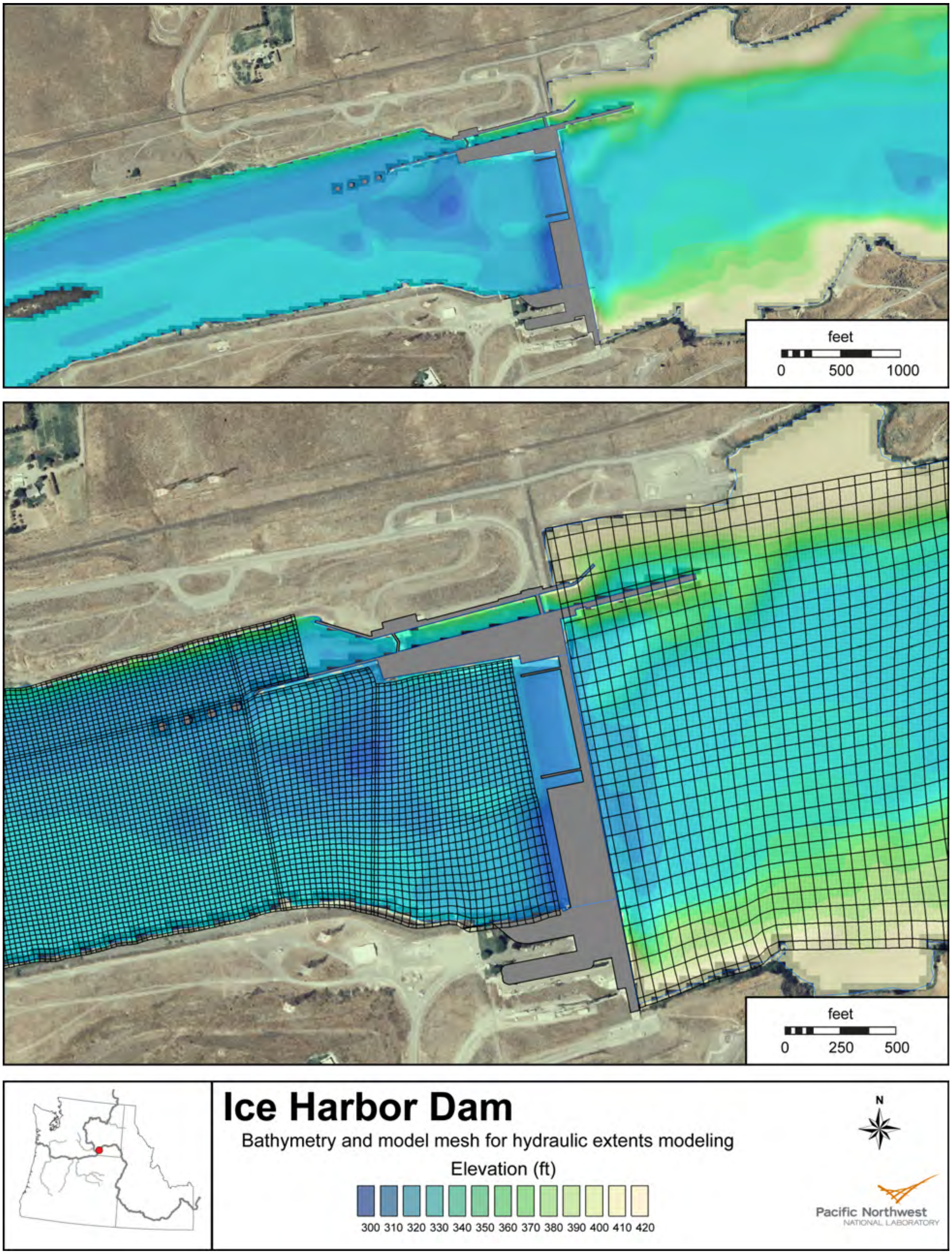

Figure 2.5. Bathymetry and Computational Mesh near the Ice Harbor Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry and computational mesh near the dam.

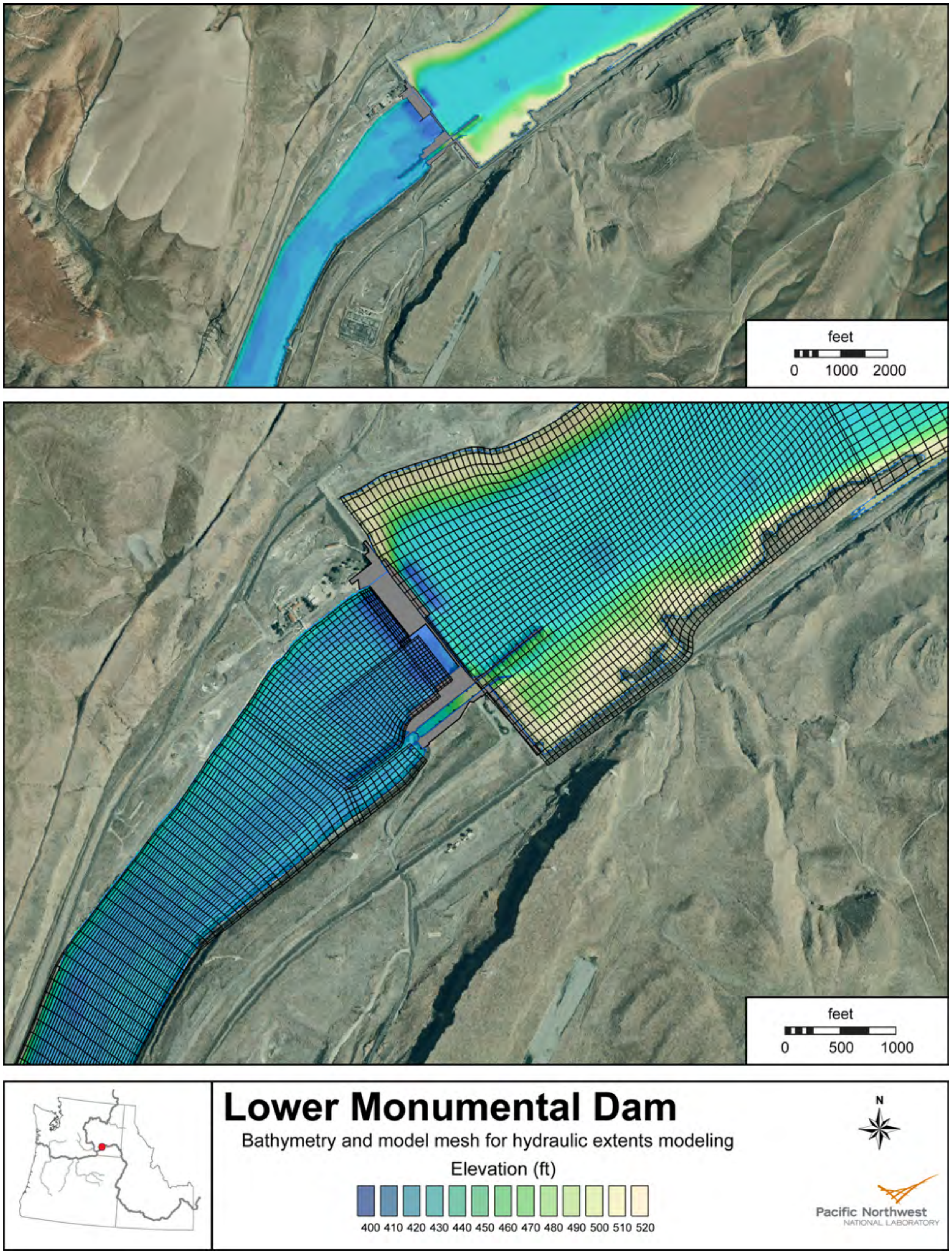

Figure 2.6. Bathymetry and Computational Mesh near the Lower Monumental Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry and computational mesh near the dam.

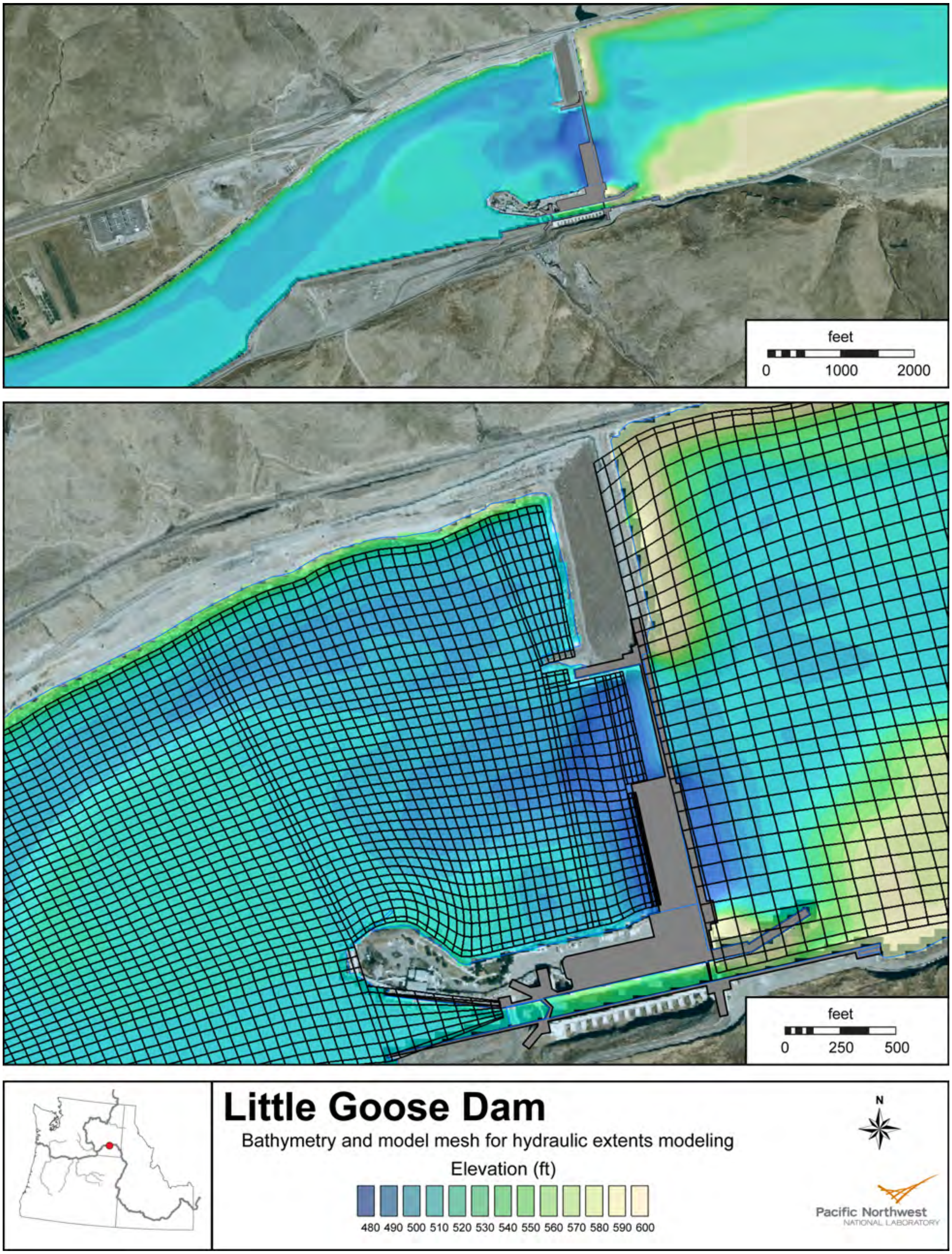

Figure 2.7. Bathymetry and Computational Mesh near the Little Goose Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry and computational mesh near the dam.

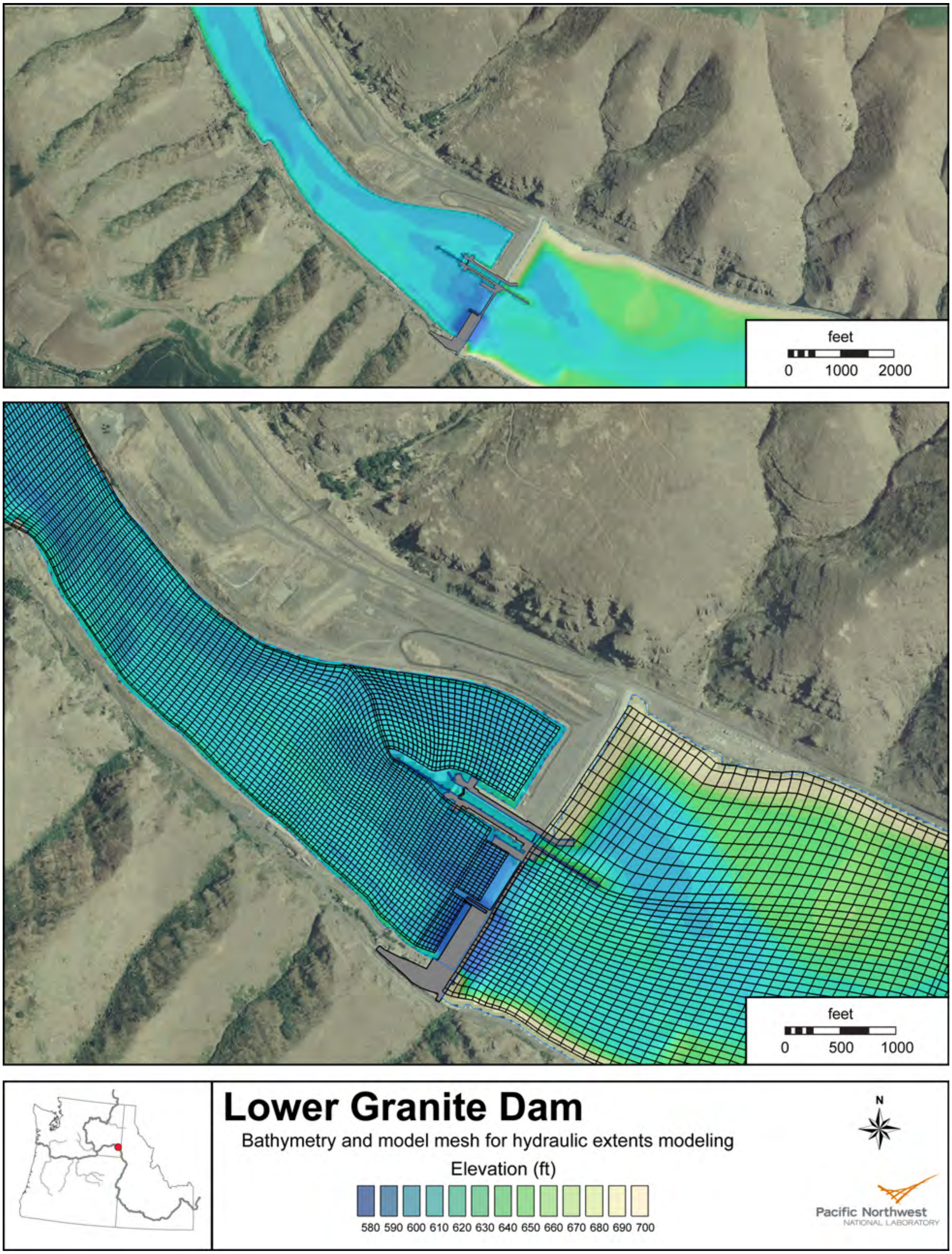

Figure 2.8. Bathymetry and Computational Mesh near the Lower Granite Project. The upper panel shows the overall river bathymetry. The lower panel shows the bathymetry and computational mesh near the dam.

a 7-mile segment of the Clearwater River. In the LGR forebay, there are two cells per turbine unit and one per spill bay (Figure 2.8). The shallow draft boom that extends attaches between the powerhouse and spillway and extends upstream to the south shore was ignored, per guidance from CENWW.

2.4 Model Configuration and Scenarios

The project operations were specified by CENWP and CENWW for each project. For each project, the forebay and tailrace models both needed to be configured and run for each specified operation.

The forebay models were configured with a specified total river flow at the next dam upstream and bay-by-bay, unit-by-unit operations in the forebay. A single bay was specified as a water surface elevation boundary so as to not over constrain the model. As model conditions changed, this "open" boundary allowed the forebay hydraulics to adjust more quickly to changing boundary conditions. Travel time data provided by CENWP and CENWW were used to estimate the time needed for a steady state to be achieved after changing the total river flow for a given reach and flow. One day of time was typically used for changing project operations for the same total river flow.

For the tailrace models, bay-by-bay, unit-by-unit operations were specified at the project, and the downstream boundary was run as a specified water surface elevation.

For all river reaches, the most recent validated Manning's n value was used. New meshes, however, were not re-validated against field measured data. Time steps small enough to have convergent models were used. Time steps were typically 30 s, although 15 s were used in some models.

The boundary condition spreadsheets were used to create the ASCII text files required as input files for MASS2. Each total river flow was run to to a converged steady-state solution for particular total river discharge, and then the model was run for an additional 24 h before writing the modeled flows for each operational scenario. MASS2 writes out the dates associated with model output, and those dates are used to track the scenario.

Water mass imbalances were checked for all model runs to ensure convergence. The typical allowed imbalance was 100 cfs; however, most runs had a much smaller block imbalance (1̃ cfs). Flow volumes were checked to make sure the model was properly configured and converged. Inflow and outflow locations at the projects were checked to make sure that the unit numbering was correct in the configuration files and flow locations were properly assigned.

2.4.1 General MASS2 Configuration

A MASS2 simulation case is configured using a series of text files for the computational mesh, model parameters, and flow conditions (see Perkins and Richmond (2004b) for details). In this study, a large range of flows was simulated. In the lower Columbia, the range of total river flows were from the lower typical summers flows to the maximum flows at which the Fish Passage Plan (FPP) (USACE–Northwestern Division 2008) can be used. At higher flows, there would be involuntary spill. The operations at each project were for the minimum and maximum powerhouse loading. For the Snake River dams and McNary Dam, the range was from minimum flow to high flows. The specified project operations were selected to explore the largest possible differences by modeling maximum powerhouse or minimum powerhouse flow. Additional runs had the flow centered mid-river for the maximum momentum concentration. Specific project operations are detailed in the sections below.

2.4.2 Bonneville Project

At Bonneville, the river is split by two islands with a spillway between the two islands, Powerhouse 1 (B1) between Bradford Island and the Oregon shore, and Powerhouse 2 (B2) between Cascade Island and Washington shore. Flow distributions were specified to include priority flow in both powerhouses and the spillway, but only for flow patterns that would be allowed operations (Tables 2.10 and 2.11). The spillway had an almost flat pattern: the spill flow was evenly distributed between Bays 2 to 17, but half the flow volume in Bays 1 and 18. Total spill flow was divided by 17 to get the unit flow; that unit flow was used in Bays 2-12, and half that flow was used in Bays 1 and 18.

Table 2.10. Bonneville Scenarios

Case	Description	Total River (kcfs)	B1 (kcfs)	B2 (kcfs)	Spillway (kcfs)
1	Typical summer flow, Existing FPP	150	60		90
2	Typical summer flow, Full B1	150	120	30	
3	Typical summer flow, Full B2	150		150	
4	Typical spring flow, Min. PH loading	250		150	100
5	Typical spring flow, Existing FPP	250	120		130
6	Typical spring flow, Max. PH	250	100	150	
7	Max flow for FPP, Min. PH, B2	350		30	320
8	Max flow for FPP, Min. PH, B1	350	30		320
9	Max flow for FPP, B2 priority, B1	350	100	150	100
10	High flow, Min. PH, B1	450	0	30	420
11	High flow, Min. PH, B2	450	30	0	420
12	High flow, Max. PH	450	100	150	200

Table 2.11. Bonneville Powerhouse 1 and Powerhouse 2 Operations

Case	Spill	Powerhouse 1 (kcfs)										Powerhouse 2 (kcfs)										
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	F1	F2	Total
1	90	10	10	10	10	10	10															150
2		10	10	10	10	10	10	10	10	10	10							10	15	2.5	2.5	130
3												18	18	18	18	18	18	18	18	3	3	150
4	100											18	18	18	18	18	18	18	18	3	3	250
5	130	12	12	12	12	12	12	12	12	12	12											250
6		10	10	10	10	10	10	10	10	10	10	18	18	18	18	18	18	18	18	3	3	250
7	320																	10	15	2.5	2.5	350
8	320	10	10	10																		350
9	100	10	10	10	10	10	10	10	10	10	10	18	18	18	18	18	18	18	18	3	3	350
10	420																	10	15	2.5	2.5	450
11	420	10	10	10																		450
12	200	10	10	10	10	10	10	10	10	10	10	18	18	18	18	18	18	18	18	3	3	450

2.4.3 The Dalles Project

A summary of flows is in Table 2.12 with with unit-by-unit details of flow distribution in Table 2.13.

Table 2.12. The Dalles Scenarios

Case	Description	Total River (kcfs)	Powerhouse (kcfs)	Spillway (kcfs)
1	Summer flow, Min. PH	150	50	100
2	Summer flow, Existing FPP	150	90	60
3	Summer flow, Full PH, no spill	150	150	0
4	Spring flow, Min. PH	250	50	200
5	Spring flow, Existing FPP, 40% spill	250	150	100
6	Spring flow, Max. PH, no spill	250	250	0
7	Spring flow at Max. PH, Min. PH	270	50	220
8	Spring flow at Max. PH, Existing FPP, 40% spill	270	162	108
9	Spring flow at Max. PH, Max. PH, no spill	270	270	0
10	High Flow, Min. PH	450	50	400
11	High Flow, Max. PH, 40% spill	450	270	180

Table 2.13. The Dalles Operations

Case	Powerhouse (kcfs)																							Total
	FU	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	Total
1	5	12		12		12		9																150
2	5	14		14		14		14		14		15												150
3	5	14		14		14		14		14		15		15		15		15		15				150
4	5	12		12		12		9																250
5	5	14		14		14		14		14		15		15		15		15		15				250
6	5	13	13	13	13	13	13	13	14	14	14	14	14	14	14	14		14		14		14		250
7	5	12		12		12		9																270
8	5	14		14		14		14		14		14		14		14		15		15		15		270
9	5	13	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		14		14		270
10	5	12		12		12		9																450
11	5	13	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		14		14		450

2.4.4 John Day Project

These runs were previously reported in Rakowski et al. (2008b). However, the analysis of the simulation results evolved since the initial work. For completeness, the runs and results in consistent format are reported here. CENWP specified 11 flow scenarios to be run (Table 2.14) for four total river flows. For each given flow, a scenario for minimum powerhouse, full powerhouse, and an existing FPP operation was run. In the case of the 450 kcfs Total River, the maximum powerplant capacity case is almost identical to the existing FPP Pattern. Hence, there are two rather than three scenarios for a 450 kcfs Total River. The difference between "Full PH" and "Max. PH" in Table 2.14 is that for the full powerhouse, the turbines are operated within the 1% range of peak efficiency, and the maximum is passing the most water possible through the powerhouse.

Table 2.14. John Day Project Scenarios

Case	Description	Total River (kcfs)	Spillway (kcfs)	Powerhouse (kcfs)
1	Typical Summer, Min. PH	150	100	50
2	Typical Summer, Existing FPP	150	45	105
3	Typical Summer, Full PH	150	0	150
4	Typical Med. Flow, Min. PH	250	200	50
5	Typical Med. Flow, Existing FPP	250	75	175
6	Typical Med. Flow, Full PH	250	0	250
7	Spring Flow, Min. PH	320	270	50
8	Spring Flow,Existing FPP	320	96	224
9	Spring Flow, Max. PH	320	0	320
10	High Flow with FPP, Min. PH	450	400	50
11	High Flow with FPP, Existing FPP	450	135	315

Table 2.15. John Day Operations

Case	Powerhouse Units in kcfs															
	PH-1	PH-2	PH-3	PH-4	PH-5	PH-6	PH-7	PH-8	PH-9	PH-10	PH-11	PH-12	PH-13	PH-14	PH-15	PH-16
1	12.5	12.5	12.5		12.5											
2	15	15	15	15	15									15		15
3	15	15	15	15	15			15		15		15		15		15
4	12.5	12.5	12.5		12.5											
5	12.5	12.5	12.5	12.5	12.5	12.5		12.5		12.5	12.5	12.5	12.5	12.5	12.5	12.5
6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
7	12.5	12.5	12.5		12.5											
8	16	16	16	16	16	16		16		16	16	16	16	16	16	16
9	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
10	12.5	12.5	12.5		12.5											
11	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7

Case	Spillway Bays in kcfs																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	6.4	8	8	8	6.4	6.4	6.4	6.4	6.4	4.8	4.8	4.8	4.8	4.8	4.8	3.2	3.2	1.6	
2	0	4.8	4.8	4.8	4.8	4.8	4.8	3.2	3.2	3.2	3.2	3.2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	6.4	9.6	11.2	11.2	11.2	11.2	11.2	9.6	11.2	9.6	11.2	9.6	11.2	11.2	11.2	11.2	11.2	11.2	9.6
5	0	6.4	8	6.4	6.4	6.4	4.8	4.8	4.8	4.8	3.2	3.2	3.2	3.2	3.2	3.2	3.2	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	6.4	9.6	12.8	16	14.4	14.4	16	14.4	16	14.4	16	14.4	14.4	16	14.4	16	14.4	16	14.4
8	0	6.4	8	8	8	6.4	6.4	6.4	6.4	4.8	4.8	4.8	4.8	4.8	4.8	4.8	3.2	3.2	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	16.5	20	22	22	23	22	23	22	23	22	23	22	23	22	23	22	16.5	16.5	16.5
11	0	6.4	8	8	8	6.4	6.4	8	6.4	8	6.4	6.4	6.4	6.4	8	6.4	8	6.4	8	6.4

2.4.5 McNary Project

CENWW hydro projects (the lower Snake River dams and McNary Dam), the flows were determined somewhat differently. For each project, simulations were run for the range of total river flows: minimum flow, low flow, medium flow, and high flow. For each total river flow, operations for the maximum and minimum powerhouse flows were simulated. In addition, for the minimum and low flows, an additional simulation was run with the flow at the project being in the center of the river. A summary of flows is in Table 2.16 with unit-by-unit details of flow distribution in Table 2.17.

Table 2.16. McNary Scenarios

Case	Description	Total River (kcfs)	Spillway (kcfs)	Powerhouse (kcfs)
1	Min. Flow, Min. PH	100	50	50
2	Min. Flow, Max. PH	100	0	100
3	Low Flow, Min. PH	150	100	50
4	Low Flow, Max. PH	150	0	150
5	Mid Flow, Min. PH	250	200	50
6	Mid Flow, Max. PH	250	75	175
7	High Flow, Min. PH	350	300	50
8	High Flow, Max. PH	350	175	175
9	Max. PH Flow, Max. PH	175	0	175
10	Min. Flow, Max. Center	100	50	50
11	Low Flow, Max. Center	150	75	75

Table 2.17. McNary Operations

Case	Spillway in kcfs																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	13.6	13.6	13.6	9.2																		
2																						
3	13.6	13.6	13.6	13.6	13.6	13.6	13.6	4.6														
4																						
5	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	9.1							
6																	6.8	13.6	13.6	13.6	13.6	13.6
7	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6
8										11.4	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6
9																						
10																			9.2	13.6	13.6	13.6
11																	7.0	13.6	13.6	13.6	13.6	13.6

Case	Powerhouse in kcfs													
	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	12.5	12.5	12.5	12.5										
2							12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
3	12.5	12.5	12.5	12.5										
4			12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
5	12.5	12.5	12.5	12.5										
6	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
7	12.5	12.5	12.5	12.5										
8	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
9	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
10	12.5	12.5	12.5	12.5										
11	12.5	12.5	12.5	12.5	12.5	12.5								

2.4.6 Ice Harbor Project

A summary of flows is in Table 2.18 with with unit-by-unit details of flow distribution in Table 2.19.

Table 2.18. Ice Harbor Scenarios

Case	Description	Total River (kcfs)	Spillway (kcfs)	Powerhouse (kcfs)
1	Min. Flow, Min. PH	19	0	11
2	Min. Flow, Max. PH	19	0	19
3	Low Flow, Min. PH	30	19	11
4	Low Flow, Max. PH	30	0	30
5	Mid Flow, Min. PH	85	74	11
6	Mid Flow, Max. PH	85	0	85
7	High Flow, Min. PH	120	109	11
8	High Flow, Max. PH	120	21	99
9	Max. PH Flow, Max. PH	99	0	99
10	Min. Flow, Max. Center	19	10	9
11	Low Flow, Max. Center	30	15	15

Table 2.19. Ice Harbor Operations

Case	Spillway in kcfs										Powerhouse in kcfs					
1	10	9	8	7	6	5	4	3	2	1	6	5	4	3	2	1
2	8.0										11					
3															9	10
4	10	9									11					
5															15	15
6	10.0	10	10	10	10	10	10	10	4		11					
7											11	11	18	15	15	15
8	11	11	11	11	11	11	11	11	11	10	11					
9									10	11	18	18	18	15	15	15
10											18	18	18	15	15	15
11										10	9					
12									4	11	15					

2.4.7 Lower Monumental Project

A summary of flows is in Table 2.20 with unit-by-unit details of flow distribution in Table 2.21.

Table 2.20. Lower Monumental Scenarios

Case	Description	Total River (kcfs)	Spillway (kcfs)	Powerhouse (kcfs)
1	Min. Flow, Min. PH	19	5	14
2	Min. Flow, Max. PH	19	0	19
3	Low Flow, Min. PH	30	16	14
4	Low Flow, Max. PH	30	0	30
5	ADCP 4/30/2010	62	27	35
6	Mid Flow, Min. PH	85	71	14
7	Mid Flow, Max. PH	85	0	85
8	High Flow, Min. PH	120	106	14
9	High Flow, Max. PH	120	0	120
10	Mid Flow, Typical	85	27	58
11	Min Flow, Max Center	19	5	14
12	Low Flow, Max Center	30	13.3	16.7

Table 2.21. Lower Monumental Operations

Case	Powerhouse Units (kcfs)						Spillway Bays (kcfs)							
	1	2	3	4	5	6	8	7	6	5	4	3	2	1
1						14								5
2	19													
3						14							6	10
4	15	15												
5		17.5			17.5		7		9	3	2	2	2	2
6						14		10	10	10	10	10	10	11
7	20	20	15	15	15									
8						14	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
9	20	20	20	20	20	20								
10		14	14	15	15		7.6		8.9	3.3	1.8	1.8	1.8	1.8
11						14	5							
12						16.7	13.3							

2.4.8 Little Goose Project

A summary of flows is in Table 2.22 with unit-by-unit details of flow distribution in Table 2.23.

Table 2.22. Little Goose Scenarios

Case	Description	Total River (kcfs)	Spillway (kcfs)	Powerhouse (kcfs)
1	Min. Flow, Min. PH	19	5	14
2	Min. Flow, Max. PH	19	0	19
3	Low Flow, Min. PH	30	16	14
4	Low Flow, Max. PH	30	0	30
5	Mid Flow, Min. PH	85	71	14
6	Mid Flow, Max. PH	85	0	85
7	High Flow, Min. PH	120	106	14
8	High Flow, Max. PH	120	0	120
9	Mid Flow, Typical	85	27	58
10	Min. Flow, Max. Center	19	5	14
11	Low Flow, Max. Center	30	13.3	16.7

Table 2.23. Little Goose Operations

Case	Spillway Bays (kcfs)								Powerhouse (kcfs)					
	8	7	6	5	4	3	2	1	6	5	4	3	2	1
1	5								14					
2														19
3	10	6							14					
4													15	15
5	11	10	10	10	10	10	10		14					
6										15	15	15	20	20
7	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	14					
8									20	20	20	20	20	20
9	1.8	1.8	1.8	1.8	2.0	3.3	3.3	11.2			15	15	14	14
10								5	14					
11								13.3	16.7					

2.4.9 Lower Granite Project

A summary of flows is in Table 2.24 with unit-by-unit details of flow distribution in Table 2.25.

Table 2.24. Lower Granite Scenarios

Case	Description	Total River (kcfs)	Spillway (kcfs)	Powerhouse (kcfs)
1	Min. Flow, Min. PH	19	5	14
2	Min. Flow, Max. PH	19	0	19
3	Low Flow, Min. PH	30	16	14
4	Low Flow, Max. PH	30	0	30
5	Mid Flow, Min. PH	85	71	14
6	Mid Flow, Max. PH	85	0	85
7	High Flow, Min. PH	120	106	14
8	High Flow, Max. PH	120	0	120
9	Mid Flow, Typical	85	27	58
10	Min. Flow, Max. PH	19	5	14
11	Low Flow, Min. PH	30	13.3	16.7

Table 2.25. Lower Granite Operations

Case	Spillway Bays (kcfs)								Powerhouse (kcfs)					
	8	7	6	5	4	3	2	1	6	5	4	3	2	1
1	5								14					
2														19
3	10	6							14					
4													15	15
5	11	10	10	10	10	10	10		14					
6										15	15	15	20	20
7	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	14					
8									20	20	20	20	20	20
9	1.8	1.8	1.8	1.8	2	3.3	3.3	11.2			15	15	14	14
10								5	14					
11								13.3	16.7					

2.5 Analysis of Simulation Data

Hydraulic influence is defined as the zone where project flow distributions (operations) impact river flow up- and downstream of the dam. Each distribution of discharges through a dam results in a unique set of hydraulic characteristics, such as flow velocity and water-surface elevation, in the river channel adjacent to the project. As one moves away from the project, the river gradually reverts to a stable flow configuration that is unaffected by flow distributions at the dam. The point at which project operations no longer influence the hydraulic characteristics of the river is the hydraulic extent. Because, theoretically, any change in operations will have at least some infinitesimal influence at all points in the flow domain, a threshold level must be defined to establish a definite boundary.

The strategy presented in this document for locating the hydraulic extent is to simulate a wide range of plausible operating conditions and calculate the differences in hydraulic characteristics among the scenarios. The scenarios typically include maximum spill, maximum powerhouse, and balanced patterns for each of four total river discharges. Only scenarios with the same total river discharge are compared. Velocity magnitude and direction are the two hydraulic characteristics used in this study. The comparison metrics are the maximum spread (S) in velocity magnitude and velocity direction at each point in the model, computed as:

$$S_{vmag} = \mid U \mid_{max} - \mid U \mid_{min}$$

$$S_{dir} = \mid \theta_{max} - \theta_{min} \mid$$

where $\mid U \mid$ is the velocity magnitude, and θ is the velocity direction, in degrees.

Comparison metrics are computed using a script developed in Tecplot360^{TM} (Tecplot, Inc.). The script adds the comparison metrics to a model grid dataset and plots the values for analysis. The metrics are contoured according to proposed threshold spread values.

USACE fishery biologists requested data analysis to determine the project hydraulic extent based on the following criteria:

- For areas where the mean velocities are less than 4 ft/s, the differences in the magnitude water velocity between operations are not greater than 0.5 ft/sec, and/or the differences in water flow direction (azimuth) are not greater than 10°.

- If mean water velocity is 4.0 ft/s or greater, the boundary is determined using the differences in water flow direction (i.e., not greater than 10°)

Based on these criteria, and not including areas with a mean velocity of less than 0.1 ft/s (within the error of the model), a final set of graphics was developed that included data from all flows and all operations.

3.0 Results and Discussion

Results are presented in map format by project for each total river flow (Sections 3.1 to 3.8). For each total river flow, the multiple scenarios were analyzed for average velocity magnitude, spread of velocity magnitude, and the spread in maximum difference in flow direction (azimuth). The method is described in Section 2.5. The BRZ is delineated with a pink line.

In Section 3.9, the hydraulic extent criteria are applied and summarized.

Although the same computational meshes were used for the tailrace of one project and the forebay of the next project downstream, the operational conditions were specified by project with the same conditions used for the forebay and tailrace. Results are discussed in order from downstream to upstream. The maps are organized with three maps per page, each page dedicated to a total river flow. The top graphic has contours of average velocity magnitude and hence increases with river flow. The middle graphic has contours of the spread in velocity magnitude, and the lower figure has contours of the spread of difference in flow direction.

In general, the downstream (tailrace) extent of the impact of project operations is much greater than the upstream (forebay) extent. The forebays are much deeper than the tailrace, so the approach velocities to the project are much lower, and the absolute velocity difference across the channel is much less. In the tailrace, the impact of changing operations extends much further downstream.

There was also a pattern of response to increasing river flow. In the forebays, the upstream extent of the impact of project operations increased between the low and medium flows, but then the upstream impact decreased at the higher flows. In the tailrace, it is the difference in the direction of flow, rather than the velocity difference, that is most flow dependent. The greatest longitudinal extent of flow direction differences is at the lowest flows. The spread in flow directions decreases as the channel competence is approached or downstream constrictions (either by bank shape or mid-stream islands) regulate the flow direction.

3.1 Bonneville Project

Bonneville is the most complex channel setting of this study. The river is split by Cascade and Bradford Islands. Operations are detailed in Tables 2.10 and 2.11. The river is split by the islands into three parts, and each part of the river is controlled by a powerhouse or spillway. Hence, the impacts of varying project operations are very large between the project structure and the confluence of the three parts of the river. Figures 3.1 to 3.4 show the results of the MASS2 runs. Downstream, between the BRZ and the Ives Island complex, the overall channel width is much narrower; the relative constriction helps to limit the downstream extent of the impact of project operations at the higher flows. Note that the spread in velocity magnitude is not much different between 350 kcfs and 450 kcfs, nor is there much change in flow direction for any of the total river flows.

In the forebay, the greatest impact of project operations is at 250 kcfs. At lower and higher flows, the upstream extent is more limited. In the tailrace, the hydraulic extent increases with increasing discharge.

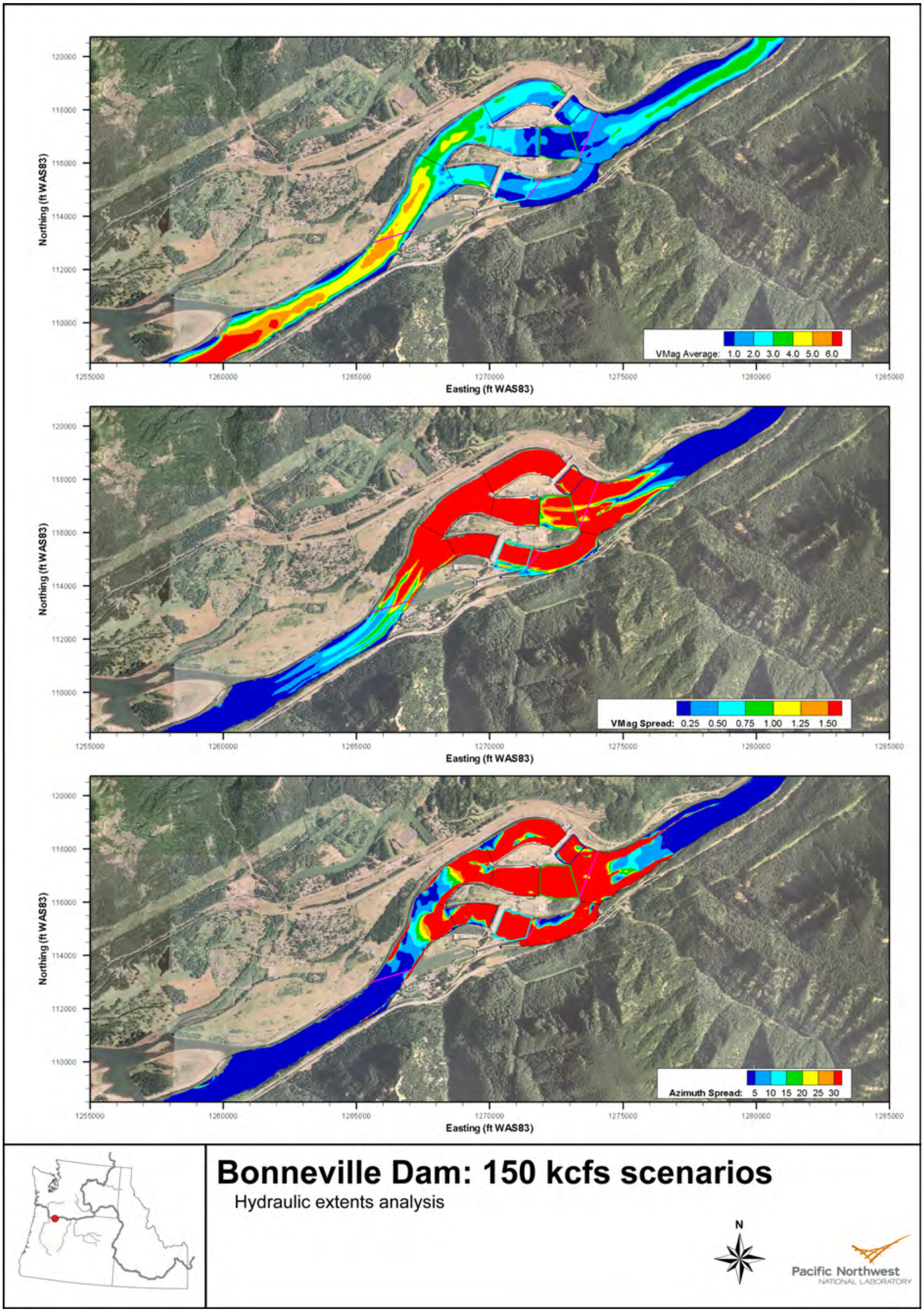

Figure 3.1. Bonneville Dam for 150 kcfs. Velocities in ft/s.

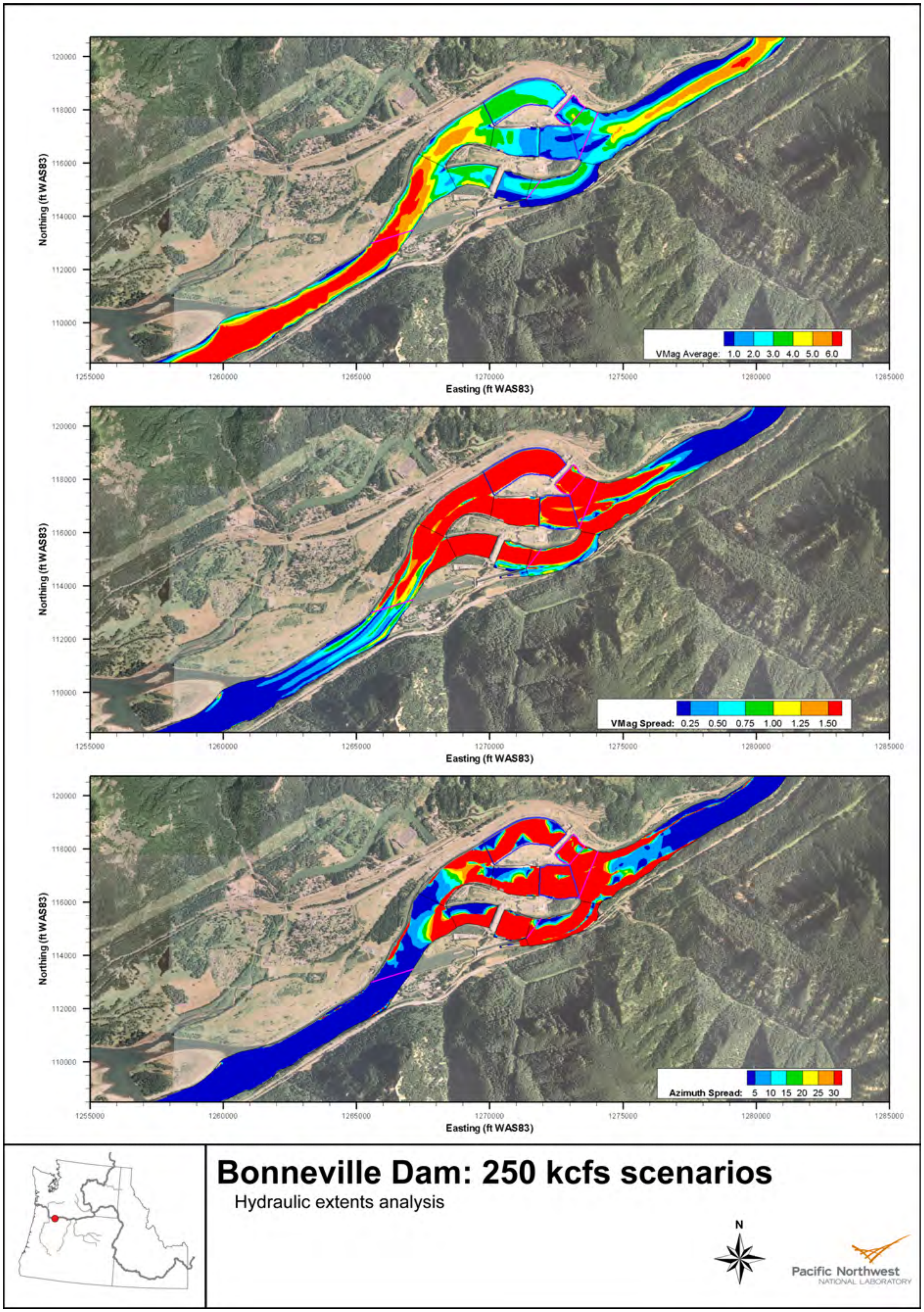

Figure 3.2. Bonneville Dam for 250 kcfs. Velocities in ft/s.

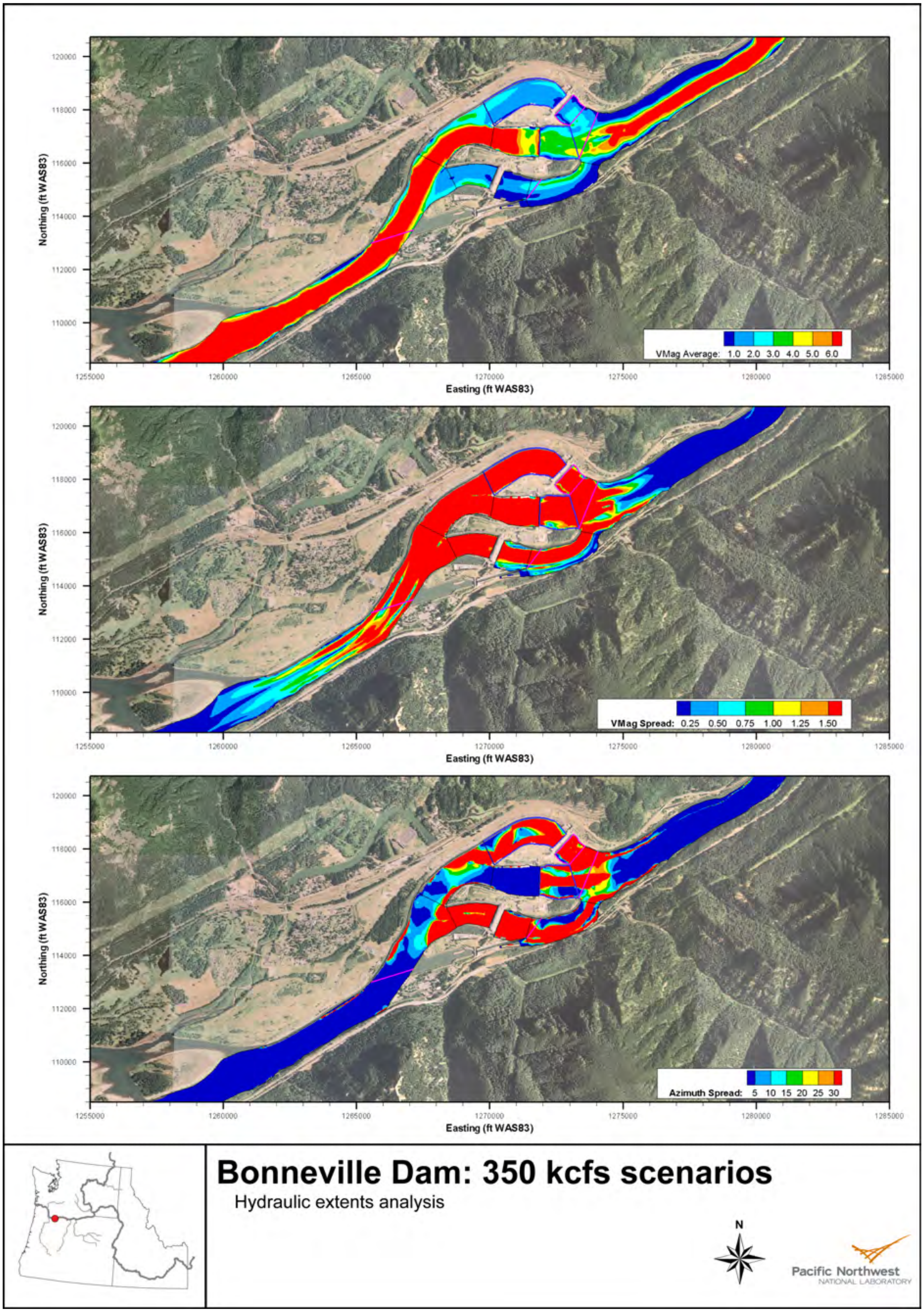

Figure 3.3. Bonneville Dam for 350 kcfs. Velocities in ft/s.

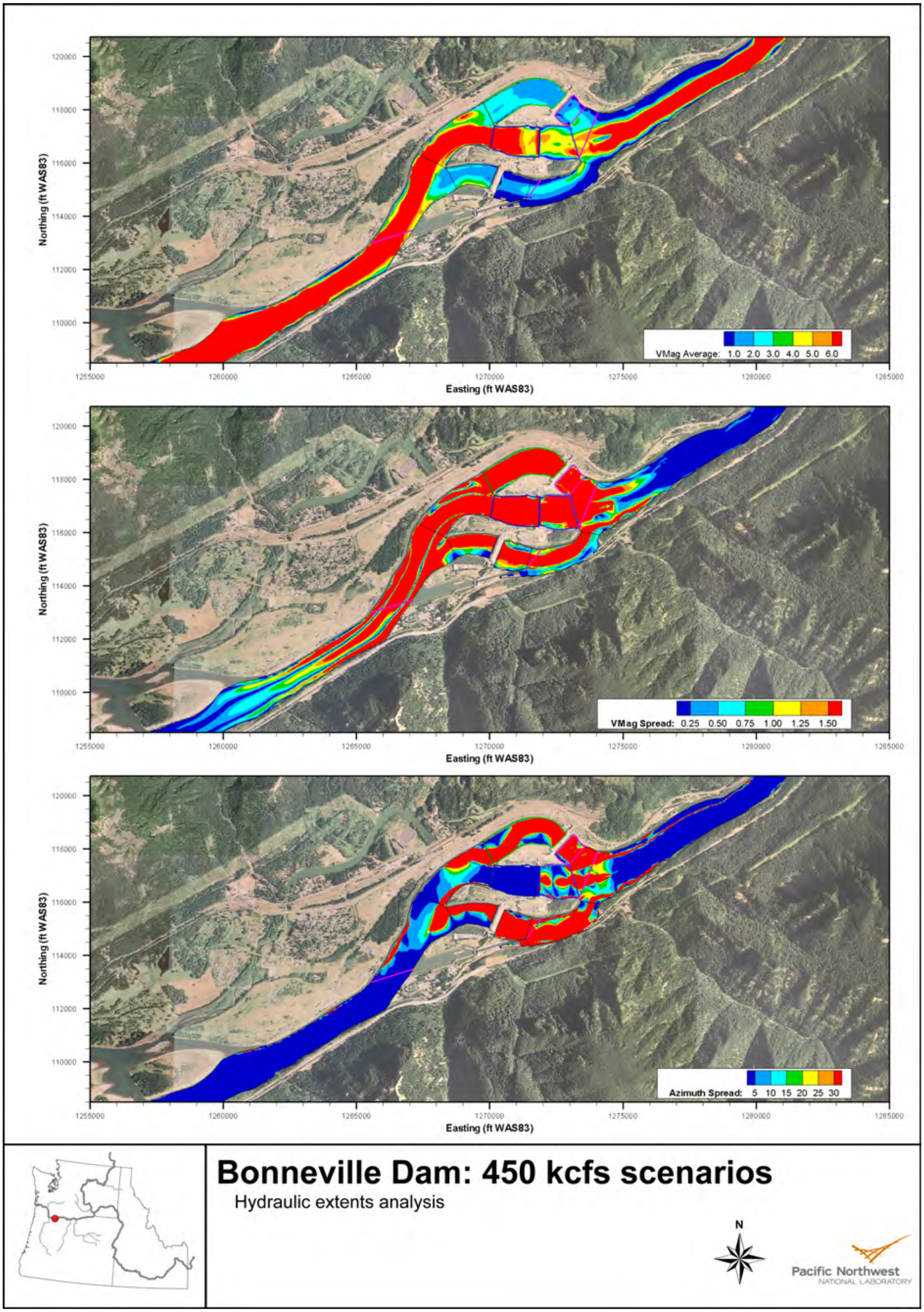

Figure 3.4. Bonneville Dam for 450 kcfs. Velocities in ft/s.

3.2 The Dalles Project

The Dalles has the powerhouse located perpendicular to the thalweg in the forebay, and the spillway and powerhouse are well separated. In addition, the spillway is operated by spilling preferentially from the north shore, that is, as far from the powerhouse as possible. Operations are detailed in Tables 2.12 and 2.13.

The Dalles tailrace has very complex bathymetry (Figure 2.2). From previous work with 3D numerical models and reduced-scale physical models as well as from prototype velocity measurements, we know the flow structure is very 3D in some locations. As such, results in the near-project areas should be used with caution.

In the tailrace, the spillwall limits the extent of spill flow influence (Figures 3.5 to 3.8). The wide separation of the powerhouse and spillway flows ensures that the downstream extent of hydraulic influence is downstream of the bridge islands. The channel geometry limits the downstream extent, and like in the Bonneville forebay, the extent is greatest at 250 kcfs, and much more limited at 450 kcfs.

In the forebay, there is little difference in the hydraulic extents between the 250-, 270-, and 450-kcfs flows.

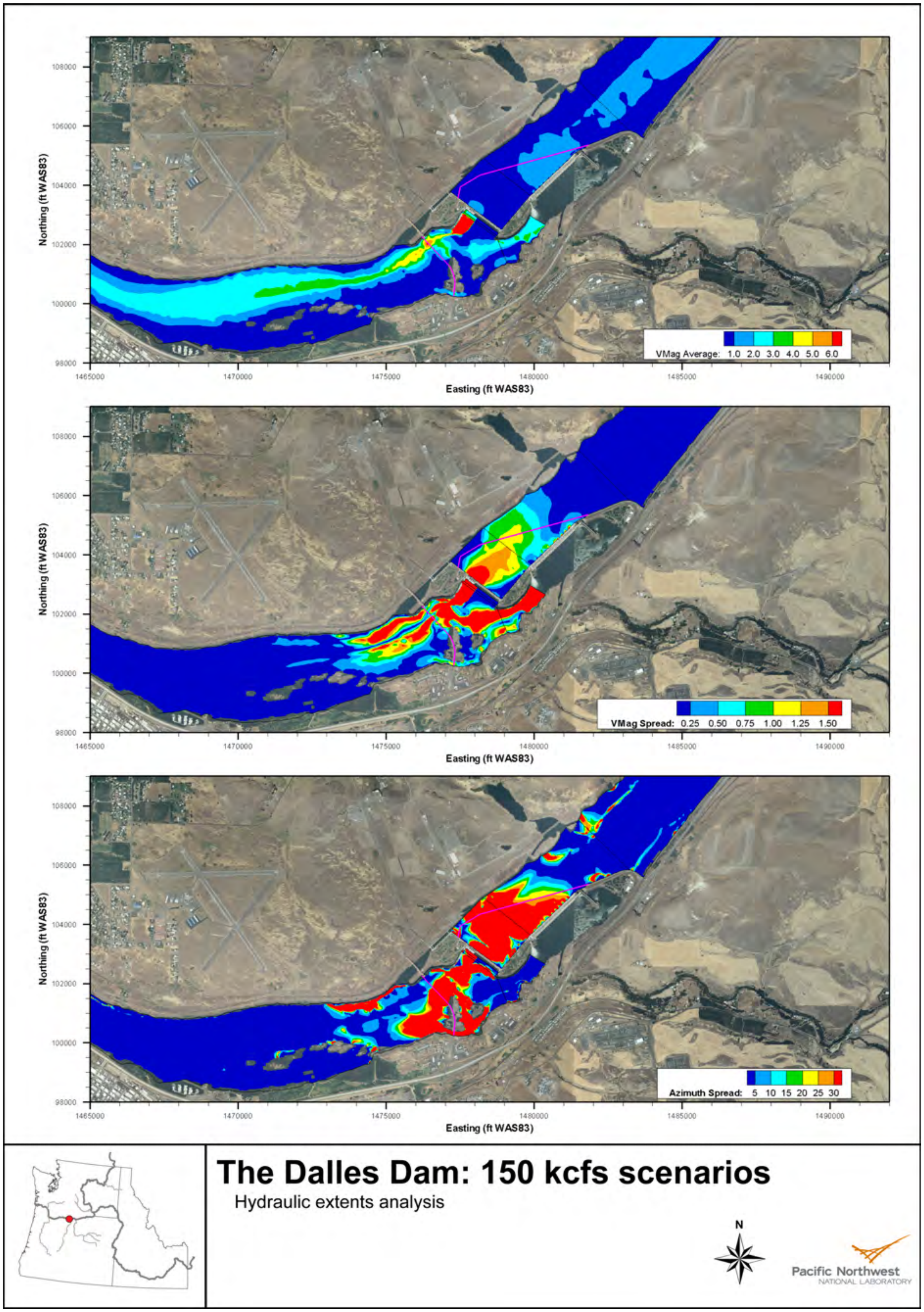

Figure 3.5. The Dalles Project for 150 kcfs. Velocities in ft/s.

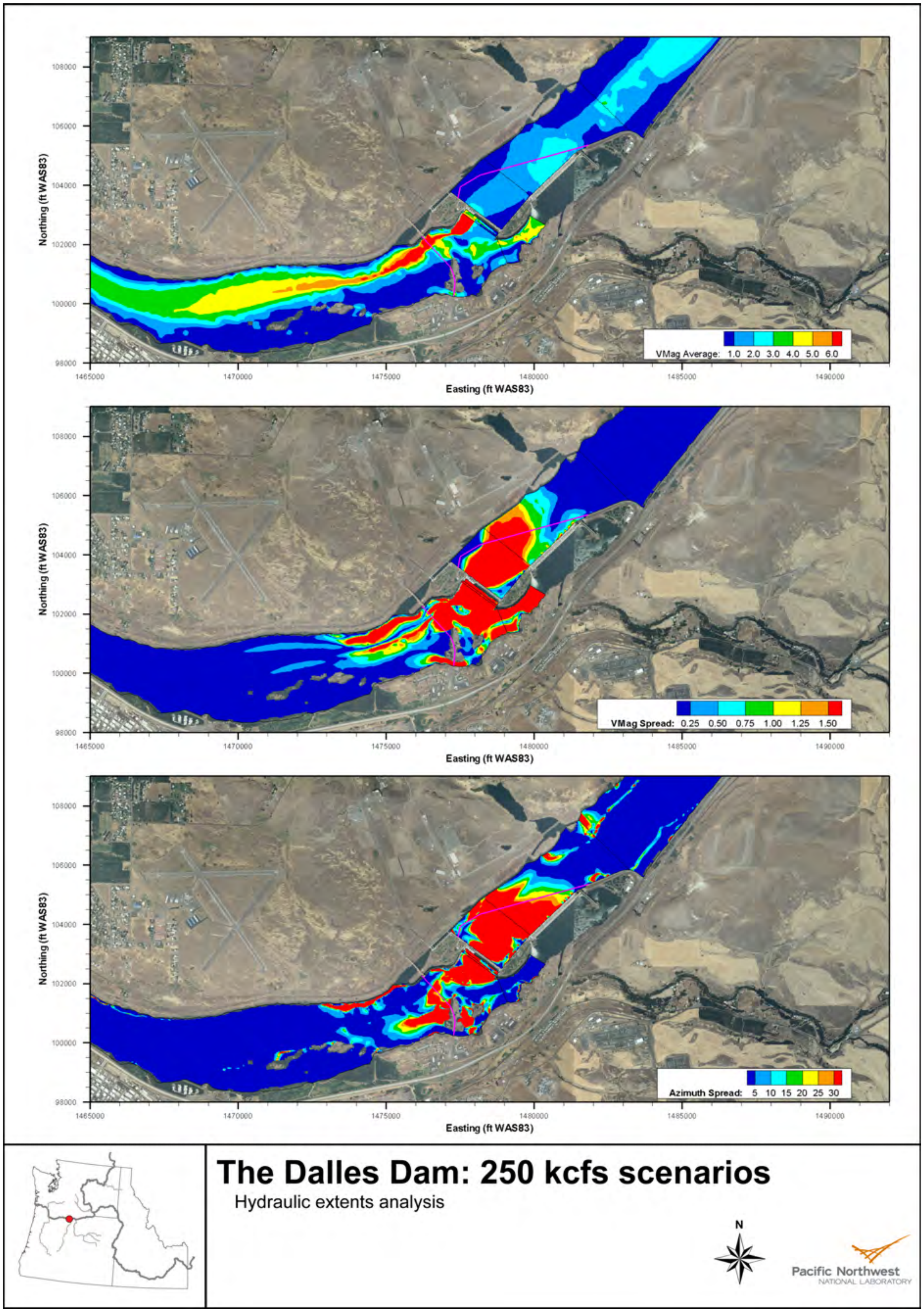

Figure 3.6. The Dalles Project for 250 kcfs. Velocities in ft/s.

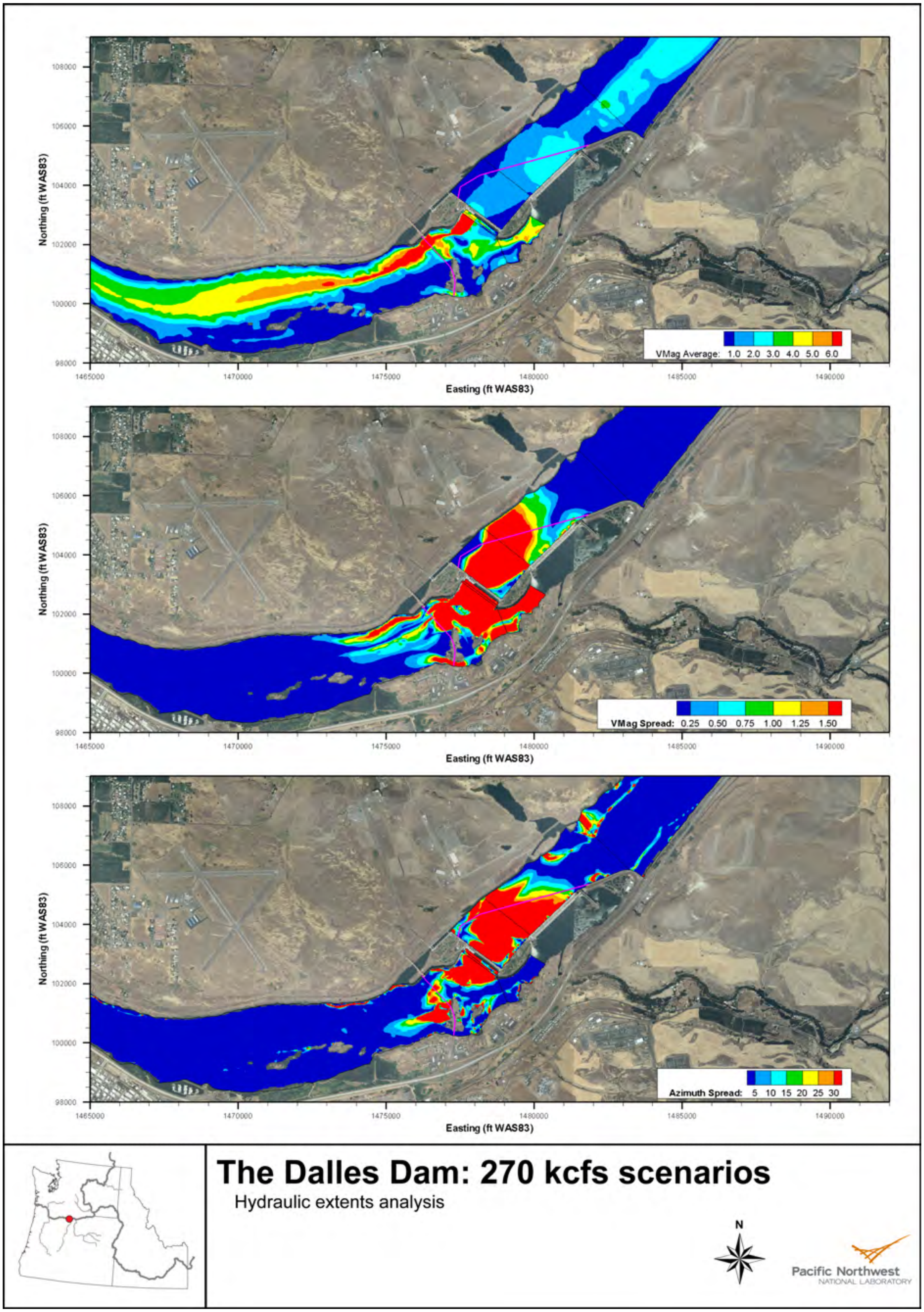

Figure 3.7. The Dalles Project for 270 kcfs. Velocities in ft/s.

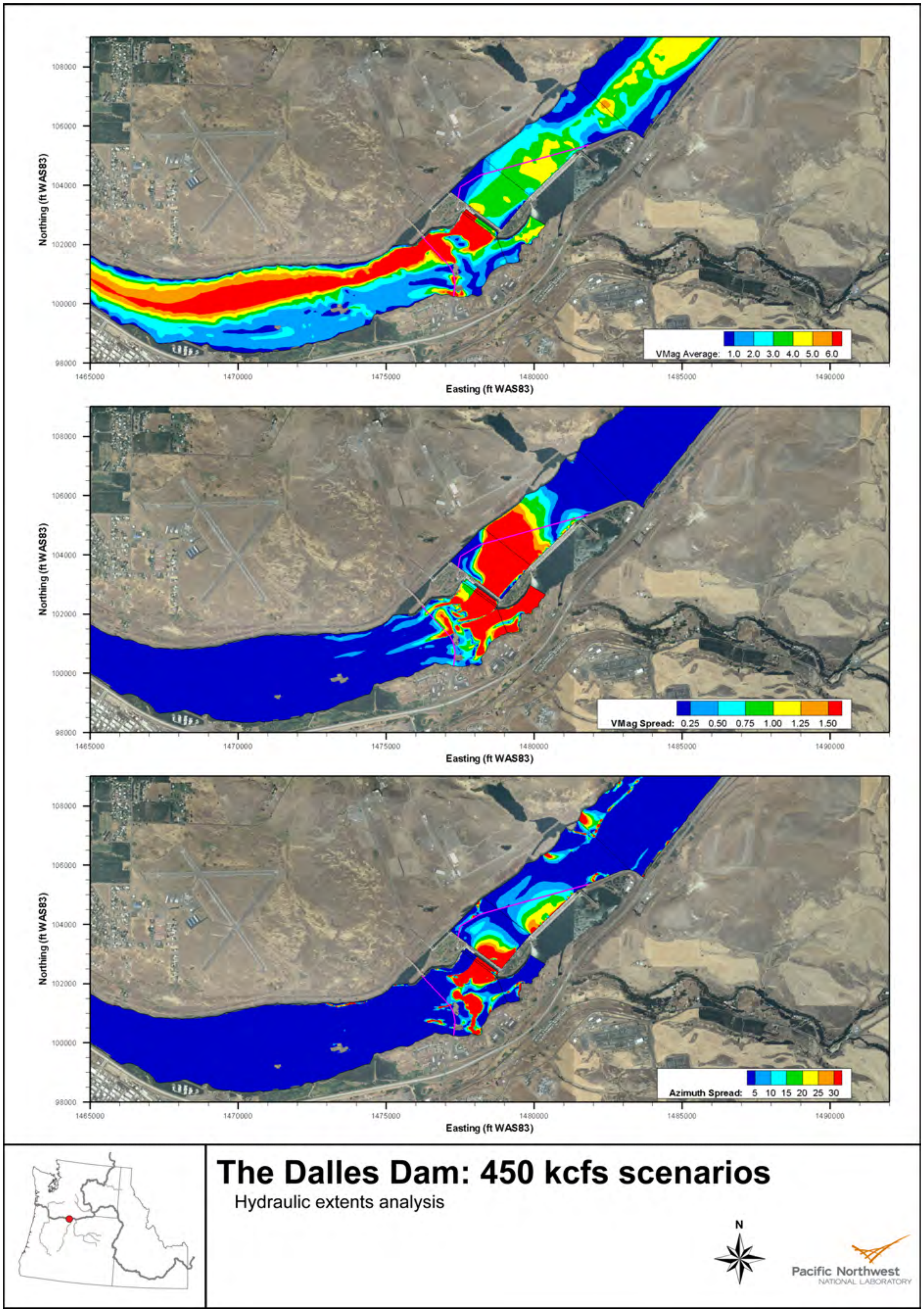

Figure 3.8. The Dalles Project for 450 kcfs. Velocities in ft/s.

3.3 John Day Project

Operations are detailed in Tables 2.14 and 2.15. Figures 3.9 to 3.12 show the results of the MASS2 runs. Downstream of John Day, the channel constricts and a mid-channel island exists. These features limit the extent of the downstream impact of operations at the higher flows. At this project, it is known that both the physical and 2D model under predict the lateral entrainment of flow from the powerhouse and hence the downstream extent of the influence of operations. However, the channel flow constrictions rather than operations will tend to limit the downstream hydraulic extent. Upstream of the dam, the average velocities are much less, and the hydraulic extent of project operations is mostly contained within the BRZ for all flows modeled.

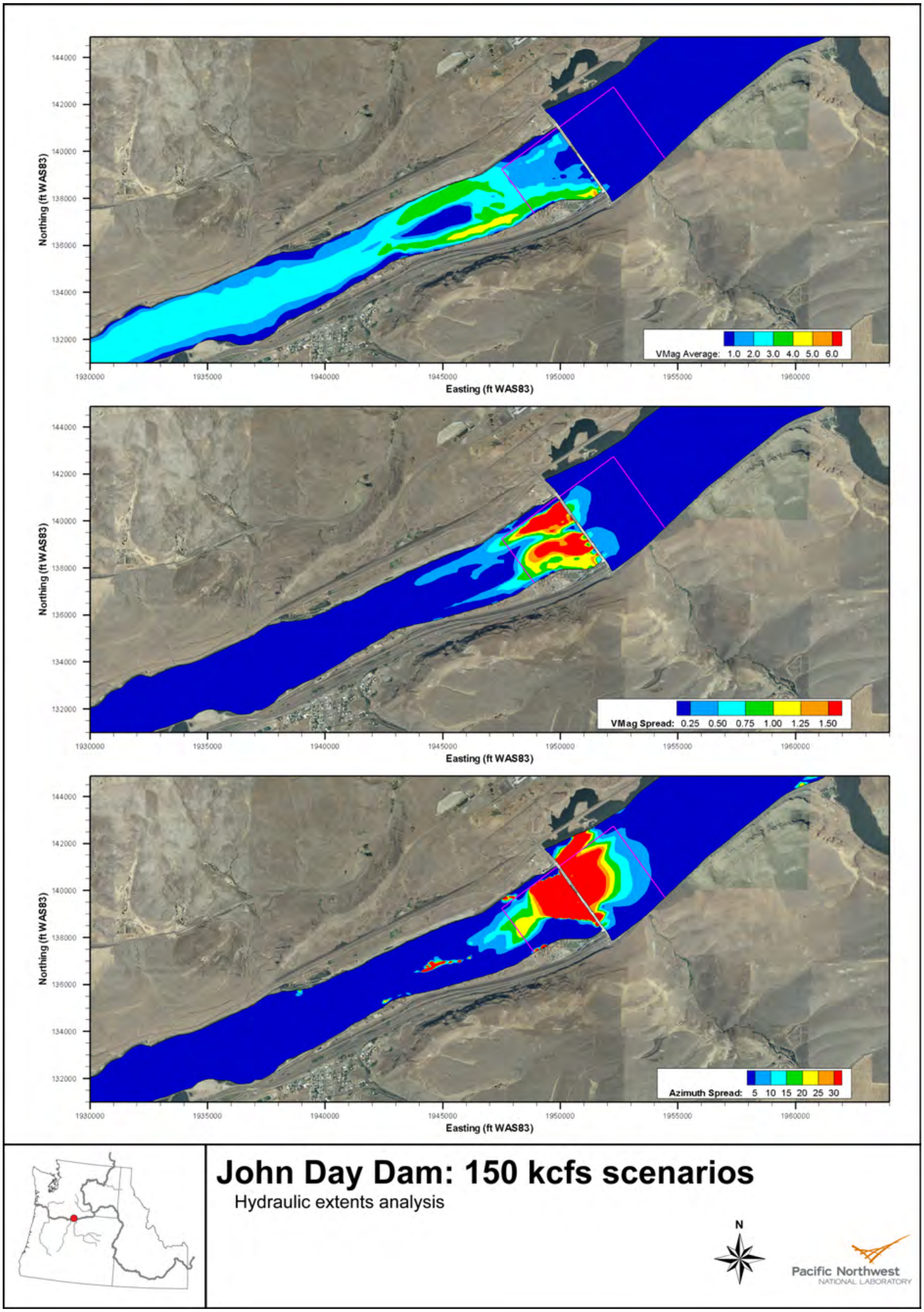

Figure 3.9. John Day Project for 150 kcfs. Velocities in ft/s.

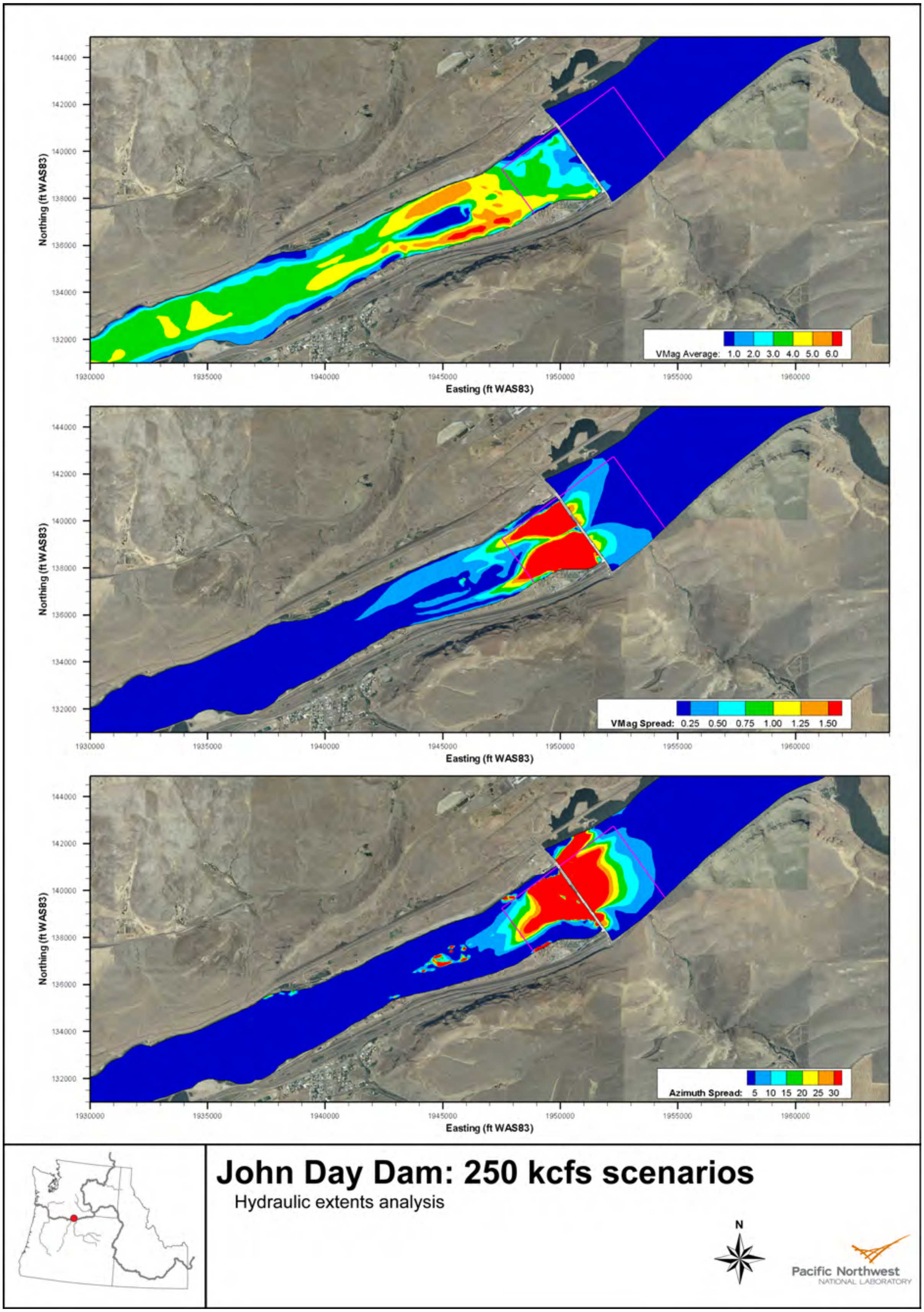

Figure 3.10. John Day Project for 250 kcfs. Velocities in ft/s.

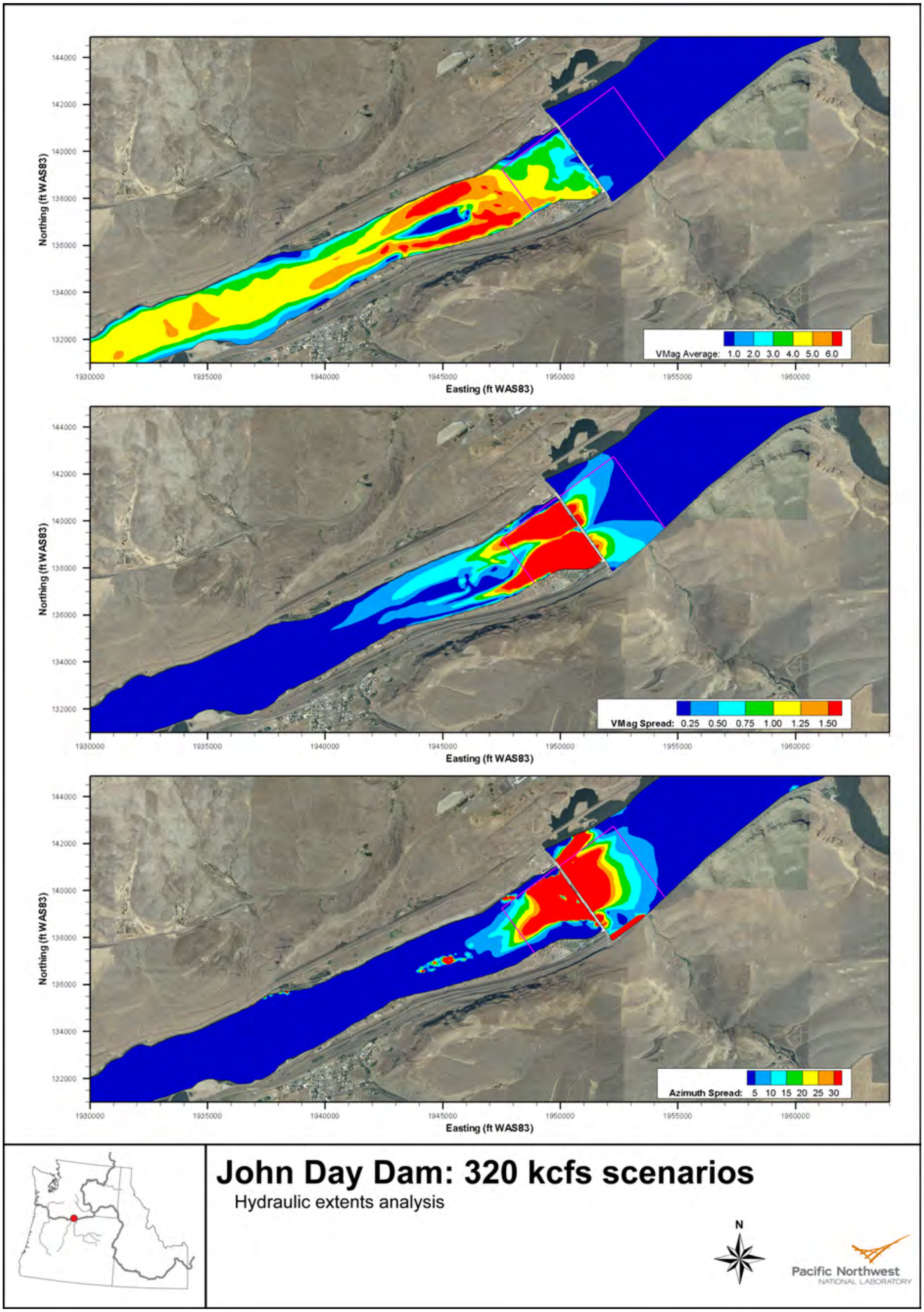

Figure 3.11. John Day Project for 320 kcfs. Velocities in ft/s.

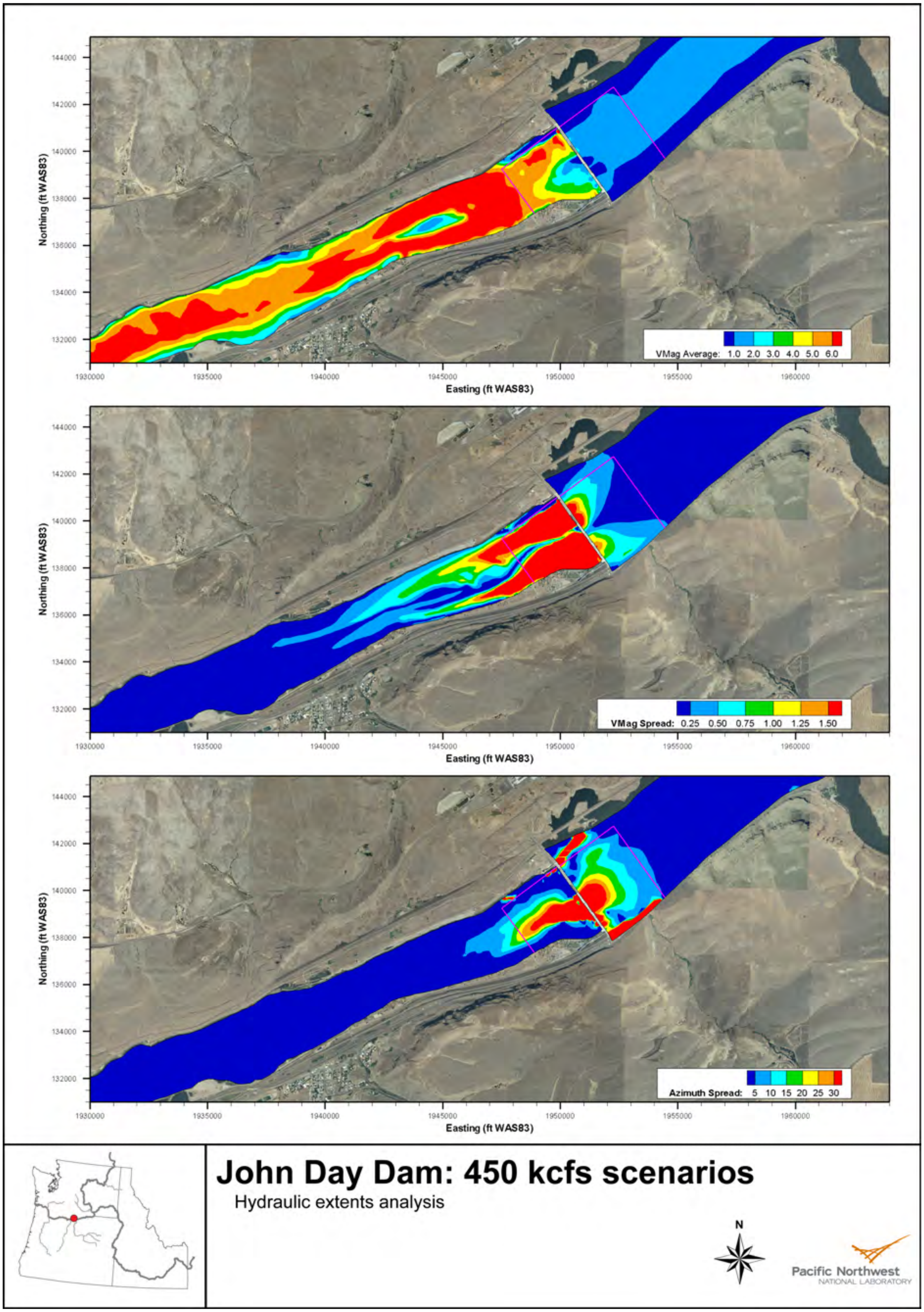

Figure 3.12. John Day Project for 450 kcfs. Velocities in ft/s.

3.4 McNary Project

Operations are detailed in Tables 2.16 and 2.17. Figures 3.13 to 3.16 show the results of the MASS2 runs. At McNary, the hydraulic extent is greatest at the mid-range flows. At 350-kcfs total river, both the upstream and downstream extent is reduced for both flow-direction and velocity-magnitude differences. For flow direction, the largest downstream extent is at the lowest modeled total river (Figure 3.13), while the greatest downstream extent of differences in velocity magnitude is at 150 and 250 kcfs total river (Figures 3.14 and 3.15).

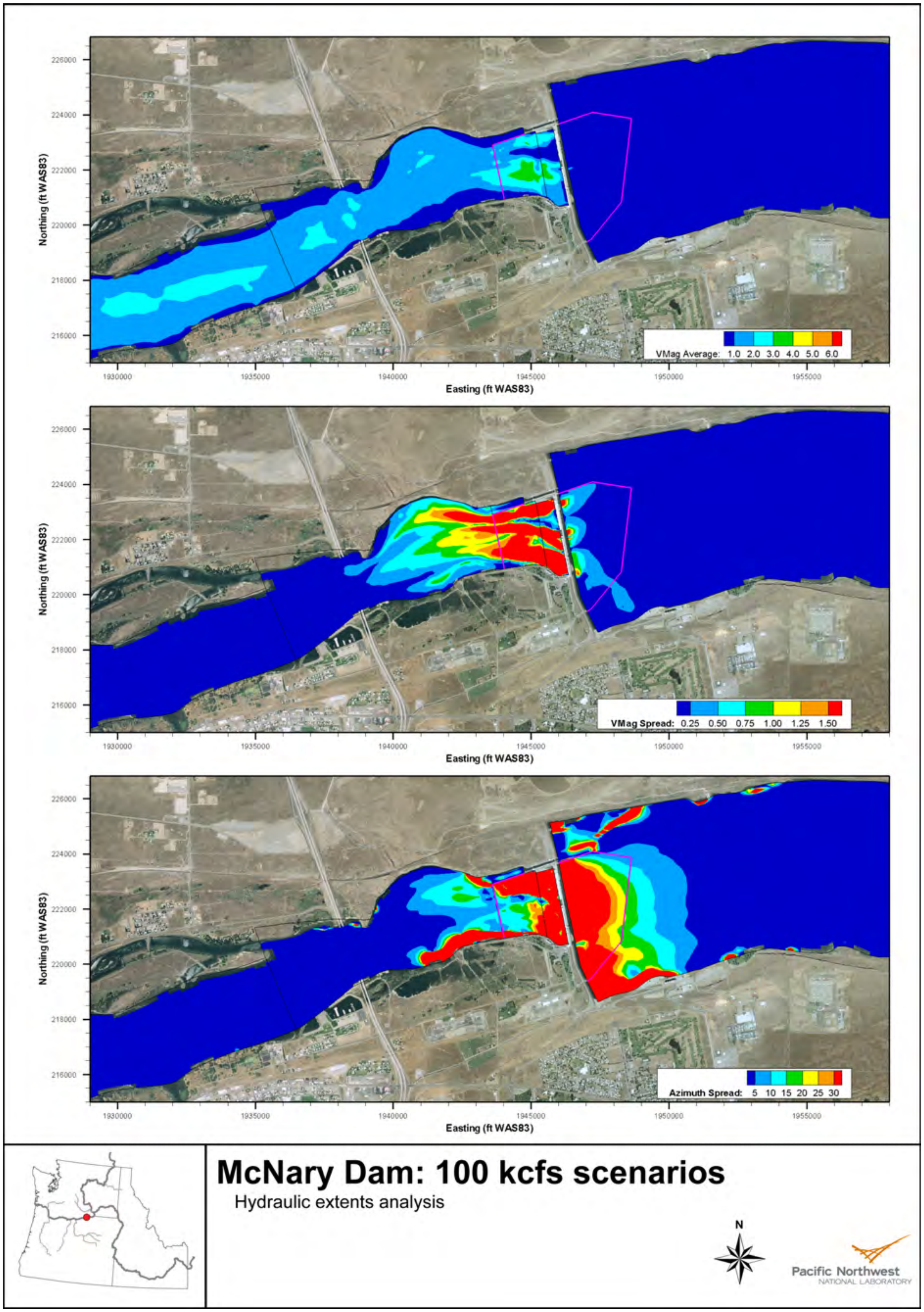

Figure 3.13. McNary Project for 100 kcfs. Velocities in ft/s.

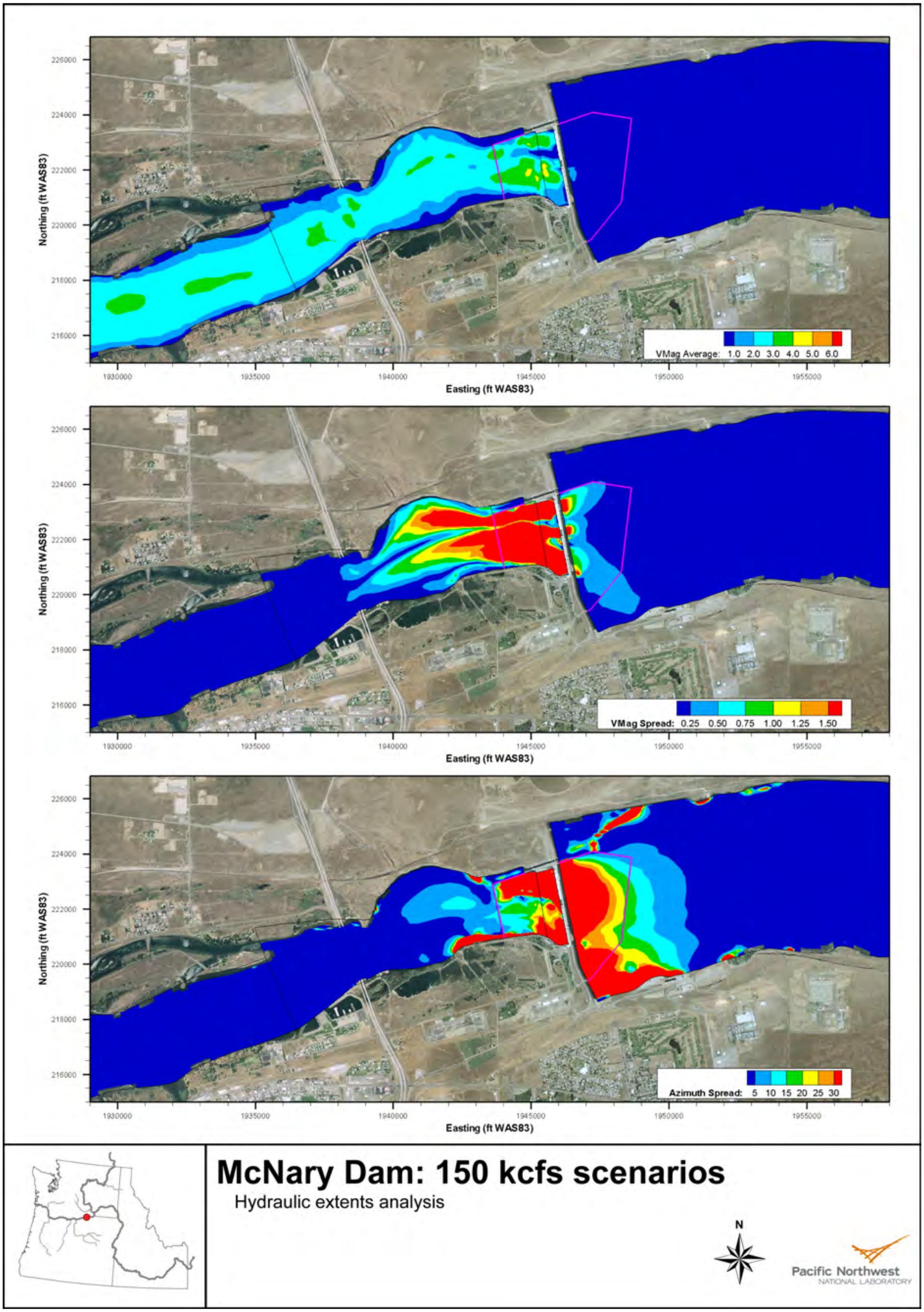

Figure 3.14. McNary Project for 150 kcfs. Velocities in ft/s.

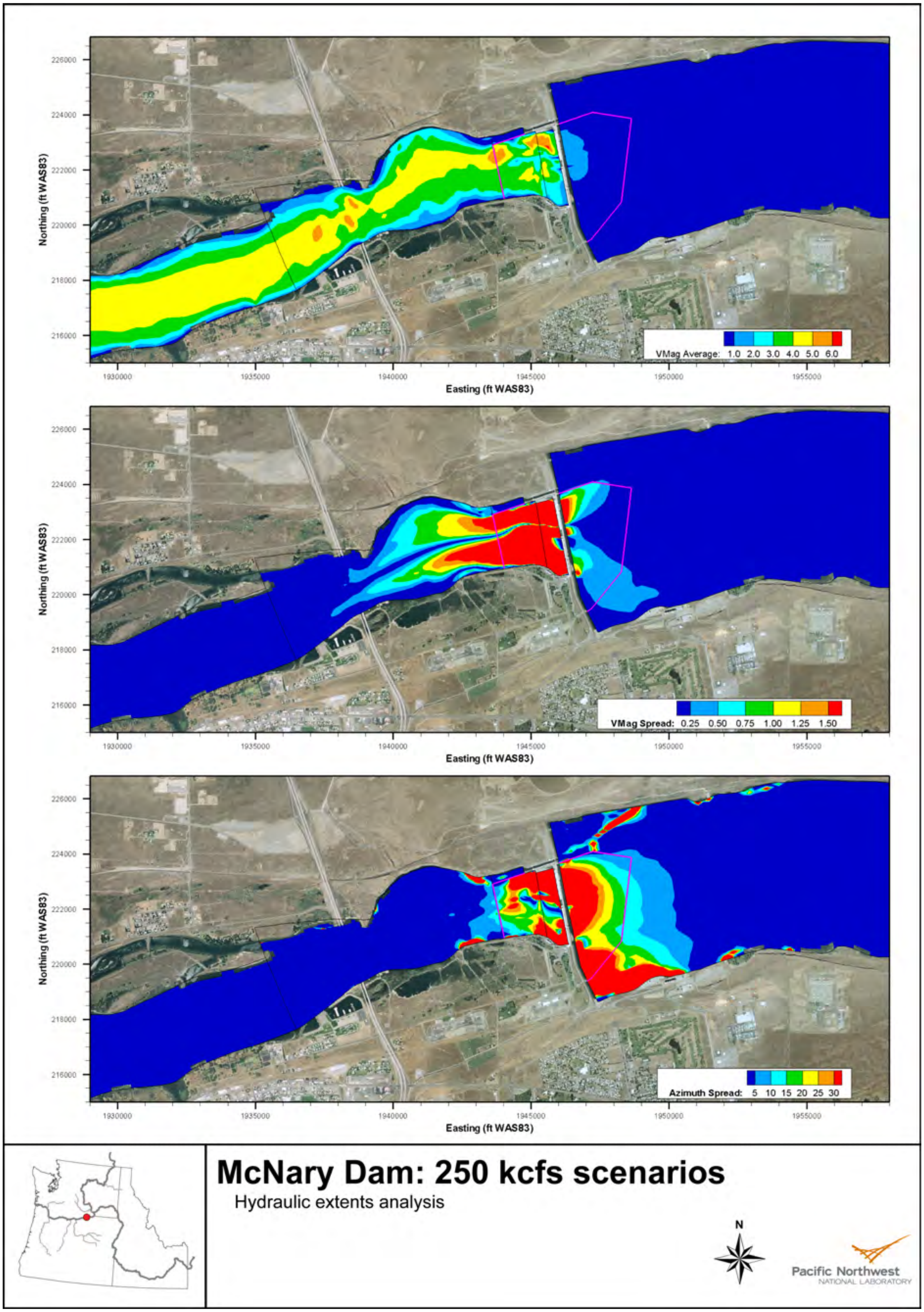

Figure 3.15. McNary Project for 250 kcfs. Velocities in ft/s.

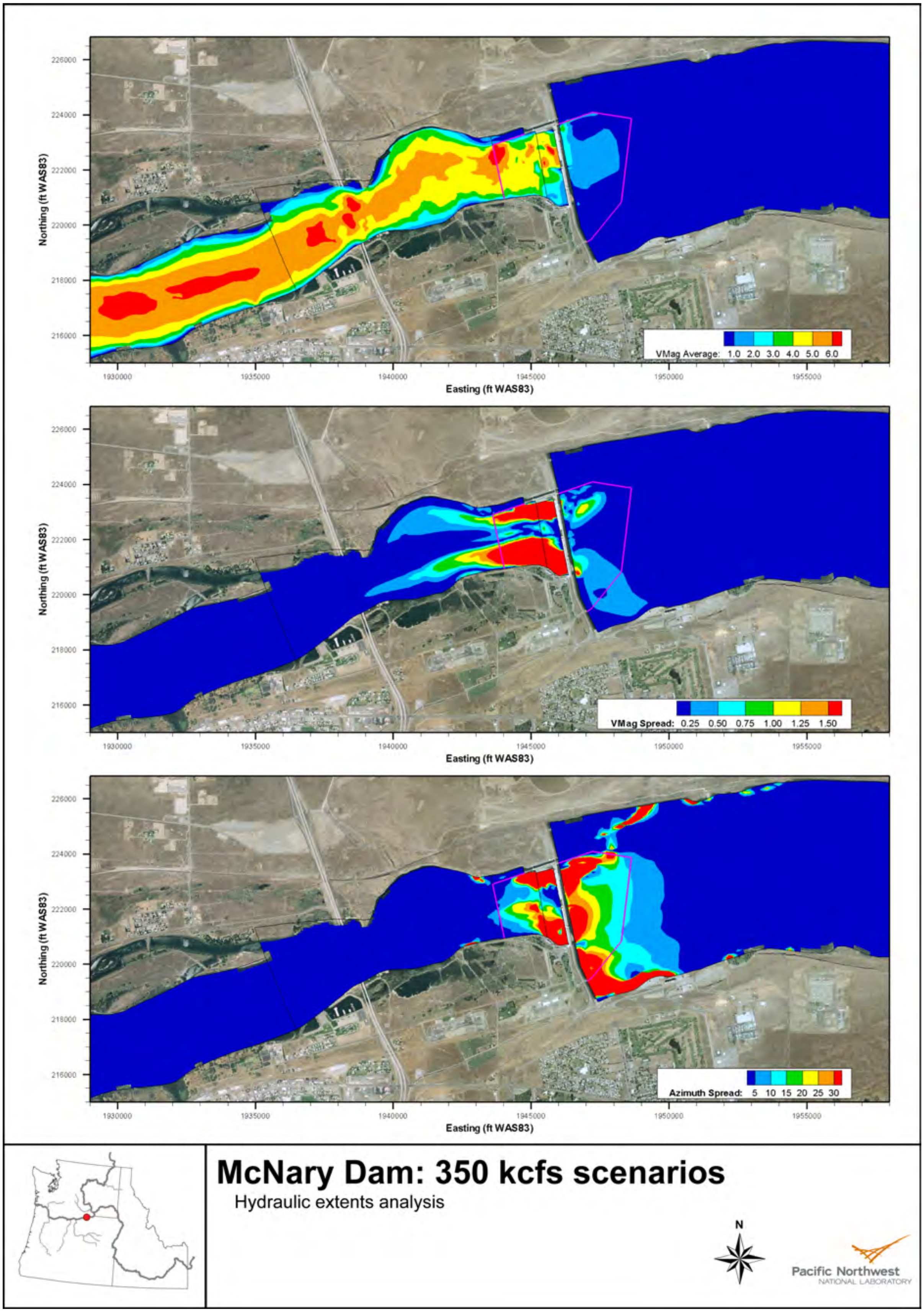

Figure 3.16. McNary Project for 350 kcfs. Velocities in ft/s.

3.5 Ice Harbor Project

Operations are detailed in Tables 2.18 and 2.19. Figures 3.17 to 3.20 show the results of the MASS2 runs. The Snake River flows are much less than the main stem of the Columbia River. The greatest impacts on flow are, for the most part, limited to within the BRZ both upstream and downstream of the project. At the lower flows (19 and 30 kcfs, Figures 3.17 and 3.18, respectively), there is an additional area of large differences in the center of the channel. These are from the flow scenarios that were specified to have the maximum momentum in the center of the river in addition to the powerhouse and spillway priority flow scenarios.

In the forebay, there is little difference in the upstream extent of the difference of flow directions.

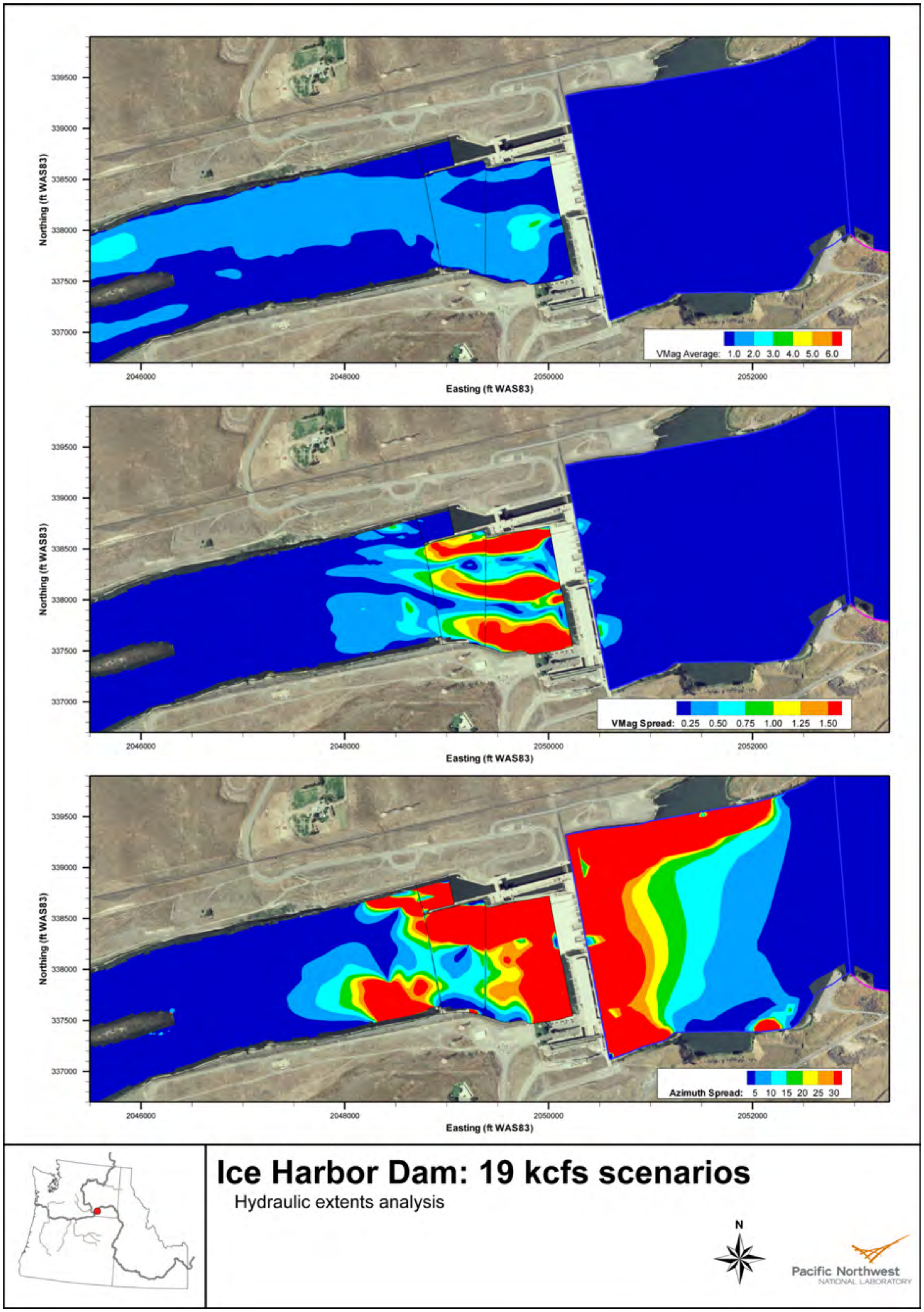

Figure 3.17. Ice Harbor Project for 19 kcfs. Velocities in ft/s.

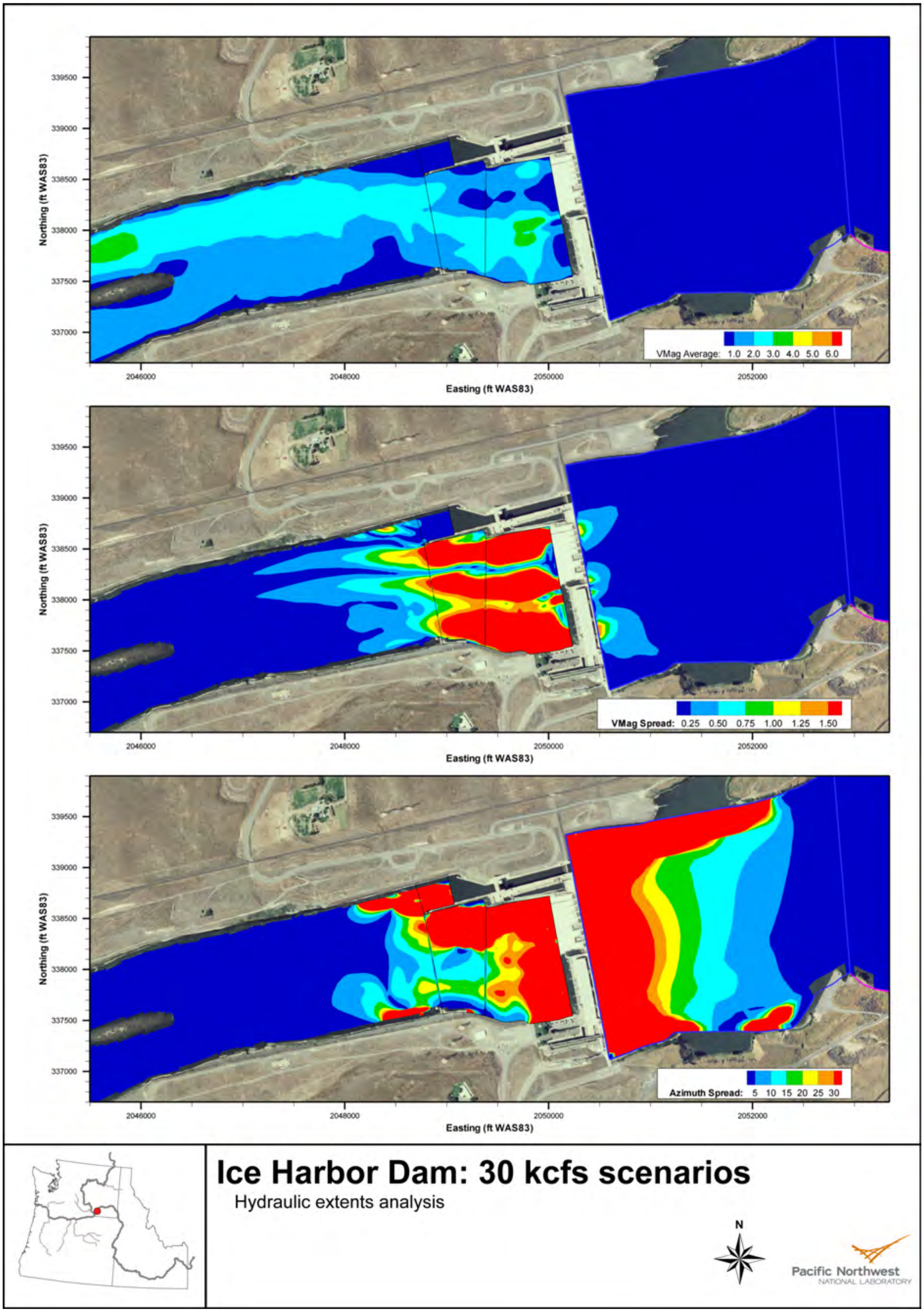

Figure 3.18. Ice Harbor Project for 30 kcfs. Velocities in ft/s.

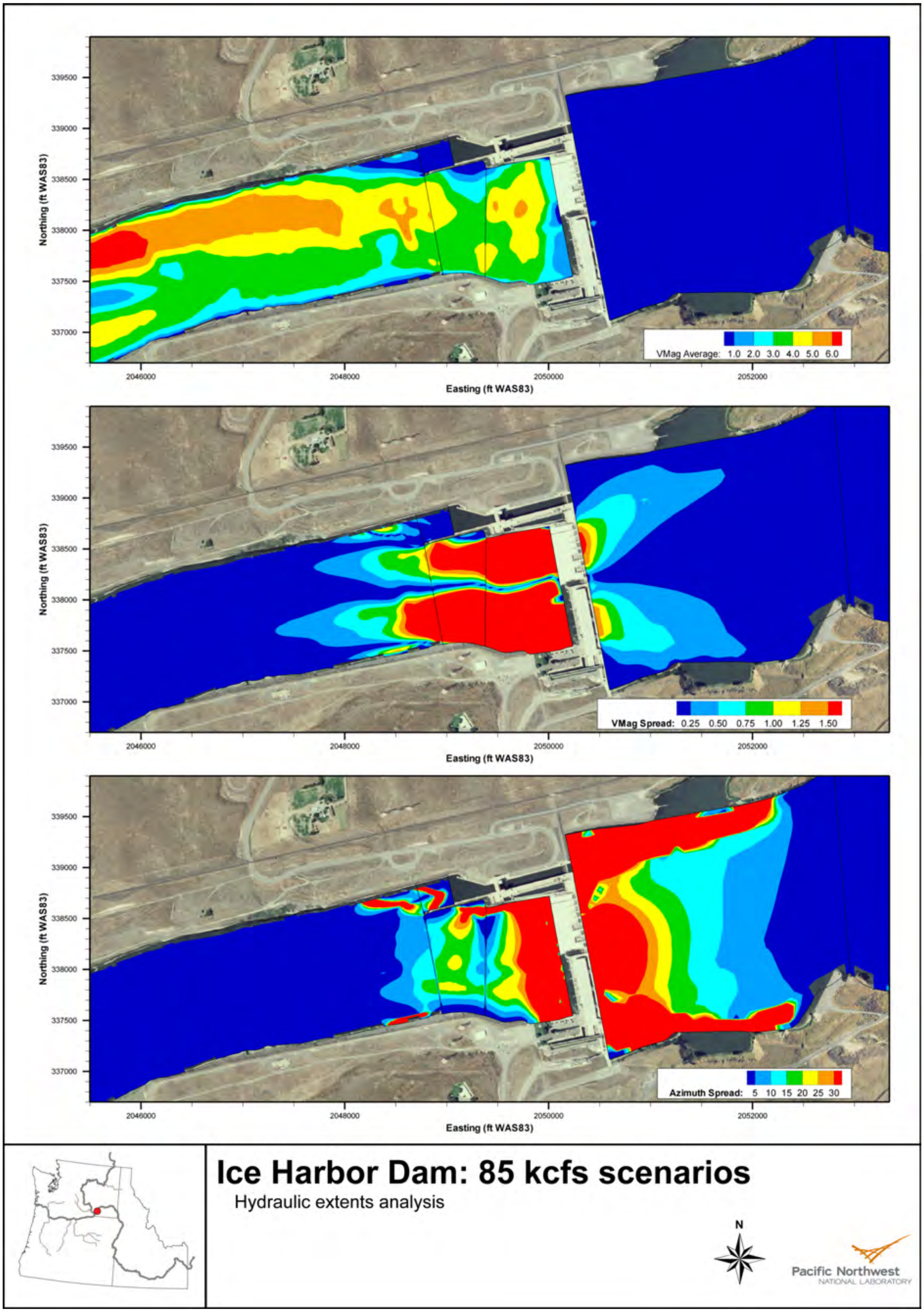

Figure 3.19. Ice Harbor Project for 85 kcfs. Velocities in ft/s.

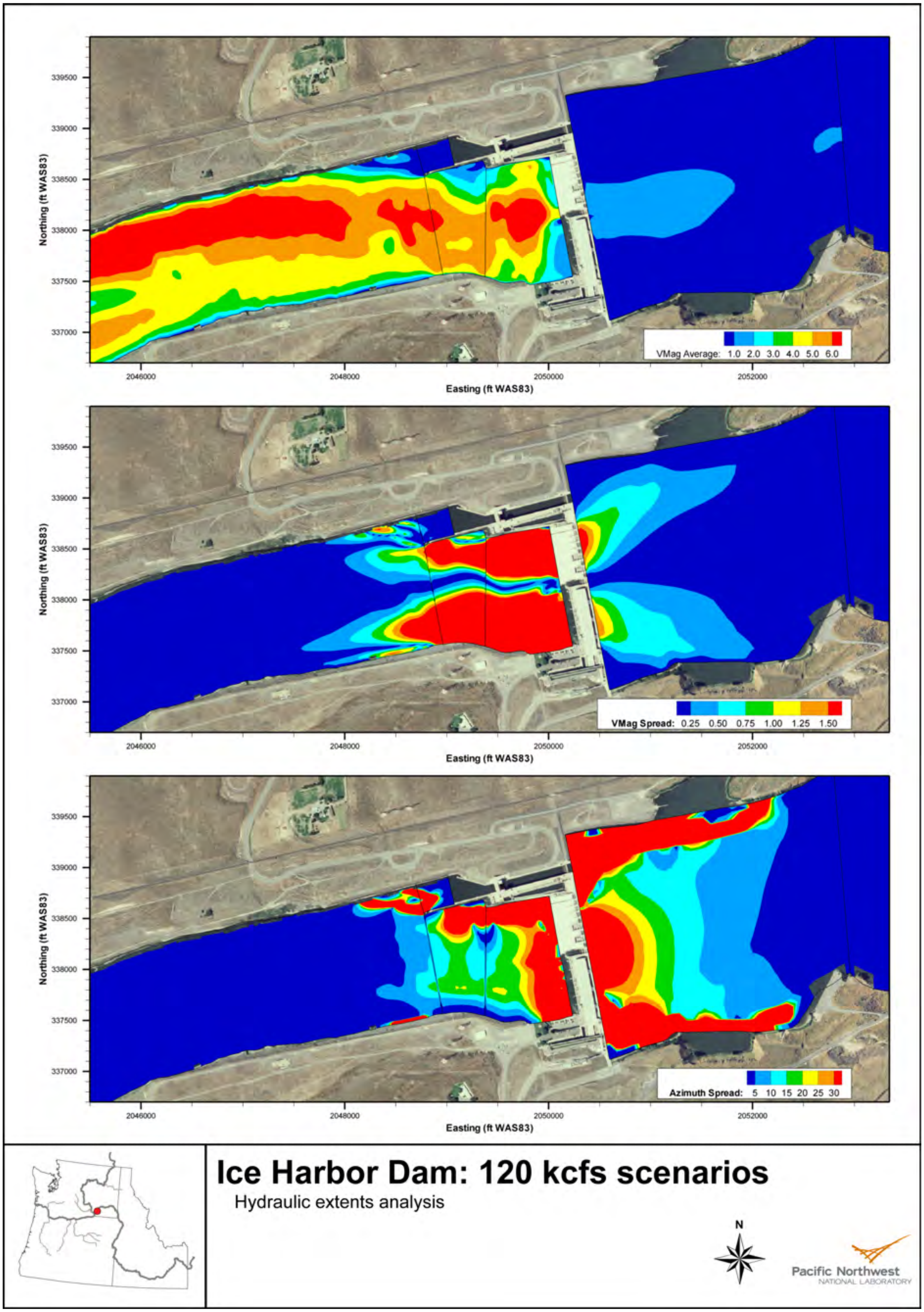

Figure 3.20. Ice Harbor Project for 120 kcfs. Velocities in ft/s.

3.6 Lower Monumental Project

Operations are detailed in Tables 2.20 and 2.21. Figures 3.21 to 3.24 show the results of the MASS2 runs. At Lower Monumental, the downstream extent in the spread of velocity magnitude is largest at 30 kcfs (Figure 3.22). The downstream hydraulic extent is probably reduced by the slight channel constriction. In the forebay, the upstream extent of spread in velocity magnitude and flow direction increases with total river flow; however, at 120 kcfs both extents are reduced.

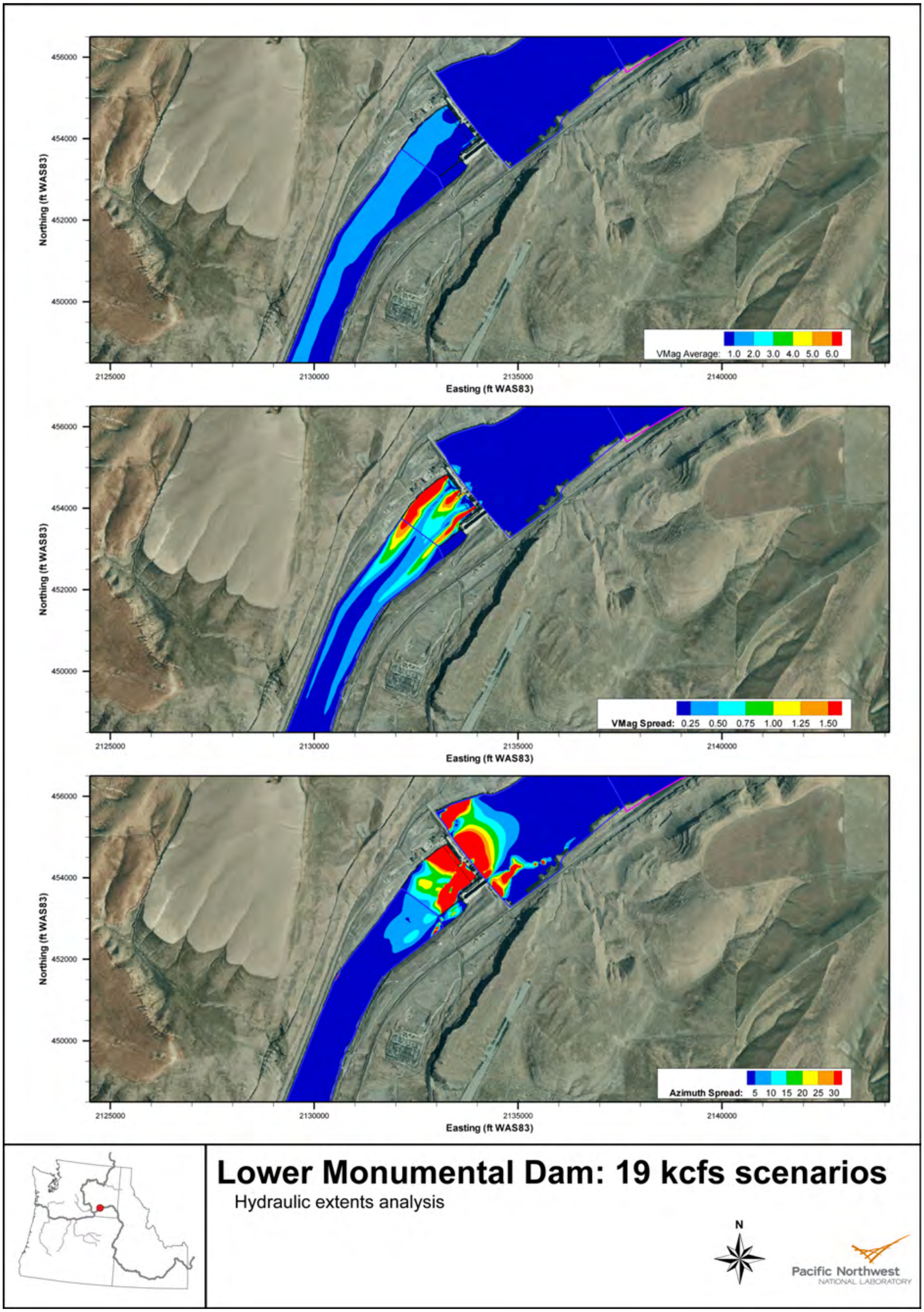

Figure 3.21. Lower Monumental Project for 19 kcfs. Velocities in ft/s.

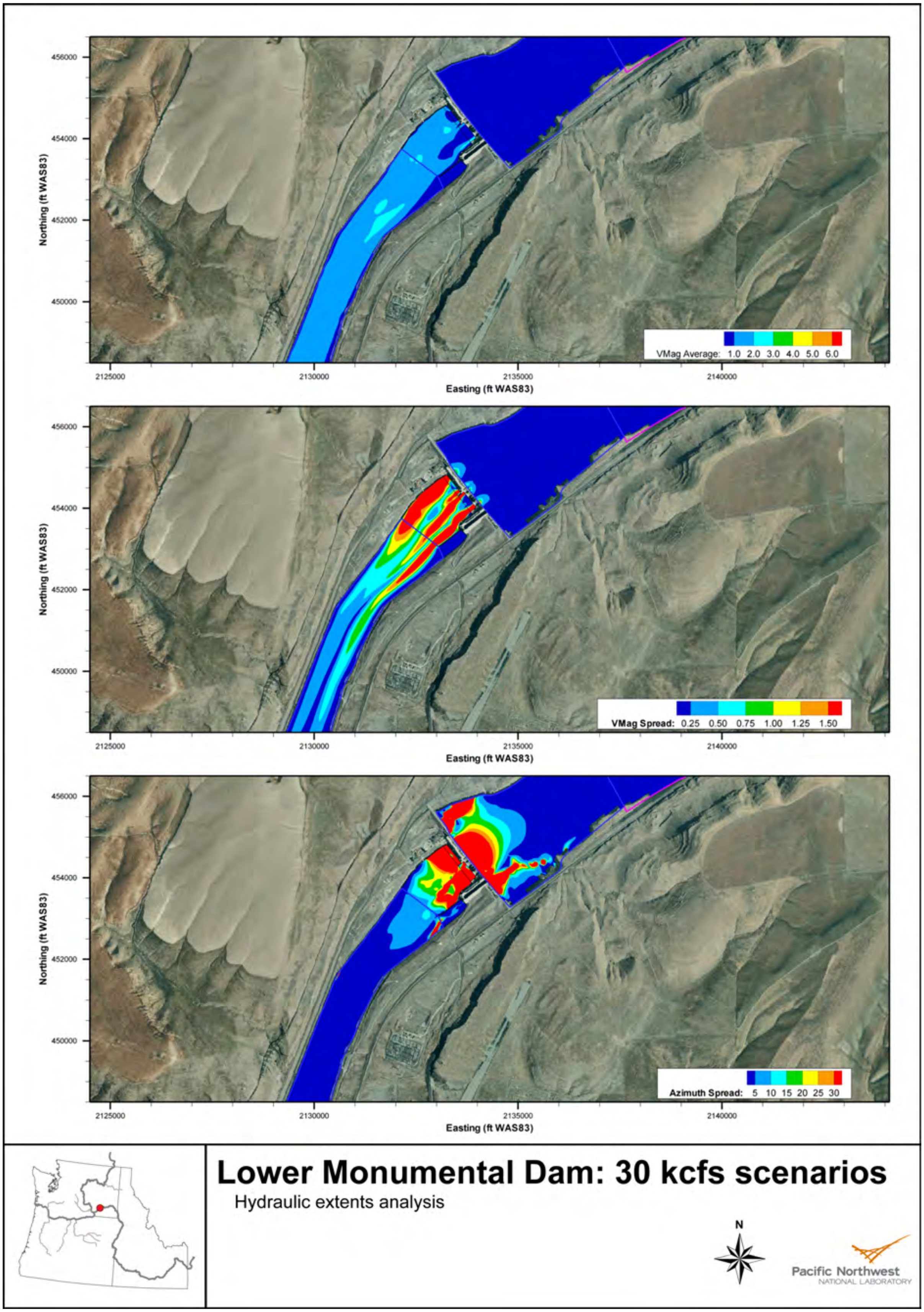

Figure 3.22. Lower Monumental Project for 30 kcfs. Velocities in ft/s.

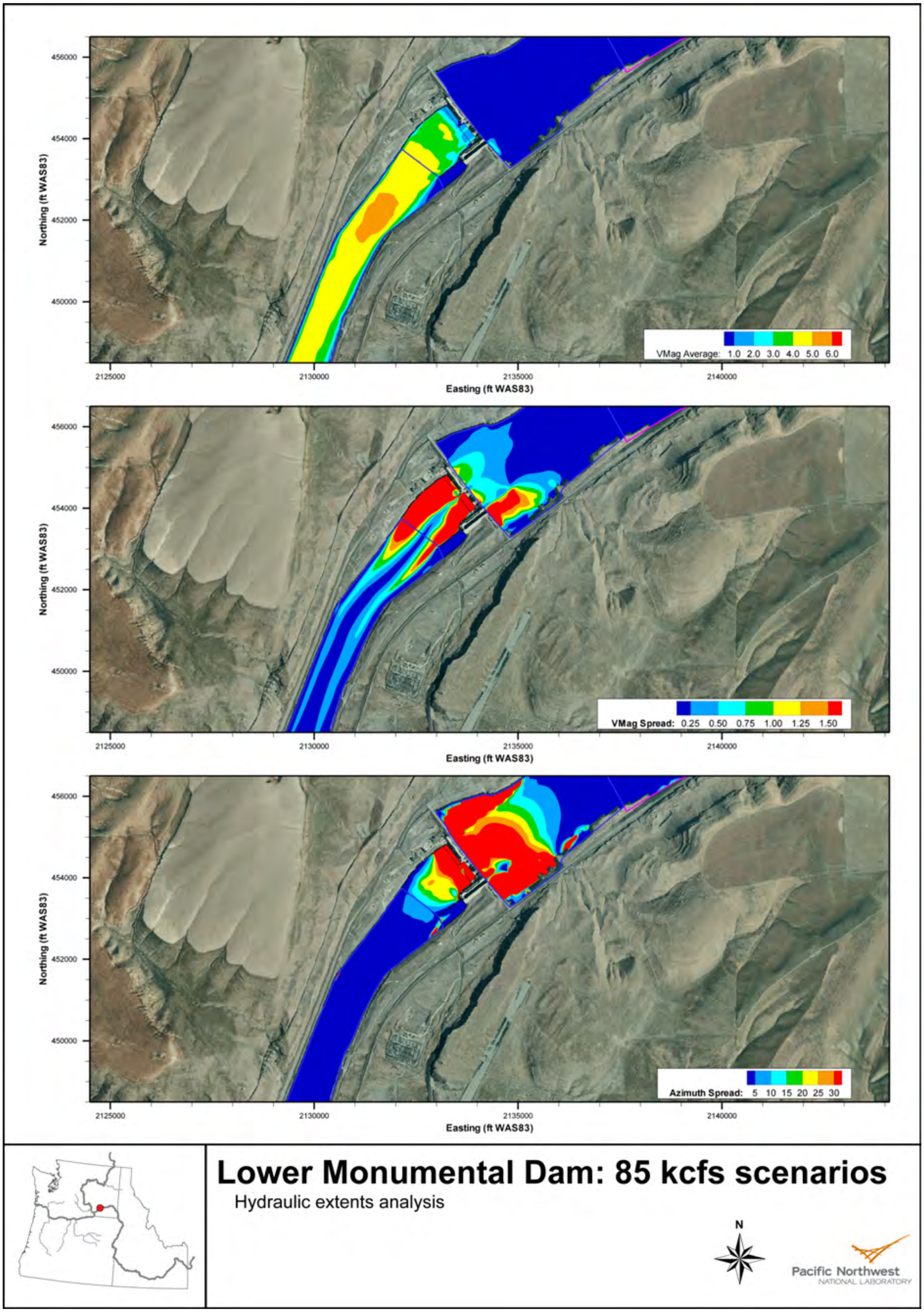

Figure 3.23. Lower Monumental Project for 85 kcfs. Velocities in ft/s.

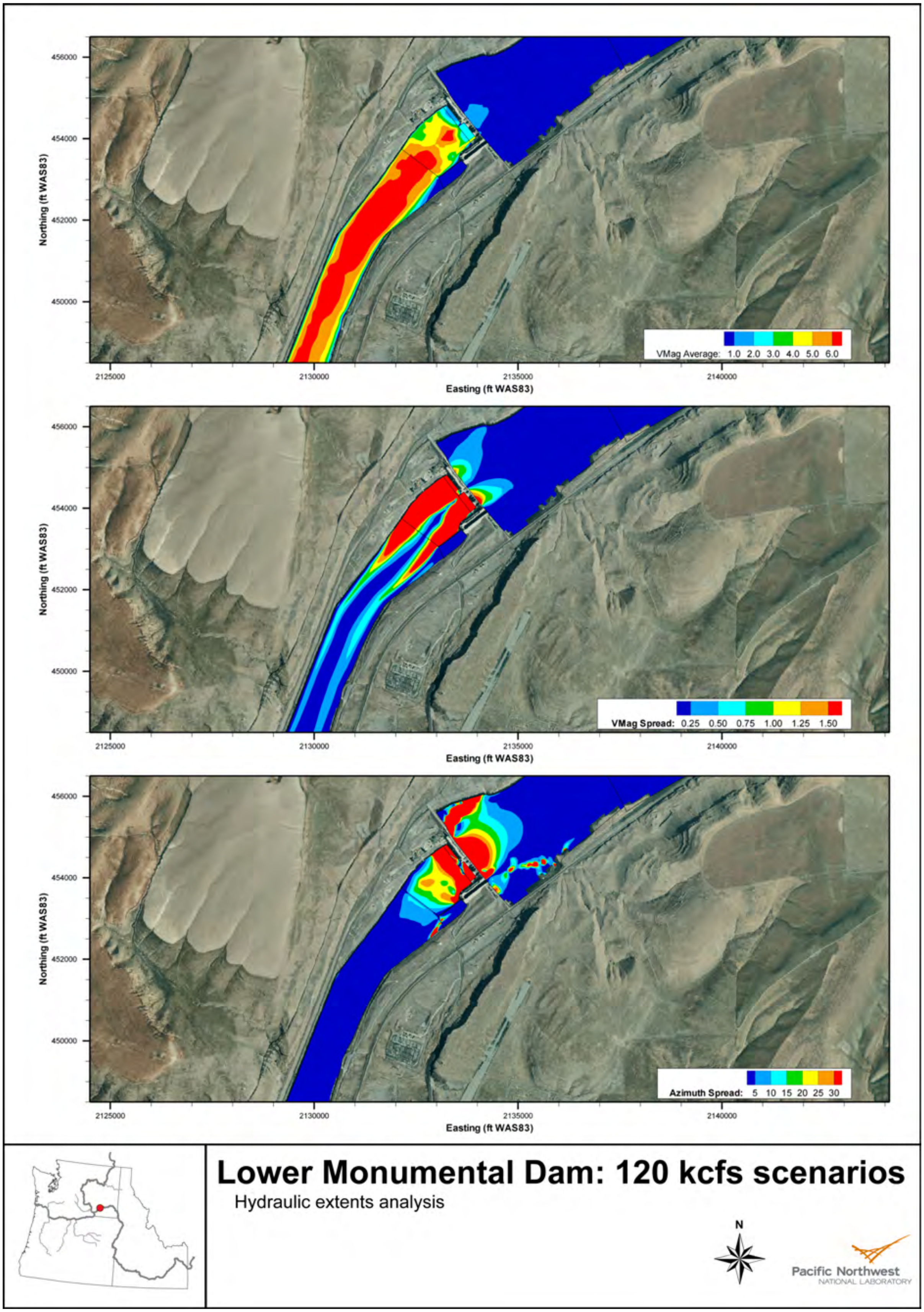

Figure 3.24. Lower Monumental Project for 120 kcfs. Velocities in ft/s.

3.7 Little Goose Project

Operations are detailed in Tables 2.22 and 2.23. Figures 3.25 to 3.28 show the results of the MASS2 runs. At Little Goose, the largest downstream hydraulic extent is at 30 kcfs (Figure 3.26). There is a flow constriction downstream of the project that reduces the hydraulic extent at the higher flows. In the forebay, the upstream extent of the spread in velocity magnitude increases with increasing flow volume. However, the magnitude and extent of the differences in flow direction are very similar for all river flows.

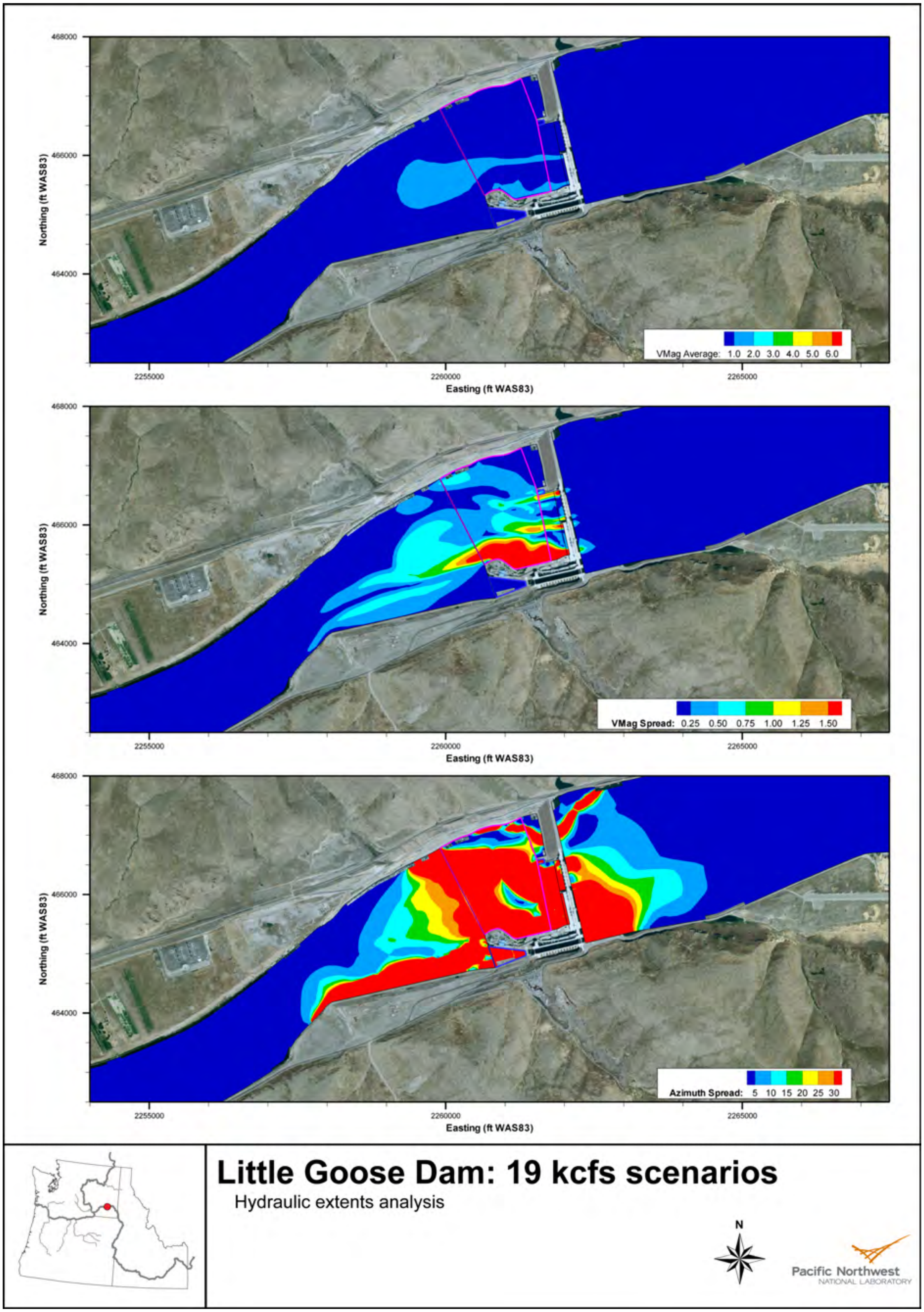

Figure 3.25. Little Goose Project for 19 kcfs. Velocities in ft/s.

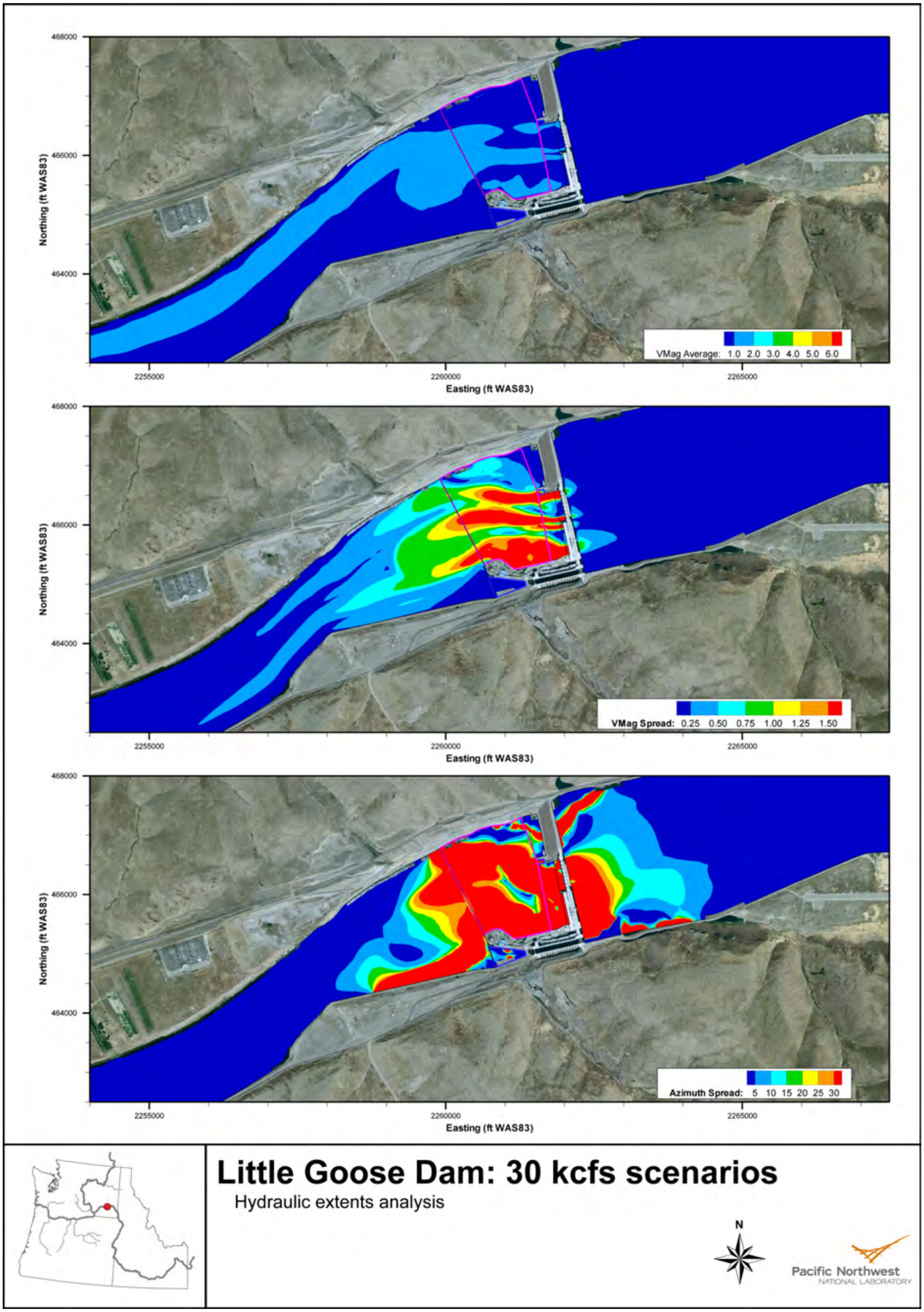

Figure 3.26. Little Goose Project for 30 kcfs. Velocities in ft/s.

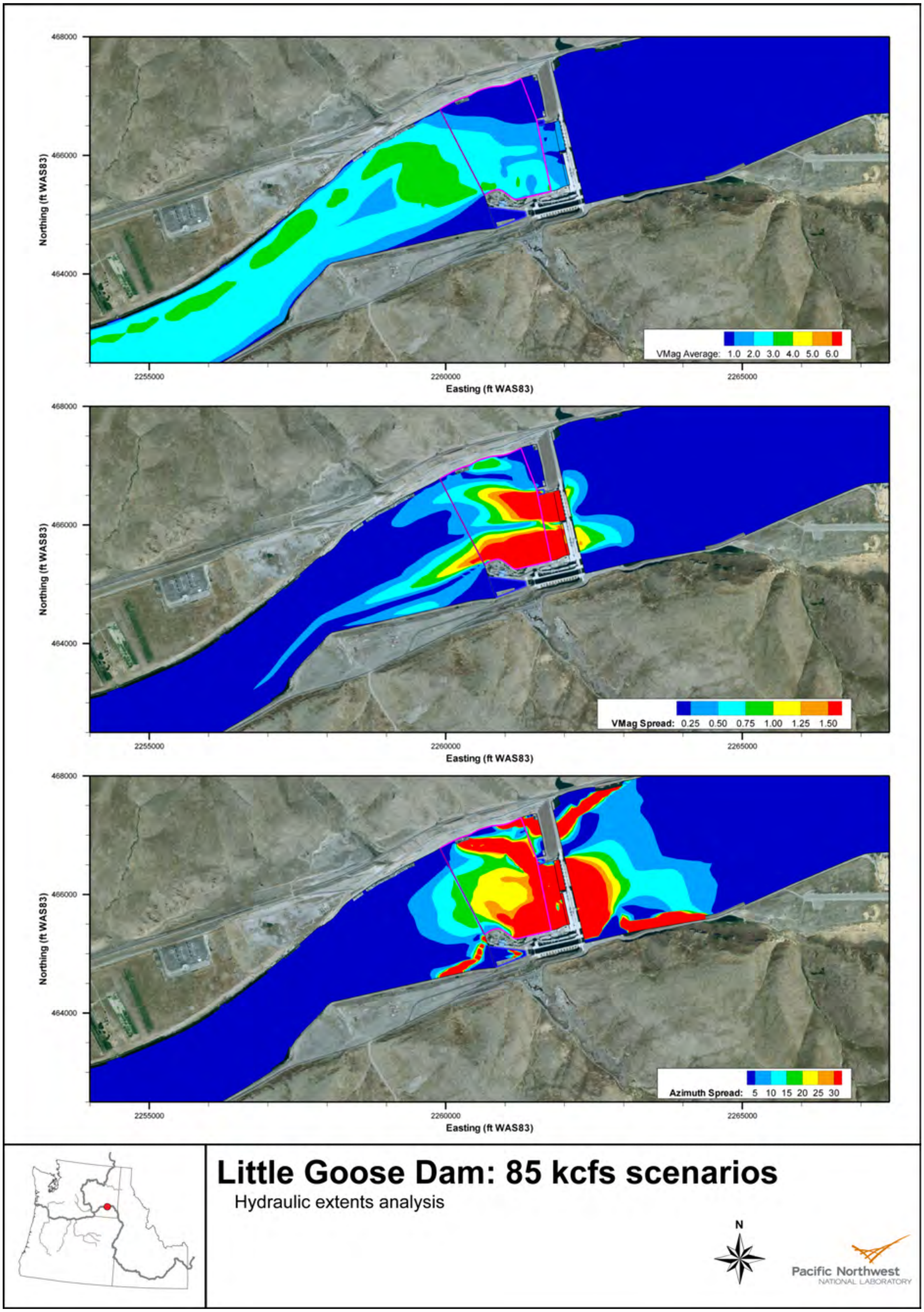

Figure 3.27. Little Goose Project for 85 kcfs. Velocities in ft/s.

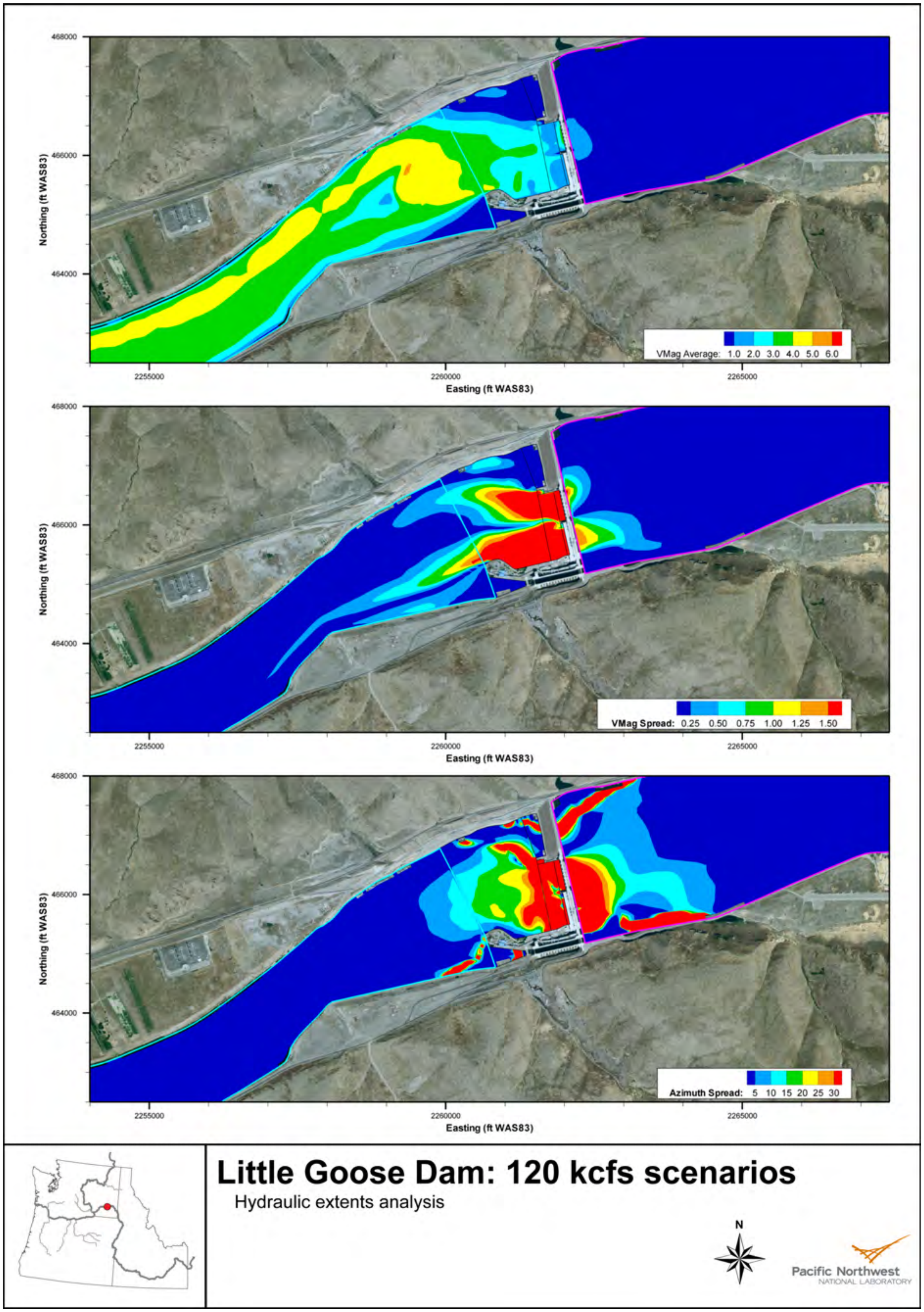

Figure 3.28. Little Goose Project for 120 kcfs. Velocities in ft/s.

3.8 Lower Granite Project

Operations are detailed in Tables 2.24 and 2.25. Figures 3.29 to 3.32 show the results of the MASS2 runs. In the tailrace, the downstream hydraulic extent of velocity magnitude differences is very similar for all flows. For flow direction, however, the greatest downstream impact is at the lowest flows with the least extent at the largest total river flow. In the forebay, the upstream hydraulic extent is limited.

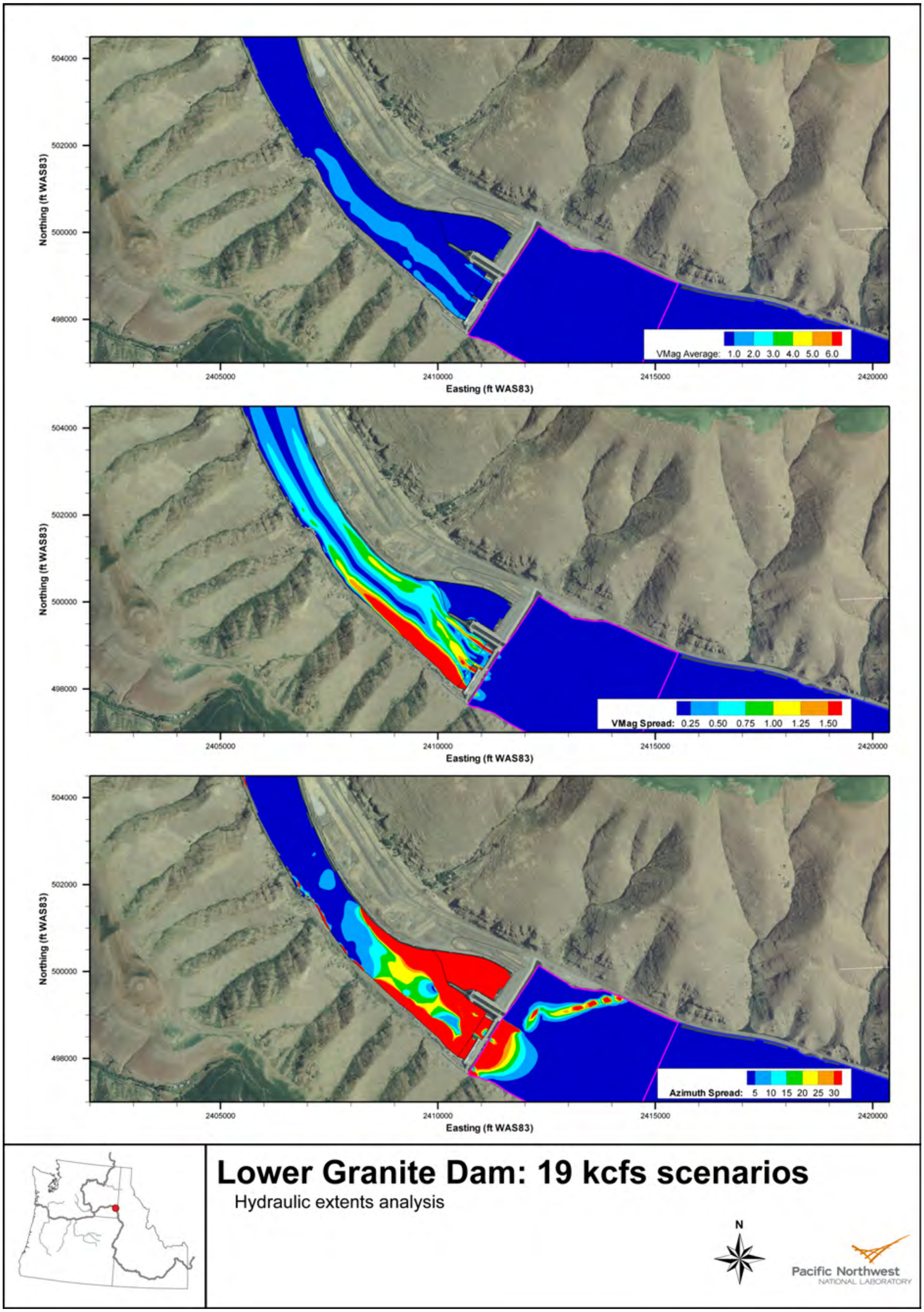

Figure 3.29. Lower Granite Project for 19 kcfs. Velocities in ft/s.

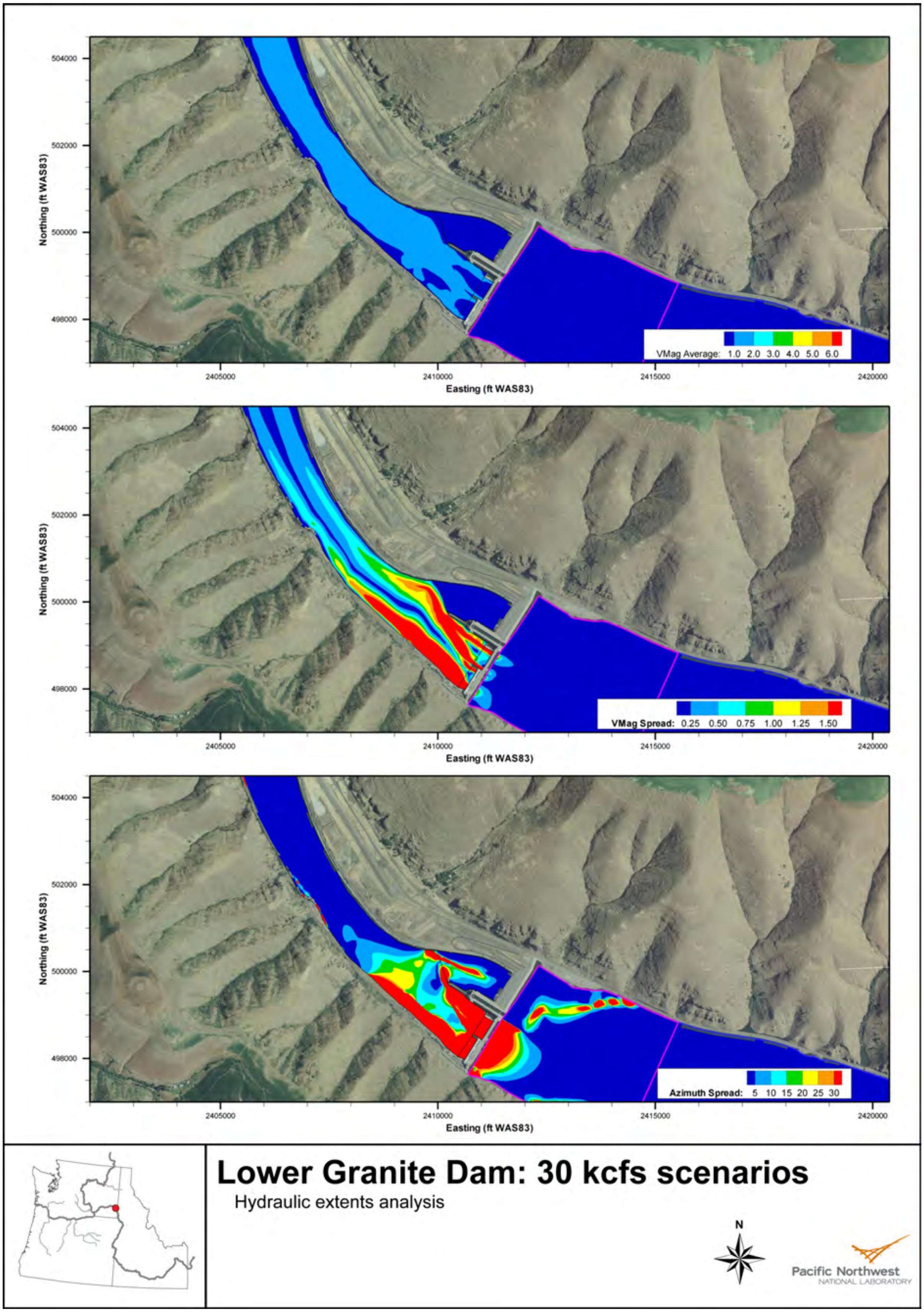

Figure 3.30. Lower Granite Project for 30 kcfs. Velocities in ft/s.

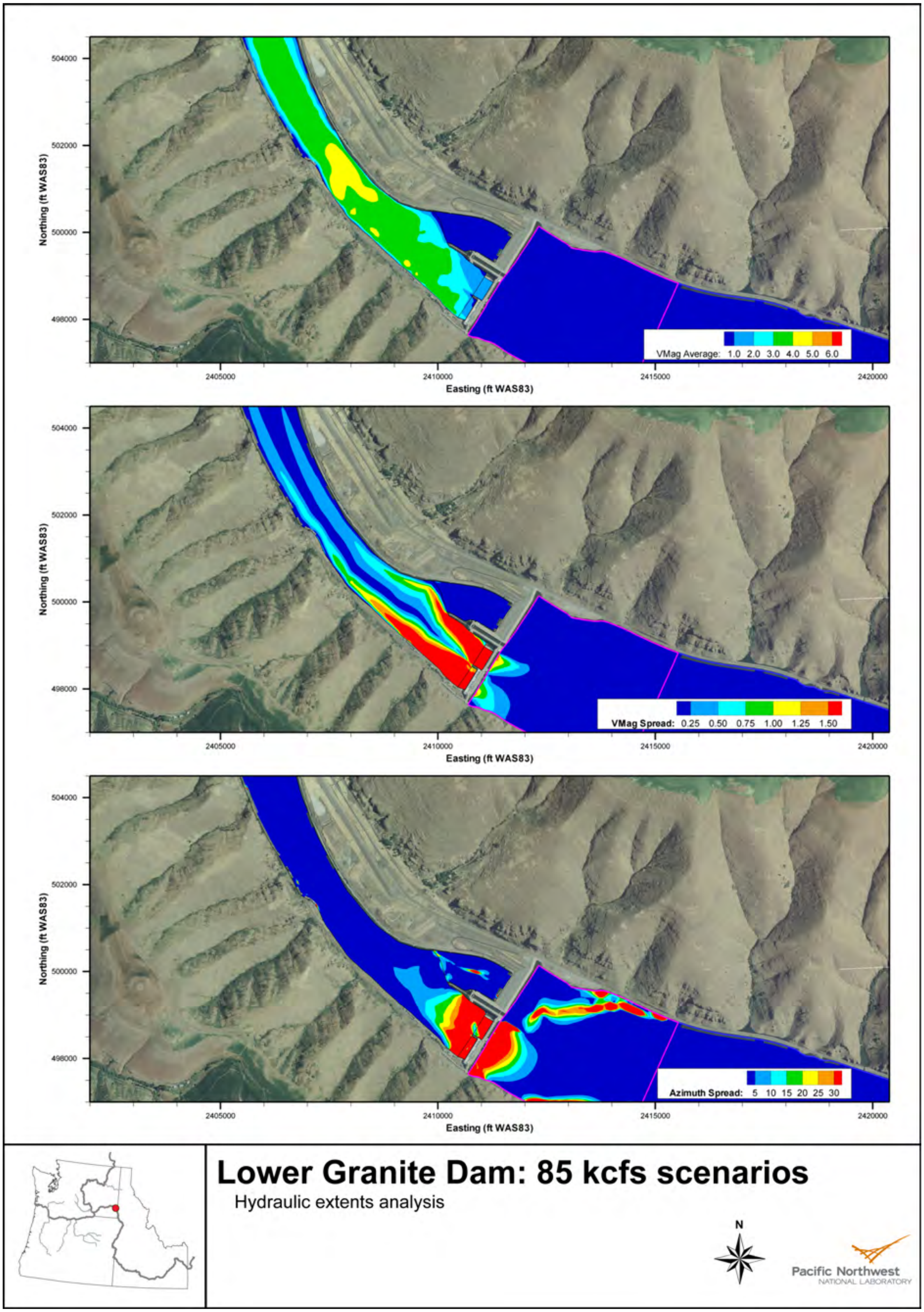

Figure 3.31. Lower Granite Project for 85 kcfs. Velocities in ft/s.

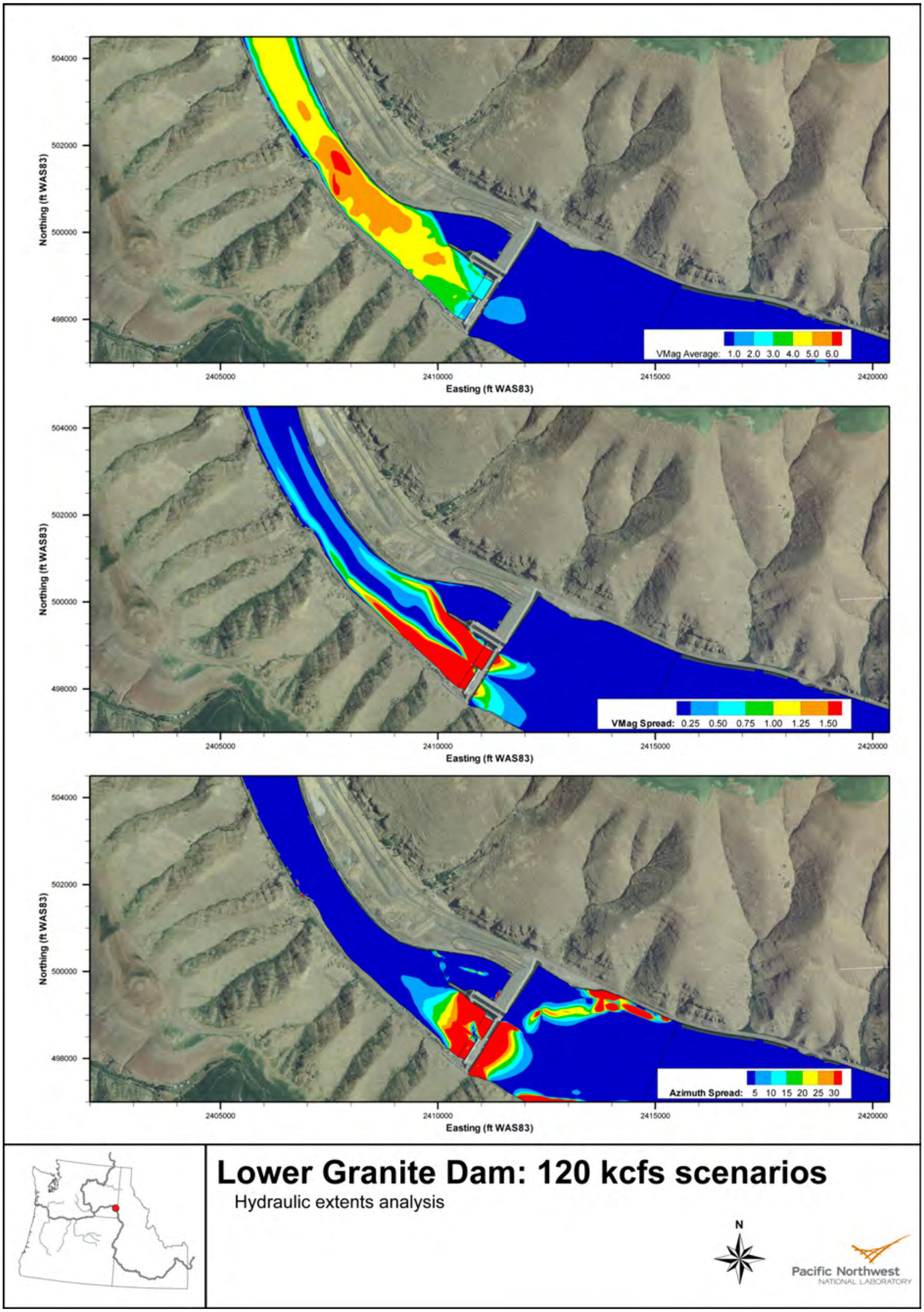

Figure 3.32. Lower Granite Project for 120 kcfs. Velocities in ft/s.

3.9 Hydraulic Extents

The hydraulic extents criteria were applied to the MASS2 results for all flows at each project. Table 3.1 summarizes the distance and the Snake or Columbia River Mile of the extent location. Figures 3.33 to 3.40 show the area influenced by project operations (based on the hydraulic extents criteria) and a line showing the proposed hydraulic extent. The location of the BRZ is shown in pink on the Columbia River dams for reference.

Table 3.1. Hydraulic Extents Summary

Project	**Forebay**		**Tailrace**	
	Distance (ft)	River Mile	Distance (ft)	River Mile
Columbia River				
Bonneville	5900	147.2	11,500	143.9
The Dalles	6300	192.9	5800	190.6
John Day	2800	216.2	7600	214.2
McNary	3700	292.7	7600	290.6
Snake River				
Ice Harbor	2200	10.3	2700	9.4
Lower Monumental	2400	42.1	6900	40.3
Little Goose	2200	70.7	5100	69.3
Lower Granite	1100	107.5	7300	105.9

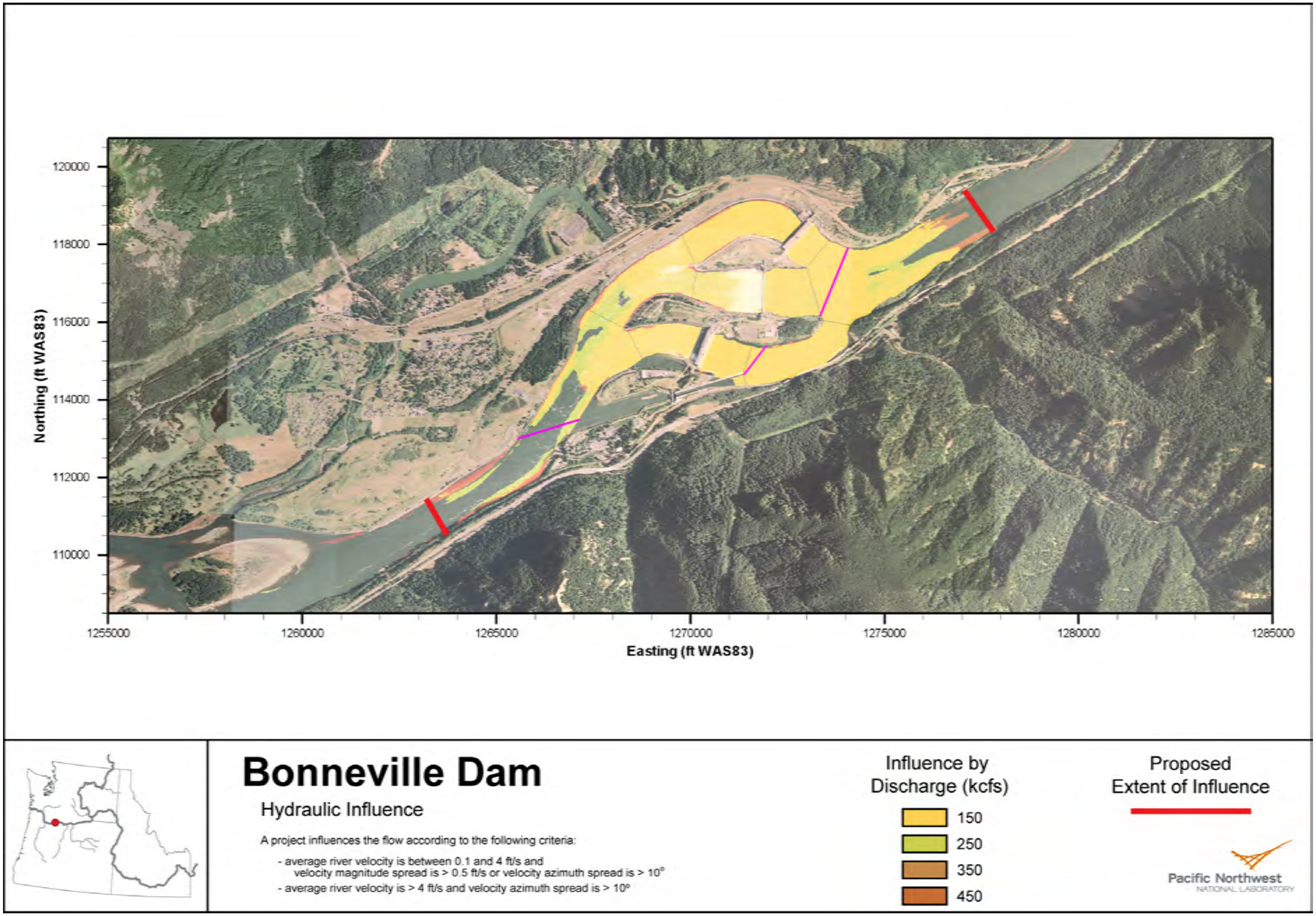

Figure 3.33. Bonneville Proposed Hydraulic Extents

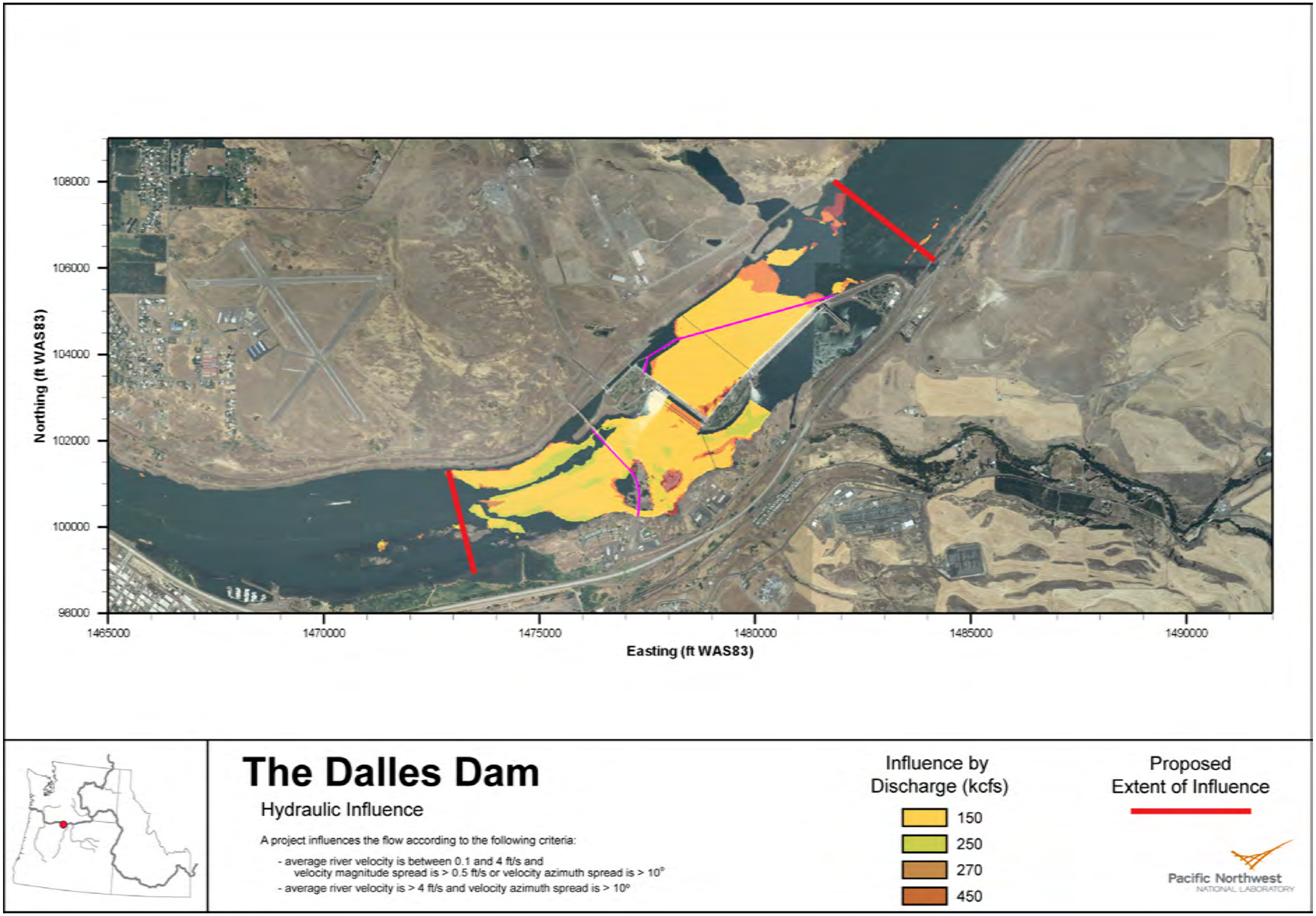

Figure 3.34. The Dalles Project Proposed Hydraulic Extents

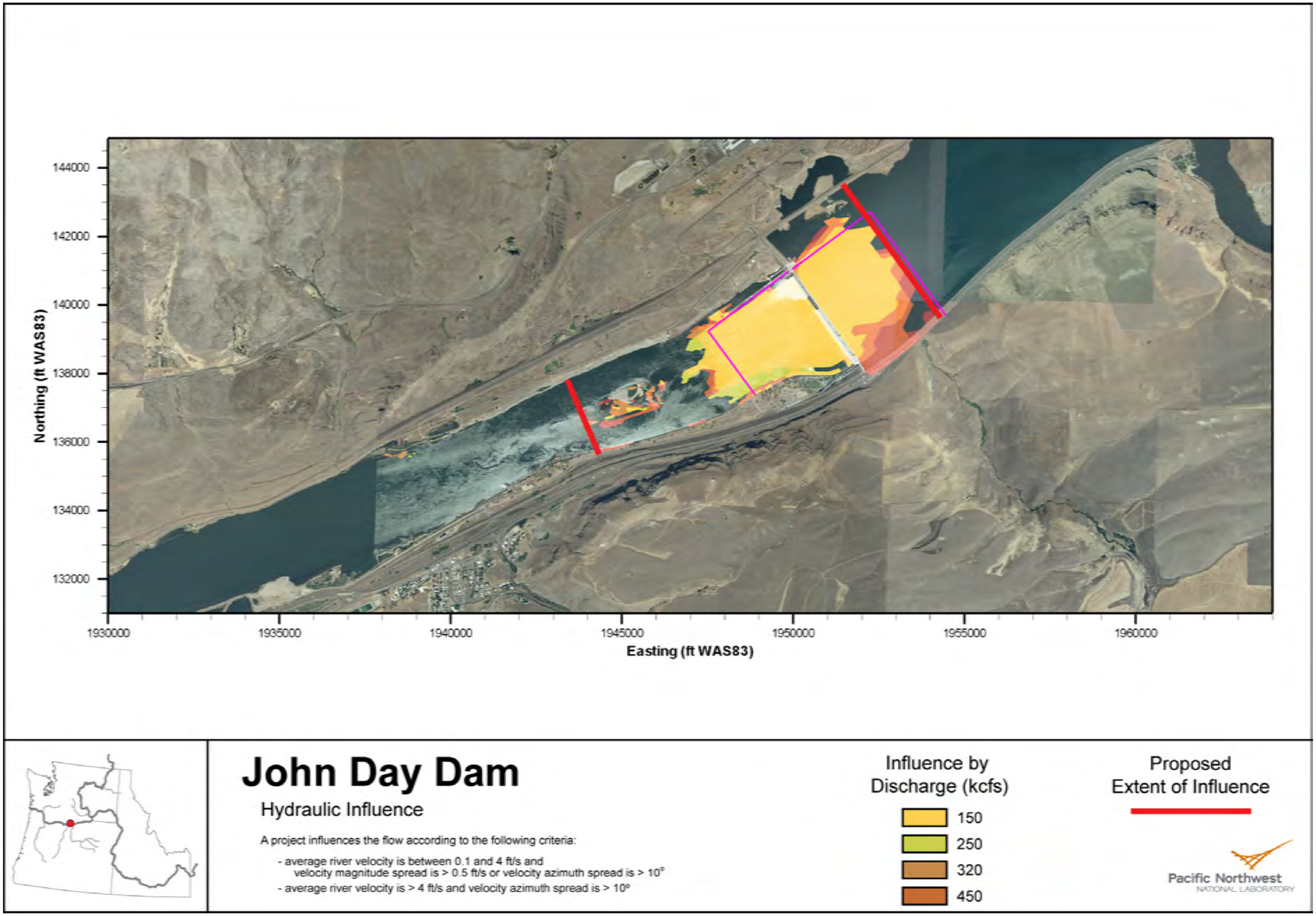

Figure 3.35. John Day Project Proposed Hydraulic Extents

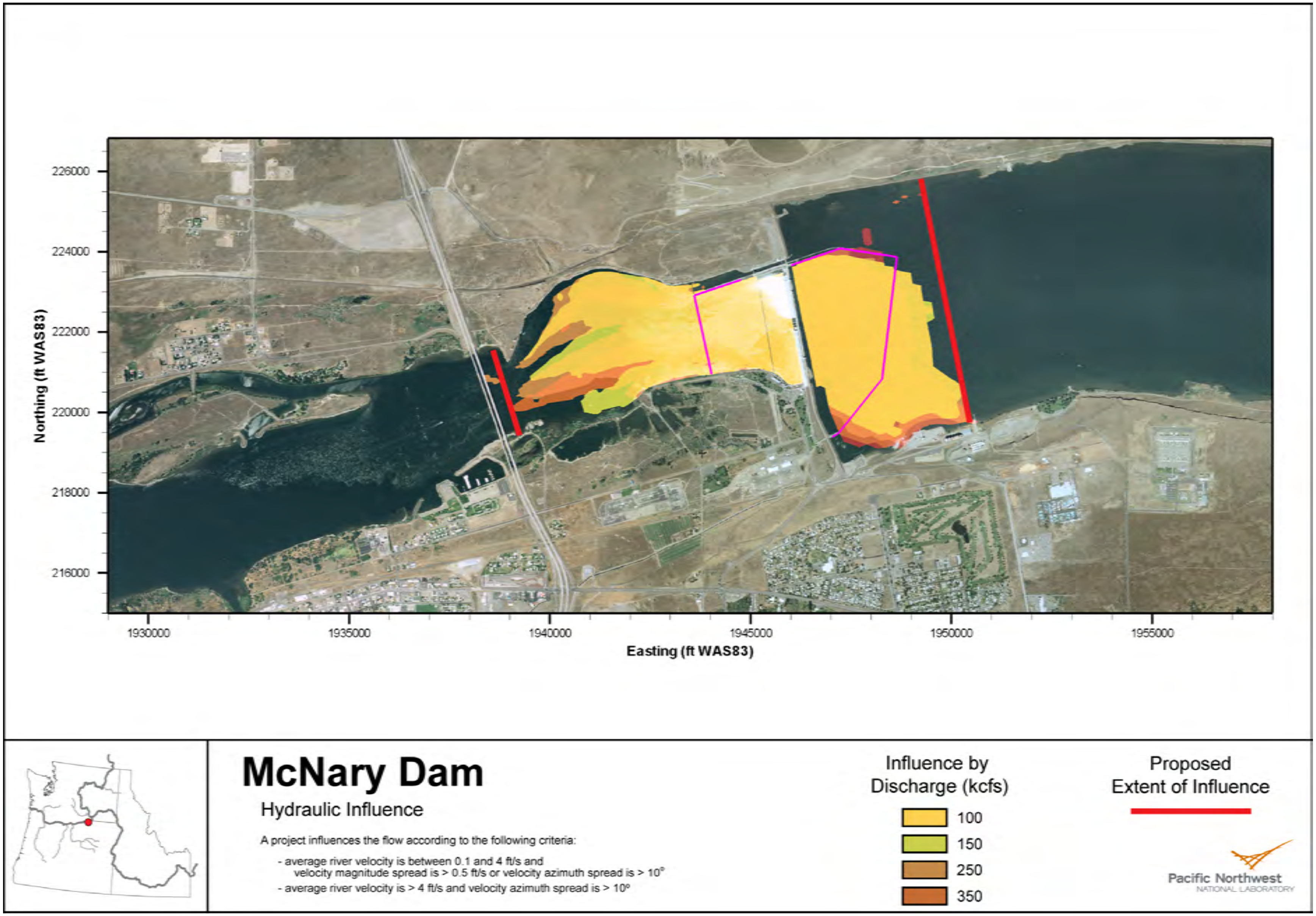

Figure 3.36. McNary Project Proposed Hydraulic Extents

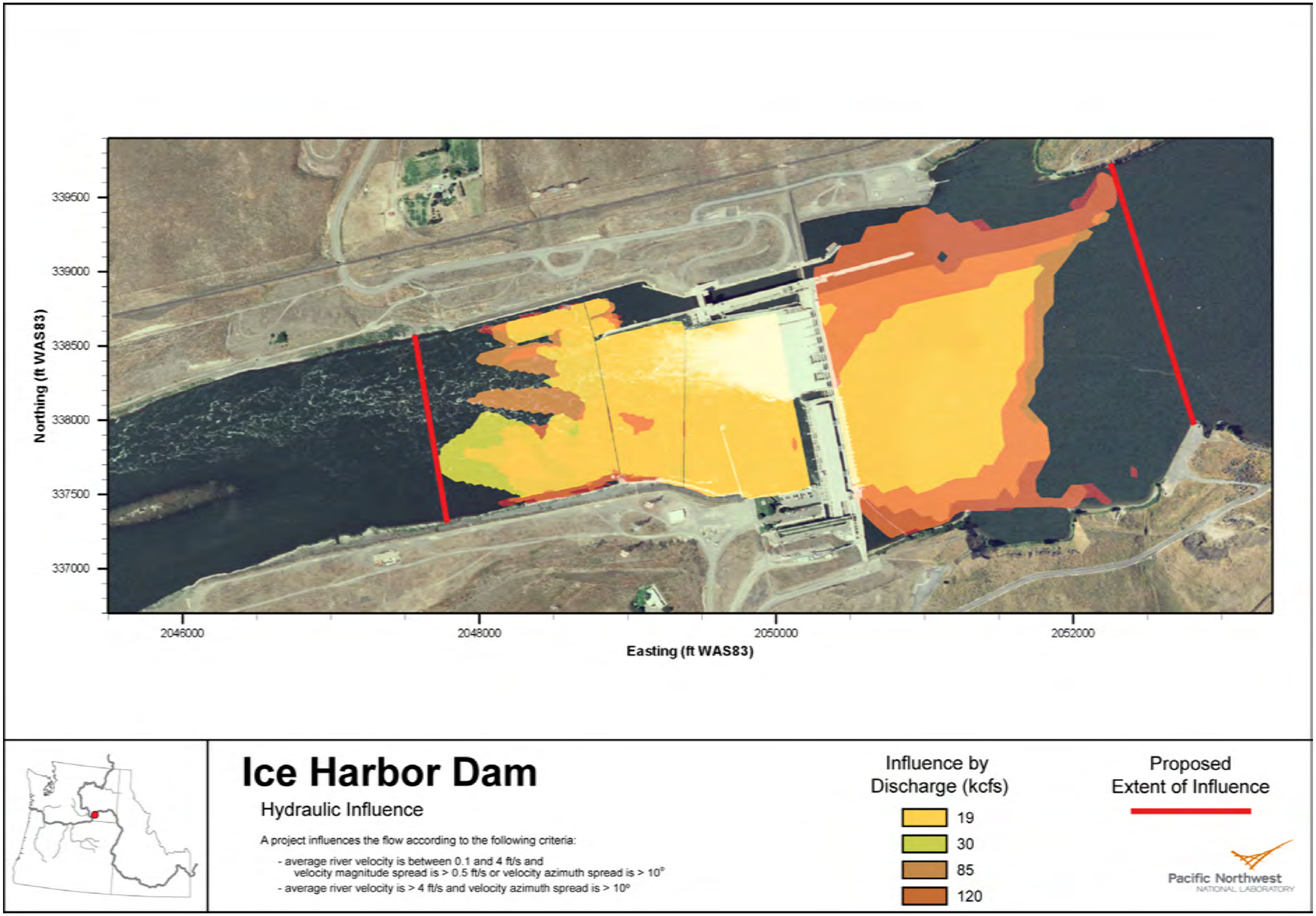

Figure 3.37. Ice Harbor Project Proposed Hydraulic Extents

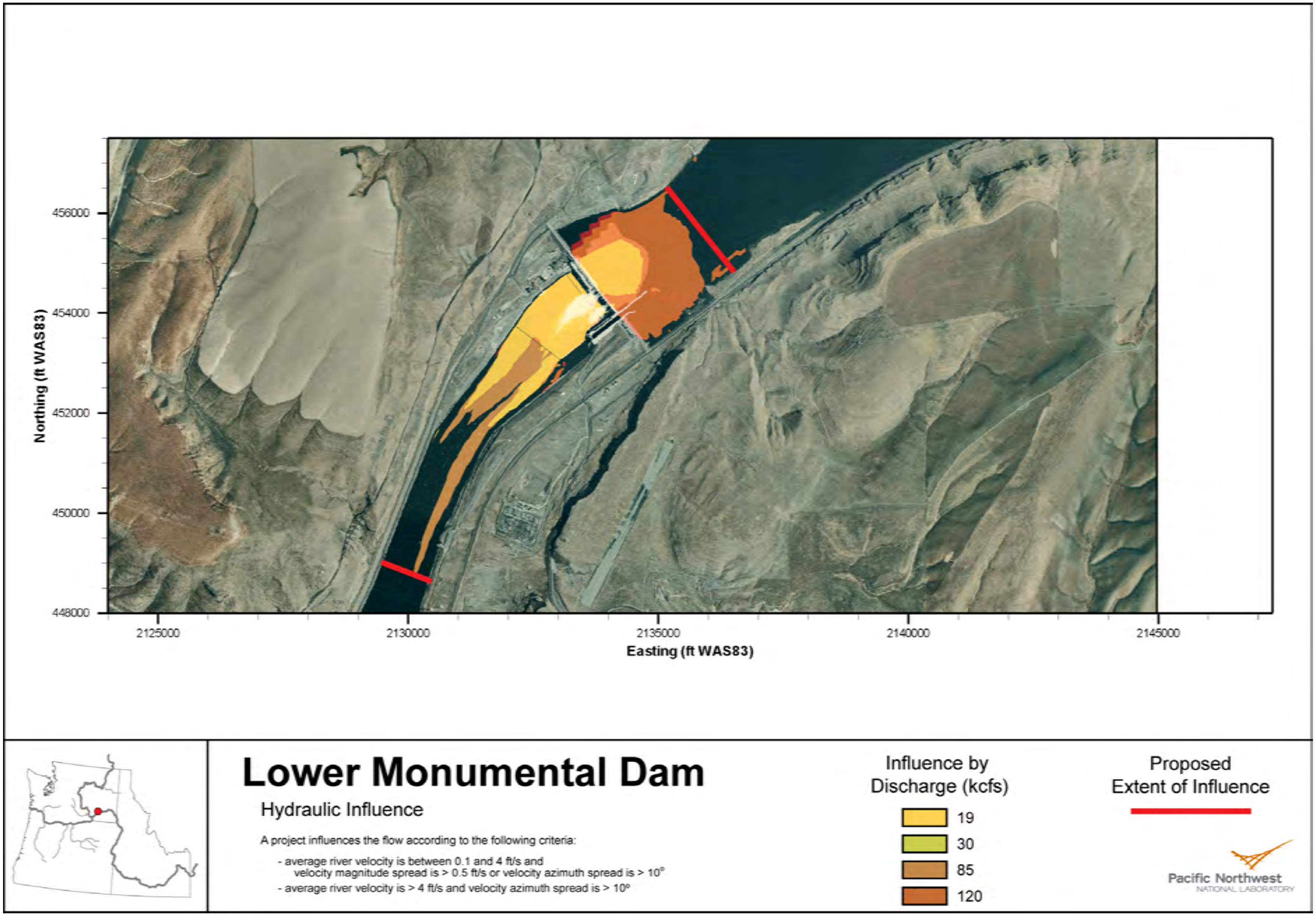

Figure 3.38. Lower Monumental Project Proposed Hydraulic Extents

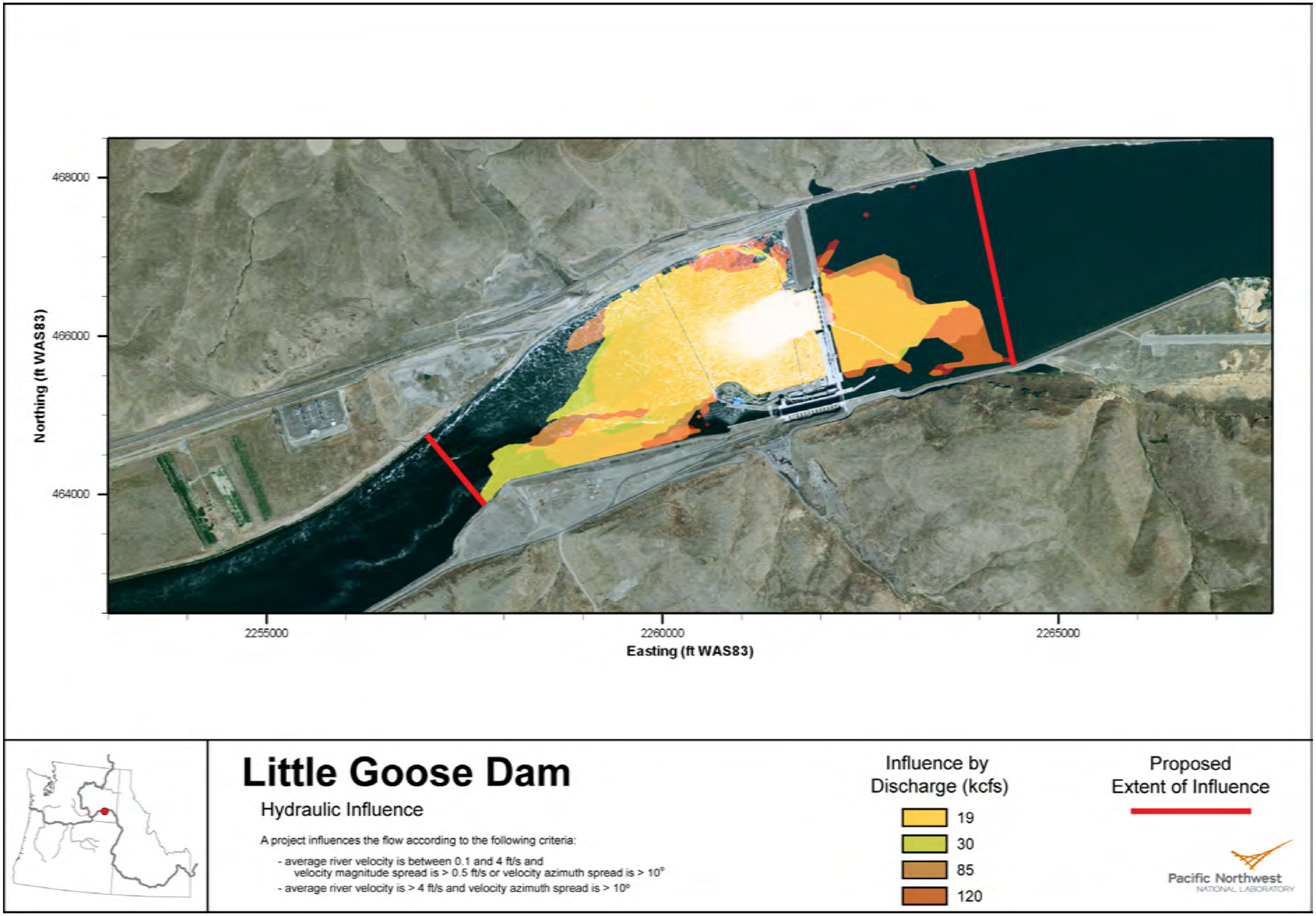

Figure 3.39. Little Goose Project Proposed Hydraulic Extents

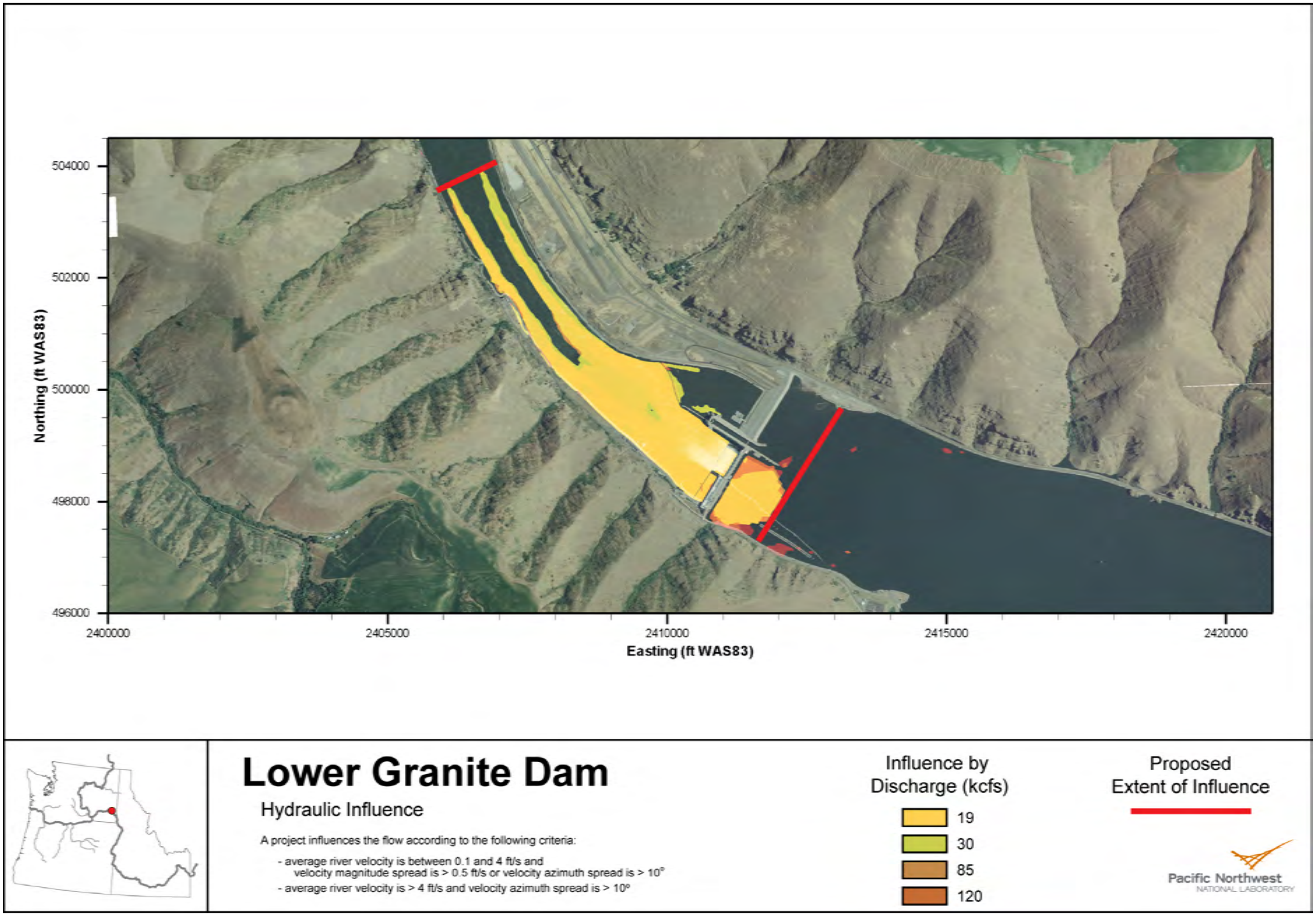

Figure 3.40. Lower Granite Project Proposed Hydraulic Extents

4.0 Conclusions

The purpose of this study was to delineate the hydraulic extents of the hydroelectric projects on the lower Columbia and lower Snake rivers in a consistent manner. Based on results from a 2D depth-averaged river model, MASS2, and criteria from USACE-CENWP, the extents were delineated for each project.

In many studies, the location of the BRZ has been used for the hydraulic extent in the lower Columbia River, and the feasibility project at John Day supported the BRZ as largely encompassing the area of project influence. For all these Columbia River projects, however, this is not consistently the case.

Although each hydroelectric project has a different physical setting, there were some common results. The downstream hydraulic extent tended to be greater than the hydraulic extent in the forebay; The Dalles is the exception. The hydraulic extent of the projects was generally larger at the mid-range flows. At higher flows, the channel geometry (in particular the channel constrictions) reduced the impact of project operations.

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