Oregon Spotted Frog and Deschutes Redband Trout Habitat Modeling and Riparian Analysis at Two Sites on the Upper Deschutes River

Prepared for:

Deschutes Basin Board of Control on behalf of the Basin Study Work Group

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Executive Summary

Introduction

The Deschutes Basin Board of Control (DBBC), on behalf of the Deschutes Basin Study Work Group (BSWG), contracted River Design Group, Inc. and HDR, Inc. (hereafter referred to as "study team") to prepare an instream flow study at two sites on the upper Deschutes River near La Pine, Oregon. The two sites, known as Bull Bend (upstream) and Dead Slough (downstream) are located downstream from Wickiup Dam, one of two primary storage reservoirs on the upper Deschutes River. The two sites, each of which are approximately 1 mile in length, were selected to analyze existing and potential habitat conditions for Oregon spotted frog (*Rana pretiosa*) and Deschutes redband trout (*Oncorhynchus mykiss gairdnerii*). Oregon spotted frog and redband trout are native to the upper Deschutes River and are known to use these two reaches of the river. Conditions associated with Oregon spotted frog overwintering and breeding habitats, and adult redband trout holding habitat, were the primary habitats of interest. The study included 2-dimensional hydraulic and habitat modeling using the River2D model platform (University of Alberta 2002), habitat suitability criteria, and river flows ranging from current winter storage flows (20 cfs) to peak irrigation season flows (1,800 cfs).

Study Objectives

The BSWG directive for the instream flow study was to complete an analysis that evaluates the relationships between streamflow and instream and adjacent riparian wetland habitats. The Oregon spotted frog analysis focused on overwintering and breeding habitat as habitat suitability criteria for these life stages are better defined than for other life stages. The redband trout analysis focused on adult holding habitat. The study objectives included:

- Determine potential reductions or increases in Oregon spotted frog overwintering and breeding habitat, and redband trout holding habitat associated with flows ranging from 20 cfs to 1,800 cfs.
- Determine flow effects on emergent riparian wetland vegetation and potential emergent vegetation response associated with existing flows and a modified flow regime characterized by lower summer flows.

Methods

From September 9, 2015 through March 3, 2016, the study team collected data at the study sites. Collected data include channel and floodplain topography; hydraulic data including water surface elevations and point velocities; and habitat and substrate characterization. Hydraulic simulations were conducted over 16 flows ranging from 20 cfs to 1,800 cfs as recorded at the Deschutes River Below Wickiup Reservoir near La Pine, OR (#14056500) gage. The flow range included from typical winter time storage flows to flows exceeding typical summer irrigation season flows.

Results

Weighted usable area (WUA) was calculated for Oregon spotted frog and redband trout using hydraulic model outputs and species-life stage habitat preference information. Habitat modeling results suggest Oregon spotted frog overwintering habitat suitability at both sites increases with flow as off-channel habitats are inundated by low velocity inflows. Overwintering habitat suitability at Bull Bend increases rapidly from 20 cfs to 200 cfs, and then remains relatively consistent until 1,000 cfs (Figure ES-1). The consistent WUA results suggest smaller areas of higher suitability habitat were generated as flows increased, while broader areas of lower suitability habitat were displaced. Overwintering habitat suitability at Dead Slough exhibits a steady upward trend from 20 cfs to 400 cfs. Between 400 cfs and 500 cfs, the Deschutes River water surface elevation exceeds the bed elevation of the Dead Slough outlet and the river flows into Dead Slough, resulting in an increase in the WUA values for the study site. WUA from 500 cfs to 1,000 cfs has a more gradual slope similar to the 20 cfs to 400 cfs response.

Oregon spotted frog breeding habitat suitability at the Bull Bend study site was consistently low from 20 cfs to 600 cfs (Figure ES-2). From 600 cfs to 800 cfs, breeding habitat suitability increased at a slightly faster rate before rapidly increasing from 800 cfs to 1,200 cfs. The rapid increase in WUA coincided with inundation of riparian wetland areas, particularly the half moon-shaped floodplain in the upstream half of the study site. Following the peak WUA at 1,200 cfs, WUA declined at 1,400 cfs as suitable areas experienced higher river stage and greater depths making them less suitable. Oregon spotted frog breeding habitat in the Dead Slough study site illustrated a similar pattern of low WUA values from 20 cfs to 400 cfs. From 400 cfs to 800 cfs, WUA increased as the Dead Slough oxbow connected with the mainstem Deschutes River and surface water began to interact with the vegetated floodplain adjacent to Dead Slough. WUA increased at a slower rate from 800 cfs to 1,200 cfs as the river and Dead Slough interaction with adjacent riparian wetland areas increased. Dead Slough breeding habitat WUA spiked at 1,400 cfs as the Dead Slough riparian wetland areas were extensively inundated.

Redband trout adult holding habitat WUA exhibited a similar pattern for both study sites. Holding habitat WUA increased rapidly from 20 cfs to 800 cfs at Bull Bend as increasing river stage corresponded with increasing rearing habitat suitability. With increasing stage, the river also interacts with channel margin wood at both study sites. WUA increases at a slower rate through 1,400 cfs before an uptick to the peak adult rearing WUA at 1,800 cfs. Increasing WUA is related to the expanding influence of large wood complexes at increasing flows.

Redband trout adult holding habitat WUA in the Dead Slough site crested at 600 cfs and remained relatively consistent through 1,800 cfs. Redband trout holding habitat at the Dead Slough site is limited to the mainstem river due to the low velocities in the Dead Slough oxbow which are assigned a low habitat suitability. Redband trout holding habitat is therefore limited to the mainstem channel which is approximately half the length of the Bull Bend site.

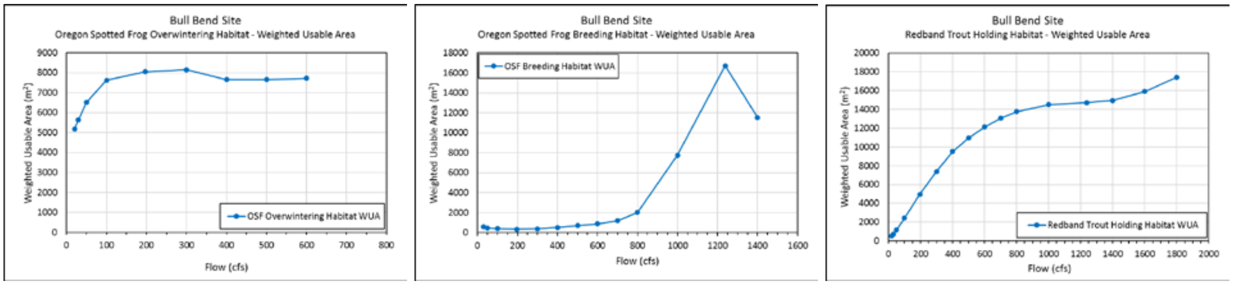


Figure ES-1. Bull Bend study site WUA results for (from left to right) Oregon spotted frog overwintering and breeding habitat, and redband trout adult holding habitat.

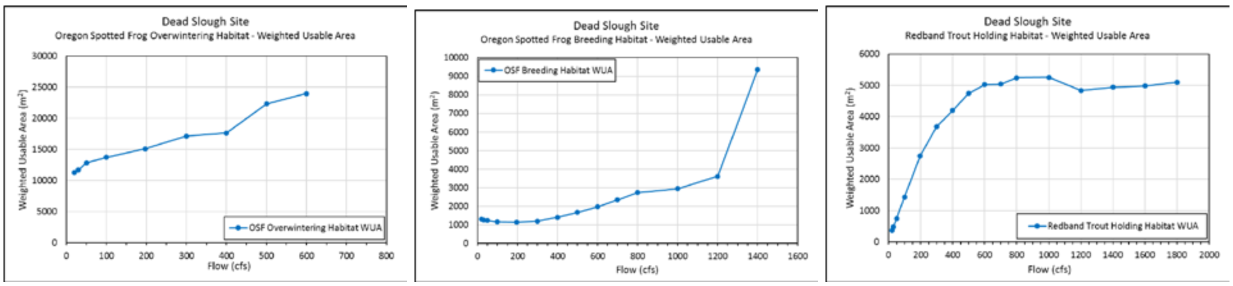
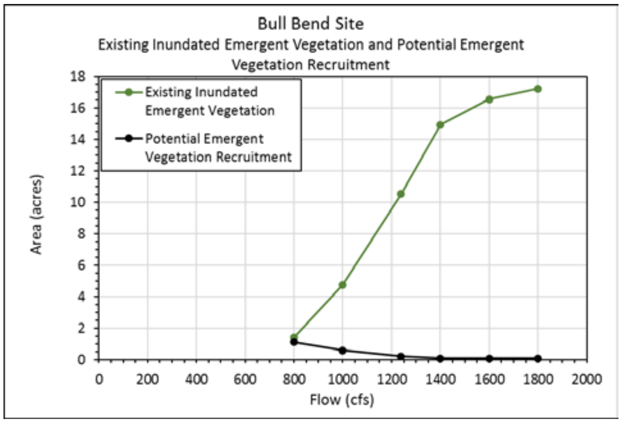


Figure ES-2. Dead Slough study site WUA results for (from left to right) Oregon spotted frog overwintering and breeding habitat, and redband trout adult holding habitat.

Emergent vegetation in the upper Deschutes River study sites is believed to be controlled mainly by the summer growing season water surface elevation. Under the current flow regime, inundated riparian wetland acreage at the Bull Bend study site ranges from 1.43 acres at 800 cfs to 17.24 acres at 1,800 cfs (Figure ES-3). A modified flow regime characterized by lower summer flows would be expected to result in emergent vegetation recruitment into the channel. Lower summer flows could increase the distribution of emergent vegetation by 1.11 acres at 800 cfs and by less than 0.10 acres at 1,800 cfs.

Under the current flow regime, inundated riparian wetland acreage at the Dead Slough study site ranges from 1.23 acres at 800 cfs to 9.68 acres at 1,800 cfs (Figure ES-3). Lower summer flows could increase the distribution of emergent vegetation by 2.92 acres at 800 cfs and by less than 0.10 acres at 1,800 cfs.



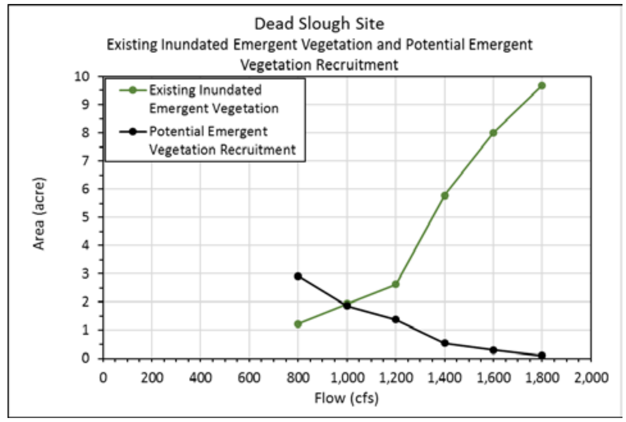


Figure ES-3. Bull Bend (left) and Dead Slough (right) existing inundated emergent vegetation acreage, and potential emergent vegetation recruitment over a range of flows.

Discussion

Habitat study results suggest Oregon spotted frog overwintering and breeding habitat suitability generally increase with increasing flows. Peak habitat suitability is associated with shallow water depths, low velocities, and inundated emergent vegetation on the upper Deschutes River floodplain. Redband trout adult holding habitat suitability similarly increases with increasing flow as the river interacts with mid-channel and channel margin woody debris. Low velocity off-channel areas offer poor redband trout adult holding habitat suitability.

We also calculated river inundation of riparian wetland floodplain surfaces under the current water management regime characterized by summer flows between 800 cfs and 1,800 cfs, and potential riparian vegetation recruitment associated with lower summer flow releases. Under the existing flow regime, Bull Bend has nearly twice the inundated riparian wetland vegetation at a given flow compared to Dead Slough. Riparian wetland floodplain surfaces are more extensive and exist at lower elevations relative to the river at Bull Bend than they do at Dead Slough. Conversely, minimal riparian wetland vegetation recruitment gains would be achieved at Bull Bend with reduced summer flows as there is less bare draw down area at Bull Bend relative to Dead Slough.

The bare draw down region at the Dead Slough site, particularly in the Dead Slough itself, is larger and more conducive to emergent vegetation recruitment with lower summer flows. A modified flow regime characterized by lower summer flows would potentially result in emergent vegetation recruitment into the channel at the Dead Slough site, improving Oregon spotted frog breeding habitat suitability.

Finally, we analyzed how a modified flow regime could affect Oregon spotted frog breeding habitat suitability at the Dead Slough site. Existing silt and sand substrates at the channel margin would potentially convert to emergent vegetation with lower summer flows. Emergent vegetation recruitment into the channel, combined with lower summer flows and higher flows during the Oregon spotted frog breeding, would result in higher breeding habitat suitability at moderate flows relative to existing conditions (Figure ES-4). Additional analysis is needed to further evaluate potential summer and breeding period flows that meet downstream water needs and improve Oregon spotted frog habitat suitability.

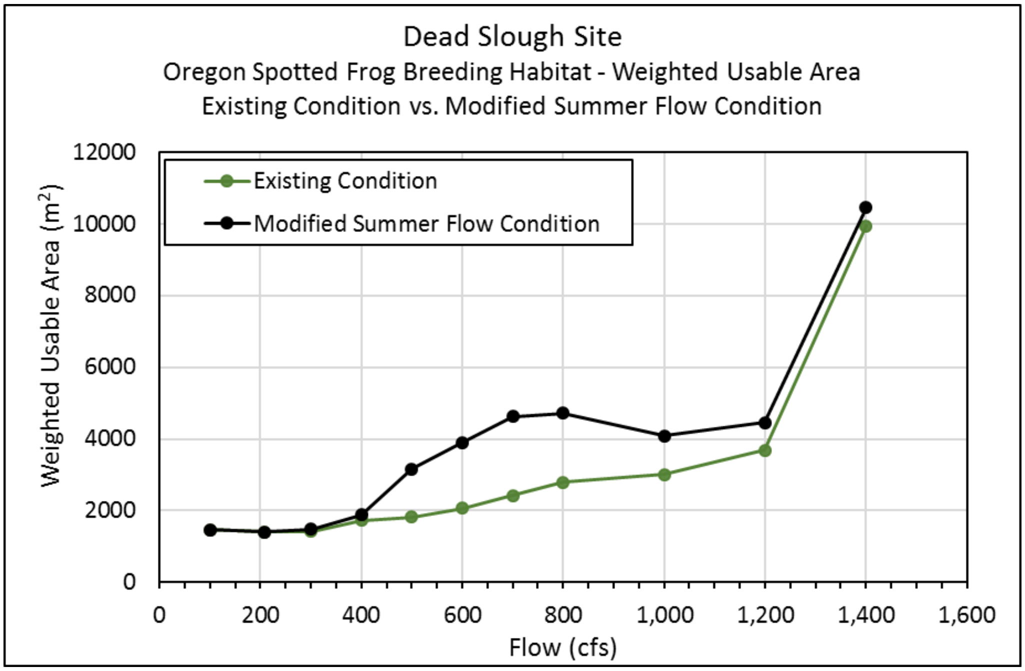


Figure ES-4. A comparison of Oregon spotted frog breeding habitat suitability WUA for the existing condition and potential condition associated with a modified summer flow. Conversion of silt and sand substrate to emergent vegetation along channel margins which would be expected to occur with lower summer flows, would increase the breeding habitat suitability at the Dead Slough site at moderate flows relative to the existing condition.

Acknowledgements

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Glossary – Definitions of Terms, Acronyms and Abbreviations

BSWG – Basin Study Work Group

CFS – cubic feet per second

CMS – cubic meters per second

DBBC – Deschutes Basin Board of Control

DRC – Deschutes River Conservancy

GPS – global positioning system

HSC – habitat suitability criteria

ODFW – Oregon Department of Fish and Wildlife

OPRD – Oregon Parks and Recreation Department

Study Team – River Design Group, Inc. and HDR, Inc.

USBR – U.S. Bureau of Reclamation

USFWS – U.S. Fish and Wildlife Service

USFS – U.S. Forest Service

USGS – U.S. Geological Survey

WUA – Weighted area suitability

1 Introduction

1.1 Background

The Deschutes Basin Board of Control (DBBC), on behalf of the Deschutes Basin Study Work Group (BSWG), contracted River Design Group, Inc. (RDG) and HDR, Inc. (hereafter referred to as "study team") to model aquatic and riparian wetland habitat relationships at two sites on the upper Deschutes River near La Pine, Oregon. The habitat modeling effort is one of several tasks being overseen by the U.S. Bureau of Reclamation (USBR) and the BSWG as part of the Upper Deschutes River Basin Study.

1.2 Study Goals and Objectives

The BSWG directive for the upper Deschutes River instream flow study (habitat study) was to complete an analysis that evaluates the relationships between streamflow and instream and adjacent riparian wetland aquatic and riparian habitat conditions. The analysis was to address habitat availability for all life stages of Oregon spotted frog (*Rana pretiosa*), and Deschutes redband trout (*Oncorhynchus mykiss gairdnerii*) holding habitat. After consultation with project partners, the study team refined the Oregon spotted frog analysis to focus on overwintering and breeding habitat as habitat suitability criteria for these life stages are better defined than for other life stages. Habitat study objectives included:

- Determine potential reductions or increases in Oregon spotted frog overwintering and breeding habitat, and redband trout holding habitat associated with flows ranging from 20 cfs to 1,800 cfs.
- Determine flow effects on emergent riparian wetland vegetation and potential emergent vegetation response associated with existing flows and lower summer flows.

The habitat modeling study is intended to assess flows that would better support seasonal aquatic and riparian wetland habitats in the upper Deschutes River. Habitat conditions, in the context of the hydraulic and habitat modeling, serve as a surrogate for biological response as the target organisms rely on river flows to complete their life cycle. The modeling tools allow for analyzing incremental changes in river corridor conditions under baseline and proposed hydrologic regimes.

2 Existing Conditions Summary

The Deschutes River originates at the outflow of Little Lava Lake on the eastern slope of the Cascade Mountains, flows to the south through Crane Prairie Reservoir and Wickiup Reservoir before turning and trending to the northeast through La Pine, Oregon. Extensive spring complexes discharge to the upper Deschutes River upstream from Wickiup Dam. Historically, spring discharge created a hydrologic regime in the upper Deschutes River with considerably less seasonal and year-to-year variation than most other Cascade streams. USBR-owned dams on the Deschutes River create Crane Prairie Reservoir (ca. 1940; 50,000 AF of authorized storage) and Wickiup Reservoir (ca. 1942; 200,000 AF of authorized storage). The reservoirs are operated to store and release water for downstream use by four irrigation districts. Two other irrigation districts divert and distribute upper Deschutes River live flows to their respective patrons. In addition to irrigated agriculture, other water users include municipalities, individual landowners, and recreationalists. The two study sites and the upper Deschutes River from Wickiup Reservoir downstream to Sunriver, Oregon are shown in Figure 2-1.

Figure 2-1. The project vicinity map showing the locations of the Bull Bend and Dead Slough study sites on the upper Deschutes River.

2.1 Hydrology

Hydrologic characteristics such as the influence of groundwater sources, the magnitude and duration of high flows and base flows, and flow management, can greatly influence river ecology. In the case of the upper Deschutes River study sites, flow management is defined by winter storage that has historically reduced the flow below Wickiup Dam to as little as 20 cfs, and summer releases that can reach 1,800 cfs below Wickiup Dam. Flow transitions during spring ramp-up and fall ramp-down are influenced by water right schedules, irrigation needs, soil moisture and climatic conditions, resident fisheries, and the safety of recreational users. Several studies have evaluated stream flow (Golden and Aylward 2006; Cooper 2008) and groundwater inputs (Gannett et al. 2003) to the Deschutes River.

Flow management at the dams and irrigation withdrawals throughout the basin have substantially altered the historical basin hydrology. Prior to regulation, flows in the upper Deschutes River were more constant with less variability between high flows and base flows. The hydrology of the upper Deschutes River is now characterized by extremely low flows during winter reservoir storage, and extremely high flows during spring and summer months when water is released from storage to satisfy downstream water demands. Alteration of the historical hydrology has allowed basin agriculture and development to flourish, but is also responsible for diminished ecological function in the river corridor. The impacts of the regulated flow regime on river ecology become less apparent downstream from Sunriver with flow inputs from Fall River, Spring River, and the Little Deschutes River (ODFW 2015).

A weather station at Wickiup Dam, reports precipitation and air temperatures in the study area. The upper Deschutes River watershed area upstream of Wickiup Dam measures 479 square miles with a mean elevation of 5,190 ft. Average annual snow fall totals 78.5 inches and average annual minimum and maximum air temperatures range are 29.6°F to 57.5°F, respectively (WRCC 2016).

Upper Deschutes River flows are measured at several near-real time Oregon Water Resources Department (OWRD) stream gages upstream from La Pine, Oregon. The Deschutes River Below Wickiup Reservoir near La Pine, OR (#14056500) gage was the primary gage used in the habitat study. The gage is located at river mile (RM) 226.5 and is approximately 4.8 miles upstream from the Bull Bend Study Site (RM 221.7) and 18.25 miles upstream from the Dead Slough Study Site (RM 208.25).

2.2 Existing Hydraulic and Habitat Models

Riverine hydraulic models aim to characterize the hydraulic conditions that exist in a river channel. The level of hydraulic detail contained in each model depends on the spatial extent of the model, the purpose of the model, and the detail contained in the topographic input data. Flow simulations also depend on the goal of each model, and therefore range from small increment, low magnitude simulations (i.e., micro – macro habitat models) to large increment, large magnitude simulations (i.e., floodplain inundation).

Spatially-based habitat models use results from hydraulic simulations to quantify the amount of habitat that is created, available, or suitable at each simulated flow, and, depending on the type of model, where the habitat occurs.

A one-dimensional habitat model Physical Habitat Simulation Model (PHABSIM) was developed in 1991 to model river flow and spawning and rearing habitat for brown trout and redband trout at 26 transects between Wickiup Reservoir and Sunriver, Oregon (Hardin-Davis, Inc. 1991). The study found adult holding and spawning habitat peaked at flows up to 400 cfs in the reach investigated in the current habitat study.

2.3 General Topography and Geomorphology

Studies have documented the unstable state of the upper Deschutes River in the Wickiup Dam to La Pine reach (Cameron and Major 1987; Hardin-Davis 1991; Walker and Tanner 2012). Cameron and Major (1987) cited in Hardin-Davis (1991), described the present meander pattern as being several thousand years old and controlled by volcanic features such as lava flows and sedimentary characteristics of the river corridor. Walker and Tanner (2012) highlighted the effects of the modern flow regime on streambank stability and rapid changes in the channel planform due to flow management. Winter low flows expose streambanks to freeze-thaw processes that destabilize the bank profile and increase streambank susceptibility to erosion during spring-summer high flows maintained for downstream water delivery. According to Walker and Tanner (2012):

> The duration and timing of flow fluctuations can affect erosive activity in at least two ways. First, the longer the duration of a particular flow, the more time is available for specific forces to act upon stream banks and beds. Second, when water levels fluctuate riverbanks are subject to additional disruptive forces such as frost action (USFS 1994). This is especially true when low flow conditions occur during the winter time, like in the upper Deschutes River. Frost action takes place when moisture in the stream banks freeze, expand, and then melt. The result is that bank materials are loosened and more susceptible to the erosive and transport capabilities of high flows than if they were inundated all year.
>
> Large flow fluctuations over long durations create a zone in which neither aquatic nor riparian species of plants can survive (USFS 1994). In the upper Deschutes River the high, regulated flows of irrigation season coincide with the growing season for streambank vegetation. The high flows during the growing season make the establishment or reestablishment of vegetation an unlikely proposition in the draw down zone (due to being submerged) and hinders one of the primary natural means of stabilizing the river channel. As a result, this zone is mostly devoid of aquatic and riparian vegetation which would otherwise armor the riverbed and banks and is referred to as the draw down zone.

Aerial photo analysis completed by USFS found the bankfull channel width increased by at least 20% from 1943 to 1991 (USFS 1994; 1996 cited in Walker and Tanner 2012). The increase in the channel cross-section width is attributed to the increased flows associated with summer-long irrigation. A higher frequency of meander cut-offs that was documented over the same time period, is also attributed to elevated flows.

In summary, the current river corridor exhibits the effects of nearly 70 years of river management to meet downstream water rights. Annual river drawdown, channel widening, and planform instability degrade aquatic and riparian habitats and affect the biological communities that have evolved in the upper Deschutes River.

3 Study Methods

The implementation of this habitat study was performed in several steps. The following section outlines the study methods employed for the project.

3.1 Study Sites

Two study sites, Bull Bend and Dead Slough, were selected by the study stakeholders as being representative of sites that may, or have been known to support Oregon spotted frogs in the past. Despite the representative conditions of these two sites, hydraulic modeling and habitat modeling outputs for the two sites cannot be extrapolated to other reaches of the Deschutes River.

Bull Bend, located 4.8 miles downstream from Wickiup Dam, is characterized by a tortuous meander in the Deschutes River planform. Approximately 1 mile in length, the Bull Bend site includes mainstem, off-channel, and floodplain habitats, and a multi-thread channel neck cut-off. Low elevation riparian wetland floodplain surfaces and laterally eroding banks parallel the river channel.

The Dead Slough site is located 18.3 river miles downstream from Wickiup Dam and is within La Pine State Park. The Dead Slough site is characterized by both the mainstem channel and the Dead Slough, an oxbow lake. The mainstem channel measures approximately 2,200 ft in length and is bordered by narrow floodplain surfaces and forested hillslopes. Dead Slough is approximately 4,000 ft long.

3.2 Target Species and Habitat Suitability Criteria

The primary target life stages of concern for the habitat study include Oregon spotted frog overwintering and breeding life stages, and redband trout adult holding life stage. These life stages and their associated habitat needs may be affected by the current water management regime and related river effects.

3.2.1 Habitat Suitability Criteria

Habitat suitability criteria (HSC) define the range of microhabitat variables that are suitable for a particular species and life stage of interest. Variables typically defined with HSC include depth, velocity, instream cover and channel substrate. HSC values range from 0.0 to 1.0, indicating microhabitat conditions that range from unsuitable to optimal, respectively. HSC provide the biological criteria input to the River2D model. The model then combines the physical habitat data and the habitat suitability criteria into a habitat suitability index (i.e., weighted usable area or WUA) over a range of simulation flows. WUA is defined as the sum of stream surface area within a nodal area model domain or stream reach, weighted by multiplying the surface area by habitat suitability variables, most often velocity, depth, and substrate or cover, which range from 0.0 to 1.0 each.

WUA is a metric for comparing microhabitat conditions in response to changes in river flow. While WUA may be a useful metric to evaluating changes in microhabitat conditions, the metric also has its limitations and must be appropriately applied within the limitations of the HSC data, modeling output, and the study context. For example, peak WUA may be associated with flows that did not historically or currently occur within a study site. Using the upper Deschutes River and Oregon spotted frog as an example, WUA results peaks for Oregon spotted frog overwintering habitat at flows exceeding 1,000 cfs, flows that were likely rare even during the historical, pre-regulation period. Therefore, WUA results must be accurately communicated with the context the results were developed.

Oregon spotted frog HSC were developed with input from Oregon spotted frog experts and literature reviews. Redband trout HSC were derived from redband trout HSC developed for instream flows studies completed on the Klamath River (Thomas R. Payne & Associates 2004), Tumalo Creek (HDR, Inc. 2012), and the Deschutes River (Hardin-Davis 1991).

3.2.2 Oregon Spotted Frog Life History and Habitat Information

The USFWS listed the Oregon spotted frog as a threatened species under the Endangered Species Act on August 28, 2014 (USFWS 2014); critical habitat was designated by USFWS for the species on May 11, 2016 (USFWS 2016).

Oregon spotted frog is the most aquatic native frog in the Pacific Northwest. Nearly always found in or near perennial water bodies with abundant vegetation, Oregon spotted frog have been extirpated from approximately 70% of their historical range in the Pacific Northwest (Pearl et al. 2009) due to habitat loss, non-native plant invasions, and interactions with non-native fish and amphibians. The majority of Oregon spotted frog populations are small and isolated, increasing the risk of local population extirpation (USFWS 2014).

Oregon spotted frogs are found over an elevational range spanning from lowland valleys to higher elevation mountain streams. Oregon spotted frog breeding habitats in higher elevation areas of Oregon, including the upper Deschutes River basin, are characterized by open, shallow sloped wetlands with moderate to dense emergent vegetation including grasses and sedges (Pearl et al. 2009). Shallow wetland margins with emergent vegetation provide refuge from predators, and warmer water for egg mass and larvae development (USFWS 2014).

Oregon spotted frogs seem to prefer expansive wetlands with the following characteristics (USFWS 2014):

- Good breeding and overwintering habitats connected by year-round water;
- Reliable water levels that maintain depth throughout the period between oviposition and metamorphosis;
- The absence of introduced predators, especially warm-water game fish and bullfrogs.

Other habitat characteristics that are believed to be important to Oregon spotted frogs include water temperature, waterbody aspect, shallow pond/channel bottom gradients, the presence of submerged vegetation, and access to underground habitats like beaver dens.

Figure 3-1 includes Oregon spotted frog life stage time in relation to the average annual hydrograph for the upper Deschutes River.

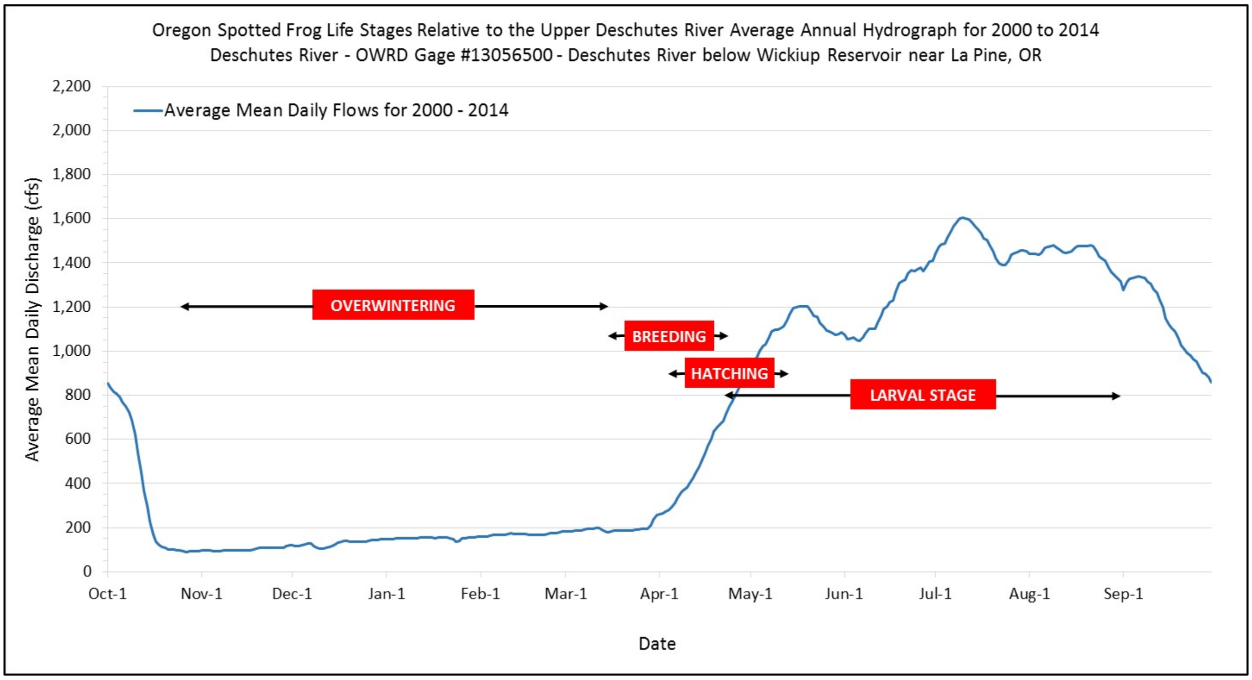

Figure 3-1. Oregon spotted frog life stage timing relative to the upper Deschutes River's average annual hydrograph.

3.2.3 Oregon Spotted Frog HSC

The following is a summary of Oregon spotted frog HSC development for use in the UDEA habitat model. HSC data for hydraulic-habitat modeling have not been previously established for Oregon spotted frog. Therefore, Category II HSC were developed through professional judgment, review of habitat use data collected by the U.S. Geological Survey (USGS) and USFWS for Oregon spotted frog in the upper Deschutes River, and from habitat use data for Oregon spotted frog from outside of the Deschutes Basin.

The study team collaborated with USGS, USFWS, and U.S. Forest Service (USFS) personnel with Oregon spotted frog expertise to develop the HSC. Habitat use data were taken from the literature and provided by USGS (Christopher Pearl, personal communication, January 13, 2016), and unpublished USFWS data (Jennifer O'Reilly, personal communication, February 3, 2016). Data sources for the HSC are outlined in Table 3-1. Tabular data and associated HSC curves for Oregon spotted frog overwintering and breeding habitat are provided in subsequent tables and graphs.

Table 3-1. Habitat suitability criteria development for Oregon spotted frog.

Life stage	Attribute	Data Source(s)	Rationale
Overwintering	Water Depth	Hallock and Pearson 2001; Pearl and Hayes 2004; Pearl et al. 2009	Water depths based on observed overwintering habitat use in the upper Deschutes River, use summarized in the literature, unpublished data, and professional judgment.
	Water Velocity	Pearl and Hayes 2004; Pearl et al. 2009	Water velocities based on observed overwintering habitat use in the upper Deschutes River, use summarized in the literature, unpublished data, and professional judgment.
	Substrate Composition (index)	Germaine and Cosentino 2004	Overwintering substrates based on literature, unpublished data, and professional judgment.
Breeding	Water Depth	Pearl and Hayes 2004; Pearl et al. 2009; USGS, personal communication, 1/13/16; USFWS unpublished data, 2/3/16	Water depths based on breeding habitat use in the upper Deschutes River, use summarized in the literature, unpublished data, and professional judgment.
	Water Velocity	Pearl et al. 2009; USGS, personal communication, 1/13/16	Water velocities based on observed over-wintering habitat use in the upper Deschutes River, unpublished data, and professional judgment.
	Substrate Composition (index)	Pearl and Hayes 2004; Pearl et al. 2009; USGS, personal communication, 1/13/16	Breeding site substrates based on literature, unpublished data, and professional judgment.
	Proximity Analysis (Distance to Edge of Water - post-process attribute in ArcGIS)	Pearl et al. 2009; USGS personal communication, 2/1/17	Breeding site characteristic based on literature, unpublished data, and professional judgment. Values potential breeding habitats based on distance to the waterbody's wetted edge.

Table 3-2. Oregon spotted frog overwintering habitat depth HSC.

Water Depth (inches)	Water Depth (cm)	Suitability Index	Water Depth (inches)	Water Depth (cm)	Suitability Index
0.0	0.0	0.0	16.0	40.6	0.5
2.0	5.1	0.1	18.0	45.7	1.0
4.0	10.2	0.1	24.0	61.0	1.0
6.0	15.2	0.2	25.0	63.5	1.0
8.0	20.3	0.3	48.0	121.9	1.0
10.0	25.4	0.4	60.0	152.4	0.5
12.0	30.5	0.5	65.0	165.1	0.0
14.0	35.6	0.5			

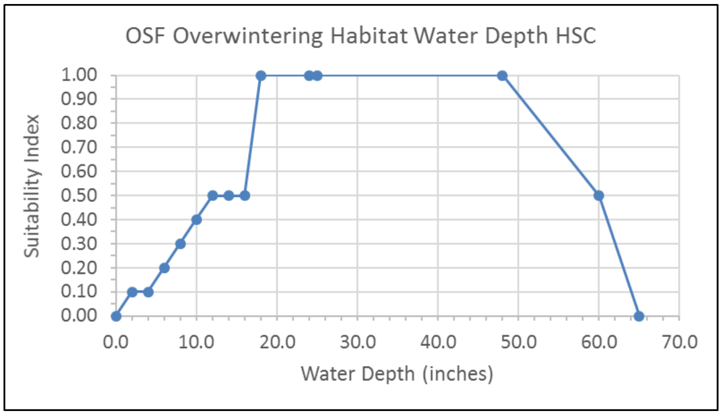

Figure 3-2. Oregon spotted frog overwintering habitat water depth HSC curve.

Table 3-3. Oregon spotted frog overwintering habitat water velocity HSC.

Velocity (fps)	Velocity (mps)	Suitability Index
0.00	0.00	1.0
0.10	0.03	1.0
0.20	0.06	1.0
0.50	0.15	1.0
1.00	0.31	0.5
1.50	0.46	0.2
2.00	0.61	0.2
2.25	0.69	0.0

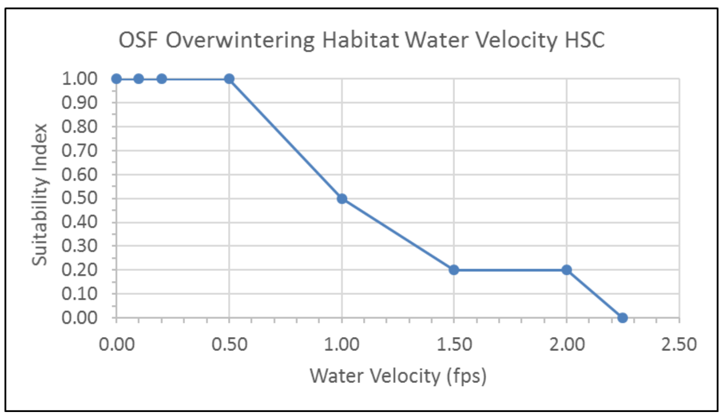

Figure 3-3. OSF overwintering habitat water velocity HSC curve.

Table 3-4. Oregon spotted frog over-wintering habitat substrate HSC.

Qualifier	Code	Suitability Index
Mud	1	0.8
Sand	2	0.2
Small Gravel	3	0.1
Large Gravel	4	0.0
Hardpan	5	0.0
Vegetation	6	1.0

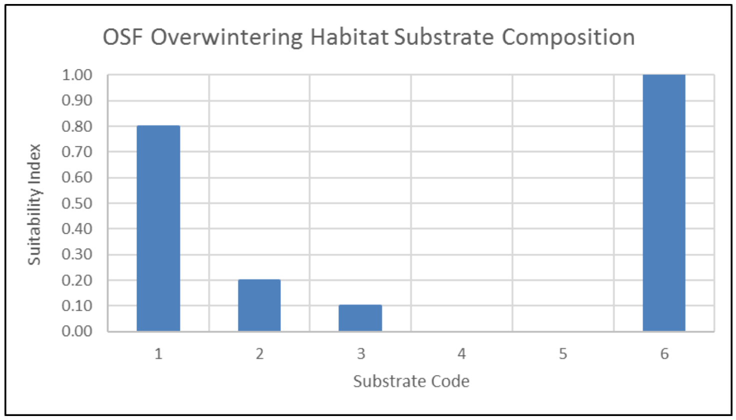

Figure 3-4. OSF overwintering habitat substrate HSC curve.

Table 3-5. Oregon spotted frog breeding habitat depth HSC.

Water Depth (inches)	Water Depth (cm)	Suitability Index	Water Depth (inches)	Water Depth (cm)	Suitability Index
0.0	0.0	0.0	10.0	25.4	0.8
2.0	5.1	0.5	12.0	30.5	0.5
3.0	7.6	0.8	13.0	33.0	0.5
4.0	10.2	1.0	14.0	35.6	0.5
6.0	15.2	1.0	16.0	40.6	0.1
8.0	20.3	1.0	18.0	45.7	0.0
9.0	22.9	1.0	24.0	61.0	0.0

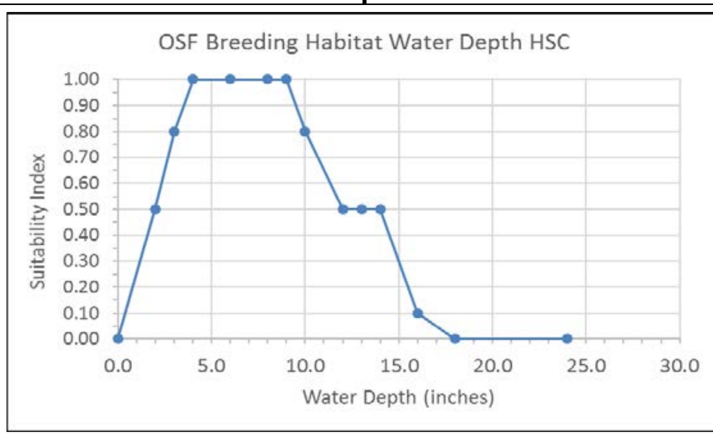

Figure 3-5. Oregon spotted frog breeding habitat water depth HSC curve.

Table 3-6. Oregon spotted frog breeding habitat water velocity HSC.

Velocity (fps)	Velocity (mps)	Suitability Index
0.00	0.00	1.0
0.10	0.03	0.5
0.20	0.06	0.0
0.50	0.15	0.0
1.00	0.31	0.0

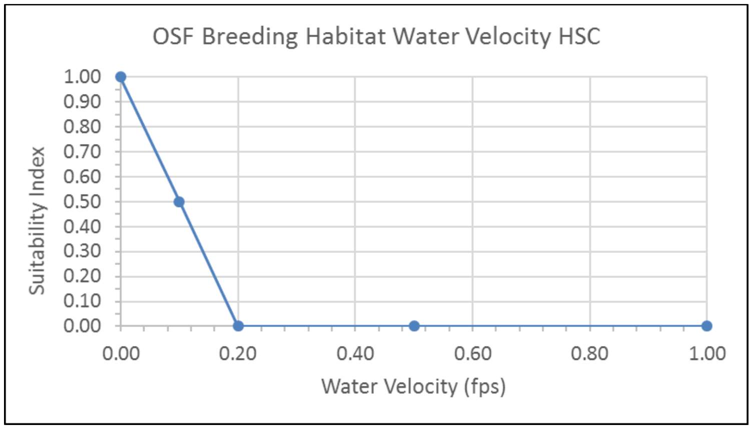

Figure 3-6. OSF breeding habitat water velocity HSC curve.

Table 3-7. Oregon spotted frog breeding habitat substrate HSC.

Qualifier	Code	Suitability Index
Mud	1	0.1
Sand	2	0.1
Small Gravel	3	0.1
Large Gravel	4	0.0
Hardpan	5	0.1
Vegetation	6	1.0

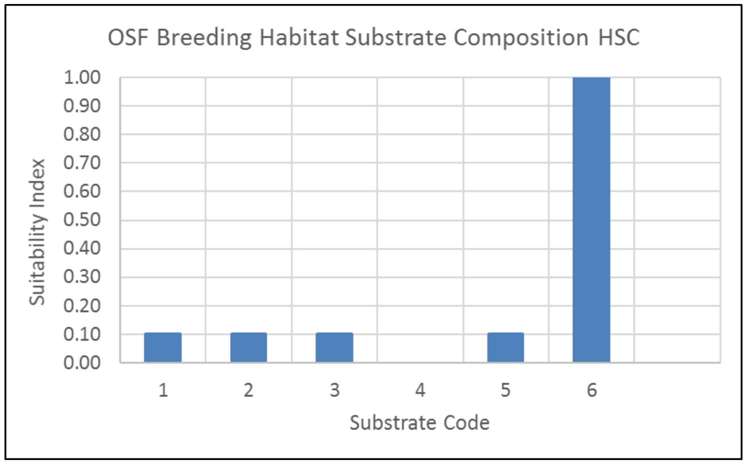

Figure 3-7. OSF breeding habitat substrate HSC curve.

Table 3-8. Oregon spotted frog breeding habitat distance to edge of water HSC.

Distance to Edge of Water (meters)	Code	Suitability Index
<2m	1	1.0
2-5m	2	0.8
5-10m	3	0.5
>10m	4	0.3

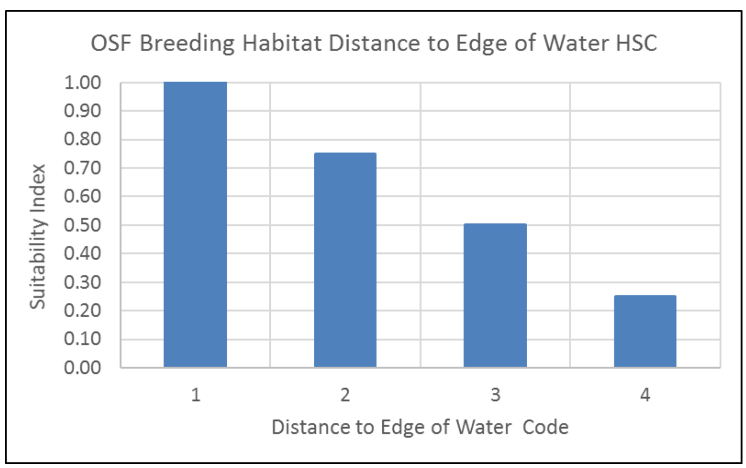

Figure 3-8. OSF breeding habitat distance to edge of water HSC curve.

In addition to the habitat variables included in the HSC, there are other habitat associations that may also be important for Oregon spotted frog overwintering and breeding site selection. Other variables that may be important, but will not be included in the habitat modeling include water temperature (Bowerman and Pearl 2010), dissolved oxygen, overhead cover, aspect (Pearl et al. 2009), distance between overwintering and breeding sites, predatory fish and bullfrog presence, and groundwater spring sources (Pearl and Hayes 2004; Chelgren et al. 2008).

3.2.4 Redband Trout Life History and Habitat Information

In addition to bull trout (*Salvelinus confluentus*) and mountain whitefish (*Prosopium williamsoni*) redband trout is one of the three salmonids native to the upper Deschutes River. Redband trout are a subspecies of rainbow trout and steelhead and are adapted to the arid conditions of the Great Basin (Fies et al. 1996). Redband trout spawn in rivers and streams during the spring, selecting cool, clean, well-oxygenated water for spawning nest (i.e., redd) locations. Fry emerge from the spawning gravels between June and July and rear near the spawning location. Redband trout mature at 3 years and few redband trout exceed 10 inches in length. Habitat productivity influences fish size and age at maturity.

Historical accounts of redband trout abundance is mainly anecdotal, but stories suggest redband trout were widely distributed and highly abundant in high quality habitats in the upper Deschutes River (Starcevich et al. 2015). Early accounts by settlers in the Bend area attest to sizeable redband trout populations (references in Fies et al. 1996).

Habitat characteristics that influence redband trout include the presence of woody debris and vegetation for cover, cool clean water and exposed gravels for spawning, and channel margin and off-channel areas for larval and juvenile rearing. In the upper Deschutes River, redband trout have been affected by dam construction and water management, diversion dams and unscreened diversion intakes, riparian vegetation conversion by residential and agricultural development, and river corridor alterations such as streambank armoring and channel straightening. Introduced fish species also impact redband trout through predation, competition, and hybridization.

3.2.5 Redband Trout Habitat Suitability Criteria

The study team developed depth, velocity, and cover HSC data for redband trout adult holding habitat by referencing several existing HSC data sets. Applied data and curves include:

- Category III data sets from the Upper Klamath Basin, Oregon (TRPA 2004). The upper Klamath Basin data set was specifically developed for redband trout.
- Upper Klamath HSC velocity data greater than 2.25 fps were replaced with category I HSC data recently developed for the Tumalo Creek redband trout instream flow study (HDR 2012). The Tumalo Creek HSC were developed using USFS redband trout observations and various existing HSC and literature data sources.

A HSC development table is included in Table 3-9. Tabular data and associated curves for redband trout adult holding habitat are provided in subsequent tables.

Table 3-9. Habitat suitability criteria development for redband trout adult holding.

Life stage	Attribute	Data Sources	Rational
Adult Holding	Depth	Upper Klamath River redband trout curve	Of the available regionally relevant HSC, the Upper Klamath Category III data represent a nearby river system which is similar in elevation and stream characteristics. Depths shifted right which typifies habitat utilization in a large river system. Depths greater than 4 feet not limiting.
	Velocity	Upper Klamath River redband trout curve and Tumalo Creek redband trout curve	Of the available regionally relevant HSC, the Upper Klamath Category III data represent a nearby river system which is similar in elevation and stream characteristics. Velocity data exhibits central tendency when compared to other regional data sets. HSC data appropriate due to the low gradient character of the Deschutes River in study area. Per comments received by T. Hardin (ODFW 3/3/2016) velocities greater than 2.25 fps replaced by Tumalo Creek data. Various redband/rainbow HSC data sets exhibit higher suitability at higher velocities than the Klamath data set.
	Cover	Upper Klamath River redband trout curve	Applied from the observations on the Yuba River documented by USFWS (2008). Reviewed with T. Hardin (ODFW 3/3/2016).

Table 3-10. Redband trout adult holding habitat water depth HSC.

Water Depth (inches)	Water Depth (cm)	Suitability Index	Water Depth (inches)	Water Depth (cm)	Suitability Index
0.0	0.0	0.00	2.1	64.0	0.50
0.1	3.0	0.02	2.3	70.1	0.63
0.3	9.1	0.04	2.5	76.2	0.73
0.5	15.2	0.06	2.7	82.3	0.77
0.7	21.3	0.08	2.9	88.4	0.77
0.9	27.4	0.11	3.1	94.5	0.78
1.1	33.5	0.14	3.3	100.6	0.82
1.3	39.6	0.18	3.5	106.7	0.89
1.5	45.7	0.22	3.7	112.8	0.95
1.7	51.8	0.29	3.9	118.9	1.00
1.9	57.9	0.38	20.0	609.6	1.00

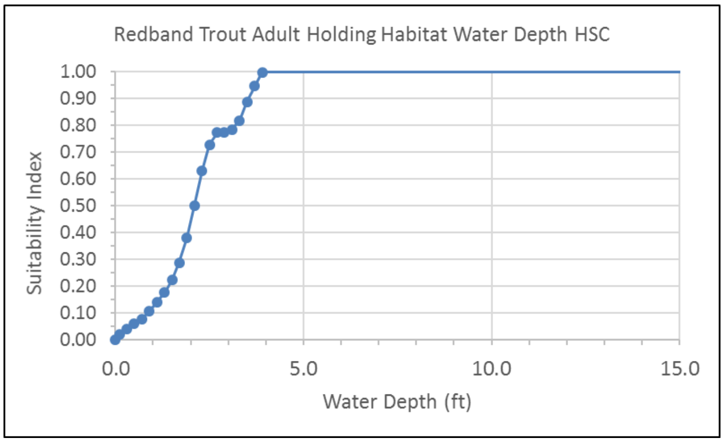

Figure 3-9. Redband trout adult holding habitat water depth HSC curve.

Table 3-11. Redband trout adult holding habitat water velocity HSC.

Water Velocity (fps)	Water Velocity (mps)	Suitability Index	Water Velocity (fps)	Water Velocity (mps)	Suitability Index
0.00	0.00	0.05	1.95	0.59	0.69
0.05	0.02	0.08	2.05	0.62	0.59
0.15	0.05	0.16	2.15	0.66	0.49
0.25	0.08	0.23	2.25	0.69	0.40
0.35	0.11	0.32	2.35	0.72	0.38
0.45	0.14	0.41	2.95	0.90	0.33
0.55	0.17	0.52	3.05	0.93	0.31
0.65	0.20	0.63	3.15	0.96	0.29
0.75	0.23	0.74	3.25	0.99	0.26
0.85	0.26	0.84	3.35	1.02	0.22
0.95	0.29	0.92	3.45	1.05	0.19
1.05	0.32	0.97	3.55	1.08	0.15
1.15	0.35	1.00	3.65	1.11	0.11
1.25	0.38	1.00	3.75	1.14	0.07
1.35	0.41	0.97	3.85	1.17	0.06
1.45	0.44	0.94	3.95	1.20	0.04
1.55	0.47	0.90	4.05	1.23	0.03
1.65	0.50	0.86	4.15	1.26	0.02
1.75	0.53	0.82	4.25	1.30	0.00
1.85	0.56	0.77			

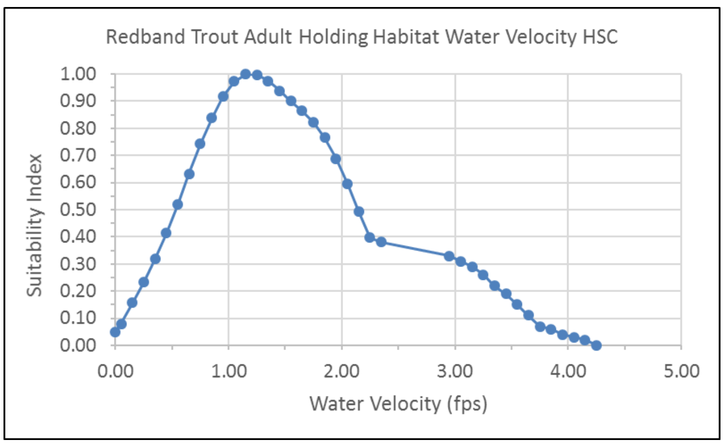

Figure 3-10. Redband trout adult holding habitat water velocity HSC curve.

Table 3-12. Redband trout adult holding habitat cover HSC.

Cover Type	Cover Code	Suitability Index
None	1	0.25
Cobble	2	0.25
Boulder	3	0.70
Riprap	4	0.25
Riparian Vegetation	5	1.00
Submerged Aquatic Vegetation	6	0.25
Stream Wood	7	1.00
Undercut Bank	8	1.00

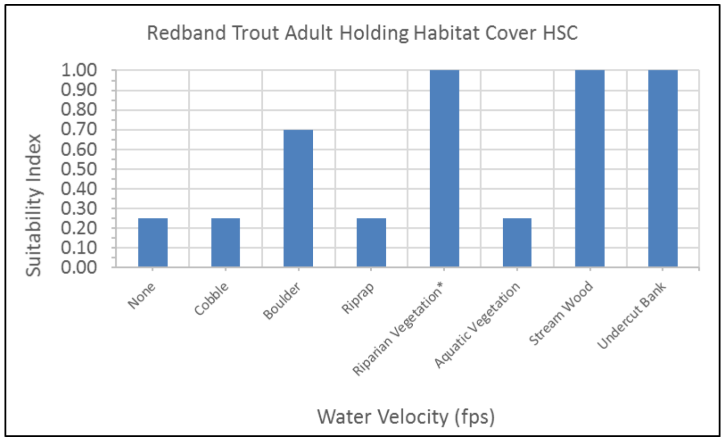

Figure 3-11. Redband trout adult holding habitat cover categories.

3.3 Data Collection

The following section provides an overview of the data collection effort. Data collection was necessary to develop the hydraulic model geometry and calibrate the hydraulic parameters in the model. The following section provides a summary of the topographic survey, substrate and cover mapping, hydraulic model calibration, and rating curve development.

3.3.1 Topographic Survey

Vertical and horizontal data were collected using a combination of Trimble R-8 and Trimble R-10 RTK base station/rover instruments and single-beam sonar. Horizontal and vertical accuracy of the survey instruments ranged from 0.03 m to 0.1 m depending on the instrument used and on satellite constellation and sky views. Single-beam sonar was used to survey the channel bed during high flows associated with the 2015 irrigation season. Supplemental channel bed surveys were completed by on-the-ground surveyors during low water. Upland topographic data were collected during all field surveys. Table 3-13 includes the field data collection schedule.

Table 3-13. Summary field data collection schedule.

Date	Activities
September 8-10, 2015	UAV aerial photos, pressure transducer install, flow measurements, survey
October 9, 2015	UAV aerial photos, pressure transducer download, survey, flow measurements, velocity calibration
November 3-5, 2015	Pressure transducer download, flow measurements, survey, cover/substrate mapping
March 30, 2016	UAV aerial photos

3.3.2 LiDAR Data Set

An existing LiDAR data set was used to characterize topographic surfaces above the water surface elevation at the time of the primary river survey (September 8-10, 2015). The LiDAR data were acquired the week of June 18, 2010 when the average daily streamflow measured at the Deschutes River Below Wickiup Reservoir near La Pine, OR (#14056500) gage was 1,350 cfs.

The project average LiDAR accuracy was 0.15 ft (0.04 m) and average ground laser point density was 0.23 points per square foot (2.5/m^2) (Watershed Sciences, Inc. 2011).

Study site topographic surface models were developed using both the LiDAR data set and topographic/bathymetric survey data collected from September through November 2015.

3.3.3 Substrate Mapping

Substrate mapping was completed using remote sensing and field methods. Remote sensing included using georeferenced aerial imagery acquired during field surveys using an unmanned aerial vehicle (UAV). Images collected during low, clear water conditions were effective for mapping substrate polygons. Hand-drawn substrate polygons were also prepared for the study sites in the field based on observed conditions. Polygons were geo-referenced in GIS for modeling purposes. Substrates were organized into five categories: mud, sand, gravel, hardpan, and emergent vegetation. Substrate gradation generally transitioned from finer particles in low velocity off-channel areas to coarser materials in the higher velocity mid-channel. Hardpan exposures were discrete features not necessarily associated with particular habitat units or velocities/stream power. Figure 3-12 includes the substrate maps for the two study sites. Substrates are similar in the two study sites although a sand/gravel substrate was mapped as the predominant substrate category in the Bull Bend study site. Substrate suitability index values differed by 0.1 (Sand = 0.2, Small Gravel = 0.1) for Oregon spotted frog overwintering habitat. Since sand and gravel were mapped in the primary channel where overwintering habitat suitability is otherwise low, differences in the mapped substrate categories has a negligible effect on Oregon spotted frog habitat suitability. Substrate is not included in the habitat suitability for redband trout.

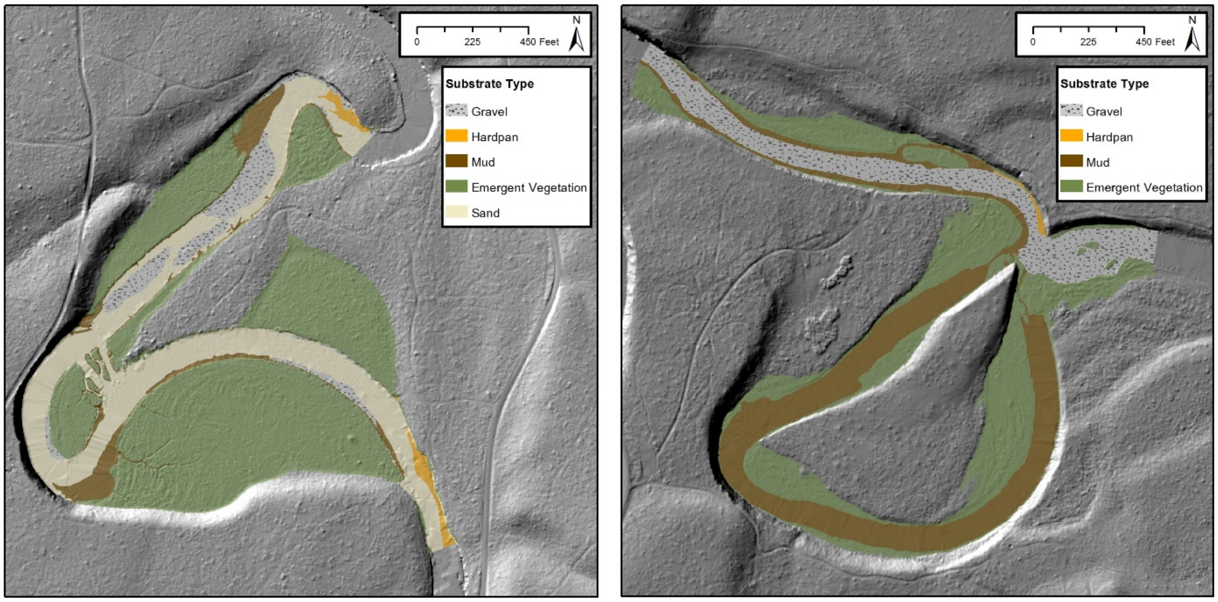

Figure 3-12. Substrate maps for Bull Bend (left) and Dead Slough (right).

3.3.4 Cover Mapping

Cover types were mapped following similar methods as the substrate mapping. Cover types included none, emergent vegetation, stream wood, undercut banks, and boulders. Stream wood included channel margin and mid-channel wood either as single pieces or complexes. Stream wood was hand-digitized from UAV aerial imagery. Remotely sensed and field mapped cover polygons were geo-referenced in GIS for modeling purposes.

Instream submerged aquatic vegetation changes seasonally from the winter to summer seasons in the upper Deschutes River. During the winter, submerged aquatic vegetation dies back, in part due to flow draw down for winter reservoir storage, and provides minimal aquatic habitat. From spring through summer, the submerged aquatic vegetation regrows and occupies a considerable portion of the wetted channel, providing cover and habitat for fish and other aquatic organisms (Figure 3-13). Figure 3-14 includes the cover maps for the two study sites that were used for habitat modeling. We selected channel conditions without aquatic vegetation as we'd expect habitat conditions for redband trout adult holding to be most limiting in the winter when submerged aquatic vegetation dies back.

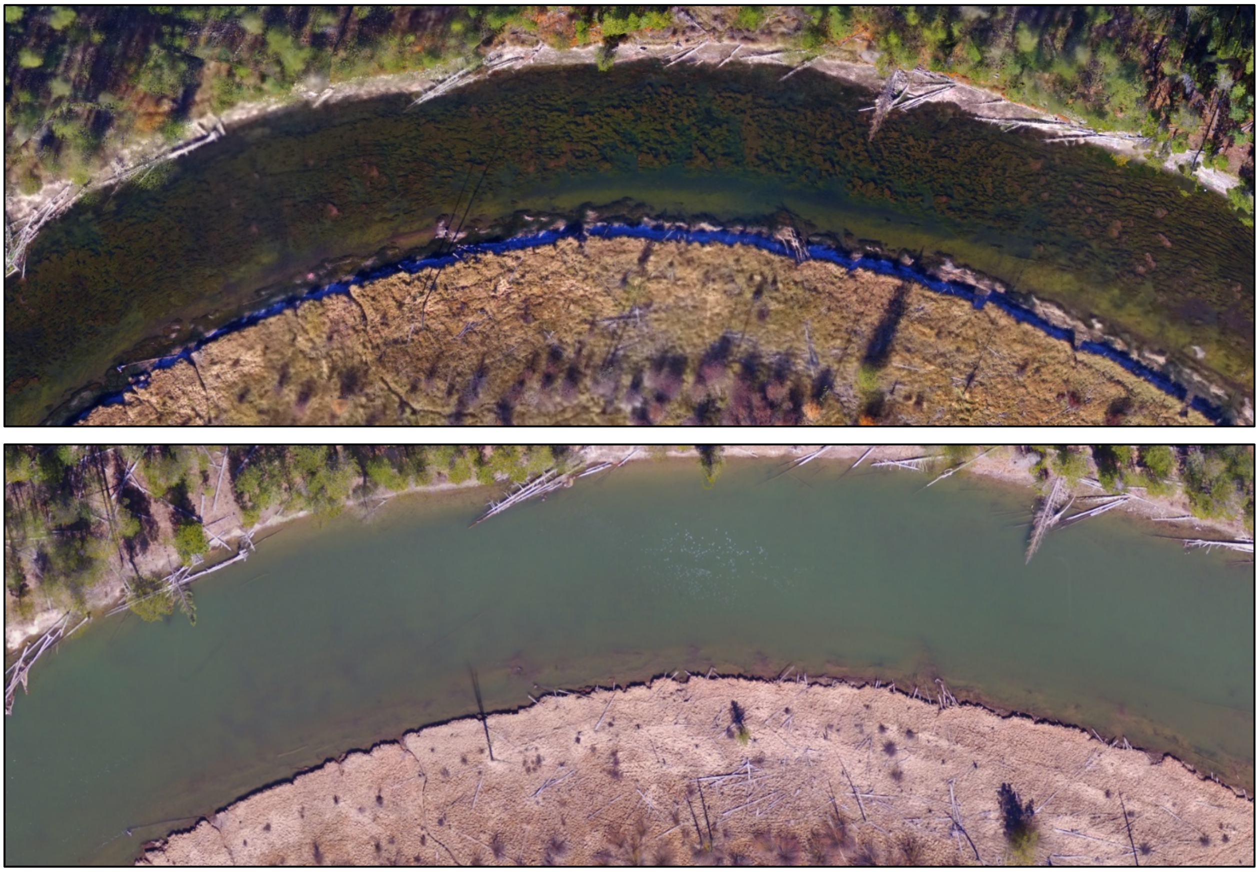

Figure 3-13. A comparison of channel conditions in November 2015 (top) and March 2016 (bottom) highlighting the presence of aquatic vegetation in the channel at the end of the growing season (November) and the end of winter (March).

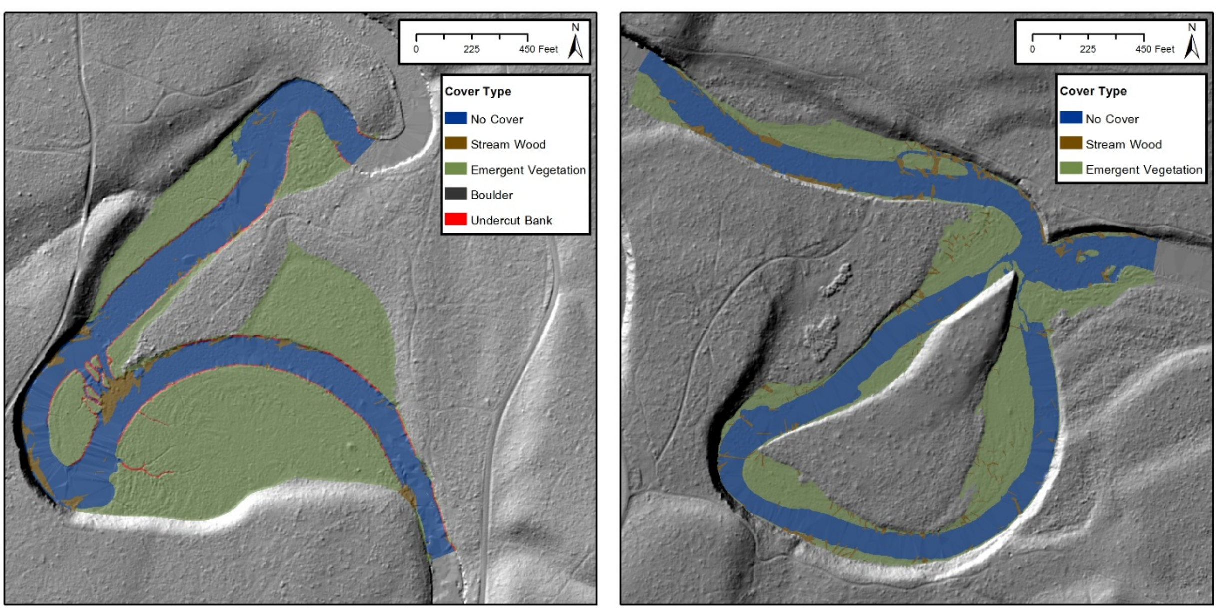

Figure 3-14. Cover maps for Bull Bend (left) and Dead Slough (right).

3.3.5 Hydraulic Calibration Data

For hydraulic model calibration purposes, field measurements of water surface elevation (WSE), water depth, and water velocity were recorded in each study site. Flow measurements were completed at the upstream and downstream extents of each study site to document flow entering and exiting the study sites. WSE, water depth, and water velocity were also measured along the longitudinal profile of each site. The number of calibration measurements varied by site depending on topographic habitat complexity and site length.

Figure 3-15 includes the location of flow measurement sections, pressure transducers, and velocity calibration points for the two study sites.

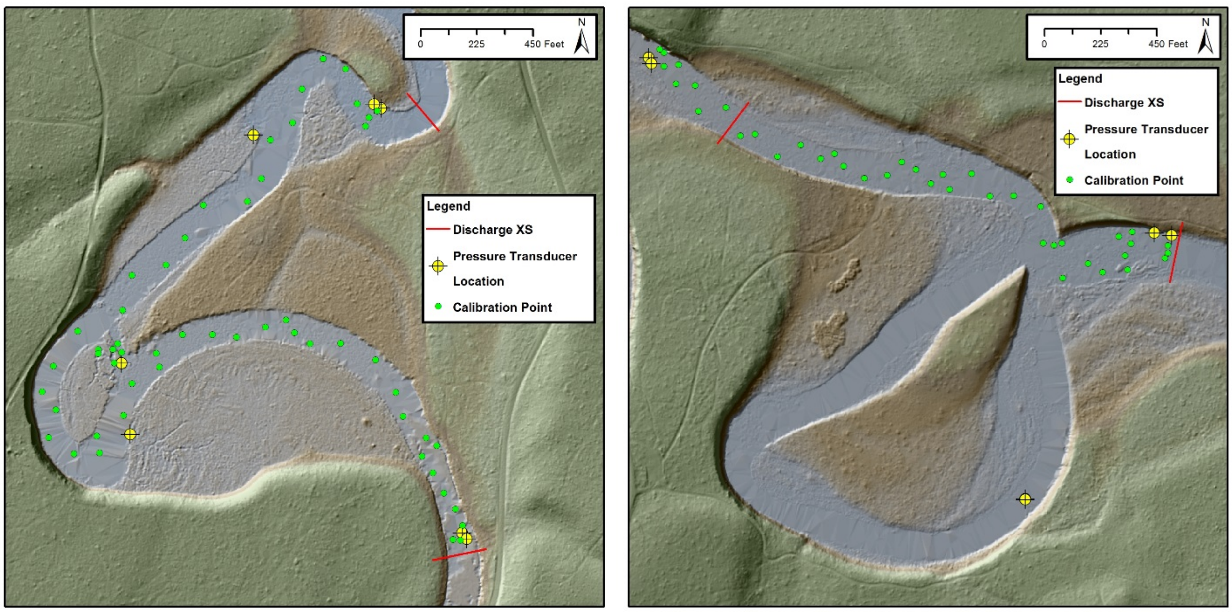

Figure 3-15. Hydraulic model calibration data points for Bull Bend (left) and Dead Slough (right). Calibration data included discharge measurement cross-sections, pressure transducer stage recorders, and velocity calibration point locations.

3.3.6 Rating Curve Development

Pressure transducers were deployed in each study site to record stage during the study. Pressure transducers were established at the upstream and downstream limits of the study sites as well as within the study sites. Within-study site pressure transducer locations were established to evaluate river stage in relation to off-channel habitat features of interest. To relate the measured river stage to discharge, water surface elevations adjacent to each pressure transducer were surveyed when stream flow was measured. The stage information recorded by each pressure transducer set at a 15 minute time interval, allowed for the development of critical model boundary stage-discharge relationships. Pressure transducers collected river stage data from September 9, 2015 to November 6, 2015. Recorded instantaneous flows during the pressure transducer deployment ranged from 22 cfs to 1,240 cfs at the OWRD-Deschutes below Wickiup gage.

One barometric pressure transducer deployed at the Bull Bend site and intended to provide atmospheric pressure correction for the river stage loggers, malfunctioned during operation. A local weather station operated by the Oregon Department of Transportation near La Pine (ODT62, US 97 MP 167) was used for atmospheric correction.

Rating curves for the two study sites are include in Figure 3-16. The stage-discharge rating curves relating modeled river stage and flow for Bull Bend (top) and Dead Slough (bottom) study sites. Measured stage-discharge calibration points are highlighted.

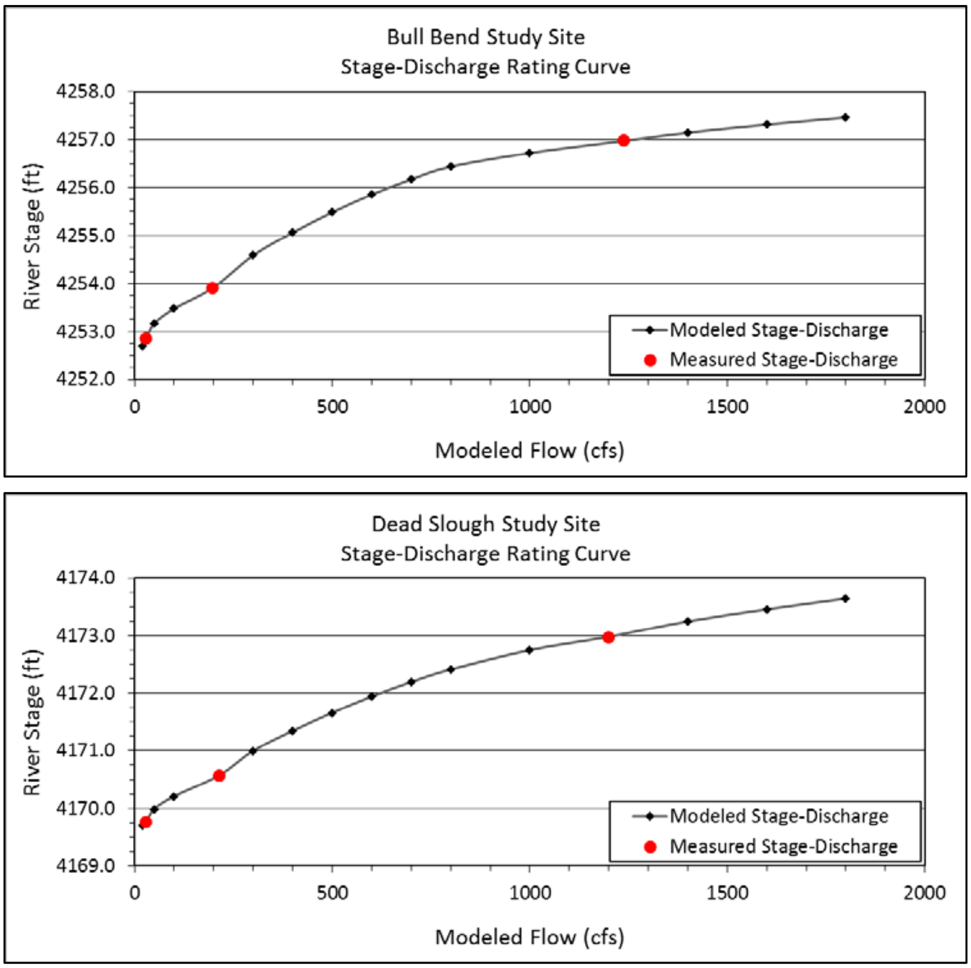

Figure 3-16. The stage-discharge rating curves relating modeled river stage and flow for Bull Bend (top) and Dead Slough (bottom) study sites. Measured stage-discharge calibration points are highlighted.

3.3.7 Miscellaneous Data Collection

Additional data were also collected during the field surveys to characterize river corridor habitat conditions. Additional data included the following information.

- UAV aerial photos during high and low flows.
- Ground photos during each site visit.
- Ground elevations associated with riparian vegetation communities.

3.3.8 Quality Control

To maintain spatial accuracy between different survey instruments and survey days, each survey was referenced to a common network of monuments located in each study site. Benchmarks were established in a projected geographic coordinate system using a survey grade static GNSS receiver that collected static positions for a minimum of 2 hours over each monument. The static data files were then processed using the Online Positioning User Service (OPUS).

3.4 Hydraulic Modeling

The following section provides a summary of hydraulic model development for the two study sites.

3.4.1 River2D Model Development

Hydraulic modeling for the two study sites was conducted using River2D (University of Alberta 2002). The River2D model uses the finite element method to solve the basic equations of vertically averaged 2D flow incorporating mass and momentum conservation in the two horizontal dimensions (Steffler and Blackburn 2002). The main input parameters for the River2D model include channel surface topography, bed roughness (in the form of an effective roughness height), and upstream and downstream hydraulic boundary conditions (i.e., water levels and discharge). Table 3-14 provides general model information for the two study sites.

Table 3-14. Deschutes River hydraulic model summary table.

Study Site	Number of topographic nodes	Average Data Density (pts/m^2)	Computational Mesh Nodes/ Elements	Model Domain Area (m^2)	Data Collection Methods
Bull Bend	293,295	0.61	45,102 / 89,300	180,140	RTK GPS, LiDAR
Dead Slough	190,034	0.86	45,441/ 89,924	220,786	RTK GPS, LiDAR

1. At flows less than 20 cfs, wetted area in model mesh refined.

Topographic surfaces were constructed by combining the RTK GPS and LiDAR data. Mesh development followed procedures outlined in the R2D_Mesh Users Manual, 2002 (Waddle and Steffler 2002). The minimum triangle quality index (QI) for each computational mesh ranged from 0.13 to 0.39. QI is a mesh quality index where a value of 1.0 represents a mesh comprised of perfect equilateral triangles. Low QI values (i.e., <0.10) does not necessarily compromise model quality, but will increase computational run times.

In addition to the QI index, two other mesh quality tools were employed. First, mesh-generated elevation contours were compared to bed elevation contours at an interval of 0.25-m with a goal of close contour approximation. Since the topographic points and mesh nodes are not in the same location, the contours will not be exactly the same. Therefore, to increase contour agreement, additional nodes were added in topographically complex areas. Second, large elevation differences between topographic data points and the interpolated elevation of each mesh triangle were identified and reviewed. Most often, large elevation differences exist in areas of high gradient (e.g., cascade) or significant localized topographic relief (e.g., cliff or vertical bank). Mesh triangles that exceeded a 0.25 m difference threshold were highlighted yellow in the mesh development software and further refined until the difference was no longer detected.

In general, one mesh representing the model domain was used for all simulation runs. However, it was necessary to make small changes if model run time errors (i.e., eddy shedding velocity oscillation, extremely high velocity or Froude number) occurred. To achieve the appropriate mesh density over all simulation flows, the single mesh was iteratively refined in the context of the full range of possible wetted area associated with lowest flow of 20.0 cfs (0.57 cms) to the highest flow of 1,800 cfs (50.97 cms). To ensure a balance between mesh density and computational burden, a procedure called 'wet refinement' which places nodes at the centroid of each mesh element, was used to ensure the appropriate mesh density in wetted areas only, while limiting mesh density in dry areas.

3.4.2 Model Calibration

Model parameters such as bed roughness (Ks, in the form of an effective roughness height), substrate transmissivity (tr) and eddy viscosity can be adjusted during model calibration to reflect field conditions. A stage-wise approach with target criteria for model performance was used to guide calibration. The specific stages and criteria are discussed below.

Bed Roughness (Ks) Calibration Procedures

The term Ks is scientific notation for bed roughness factor (in meters) and the term refers to gradation of material in the river. Compared to traditional one-dimensional models, where many two-dimensional effects are abstracted into the resistance factor, the 2D resistance term accounts only for the direct bed shear (Steffler and Blackburn 2002). Ks is iteratively varied as necessary to match observed water surface elevations using the default transmissivity of *tr* = 0.1. In general, the initial Ks value entered is 1-3 times the grain size documented during field data collection. A single optimal value of Ks (i.e., homogeneous substrate material) or multiple regional Ks values (i.e., heterogeneous substrate material and/or large elevation changes) may be selected for each study site based on the model performance results.

For each hydraulic model, initial hydraulic calibration tests were conducted using the survey calibration flow collected at each modeling site. Bed roughness was varied as necessary to match observed WSEs using the default transmissivity of *tr* = 0.1. In addition to the WSE comparisons, velocity and depth predictions were compared to field measured data to evaluate changes made to Ks.

Groundwater transmissivity (*tr*) is a user defined variable which corresponds to groundwater flow and the relationship to surface flow. The default value is 0.1 which ensures that ground water discharge is negligible. Unless subsurface flow is suspected at a study site, and inflow (Q_{in}) is greater than outflow discharge (Q_{out}), the default value of *tr* is usually suitable. The default value of *tr* was used in our study.

The target criterion for mean error in WSE between simulated versus observed data was 3.0 cm, or about 0.10 ft. The target criterion is, to a large extent, based on the accuracy of the RTK GPS equipment used to measure WSE.

No specific target criteria exist for velocity or depth parameters as these variables are greatly influenced by the differences in topographic detail between the field conditions, initial bed file detail, and the final bed detail resulting from the interpolated mesh. However, these variables are reviewed for reasonableness and significant errors in depth (i.e., > 0.10 m (0.33 ft) mean error) and velocity (i.e., >0.15 cm/s (0.5 fps) mean error) are evaluated. For all sets of model calibration variables, a correlation coefficient (*r*) was calculated and in general, coefficients greater than 0.7 were expected.

Lastly, model convergence for a given hydraulic simulation is achieved and accepted when the inflow equals outflow and the solution change is nominal. Solution change is the relative change in the solution variable over the last time step. Specific criteria thresholds do not exist for these parameters and are largely based on the magnitude of the simulation discharge and the professional judgment of the modeler. For the Deschutes River 2D hydraulic models, target criteria for the acceptable difference in Q_{in} versus Q_{out} was 2.0% or 2.0 cfs, whichever was less. The solution change goal was 0.00001, or less.

Simulation Outputs

For purposes of habitat modeling, a series of 16 flows ranging from 20.0 cfs (0.57 cms) through 1,800 cfs (50.97 cms) were modeled (Table 3-15).

Table 3-15. Modeled flows for the four habitat analyses completed for the study sites.

Modeled Flow (cfs)	Riparian Analysis	OSF Overwintering Habitat Analysis	OSF Breeding Habitat Analysis	Redband Trout Adult Holding Habitat Analysis
20		•	•	•
29		•	•	•
50		•	•	•
100		•	•	•
208		•	•	•
300		•	•	•
400		•	•	•
500		•	•	•
600		•	•	•
700		•	•	•
800	•	•	•	•
1,000	•	•	•	•
1,200	•		•	•
1,400	•		•	•
1,600	•			•
1,800	•			•

Dead Slough Inflow Supplementation

Spring inputs contribute a small volume of groundwater to the Dead Slough. To emulate observed water surface elevations in the Dead Slough, and observed Dead Slough-mainstem surface water connectivity, an additional flow input was added to the Dead Slough hydraulic model. The 5 cfs input entered the modeling domain in the Dead Slough and was included in modeling runs between 20 cfs and 400 cfs. After 400 cfs, modeled water surface elevations and Dead Slough-mainstem connectivity simulated observed conditions. Modeling run flows are name referenced by the upstream flow input (e.g., 200 cfs model run).

Assumptions and Limitations

Hydraulic computations in the River2D model include certain assumptions and limitations. Of these, the assumption that there is a constant water velocity over depth is perhaps the most important as it relates directly to the derivation of habitat suitability. In other words, the velocity predicted for a model node is a mean column velocity. This limitation is not generally significant if horizontal scales are greater than about 10 depths (Waddle 2012). Other assumptions built into the hydraulic computations in River2D include hydrostatic pressure distribution over depth and approximations of turbulent flow resistance. We also assumed 5 cfs enters the Dead Slough oxbow channel as this volume input improved the modeled water surface elevation relative to the field-observed water surface elevation in the Dead Slough.

3.5 Habitat Suitability Modeling

The following section highlights the methods used to calculate the weighted usable area.

3.5.1 Proximity Analysis

The proximity analysis was an ArcGIS-based analysis to assess potential Oregon spotted frog breeding habitat locations according to the habitat's distance from the edge of water. All other variables being equal, model nodes located closer to the edge of water at a given modeled flow were given a higher breeding habitat suitability score. The proximity analysis was post-processed in ArcGIS to evaluate node distance from the edge of water. The analysis was based on the Pearl et al. (2009) study that in part, quantified egg mass distances from the edge of water in a range of study sites in central Oregon. In the Pearl et al. (2009) study, the distance between oviposition sites and the edge of water averaged 4.1 m, with a median distance of 2.0 m, and a distance range of 0.08 m to 35.0 m. In the 2009 study, egg mass distance from the edge of water varied, although most masses tended to be close to the water's edge. Reasons for higher suitability nearer to the edge of water include closer proximity to hiding cover for breeding adults, presence of shallower and warmer water for more rapid egg development, fewer aquatic predators, and increased occurrence of vegetation which is important for maintaining egg mass location and providing cover. This analysis therefore increased the value of potential habitats near the edge of water and devalued habitats further from the wetted margin.

The workflow for the proximity analysis included five steps.

1. The water's edge geometry was exported for each modeled flow from River2D to ArcGIS.
2. Water surface extents for each modeled flow were buffered to individual distance category polygons in ArcGIS. Suitability values were then applied to distance category polygons. Table 3-16 includes the distance categories and associated suitability scores used in the proximity analysis.

Table 3-16. Distance categories and suitability index values.

Distance Category	Suitability Index
< 2m	1.0
2-5m	0.8
5-10m	0.5
>10m	0.3

3. The converted buffered polygon geometry was converted to raster grid cells in ArcGIS.
4. Combined suitability results (depth*velocity*substrate) were exported from River2D and converted to raster grids in ArcGIS. The combined suitability grids were then overlaid and multiplied by the proximity analysis suitability grids using raster math in ArcGIS to derive the overall combined suitability score.

3.5.2 Weighted Usable Area

Weighted usable area for Oregon spotted frog and redband trout was calculated for the two study sites at each simulation flow. WUA is calculated as the product of a combined suitability index at every node in the domain, and the area associated with each node. The composite suitability index requires four sets of pieces of data to be calculated, including a preference (i.e., HSC) file, a channel index, depth, and velocity.

Preference files contain suitability values (0.0 to 1.0) for velocities, depths, substrate, and cover. A preference file is loaded into River2D as a text file. A channel index file is defined over the entire mesh of each site. Channel index is a descriptive code for substrate and/or cover at each node. Depth and velocity values are provided from the hydraulic model once a simulation has converged and is at a steady state.

For this study, the WUA calculation used the triple product function which simply multiplies depth, velocity, and channel index together. Channel index interpolation was defined using discrete node selection (i.e., nearest node rather than a continuous linear interpolation of the channel index values from surrounding nodes). Discrete node selection is generally applied to substrate so the original substrate code value is maintained. Continuous interpolation may be applied to cover indices where a gradient of cover may be best described by the interpolation function. Table 3-17 below provides an example of how WUA was calculated for the habitat study sites. The depth suitability index (DSI), velocity suitability index (VSI), and the channel index suitability index (CiSI) are multiplied together to obtain a combined suitability index (CbSI). The combined suitability index was then multiplied by the proximity score (for Oregon spotted frog breeding habitat analysis only) to derive an overall combined suitability index that was then multiplied by the area represented by each node. The resulting nodal WUA (in square meters) is then summed to calculate the total site WUA.

Table 3-17. Example of a nodal attribute file showing habitat suitability and WUA results.

Node	x	y	Depth (m)	Velocity (mps)	Channel index	DSI	VSI	CiSI	CbSI	WUA (sq. m)
12781	1417565	234687.9	0.22	0.02	6	1	0.6708	1	0.6708	1.3172

Assumptions and Limitations

It is important to point out that the models were run to steady-state conditions, or in terms of flow and habitat, are ‘static’. Thus, predictions of habitat suitability across the spatial model domain at each simulated flow are a static depiction of what would otherwise be a dynamic environment.

3.6 Riparian Analysis

The study team was also tasked with completing a riparian analysis for the two study sites. The intent of the riparian analysis was to evaluate existing river interaction with riparian wetland vegetation (i.e., emergent vegetation such as slough sedge) adjacent to the channel, and to predict potential changes in emergent vegetation extents associated with a modified flow regime characterized by lower summer flows relative to existing summer flows.

The existing summer flow regime is characterized by high flows that exceed the likely historical summer flow condition. High summer flows have resulted in loss of channel margin emergent vegetation due to erosion and season-long inundation that exceeds emergent vegetation’s inundation tolerance. Loss of channel margin emergent vegetation has resulted in a bare draw down zone between approximately a half meter below the high summer flow and low winter storage flow water surface elevations. The bare draw down zone has poor habitat suitability and is susceptible to erosion. An example comparison of summer and winter flow conditions in the Dead Slough study site is provided in Figure 3-17.

Figure 3-17. Existing river corridor conditions in the Dead Slough inlet area during summer flows (left) and winter flows (right). Emergent vegetation extents are believed to be mainly controlled by high summer flows. The exposed draw down area provides poor breeding and overwintering habitat suitability.

As summer flows are believed to be the primary controlling factor influencing emergent vegetation coverage, lower summer flows are expected to result in emergent vegetation recruitment into the channel. Emergent vegetation recruitment would expand the amount of emergent vegetation available for Oregon spotted frog breeding habitat if breeding period flows exceed summer flows. For example, if summer flows are maintained at 1,000 cfs emergent vegetation would likely recruit from the existing vegetated floodplain margins, into the bare draw down zone (Figure 3-18). Flows above 1,000 cfs during the Oregon spotted frog breeding period would inundate recruited emergent vegetation, potentially increasing the amount of high quality breeding habitat available to Oregon spotted frog. Higher winter storage flows would further reduce the bare draw down area and reduce the distance between the emergent vegetation channel margin and the water's edge.

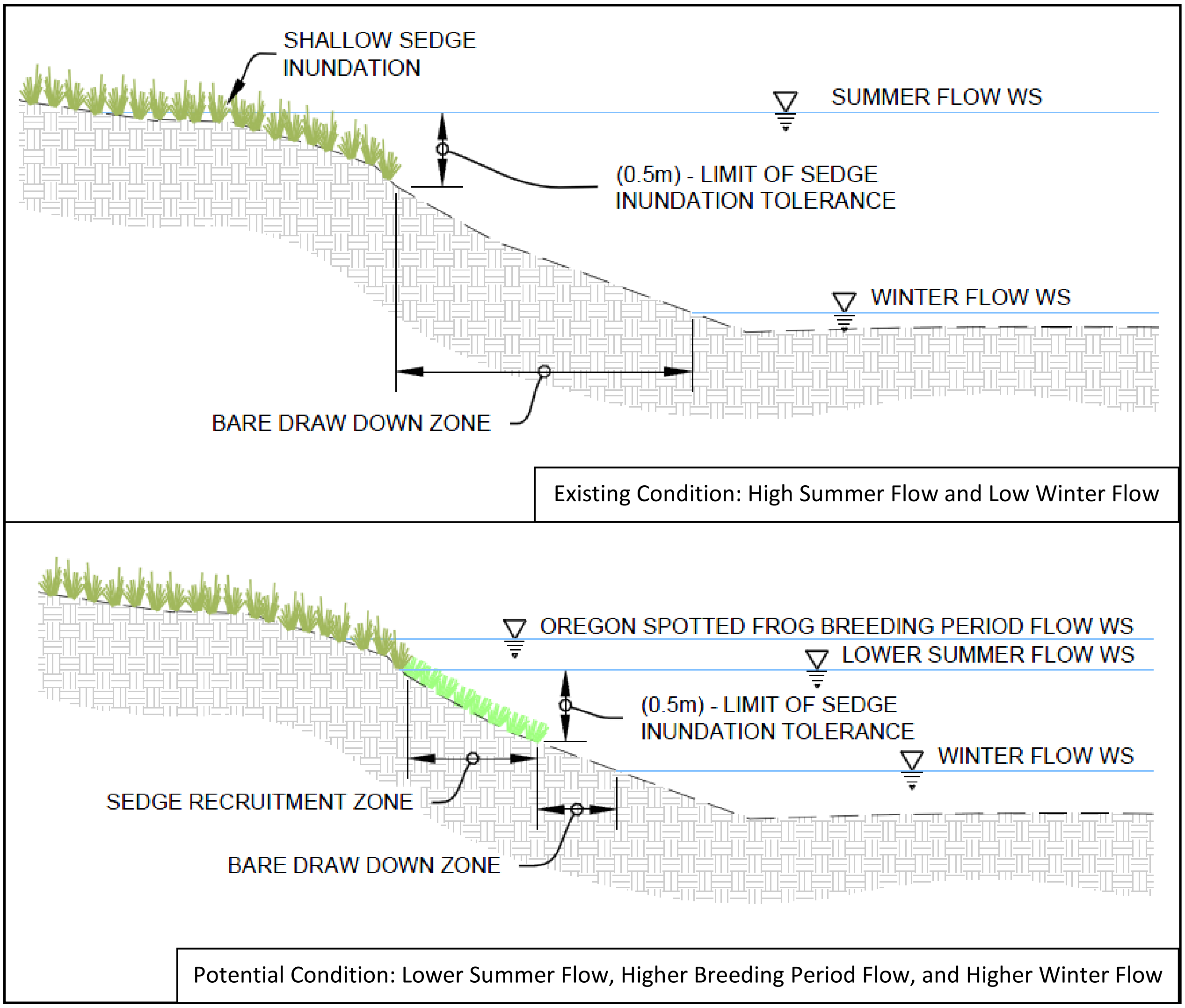

Figure 3-18. Schematic of existing condition emergent wetland sedge extents associated with existing high summer flow and low winter flows (top). A potential condition schematic includes emergent wetland sedge extents associated with lower summer flow, an Oregon spotted frog breeding period flow, and higher winter flow (bottom).

The riparian analysis included an existing condition and potential condition models. First, the existing condition model evaluated the emergent vegetation acreage that is inundated by flows ranging from 800 cfs to 1,800 cfs. We expected inundated emergent vegetation acreage to increase with increasing flows since emergent vegetation extents are limited by high flows.

Second, the potential condition model evaluated possible emergent vegetation recruitment with the assumption that the modeled flow was the only controlling factor of riparian wetland vegetation. We assumed that emergent vegetation would recruit into the channel to a depth of 0.5 m below the modeled water surface elevation. Anecdotal observations of slough sedge persistence on the upper Deschutes River suggest slough sedge can tolerate a 0.5 m inundation depth. Discussions with the Deschutes National Forest vegetation ecologist (Michael Simpson, personal communication, November 30, 2016) and observed inundation tolerance of other sedges (Anderson 2008) provide additional support for an approximate half meter of inundation tolerance for sedge during the growing season. In addition to inundation period, other factors that may affect emergent vegetation distribution in the upper Deschutes River include inundation period, substrate characteristics, and erosional processes. Potential emergent vegetation acreage presented for the analysis only includes potential emergent vegetation gains for an elevation half a meter below the modeled flow water surface elevation, up to the existing vegetated floodplain margin. We expected potential emergent vegetation acreage to be greatest since recruitment potential would be maximized at the lowest modeled flows, and least at the highest modeled flows which would be similar to the existing hydrologic condition. The calculations also do not include potential riparian wetland conversion at the riparian wetland-upland interface.

3.6.1 Surface Model Development

Hydraulic modeling results and GIS analysis determined that slough sedge extents at the study sites were associated with a WSE a half meter less than the 1,400 cfs flow WSE at Bull Bend, and a half meter less than the 1,800 cfs flow WSE at Dead Slough. Differences in riparian wetland vegetation extents at the two sites may be related to geomorphic or hydraulic characteristics unique to the sites. To simplify the analysis, the study team delineated the floodplain vegetated margin a half meter less than the 1,600 cfs flow WSE at both sites.

3.6.2 Hydraulic Modeling

Flows from 800 cfs to 1,800 cfs were modeled to evaluate inundation acreage of existing emergent vegetation. The same modeling results were then used to calculate the potential emergent vegetation recruitment by calculating the acreage between the existing vegetation margin and half a meter below the respective modeled water surface elevations.

4 Results

The following section provides a summary of the habitat study results.

4.1 Model Calibration

Initial hydraulic calibration tests were conducted using the data collected at each modeling site. Bed roughness was varied as necessary to match observed WSEs using the default transmissivity of tr = 0.1. In addition to the WSE comparisons, velocity and depth predictions were compared to field measured data to evaluate changes made to Ks. Final model parameters and calibration statistics for each study site are presented for Bull Bend and Dead Slough in Table 4-1 and Table 4-2, respectively.

Table 4-1. Summary of final hydraulic model parameter calibration statistics for the Bull Bend model. The in-channel roughness value (Ks) was modified for the high flow model (1,200 cfs to 1,800 cfs) to better match modeled and observed hydraulic parameters.

Inflow (Q_{in})[1]	Outflow (Q_{out})[2]	Statistics	WSE		Depth		Velocity	
cfs / cms	cfs / cms		Mean Error (Bias)	Absolute Mean Error	Mean Error (Bias)	Absolute Mean Error	Mean Error (Bias)	Absolute Mean Error
Bull Bend Study Site - Flows 20 cfs to 1,000 cfs - Ks=0.5, tr=0.1								
196.49 / 5.56	196.00 / 5.55	Mean Error (m)	0.018	0.028	-0.043	0.153	0.058	0.108
		Mean Error (cm)	1.8	2.837	-4.3	15.255	5.802	10.805
		Mean Error (ft)	0.059	0.093	-0.141	0.5	0.19	0.355
		Std Dev (m)	0.034	0.025	0.191	0.12	0.123	0.081
		Correlation (*r*)	0.9796		0.73		0.465	
Bull Bend Study Site - Flows 1,200 cfs to 1,800 cfs - Ks=0.25 channel, Ks=0.5 floodplain, tr=0.1								
1238.70 / 35.08	1237.99 / 35.056	Mean Error (m)	0.01	0.024	-0.165	0.194	0.085	0.14
		Mean Error (cm)	0.969	2.4	-16.461	19.36	8.502	13.962
		Mean Error (ft)	0.032	0.079	-0.54	0.635	0.279	0.458
		Std Dev (m)	0.033	0.024	0.186	0.155	0.151	0.101
		Correlation (*r*)	0.981		0.920		0.510	

1. The parameter Qin is based on discharge measurements made in the field at each study site.
2. The parameter Qout is the discharge calculated at the downstream boundary of the model domain.

Table 4-2. Summary of final hydraulic model parameter calibration statistics for the Dead Slough model. The in-channel roughness value (Ks) was modified for the high flow model (1,200 cfs to 1,800 cfs) to better match modeled and observed hydraulic parameters.

Inflow (Q_{in})[1]	Outflow (Q_{out})[2]	Statistics	WSE		Depth		Velocity	
cfs / cms	cfs / cms		Mean Error (Bias)	Absolute Mean Error	Mean Error (Bias)	Absolute Mean Error	Mean Error (Bias)	Absolute Mean Error
Dead Slough Study Site - Flows 20 cfs to 1,000 cfs - Ks=0.5, tr=0.1								
213.23 / 6.04	213.67 / 6.05	Mean Error (m)	-0.004	0.011	0.056	0.085	0.029	0.087
		Mean Error (cm)	-0.352	1.083	5.570	8.466	2.862	8.664
		Mean Error (ft)	-0.012	0.036	0.183	0.278	0.094	0.284
		Std Dev	0.037	0.007	0.107	0.085	0.102	0.056

Table 4-2. Summary of final hydraulic model parameter calibration statistics for the Dead Slough model. The in-channel roughness value (Ks) was modified for the high flow model (1,200 cfs to 1,800 cfs) to better match modeled and observed hydraulic parameters.

Inflow (Q_{in})[1]	Outflow (Q_{out})[2]	Statistics	WSE		Depth		Velocity	
cfs / cms	cfs / cms		Mean Error (Bias)	Absolute Mean Error	Mean Error (Bias)	Absolute Mean Error	Mean Error (Bias)	Absolute Mean Error
		(m)						
		Correlation (*r*)	0.936		0.9600		0.929	
Dead Slough Study Site - Flows 1,200 cfs to 1,800 cfs - Ks=0.25 channel, Ks=0.5 floodplain, tr=0.1								
1200.00 / 33.98	1201.40 / 34.02	Mean Error (m)	0.014	0.030	0.051	0.048	0.076	0.142
		Mean Error (cm)	1.426	2.996	5.056	4.815	7.648	14.237
		Mean Error (ft)	0.047	0.098	0.166	0.158	0.251	0.467
		Std Dev (m)	0.073	0.026	0.187	0.183	0.219	0.127
		Correlation (*r*)	0.957		0.957		0.958	

1. The parameter Qin is based on discharge measurements made in the field at each study site.
2. The parameter Qout is the discharge calculated at the downstream boundary of the model domain.

There was only a moderate correlation between measured and modeled water velocities at the Bull Bend site. Velocity variability at the Bull Bend site was positively biased (0.28 ft per second mean error for high flow and 0.19 ft per second mean error at the mid-flow), meaning that in general, the model over-predicted velocity as compared to our field measurements. Additionally, our results show that as velocities increased, so too did error (both within each data set and between mid-flow and high flow). We attribute much of the positive bias in velocity to aquatic vegetation that was present in the primary channel during data collection. We note that aquatic vegetation, which was observed throughout the reach, slows water in the lower portion of the water column. The River2D model does not have a computational mechanism to adequately represent this effect. The primary calibration variable that does influence velocity is roughness (Ks). Raising roughness to slow water velocities has the added effect of raising the water surface elevation.

Figure 4-1 and Figure 4-2 include modeled water depths and velocities for the high calibration flow in the Bull Bend and Dead Slough study sites, respectively.

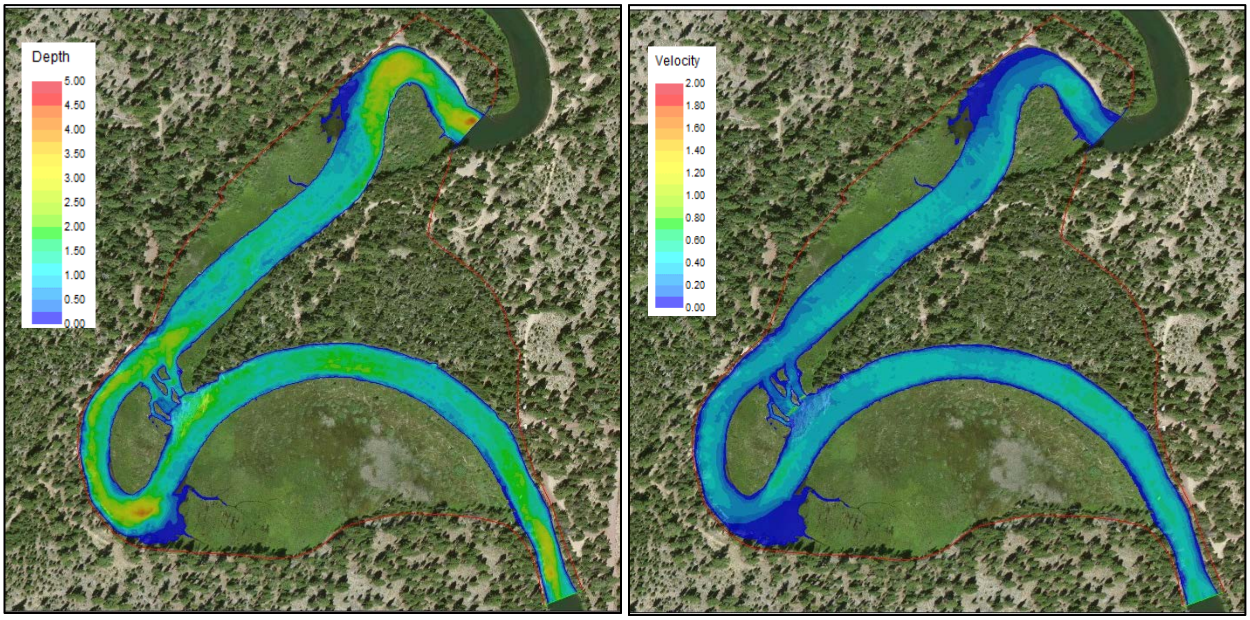

Figure 4-1. River2D depth (meters, left) and velocity (meters per second, right) output for the 1,239 cfs high calibration flow at Bull Bend.

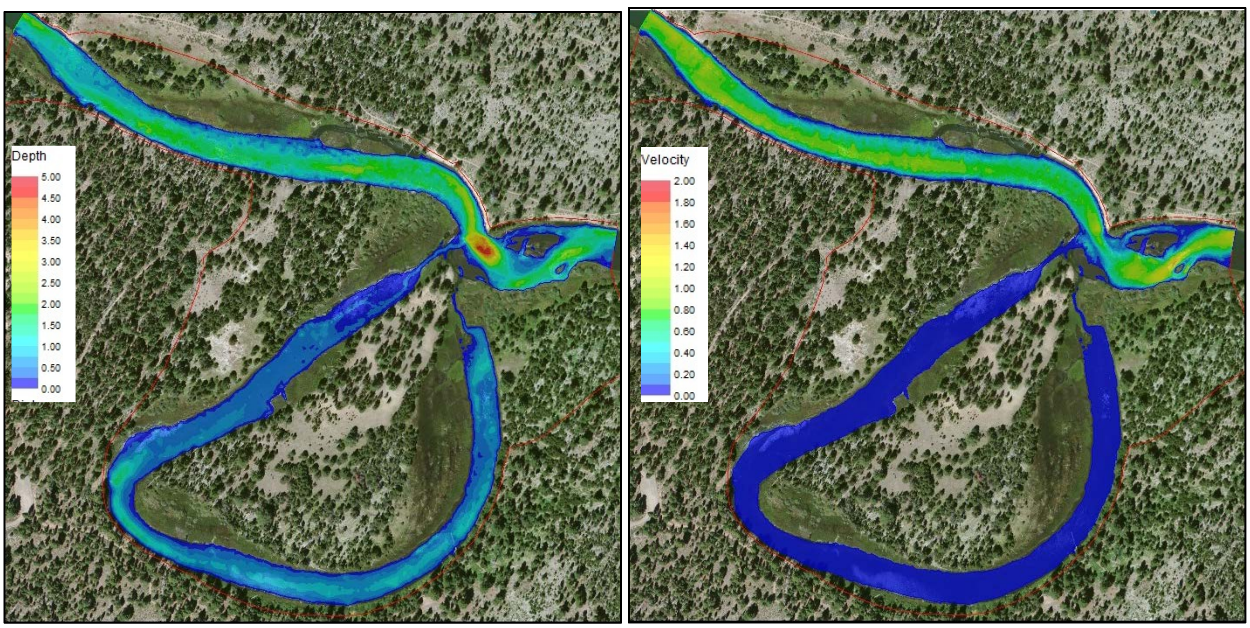

Figure 4-2. River2D depth (meters, left) and velocity (meters per second, right) output for the 1,200 cfs high calibration flow at Dead Slough.

4.2 Habitat Suitability

Habitat suitability was calculated for Oregon spotted frog and redband trout at each simulation discharge at the two study sites. To help illustrate the spatial distribution, dynamics and relationship to discharge, a description of habitat suitability over the range of modeled flows for Oregon spotted frog and redband trout is provided for each site. Additional suitability maps for the species and life stages are presented in Appendix A for Bull Bend and Appendix B for Dead Slough.

4.2.1 Bull Bend

The following section provides an overview of the Oregon spotted frog overwintering and breeding habitat suitability modeling, and redband trout holding habitat suitability modeling in the Bull Bend study site. Example maps are provided for the life stages of interest. Complete maps covering the extent of the habitat modeling are included in Appendix A.

Oregon Spotted Frog Overwintering Habitat

Water depth, velocity, and substrate were used to characterize Oregon spotted frog overwintering habitat suitability. The most suitable overwintering habitat in the Bull Bend study site relates to off-channel areas adjacent to the two tortuous meander bends in the reach (Figure 4-3). As flow increases, suitable overwintering areas expand to channel margins and the multi-thread neck cutoff. Loss of mainstem channel overwintering habitat coincides with expansion of off-channel overwintering habitats as floodplain depressions are inundated above 500 cfs. This trend continues to 600 cfs. Off-channel areas adjacent to the mainstem channel, and channel margins, increase in suitability with increasing flows.

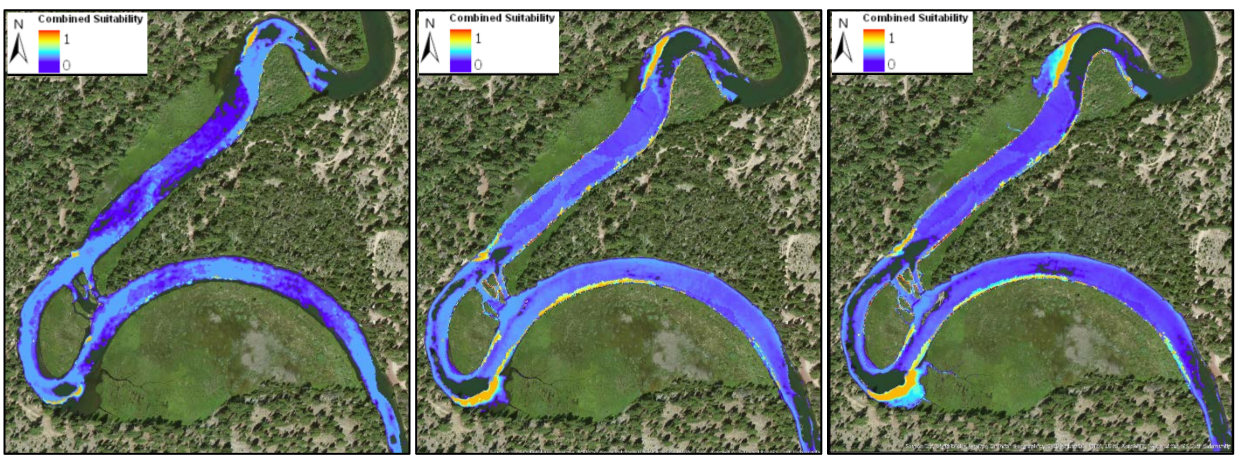

Figure 4-3. Oregon spotted frog overwintering habitat in the Bull Bend study site, from left to right: 20 cfs, 300 cfs, and 500 cfs.

The Bull Bend overwintering habitat WUA curve shows an increasing trend in habitat suitability until 300 cfs, and then a relatively consistent WUA value with increasing flows (Figure 4-4, Table 4-3). The consistent WUA value with increasing flows suggests that as more high quality overwintering habitat is created in small patches, larger areas of lower quality overwintering habitat degrades in suitability, or becomes unsuitable.

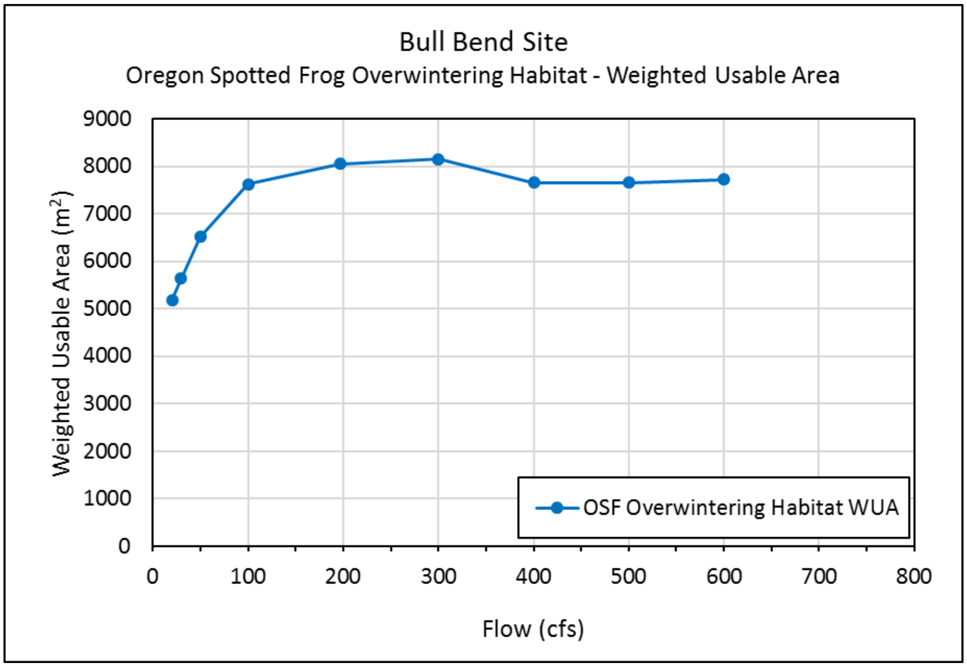

Figure 4-4. Oregon spotted frog overwintering habitat WUA in the Bull Bend study site. Overwintering habitat suitablity plateus at 200 cfs and then remains relatively conistent until 600 cfs.

Oregon Spotted Frog Breeding Habitat

Water depth, velocity, substrate, and distance to the edge of water were used to characterize Oregon spotted frog breeding habitat suitability. At low flows, marginal breeding habitat is located along the mainstem channel margins, while off-channel areas are generally too shallow to support breeding (Figure 4-5). Beginning at 300 cfs, off-channel areas provide low suitability breeding habitat. Channel margin areas in the straight reach and adjacent to the half moon-shaped floodplain provide a narrow strip of marginally suitable breeding habitat. Off-channel breeding suitability exhibits a moderate increase from 600 cfs to 800 cfs, where after breeding habitat suitability increases rapidly in response to riparian wetland inundation. Breeding habitat peaks at 1,200 cfs before declining at 1,400 cfs due to increasing depth in interior riparian wetlands.

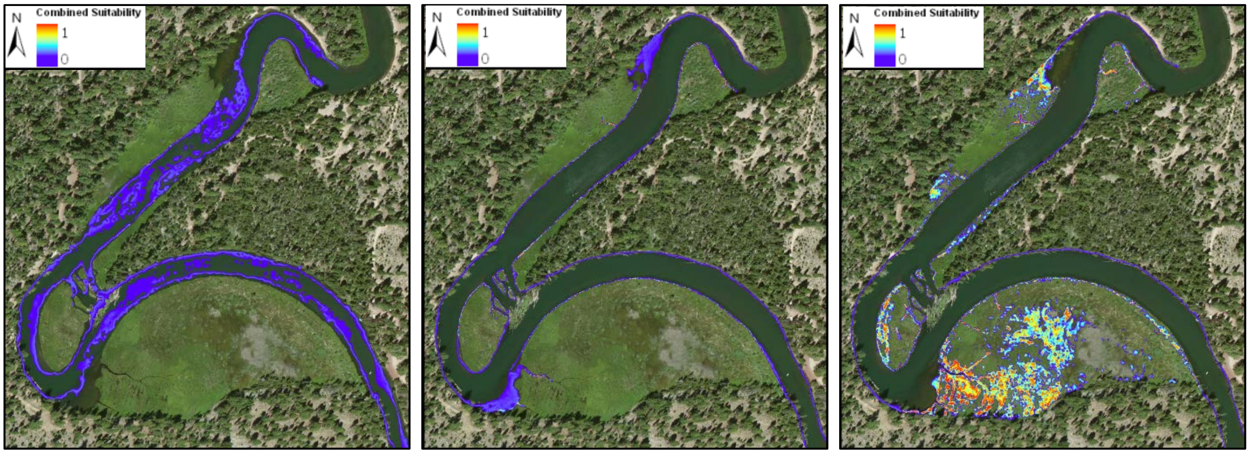

Figure 4-5. Oregon spotted frog breeding habitat in the Bull Bend study site, from left to right: 20 cfs, 400 cfs, and 1,000 cfs.

The Bull Bend breeding habitat WUA curve shows fairly consistent low breeding habitat suitability from 20 cfs to 400 cfs as breeding habitat suitability is affected by mud substrates and water depth (Figure 4-6). WUA values increase from 400 cfs to 800 cfs with a consistent slope as breeding habitat suitability gradually increases as vegetated channel margins are inundated. WUA rapidly increases from 800 cfs to 1,200 cfs as riparian wetland inundation expands into interior floodplain surfaces. WUA peaks at 1,200 cfs when the two largest riparian wetland areas are inundated.

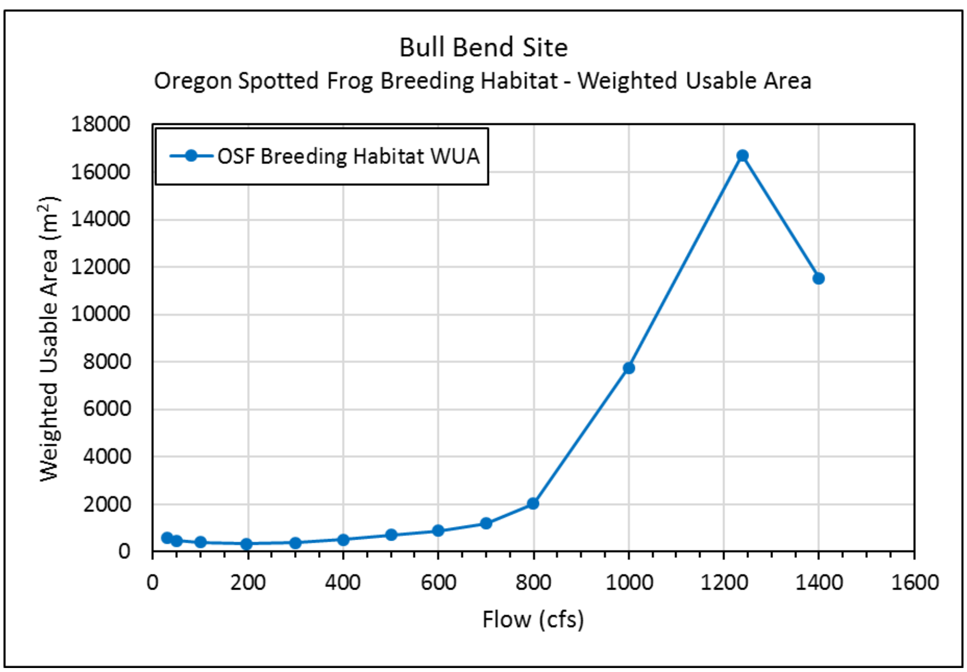

Figure 4-6. Oregon spotted frog breeding habitat WUA in the Bull Bend study site. Breeding habitat suitability is limited by mud substrates and distance to the edge of water at low flows. At increasing flows, vegetated floodplain margins are inundated and WUA values respond accordingly. At the highest modeled flows, shallow inundation of riparian wetland areas results in high WUA values. Increasing water depth in riparian wetland areas creates a reduction in WUA at 1,400 cfs.

Redband Trout Holding Habitat

Water depth, velocity, and cover were used to characterize redband trout holding habitat suitability. At low flows, there is marginal holding habitat in the mainstem channel due to shallow water depths (Figure 4-7). As river flows and stage increase, holding habitat suitability improves rapidly as velocity, depth, and river interaction with lateral habitat features increase. From 500 cfs to 1,000 cfs, holding habitat suitability continues to improve, but at a slower rate relative to the habitat suitability change between 20 cfs and 500 cfs. Suitability is consistent between 1,000 cfs and 1,400 cfs as holding habitat is increasingly focused on channel margin wood structures. Inundated floodplain surfaces provide expansive, low suitability holding habitat. Holding habitat suitability peaks at 1,800 cfs. Although there is high habitat suitability at large wood structures, suitability in the middle of the channel decreases due to increasing water velocities with increasing river stage.

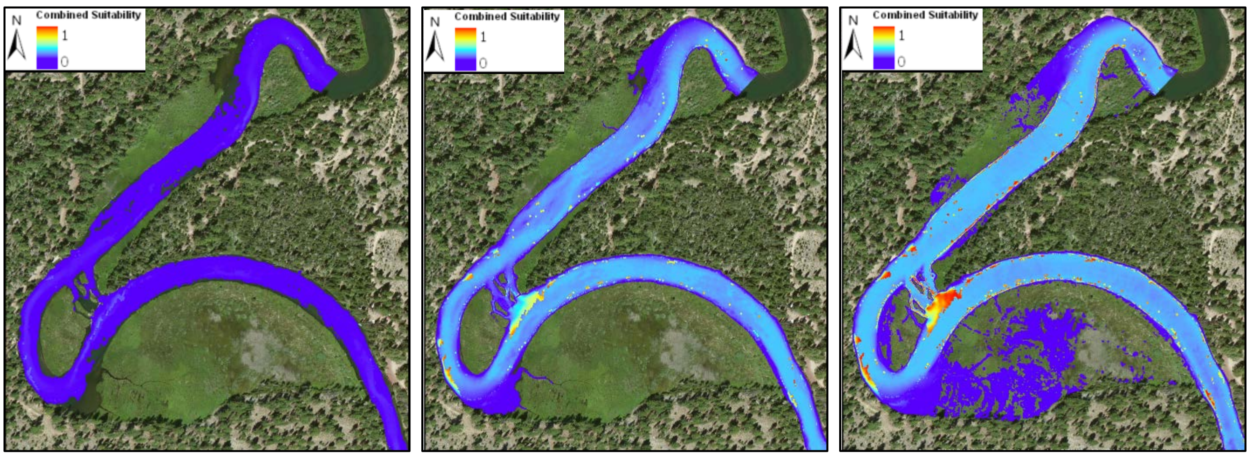

Figure 4-7. Redband trout holding habitat in the Bull Bend study site, from left to right: 20 cfs, 400 cfs, and 1,000 cfs.

The Bull Bend redband trout holding habitat WUA curve illustrates the effect of increasing flows on holding habitat from 20 cfs to 500 cfs (Figure 4-8). A steep rising trend in holding habitat quality is influenced by increasing water depths, moderate velocities, and river interaction with channel margin large wood, especially the large wood jam at the inlet to the multi-thread neck cutoff channel. WUA values flatten between 1,000 cfs and 1,400 cfs, but rise again as habitat suitability around large wood structures increases. Inundated floodplain surfaces minimally contribute to WUA values at the highest flows.

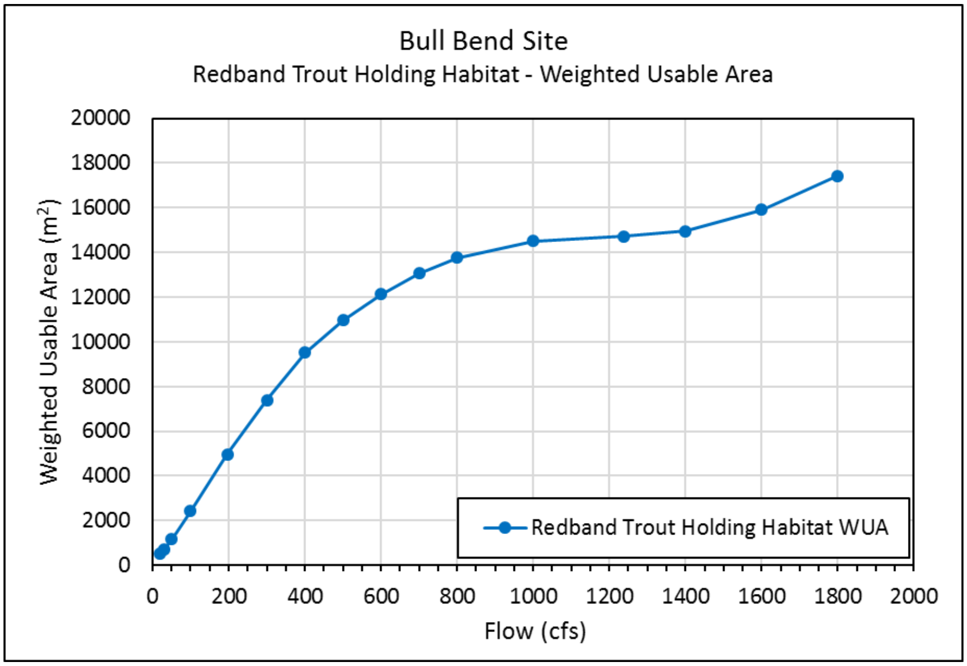

Figure 4-8. Redband trout holding habitat WUA in Bull Bend study site. Holding habitat suitability trends relate to inundation of channel margin large wood aggregations and depth-velocity relationships in the mainstem channel.

4.2.2 Dead Slough

The following section provides an overview of the Oregon spotted frog overwintering and breeding habitat suitability modeling, and redband trout holding habitat suitability modeling in the Dead Slough study site. Example maps are provided for the life stages of interest. Complete maps covering the extent of the habitat modeling are included in Appendix B.

Oregon Spotted Frog Overwintering Habitat

Water depth, velocity, and substrate were used to characterize Oregon spotted frog overwintering habitat suitability. The oxbow channel provides the most suitable overwintering habitat in the Dead Slough study site (Figure 4-9). As river flow increases, the stage in the oxbow channel increases while velocities remain low. Since velocities and the substrate in the oxbow channel remain similar over all flows, and water depth increases, overwintering habitat suitability increases with an increase in discharge at the Dead Slough site. Overwintering habitat is marginal in the mainstem channel at low and moderate flows. As water depth in off-channel areas and channel margins increases at higher stages, habitat suitability similarly increases. Water velocities at high flows limit the extent and suitability of mainstem overwintering habitat.

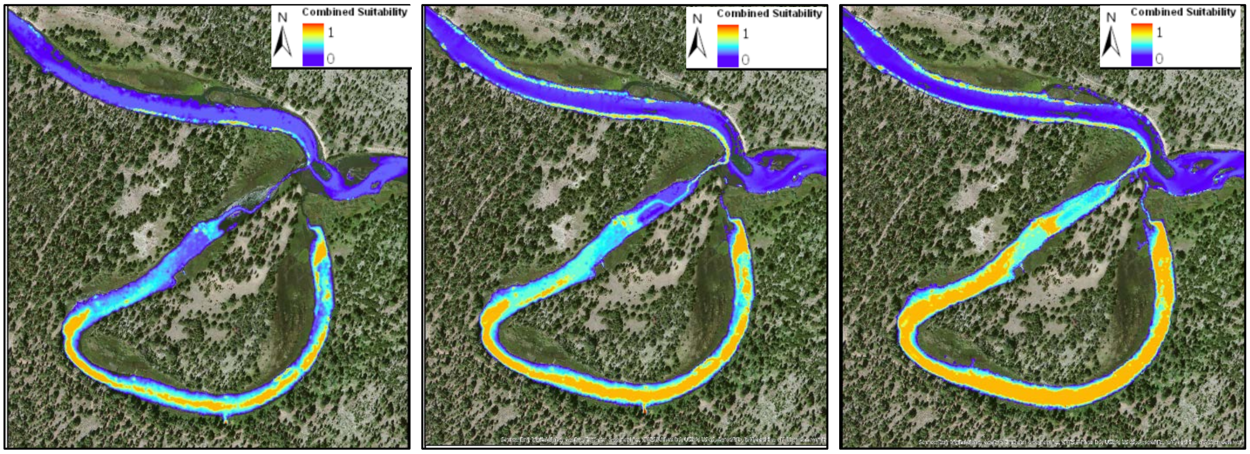

Figure 4-9. Oregon spotted frog overwintering habitat in the Dead Slough study site, from left to right: 20 cfs, 300 cfs, and 500 cfs.

The Dead Slough overwintering habitat WUA curve shows an increasing trend in habitat suitability until 400 cfs (Figure 4-10). The inflection in WUA values from 400 cfs to 500 cfs signifies the prominent connection of the mainstem channel and the oxbow channel, increasing the water surface elevation and water depth in the oxbow channel. WUA values continue to increase as suitable overwintering habitat is added along the mainstem channel margins and off-channel areas.

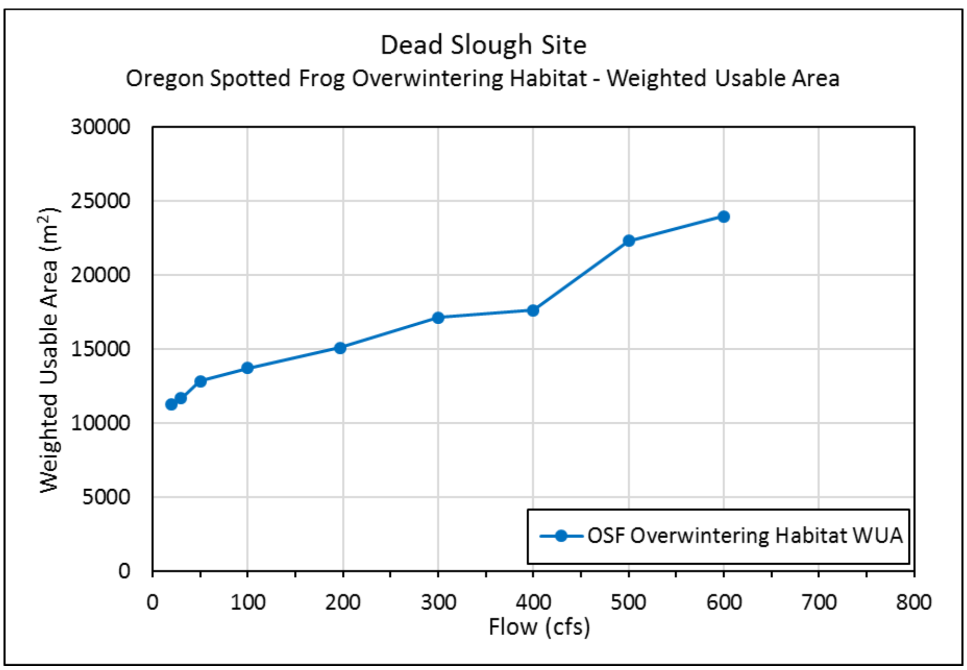

Figure 4-10. Oregon spotted frog overwintering habitat WUA in the Dead Slough study site. An inflection in the WUA values at 400 cfs signifies the prominent connection of the mainstem Deschutes River with the oxbow channel. The channel connection increases stage in the oxbow channel, enhancing overwinter habitat suitabilty.

Oregon Spotted Frog Breeding Habitat

Water depth, velocity, substrate, and distance to the edge of water were used to characterize Oregon spotted frog breeding habitat suitability. At low flows, marginal breeding habitat is located along the mainstem channel margins and in the oxbow channel (Figure 4-11). Breeding habitat quality at low flows is influenced by water depth, velocity, and substrate. Breeding habitat suitability in the oxbow channel at low flows is limited due to mud substrates which have low breeding habitat suitability.

Mainstem channel margin breeding habitat suitability is influenced by higher velocities at 300 fs. At increasing river flow, the channel margin breeding area contracts in response to increasing water velocities. Low velocity areas associated with channel margins and the oxbow channel become more prominent beginning at 300 cfs. At 600 cfs, breeding habitat suitability in the oxbow channel increases as surface water interacts with vegetated margins and riparian wetland depressions are inundated. Mid-channel areas of the oxbow channel that had low suitability at lower flows, become unsuitable due to water depth and distance from the wetted edge. Breeding habitat suitability increases with each successive flow as surface water increasingly inundates vegetated channel margins and interior floodplain habitats. The transition from inundated mud substrate to inundated vegetated substrates marks a substantial change in habitat suitability as the substrate score in the combined suitability analysis increases from 0.1 for mud to 1.0 for vegetation. Broad inundation of riparian wetland areas adjacent to the oxbow channel and the mainstem channel at 1,200 cfs and 1,400 cfs mark the peak of breeding habitat suitability in the Dead Slough study site.

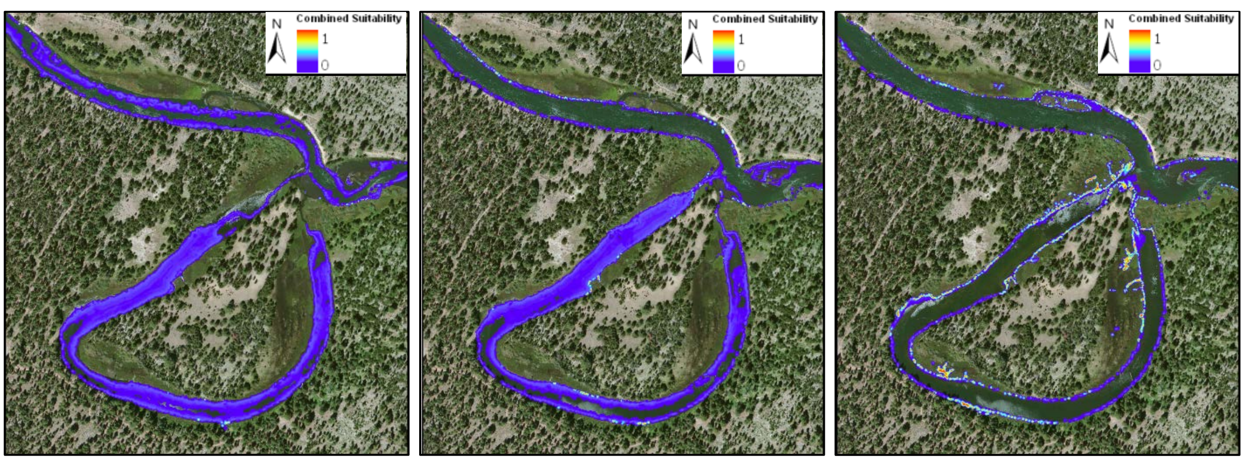

Figure 4-11. Oregon spotted frog breeding habitat Dead Slough study site, from left to right: 20 cfs, 400 cfs, and 1,000 cfs.

The Dead Slough breeding habitat WUA curve shows fairly consistent low breeding habitat suitability from 20 cfs to 300 cfs as breeding habitat scores are affected by mud substrates (Figure 4-12). WUA values increase from 400 cfs to 800 cfs with a consistent slope as breeding habitat suitability gradually increases as vegetated channel margins are inundated. WUA steadily increases from 800 cfs to 1,200 cfs as vegetated floodplain inundation expands from the channel margin to interior riparian wetland areas. WUA peaks at 1,400 cfs when nearly all vegetated floodplain extents are inundated.

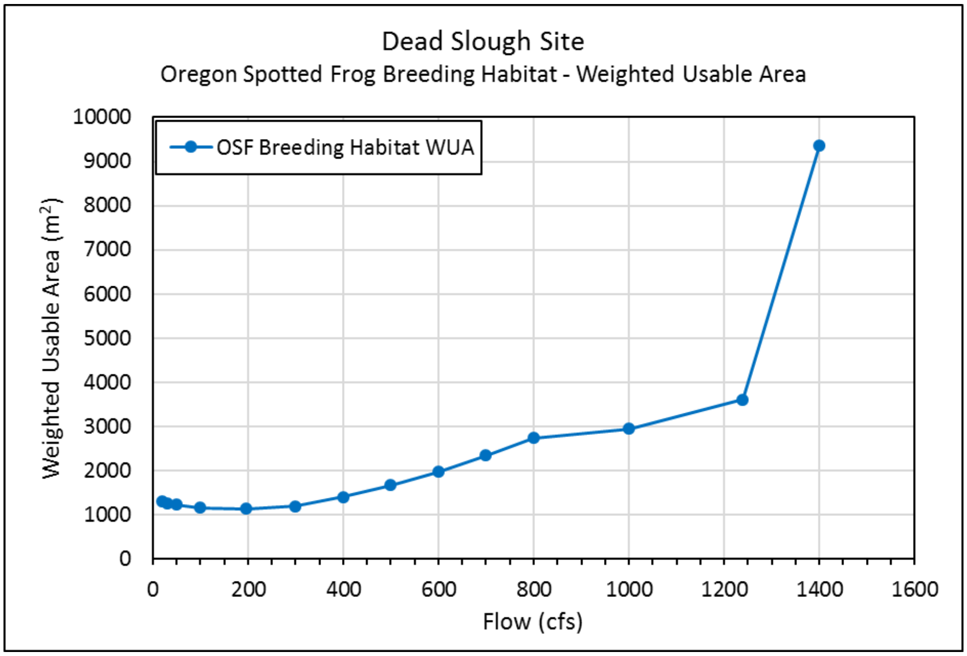

Figure 4-12. Oregon spotted frog breeding habitat WUA in the Dead Slough study site. Breeding habitat suitability is limited by mud substrates and distance to the edge of water at low flows. At increasing flows, vegetated floodplain margins are inundated and WUA values respond accordingly. At the highest modeled flows, shallow inundation of riparian wetland areas results in high WUA values.

Redband Trout Holding Habitat

Water depth, velocity, and cover were used to characterize redband trout holding habitat suitability. At low flows, there is marginal holding habitat in the mainstem channel due to shallow depths and in the oxbow channel due to low velocities (Figure 4-13). As river flows and stage increase, holding habitat suitability improves as velocity, depth, and river interaction with lateral habitat features increase. At flows above 400 cfs, there is increasing interaction between the river and cover features, mainly channel margin large wood. High quality holding habitat is limited to the mainstem channel and more specifically, habitats associated with channel margin wood. High velocities in the middle of the mainstem channel and near zero velocities in the oxbow channel, limit redband trout holding habitat extents in the Dead Slough study site.

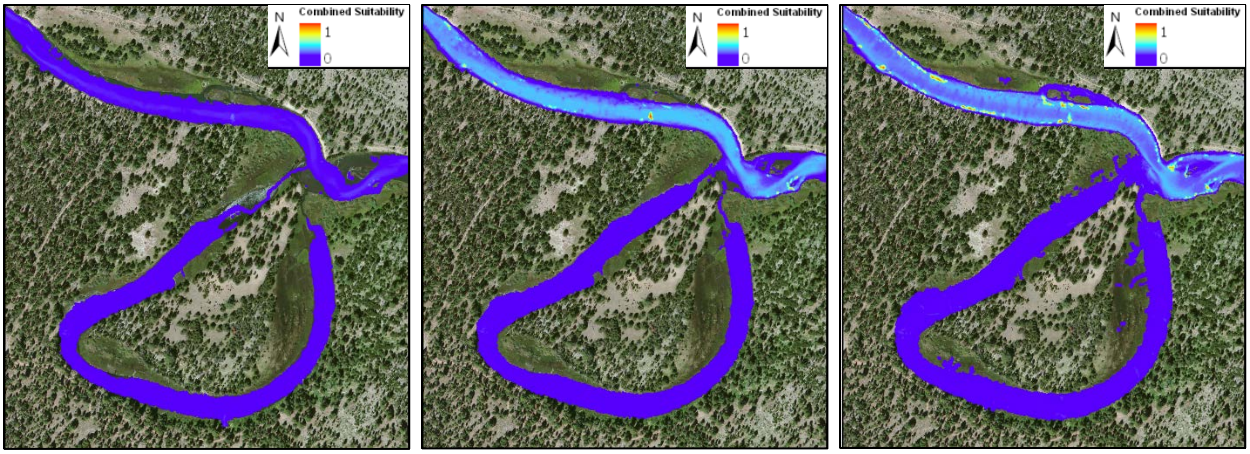

Figure 4-13. Redband trout holding habitat Dead Slough study site, from left to right: 20 cfs, 400 cfs, and 1,000 cfs.

The Dead Slough redband trout holding habitat WUA curve illustrates the effect of increasing flows on holding habitat from 20 cfs to 600 cfs. A steep rising trend in holding habitat quality is influence by increasing water depths, moderate velocities, and river interaction with channel margin large wood (Figure 4-14). Holding habitat suitability remains fairly consistent from 600 cfs through 1,800 cfs. Holding habitat suitability decreases in the mid-channel area due to high velocities, but incrases along the channel margins as large wood is increasingly inundated. The loss of broad, lower quality mid-channel habitats is off-set by increases of more spatially limited high quality habitat associated with channel margin areas. Low holding habitat suitabilty in the slough provides a minimal contribution to the overall WUA.

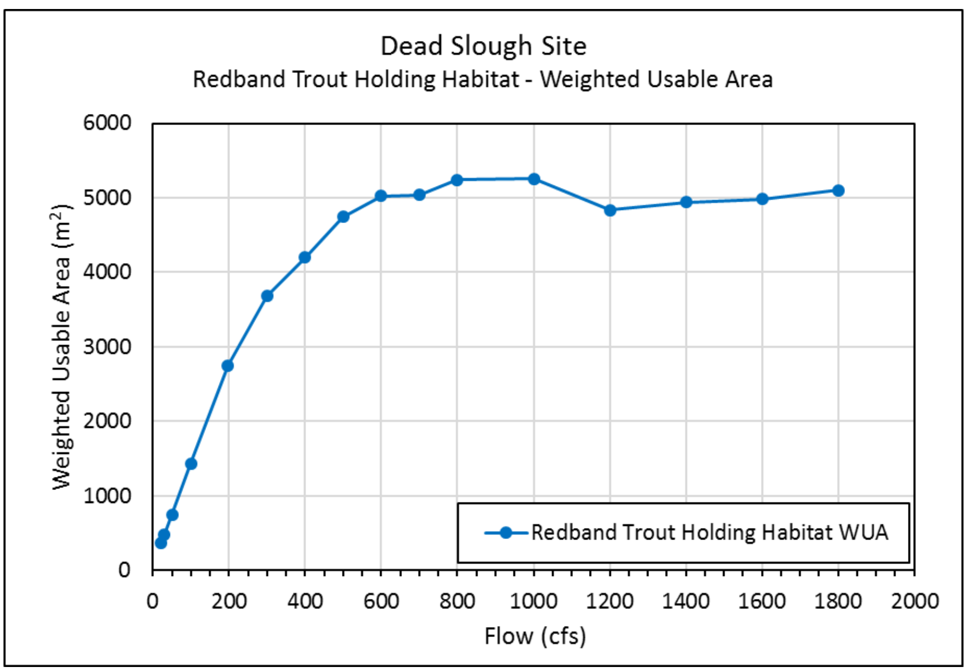

Figure 4-14. Redband trout holding habitat WUA in the Dead Slough study site. Holding habitat suitability exhibits an upward trend until 600 cfs and remains relatively stable from 600 cfs through 1,800 cfs as increasing velocities in the mainstem channel limit holding habitat suitability.

4.3 Riparian Analysis

The following section provides an overview of the riparian analysis results. To review, the goals of the riparian analysis were to 1) determine the inundated emergent vegetation acreage under existing conditions, and 2) to estimate emergent vegetation recruitment into the bare draw down zone under a modified flow regime characterized by lower summer flows. Analyzing emergent vegetation recruitment is based on the assumption that lower summer flows would allow emergent vegetation to recruit into the channel over time as the controlling summer water surface elevation is lower relative to the current condition. To maximize the Oregon spotted frog breeding habitat benefits, flows during the breeding and hatching season (approximately mid-March to mid-May) should be higher than the summer flow. Higher breeding-hatching season flows would ensure the recruited emergent vegetation would remain inundated through the breeding-hatching season.

The following sections provide results for the existing inundated emergent vegetation acreage, and the potential emergent vegetation acreage that could be recruited under low summer flows.

4.3.1 Bull Bend

Existing Inundated Emergent Vegetation Acreage

Figure 4-15 includes existing condition riparian inundation maps for the Bull Bend site. Under existing conditions, inundated riparian wetland acreage at the Bull Bend study site ranges from 1.43 acres at 800 cfs to 17.24 acres at 1,800 cfs. Additional maps are included in Appendix C.

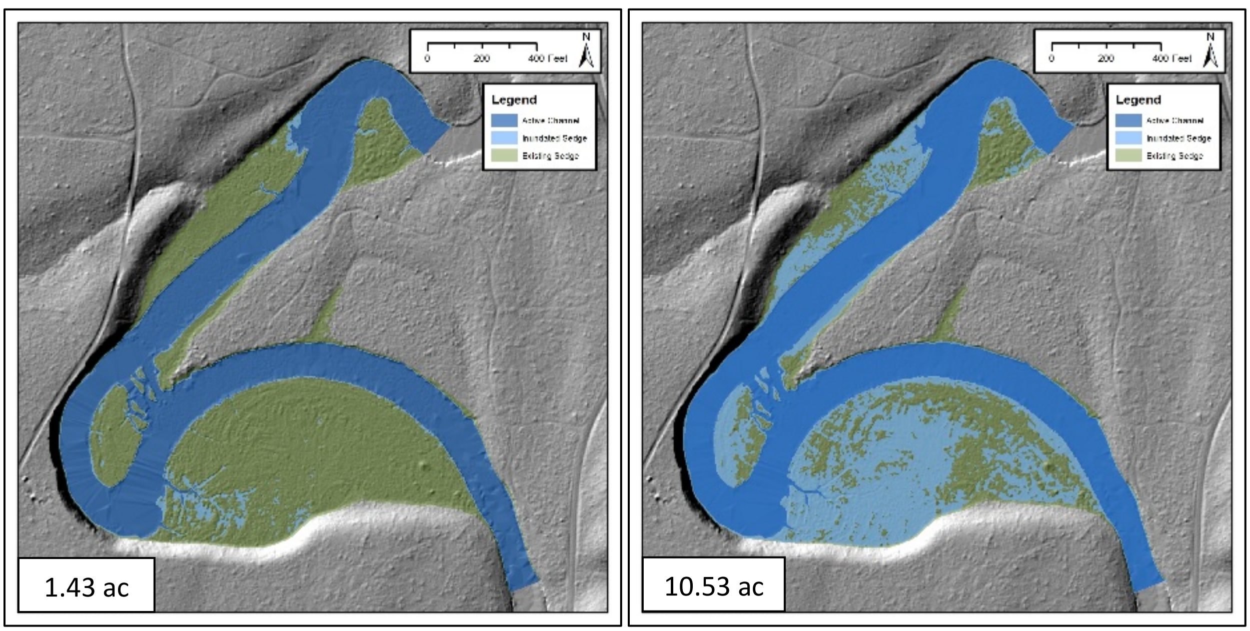

Figure 4-15. Existing condition emergent vegetation inundation analysis illustrating river-riparian wetland interaction at Bull Bend at 800 cfs (left) and 1,239 cfs (right). Acreage of inundated riparian wetland are included for both flows.

Potential Recruited Emergent Vegetation Acreage

A modified summer flow regime characterized by lower summer flows could result in emergent vegetation recruitment acreage gains ranging from 1.11 acres at 800 cfs, to less than 0.10 acres of additional emergent vegetation at 1,800 cfs (Figure 4-16). The potential additional acreage at 1,800 cfs is attributed to currently unvegetated areas that are less than 0.5 m deep (sedge inundation depth tolerance). Additional maps are included in Appendix C.

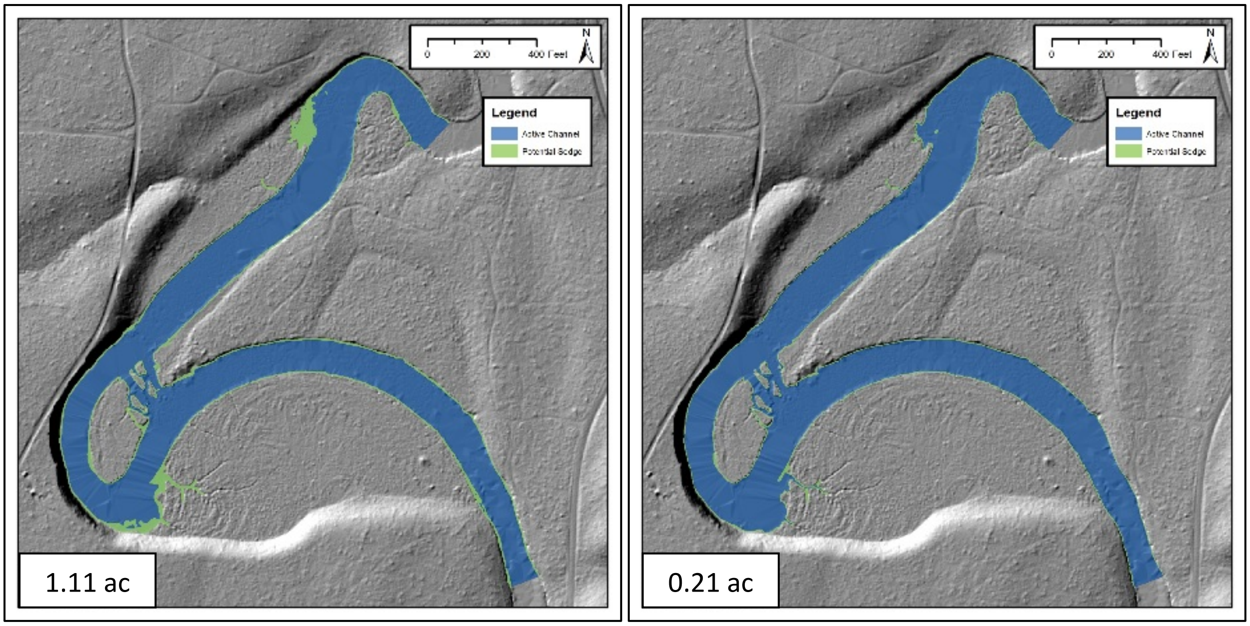

Figure 4-16. Potential emergent vegetation recruitment areas at Bull Bend at 800 cfs (left) and 1,239 cfs (right). Acreage of potential emergent vegetation recruitment is provided for both flows.

Figure 4-17 and Table 4-3 include a comparison of existing inundated emergent vegetation and potential emergent vegetation reruitment at the Bull Bend site.

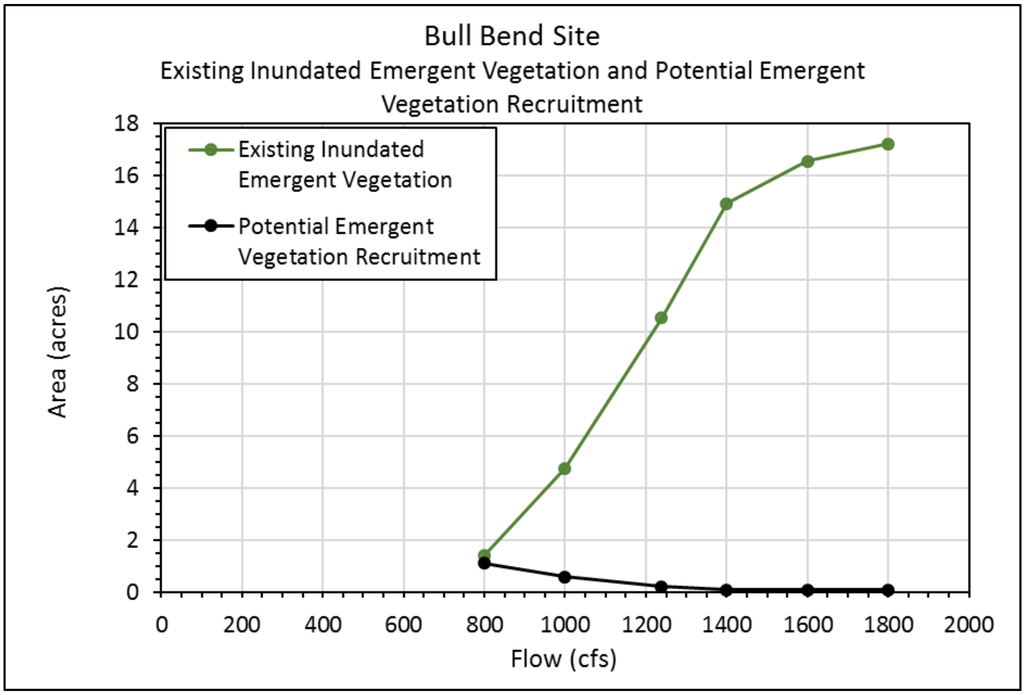

Figure 4-17. Existing inundated emergent vegetation and potential emergent vegetation recruitment at the Bull Bend study site.

Table 4-3. Existing inundated emergent vegetation and potential emergent vegetation recruitment at the Bull Bend study site over a range of potential summer flows.

Flow (cfs)	Existing Inundated Emergent Vegetation (acres)	Potential Recruited Emergent Vegetation (acres)
800	1.43	1.11
1,000	4.77	0.59
1,239	10.53	0.21
1,400	14.94	<0.10
1,600	16.56	<0.10
1,800	17.24	<0.10

4.3.2 Dead Slough

Existing Inundated Emergent Vegetation Acreage

Figure 4-18 includes existing condition riparian inundation maps for the Dead Slough site. Under the current flow regime, inundated riparian acreage at the Dead Slough study site ranges from 1.23 acres at 800 cfs, to 9.68 acres at 1,800 cfs. Additional maps are included in Appendix C.

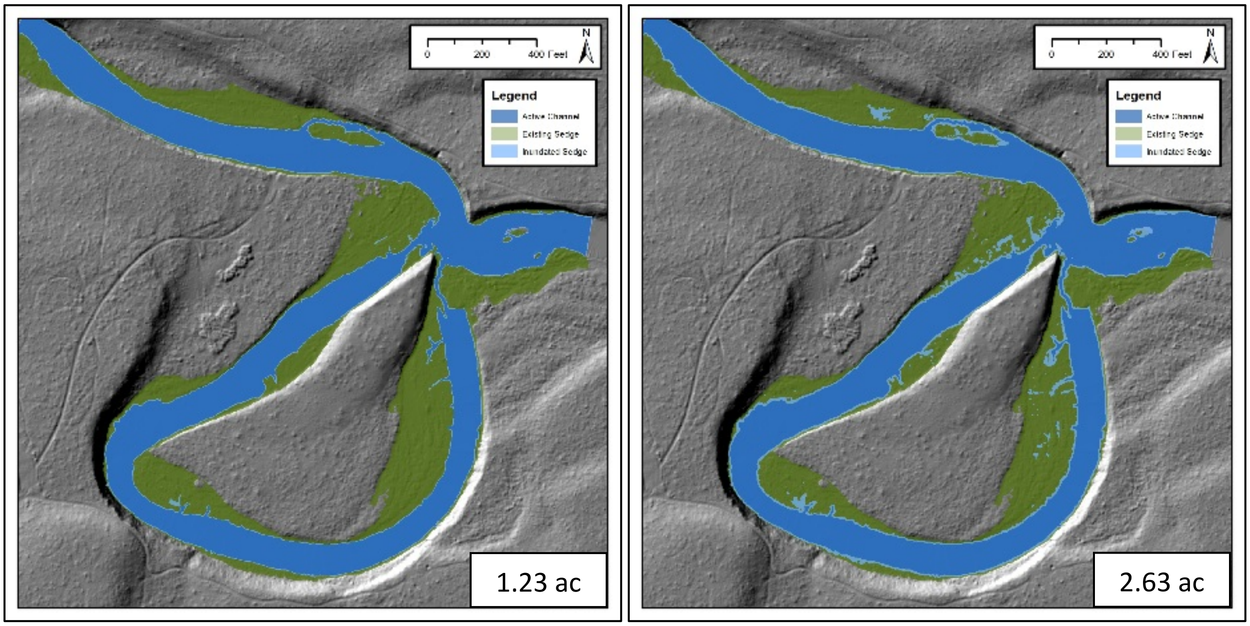

Figure 4-18. Existing condition emergent vegetation inundation analysis illustrating river-vegetated floodplain interaction at Dead Slough at 800 cfs (left) and 1,200 cfs (right). Acreage of inundated riparian wetland are included for both flows.

Potential Recruited Emergent Vegetation Acreage

A modified summer flow regime characterized by lower summer flows could result in emergent vegetation recruitment acreage gains ranging from an additional 2.92 acres of riparian vegetation at 800 cfs, to an additional 0.10 acres at 1,800 cfs (Figure 4-19). The potential additional acreage at 1,800 cfs is attributed to currently unvegetated areas that are less than 0.5 m deep (sedge inundation depth tolerance). Additional maps are included in Appendix B.

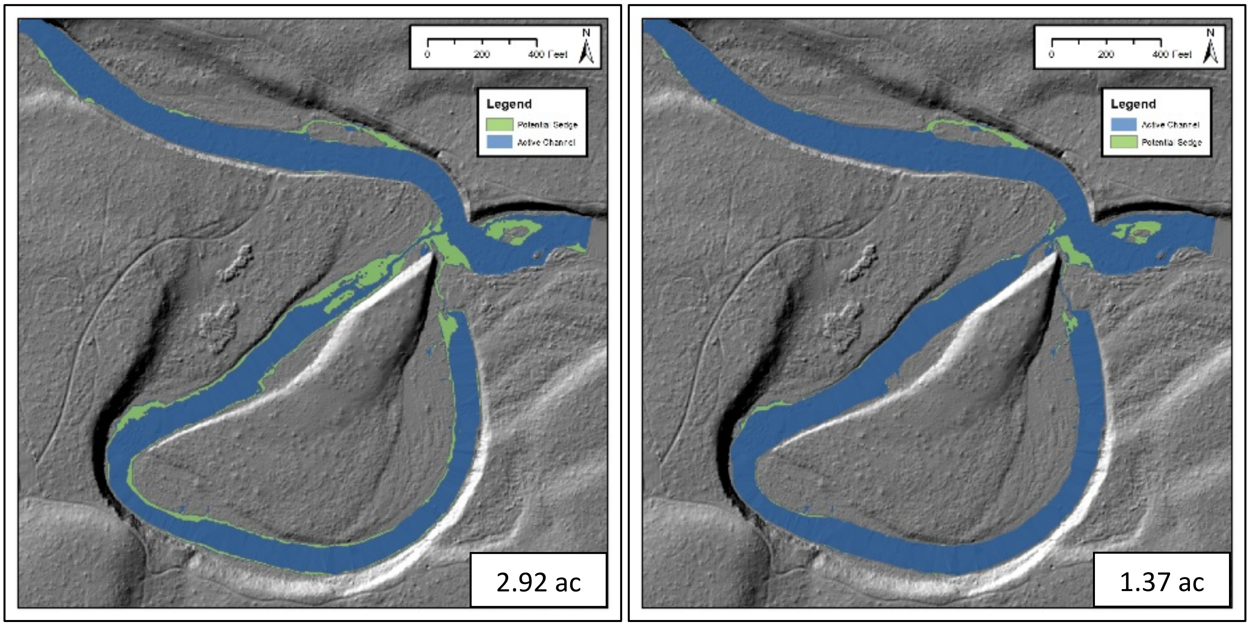

Figure 4-19. Potential emergent vegetation recruitment areas at Dead Slough at 800 cfs (left) and 1,200 cfs (right). Acreage of potential emergent vegetation recruitment is provided for both flows.

Figure 4-20 and Table 4-4 include a comparison of existing inundated emergent vegetation and potential emergent vegetation reruitment at the Dead Slough site.

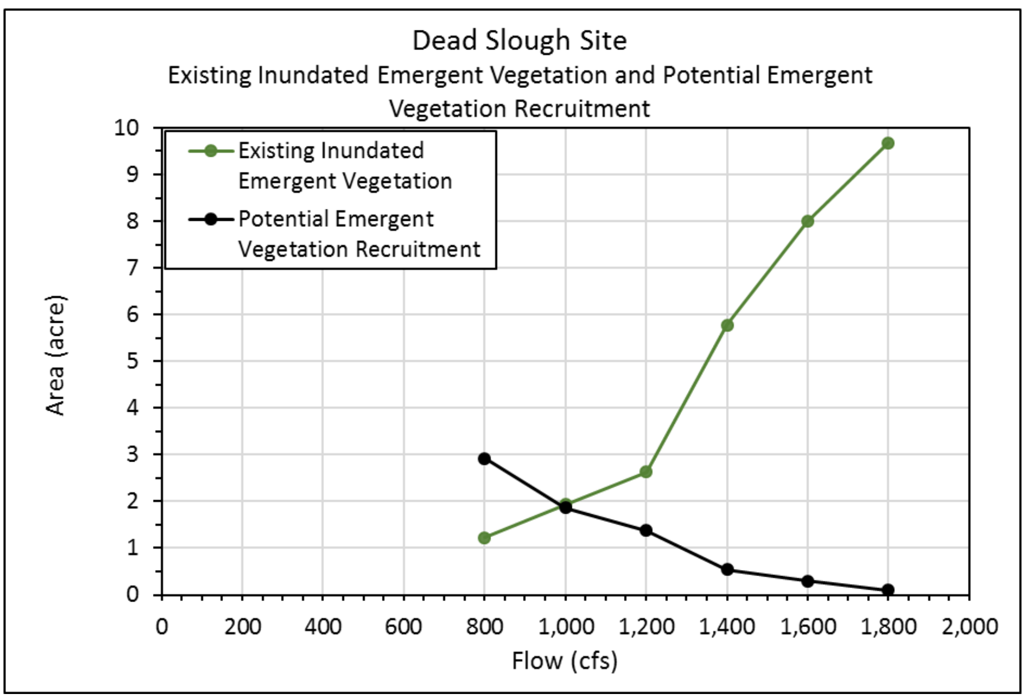

Figure 4-20. Existing inundated emergent vegetation and potential emergent vegetation recruitment at the Dead Slough study site.

Table 4-3. Existing inundated emergent vegetation and potential emergent vegetation recruitment at the Dead Slough study site over a range of potential summer flows.		
Flow (cfs)	Existing Inundated Emergent Vegetation (acres)	Potential Recruited Emergent Vegetation (acres)
800	1.23	2.92
1,000	1.94	1.87
1,239	2.63	1.37
1,400	5.78	0.54
1,600	8.00	0.29
1,800	9.68	<0.10

4.4 Potential Modified Flow Regime Habitat Suitability Scenario

We culminated the habitat study with an assessment of potential habitat suitability associated with a modified flow regime. The modified flow regime included a 1,000 cfs summer flow and then a range of flows representing potential Oregon spotted frog breeding period flows. We used the existing condition surface model, but updated the substrate file to reflect potential emergent vegetation recruitment associated with the 1,000 cfs model run from the analysis described in section 4.3 Riparian Analysis. More specifically, silt and sand substrates in the bare draw down zone from the existing vegetated floodplain margin to half a meter below the 1,000 cfs water surface elevation, were converted to emergent vegetation. As emergent vegetation is the preferred breeding habitat substrate for Oregon spotted frog, we expected breeding habitat suitability to improve under the modified flow regime.

We modeled breeding habitat suitability from 100 cfs to 1,200 cfs to simulate potential river flows during the breeding period. Figure 4-21 and Table 4-5 include summary output from the analysis. The modeling results suggest that at low from 100 cfs to 400 cfs, the existing and modified flow conditions yield similar breeding habitat suitability. This result is largely due to the water surface elevation associated with these flows inundating a similar channel footprint for both conditions. As river flow increases above 400 cfs, the water surface begins to interact with recruited emergent vegetation and breeding habitat suitability increases under the modified condition. Breeding habitat suitability levels at 700 cfs, suggesting water velocities, rather than substrate type, in the near-bank region become the limiting variable controlling breeding habitat suitability. Breeding habitat suitability under the modified condition declines slightly at 1,000 cfs before increasing again at 1,200 cfs and peaking at 1,400 cfs. Increases in breeding habitat suitability at 1,200 cfs are noted by increasing interaction between the river and the riparian wetland areas. At 1,400 cfs, the river is broadly interacting with interion riparian wetland areas. The modified and existing condition results mirror each other at flows from 1,000 cfs t 1,400 cfs as the benefits of the recruited emergent vegetation are off-set by increasing water velocities. Once the river accesses the riparian wetland floodplain areas, breeding habitat suitability rapidly increases with inundated emergent vegetation substrates and water velocities are less influential on breeding habitat suitability. Additional analysis is suggested to verify these relationships and to incorporate the proximity analysis variable in the habitat suitability calculation.

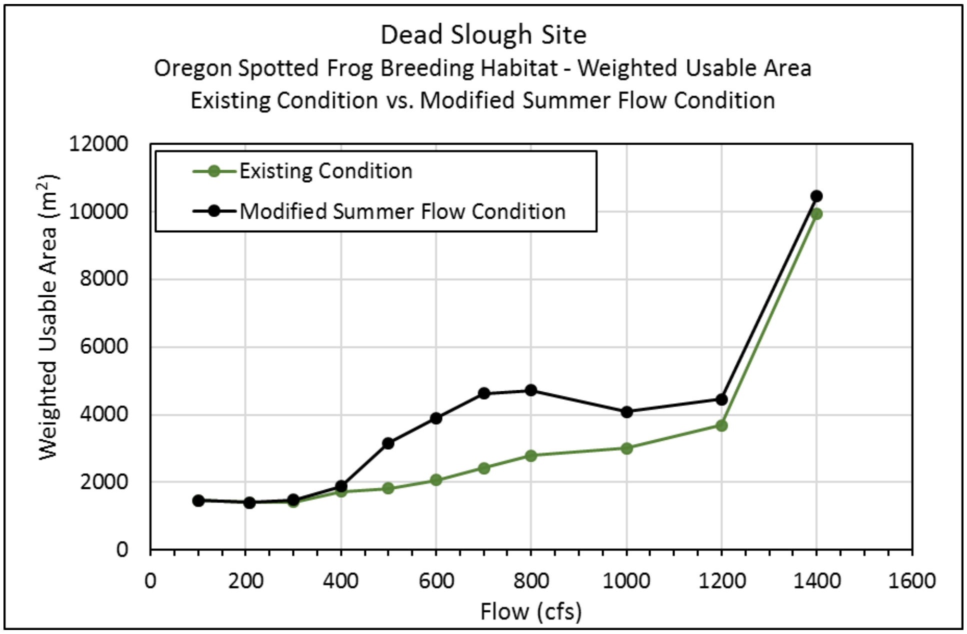

Figure 4-21. A comparison of Oregon spotted frog breeding habitat suitability WUA for the existing condition and potential condition associated with a modified summer flow. Conversion of silt and sand substrate to emergent vegetation along channel margins which would be expected to occur with lower summer flows, would increase the breeding habitat suitability at the Dead Slough site at moderate flows relative to the existing condition.

Table 4-5. Existing condition and modified summer flow condition Oregon spotted frog breeding habitat WUA for the Dead Slough site and the WUA percent difference between the compared conditions.

Flow (cfs)	Existing Condition Breeding Habitat WUA (m^2)	Modified Summer Flow Condition Breeding Habitat WUA (m^2)	Change in Oregon Spotted Frog Breeding Habitat WUA from Existing Condition to Modified Summer Flow Condition (%)
100	1,467	1,468	0%
208	1,401	1,410	1%
300	1,422	1,478	4%
400	1,731	1,876	8%
500	1,815	3,154	74%
600	2,074	3,906	88%
700	2,419	4,621	91%
800	2,793	4,709	69%
1,000	3,005	4,087	36%
1,200	3,679	4,457	21%
1,400	9,939	10,455	5%

The modified flow analysis could be developed further to evaluate other controlling summer flows and to better understand how modified summer flows affect potential Oregon spotted frog breeding habitat suitability. From the presented analysis, a high summer flow of 700 cfs combined with a higher Oregon spotted frog breeding period flow has the potential to increase breeding habitat suitability relative to current water management. Additional modeling could further clarify flow-breeding habitat relationships and help direct future flow management to improve Oregon spotted frog breeding habitat in the upper Deschutes River.

5 Discussion

Flow management practices in the upper Deschutes River have altered the historical flow regime and in doing so, have influenced aquatic and riparian conditions. High summer flows and low winter-time storage flows have led to accelerated bank erosion and channel planform instability in a system that prior to hydromodification, was characterized by a relatively stable hydrograph and channel (Walker and Tanner 2012).

Oregon spotted frog populations have declined across their historical range for a number of reasons, but foremost causes include habitat loss, introduction of non-native plants, and competition and predation by non-native fish and amphibians. Hydromodification and geomorphic channel response in the upper Deschutes River are believed to be possible drivers affecting Oregon spotted frog populations on the upper Deschutes River.

Redband trout have also experienced population declines across their range, including in the upper Deschutes River. Redband trout populations are affected by habitat loss, competition, predation, and introgression with introduced fish species, and degraded channel conditions resulting from river management.

The study team was tasked with using River2D, a 2-dimensional hydraulic and habitat model, to evaluate Oregon spotted frog overwintering and breeding habitat suitability, and redband trout adult holding habitat suitability at two sites on the upper Deschutes River. Habitat suitability criteria for Oregon spotted frog overwintering and breeding habitat was developed through discussions with agency experts and drawing on published literature. Although scientists' understanding of Oregon spotted frog habitat requirements is rapidly improving with the increased attention on the species, less is known about how Oregon spotted frogs are adapting to the regulated river environment on the upper Deschutes River downstream from Wickiup Dam. We applied three variables to assess overwintering habitat suitability and a similar suite of variables to evaluate breeding habitat. Based on water depth and velocity calculated at each flow in the hydraulic model, and substrate mapped in the field, we found that Oregon spotted frog overwintering habitat and breeding habitat is most suitable when moderately shallow surface water interacts with adjacent riparian floodplain surfaces. This relationship is more pronounced for breeding habitat as the presence of emergent vegetation is known to be an important habitat component at successful breeding sites. In addition to the habitat suitability variables already mentioned, we also incorporated a distance to the edge of water as a filter to give preference to potential habitats located near the edge of water, a breeding site characteristic identified for Oregon spotted frog.

Redband trout adult holding habitat suitability was assessed using depth, velocity, and cover. As we expect the winter period to be the limiting season for redband trout survival, we analyzed channel conditions without aquatic vegetation cover which is a prominent habitat feature during the growing season, but dies back through the winter. Highly suitable holding habitats were linked to the channel margin and mid-channel wood pieces that are common in both study sites. Low velocity areas such as Dead Slough and off-channel areas adjacent to the upper Deschutes River in the Bull Bend site, provide low habitat suitability for adult holding under the current flow regime.

The final analysis calculated river inundation of adjacent riparian wetland areas under the current water management regime, and potential emergent vegetation recruitment associated with lower summer flows. Under the existing flow regime, Bull Bend has nearly twice the inundated riparian wetland vegetation at a given flow compared to Dead Slough. Riparian wetland floodplain surfaces are more extensive and exist at lower elevations relative to the river at Bull Bend than they do at Dead Slough. Conversely, minimal riparian sedge recruitment gains would be achieved at Bull Bend with reduced summer flows as there is less drawdown area (i.e., elevation difference between the riparian sedge floodplain and modeled water surface elevations) at Bull Bend relative to Dead Slough.

Riparian sedge inundation at the Dead Slough site follows a similar, but lower magnitude trend of riparian inundation with increasing flows. Floodplain surfaces tend to be narrower and at higher elevations compared to similar floodplain features at the Bull Bend site. The drawdown region at the Dead Slough site, particularly in the Dead Slough itself, is larger and more conducive to riparian sedge recruitment with lower summer time flows which in part control sedge extents.

In summary, the upper Deschutes River provides habitat for Oregon spotted frog and Deschutes redband trout, among other species. Water management to meet downstream water demands has negatively affected channel stability and instream habitat conditions. The habitat study used a two-dimensional hydraulic and habitat model to evaluate habitat suitability with changes in flow. Under existing channel conditions, habitat suitability is maximized during high flows when the river interacts with interior riparian wetlands and vegetated channel margins. Incremental increases in river flow during the winter storage period will yield minimal benefits for Oregon spotted frog overwintering and breeding habitat suitability. Achieving marked improvements in both Oregon spotted frog and redband trout habitat suitability will likely require additional analysis to determine appropriate summer, breeding period, and winter flows that satisfy water needs but also improve river corridor habitat conditions. From the current analysis, reducing summer flows and increasing breeding period and winter flows would increase Oregon spotted frog overwintering and breeding habitat suitability, and redband trout adult holding habitat suitability.

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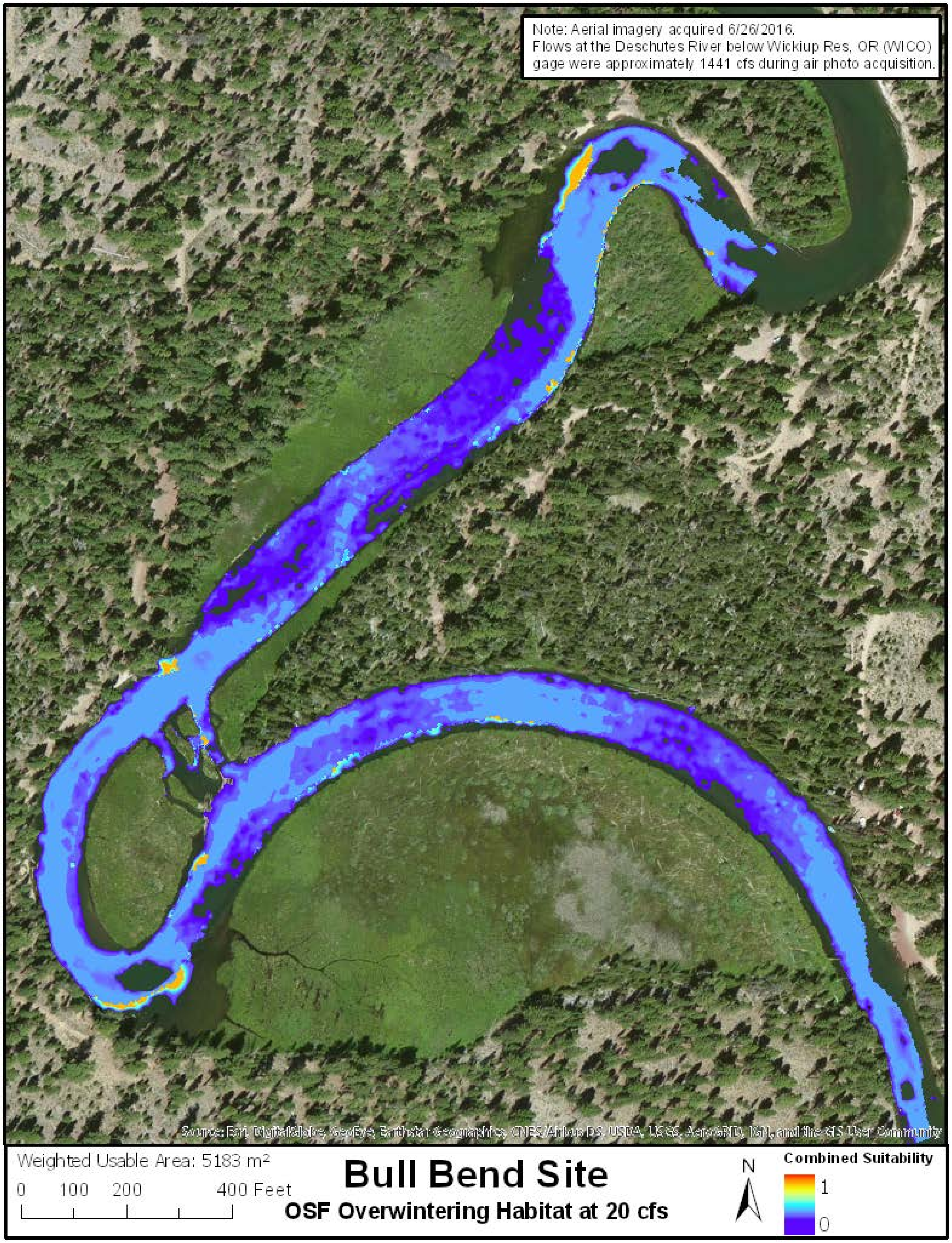
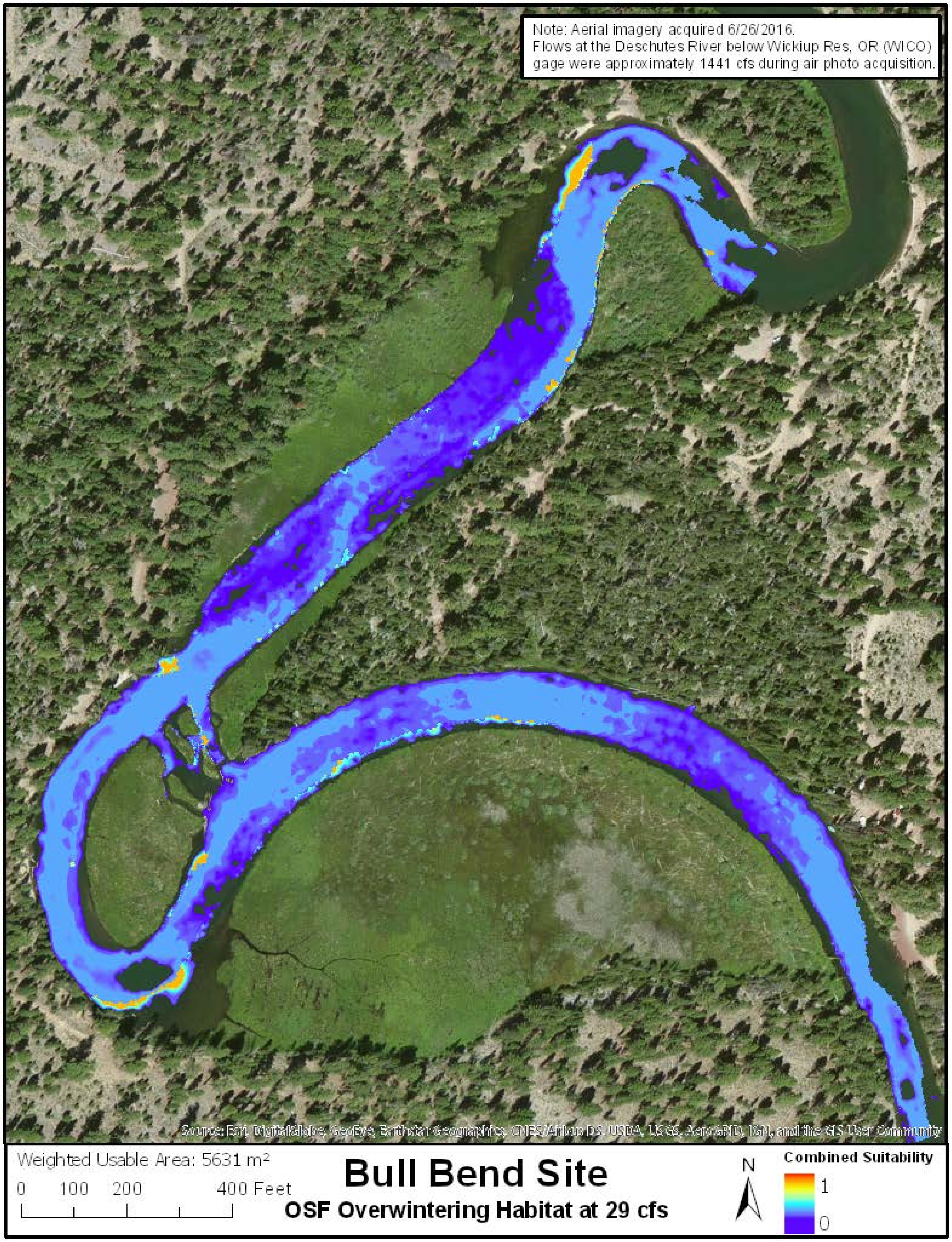
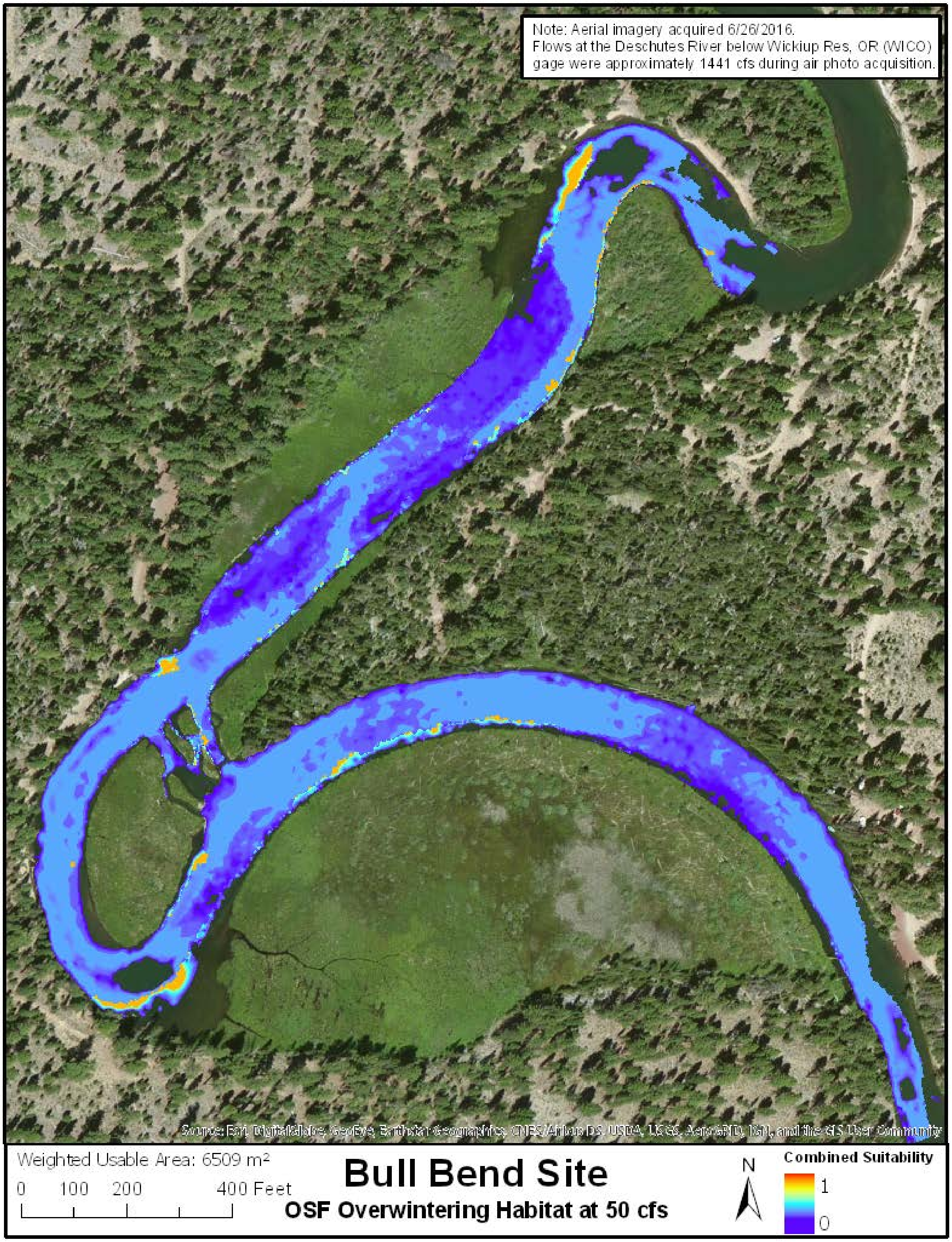
Appendix A

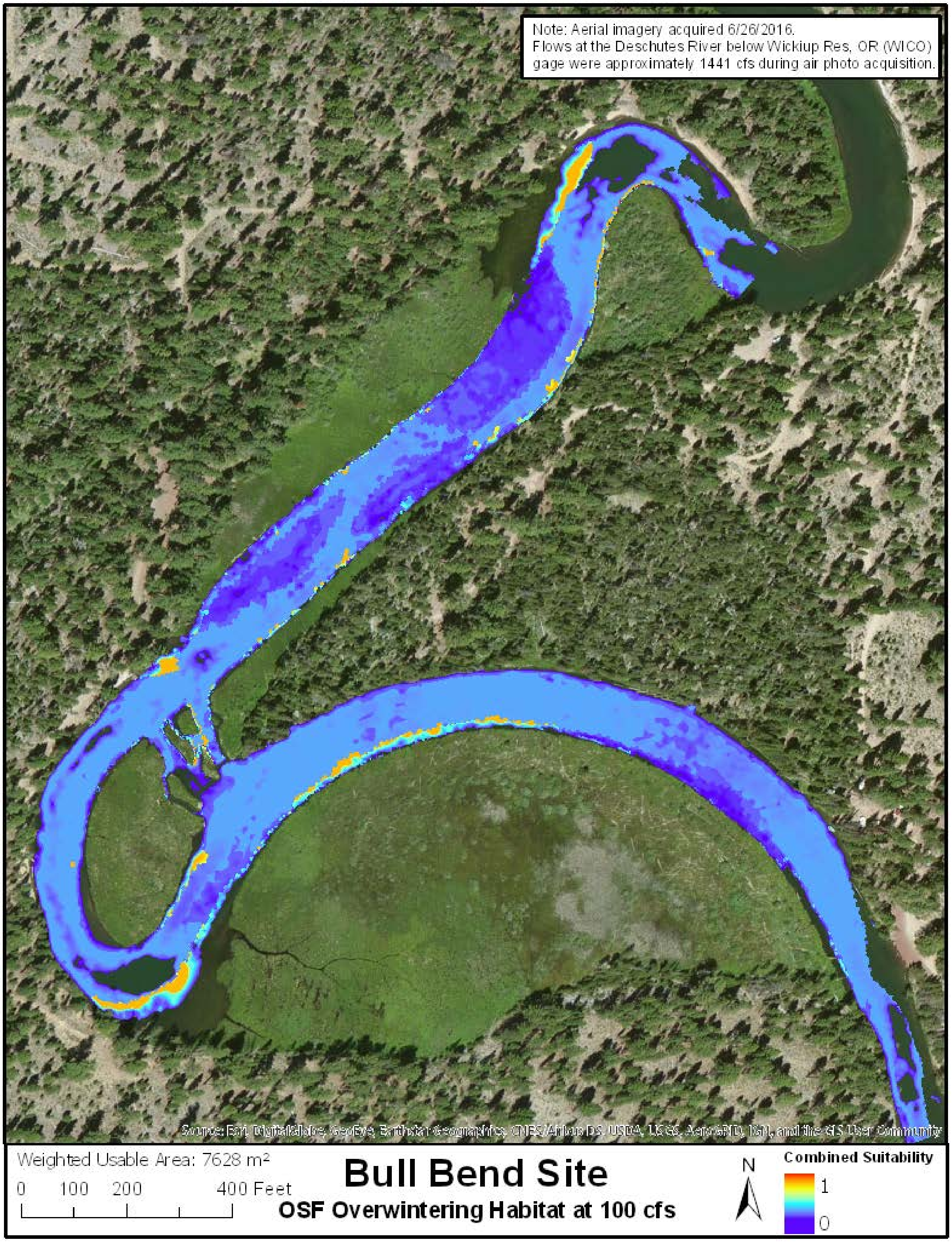
Habitat Suitability Maps - Bull Bend

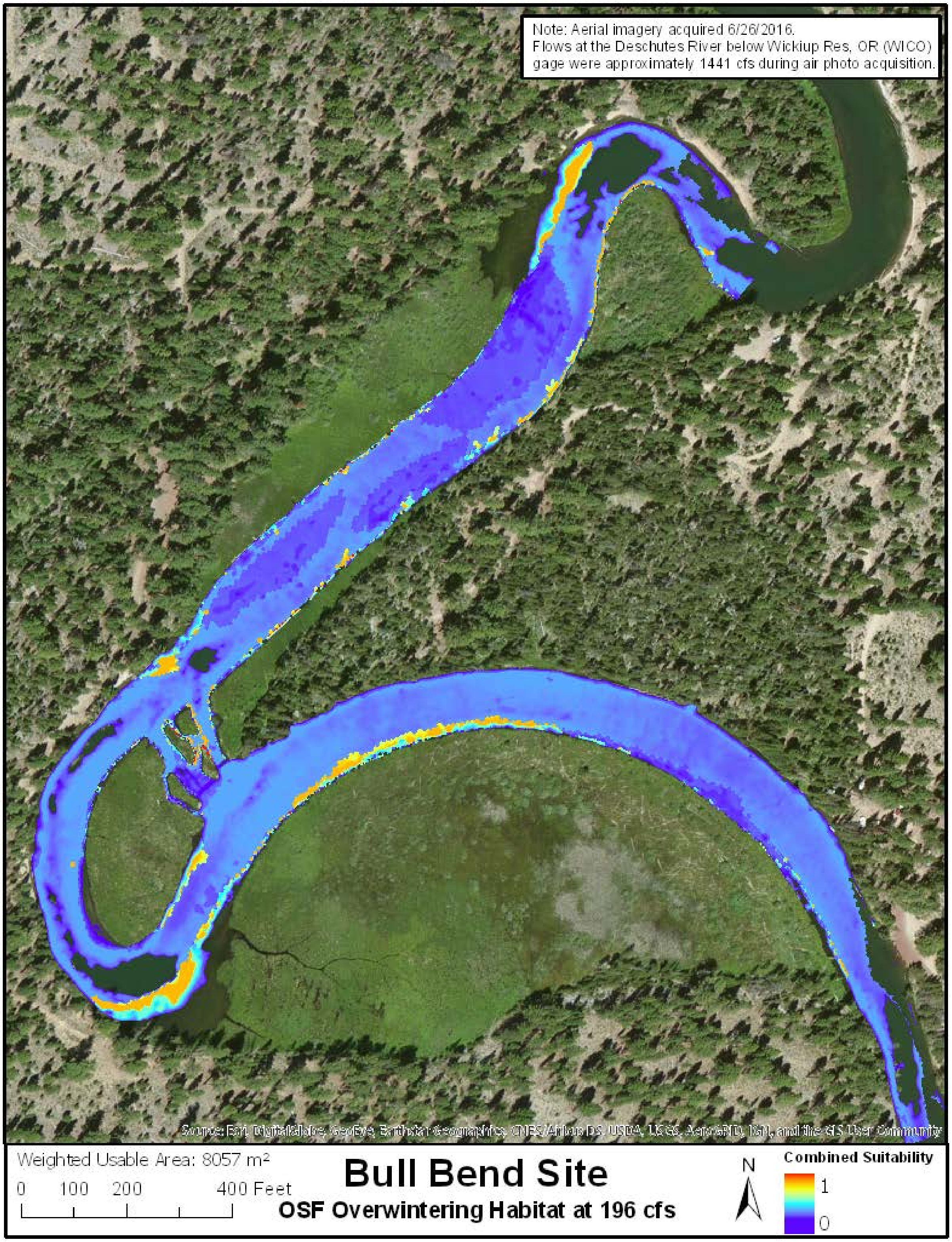
Bull Bend – Oregon Spotted Frog Overwintering Habitat

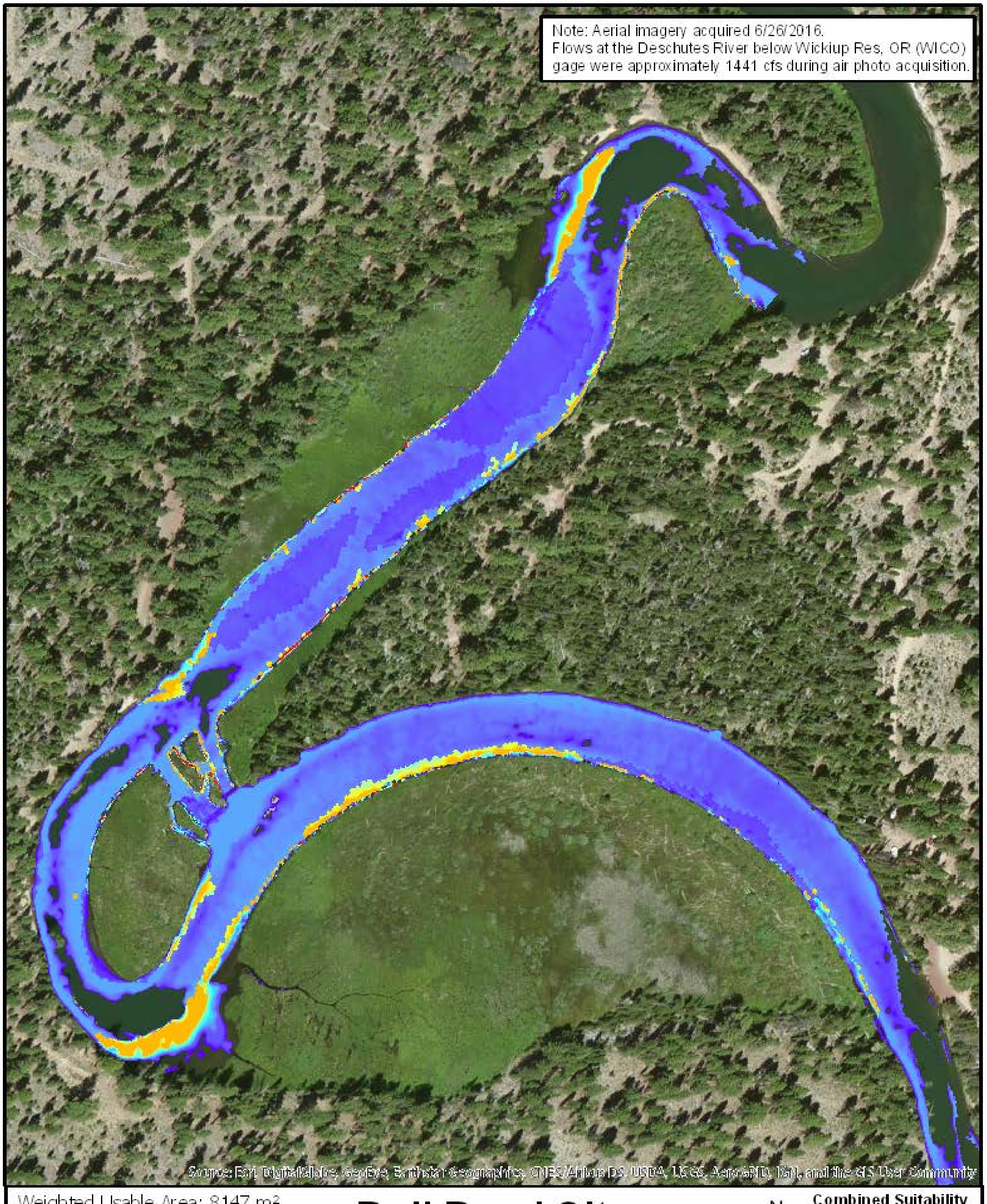



Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 5631 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 29 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 6509 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 50 cfs
N
Combined Suitability
1
0

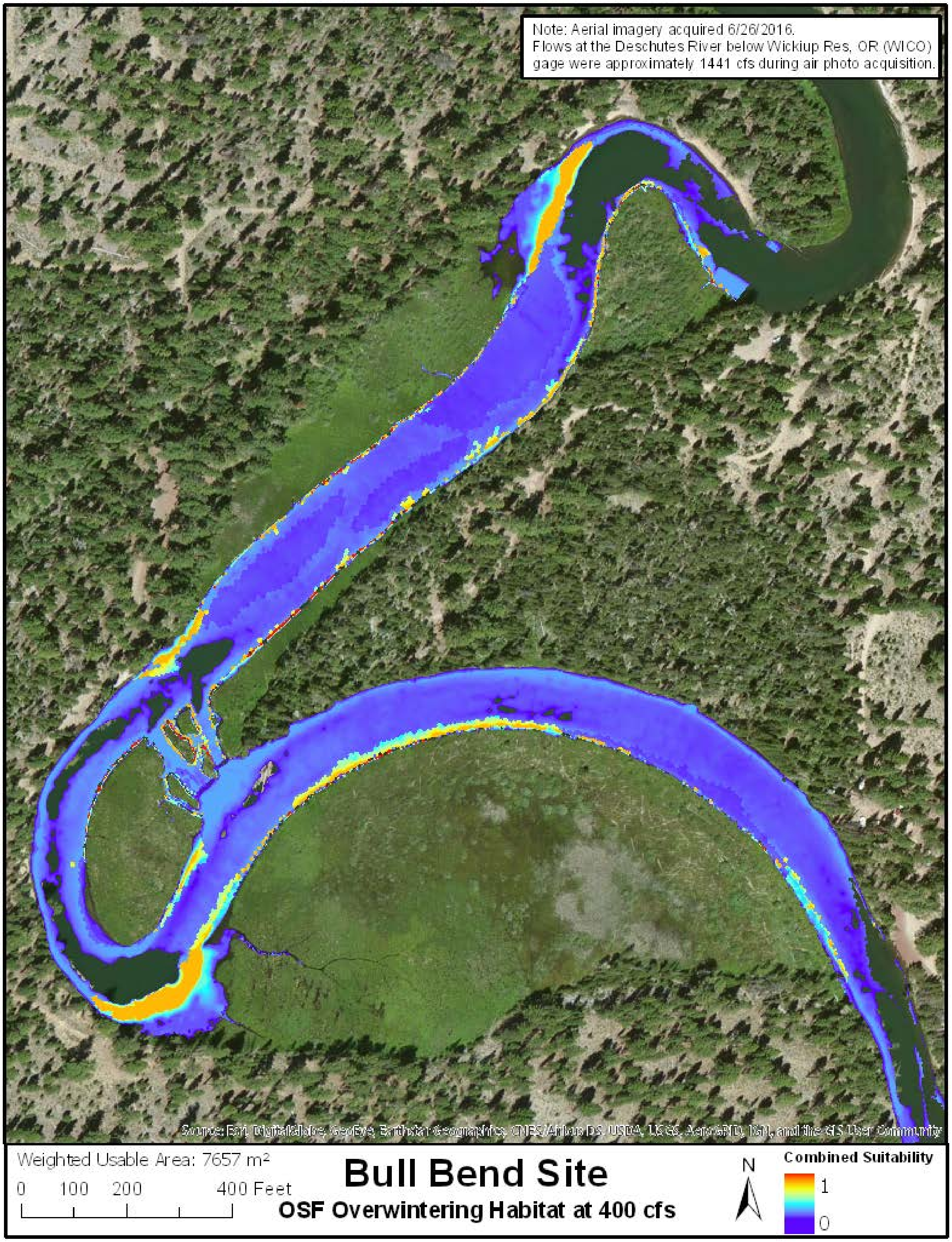

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 7628 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 100 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 8057 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 196 cfs
N
Combined Suitability
1
0

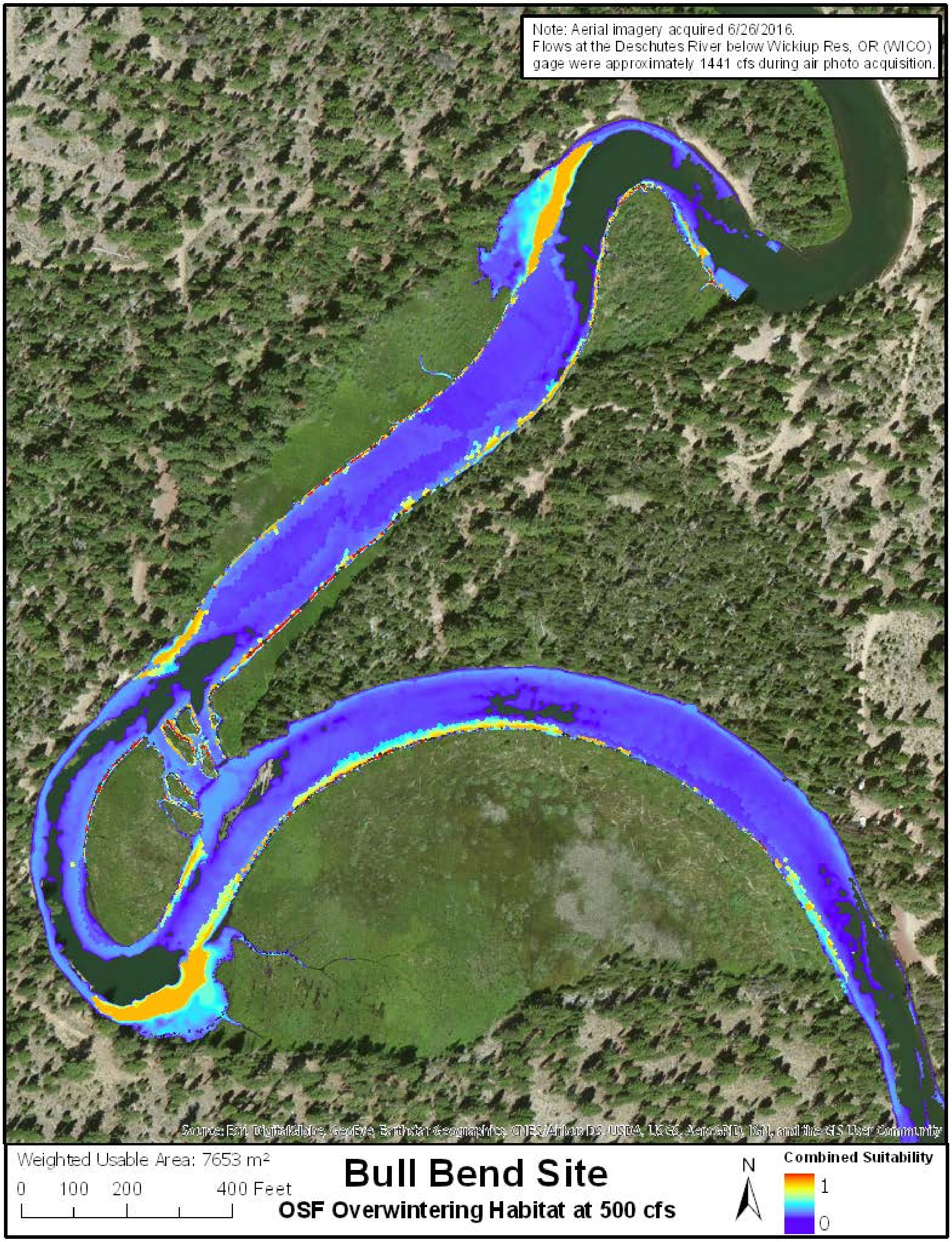


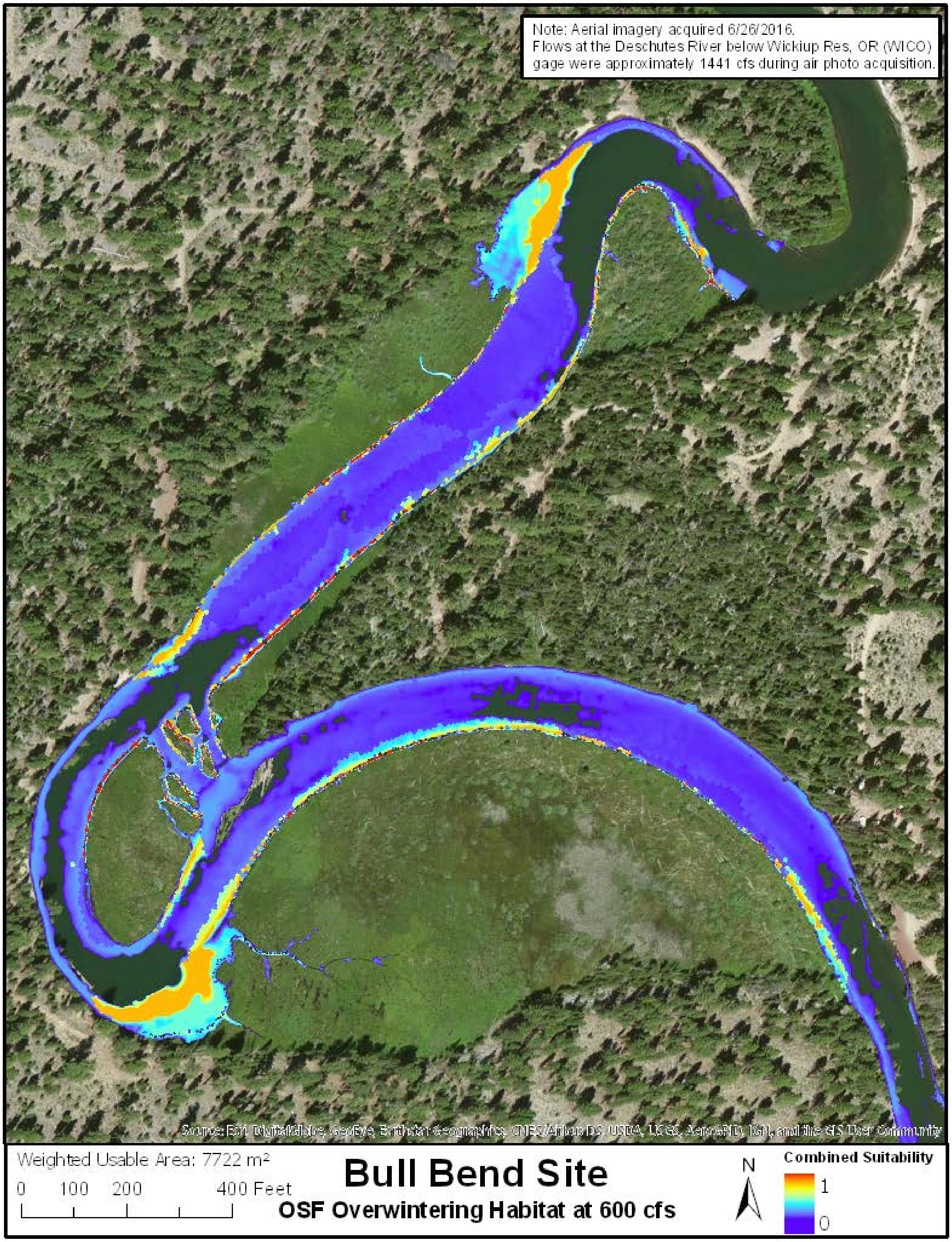
Bull Bend Site

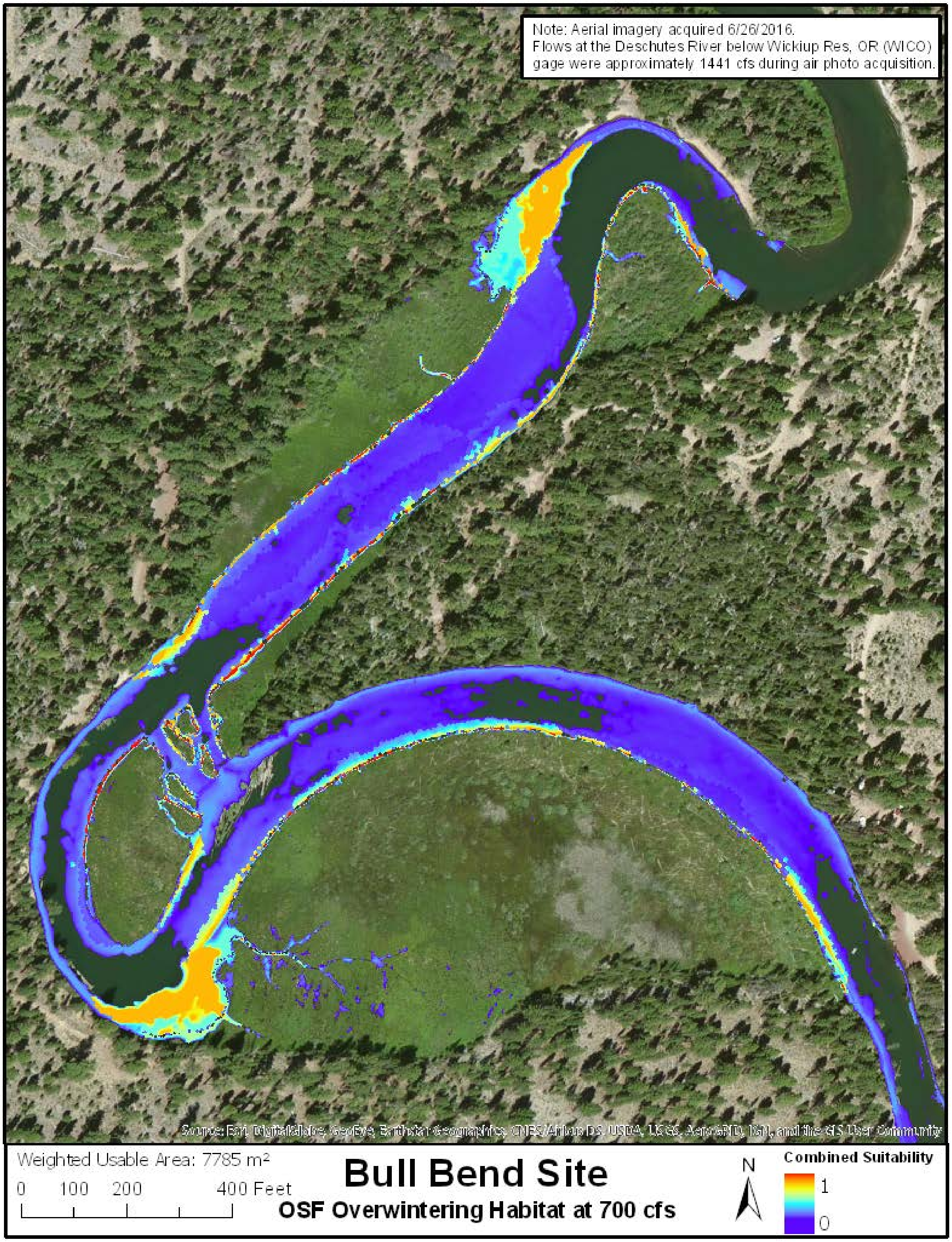
OSF Overwintering Habitat at 300 cfs

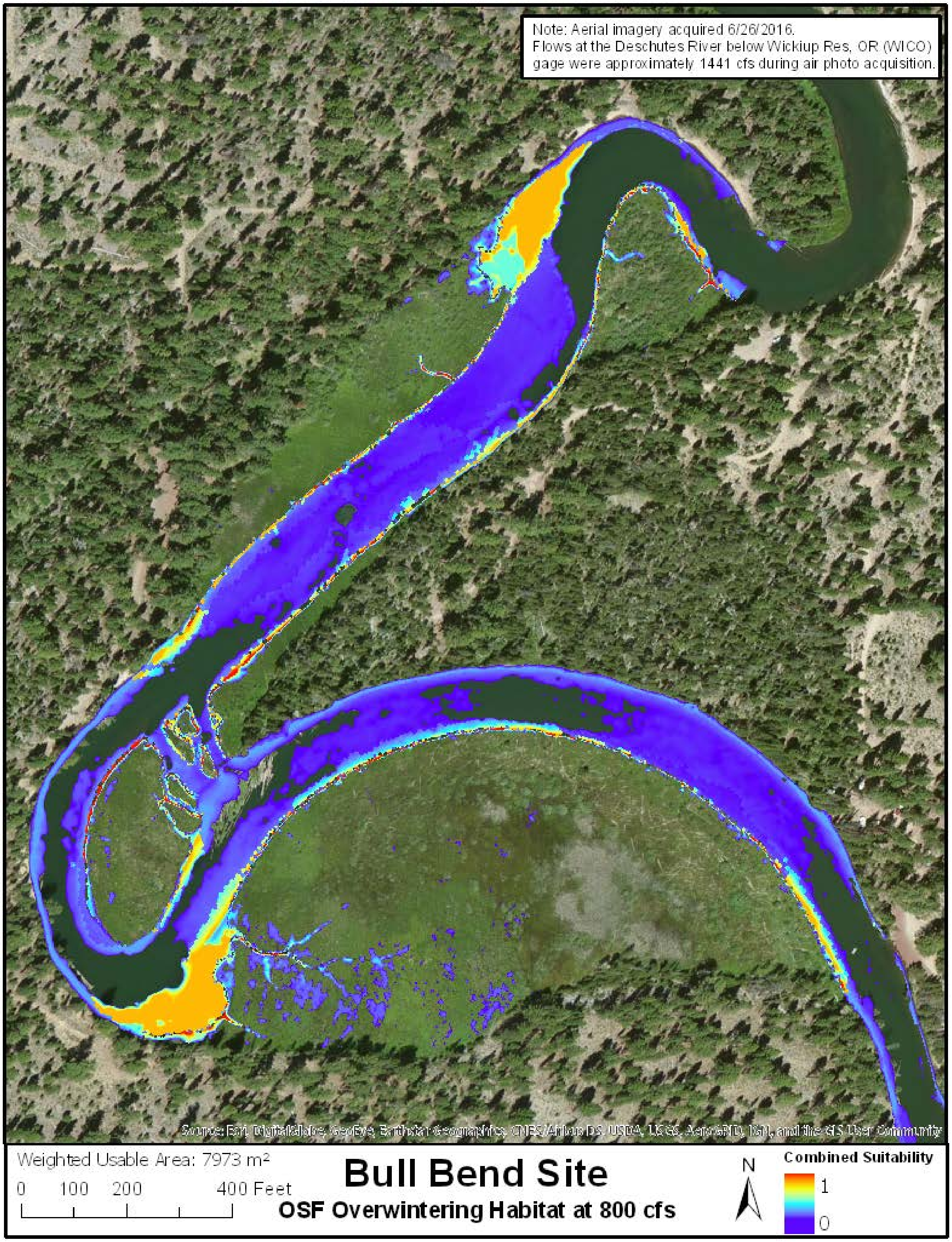


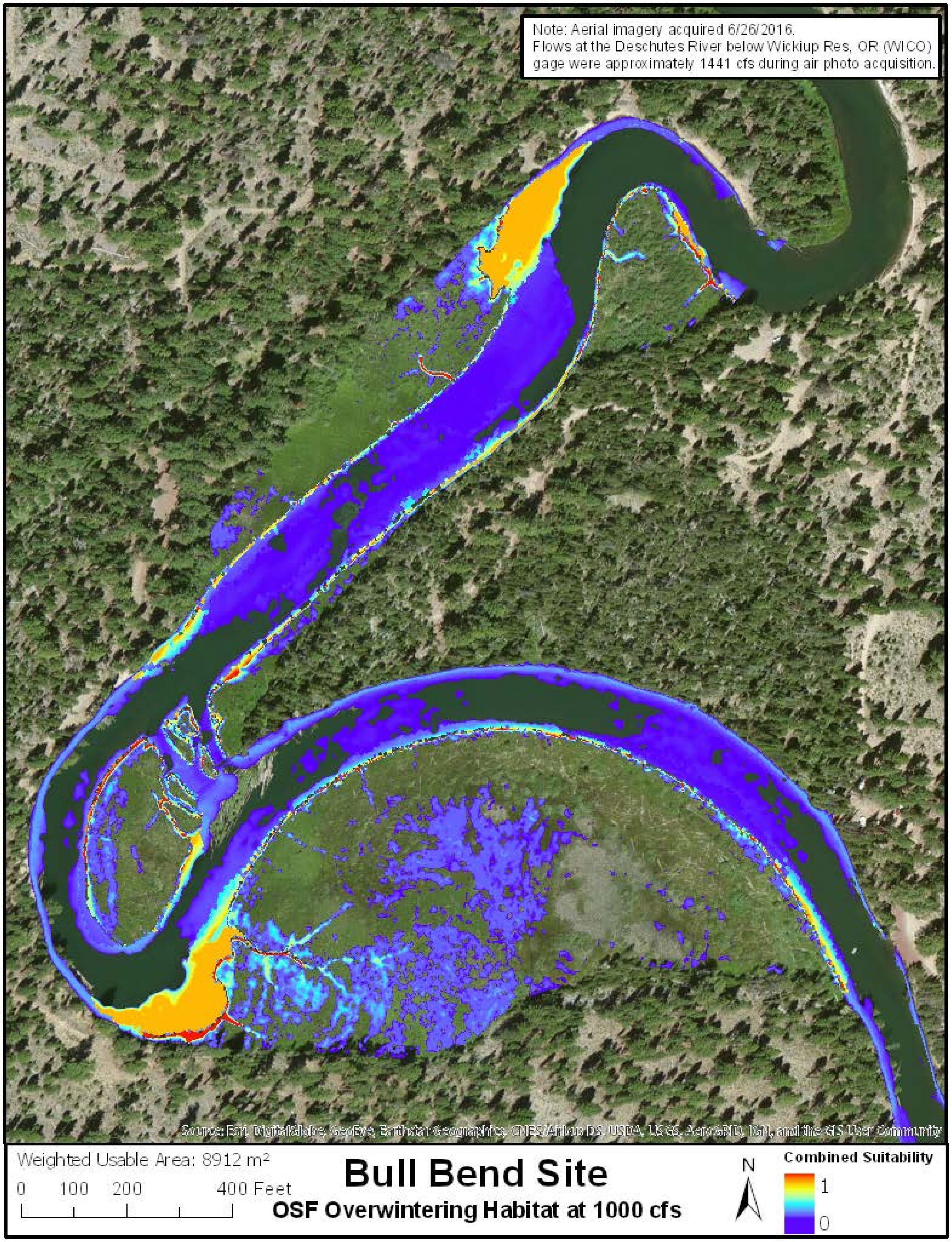
Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 7657 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 400 cfs
N
Combined Suitability
1
0

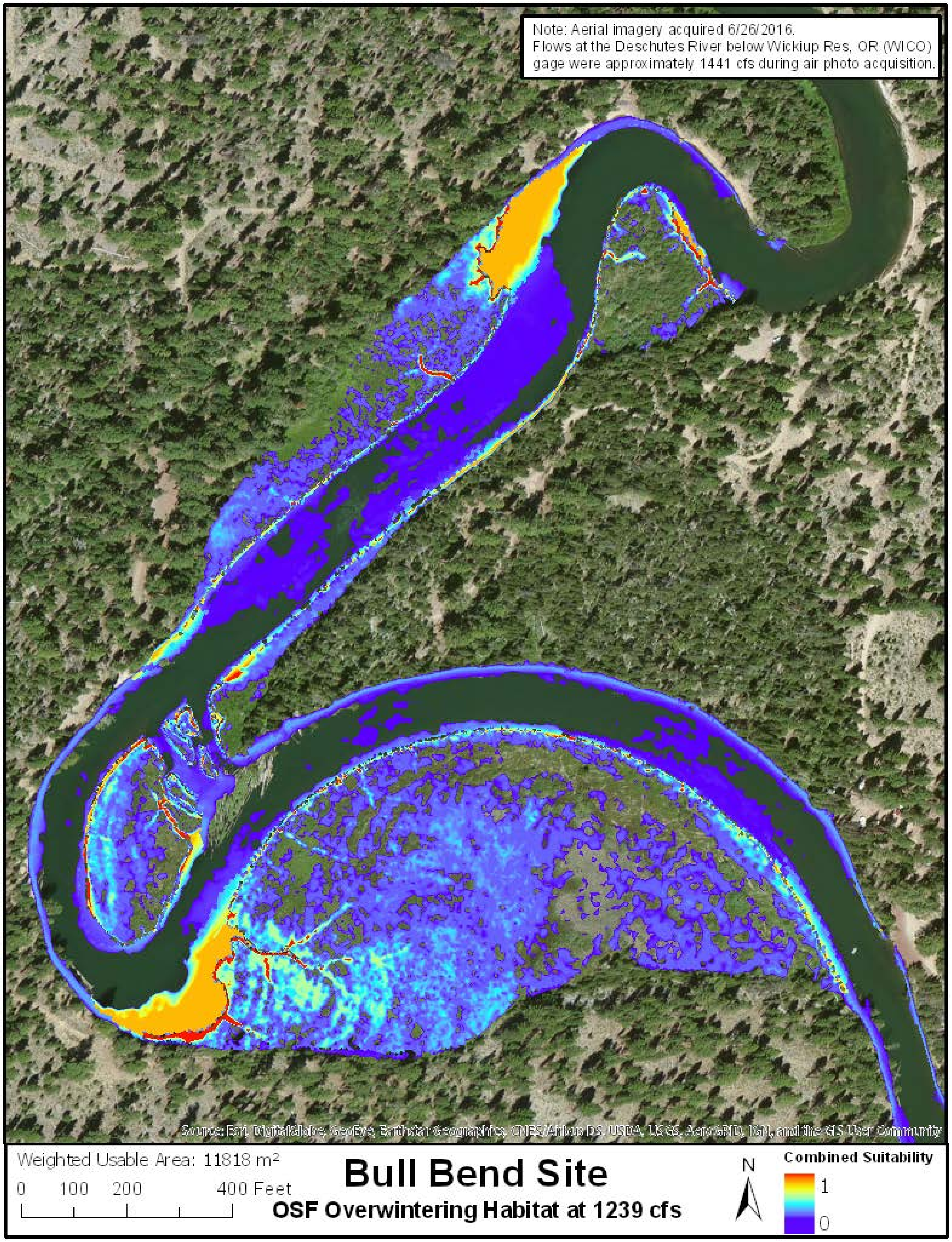

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 7653 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 500 cfs
N
Combined Suitability
1
0

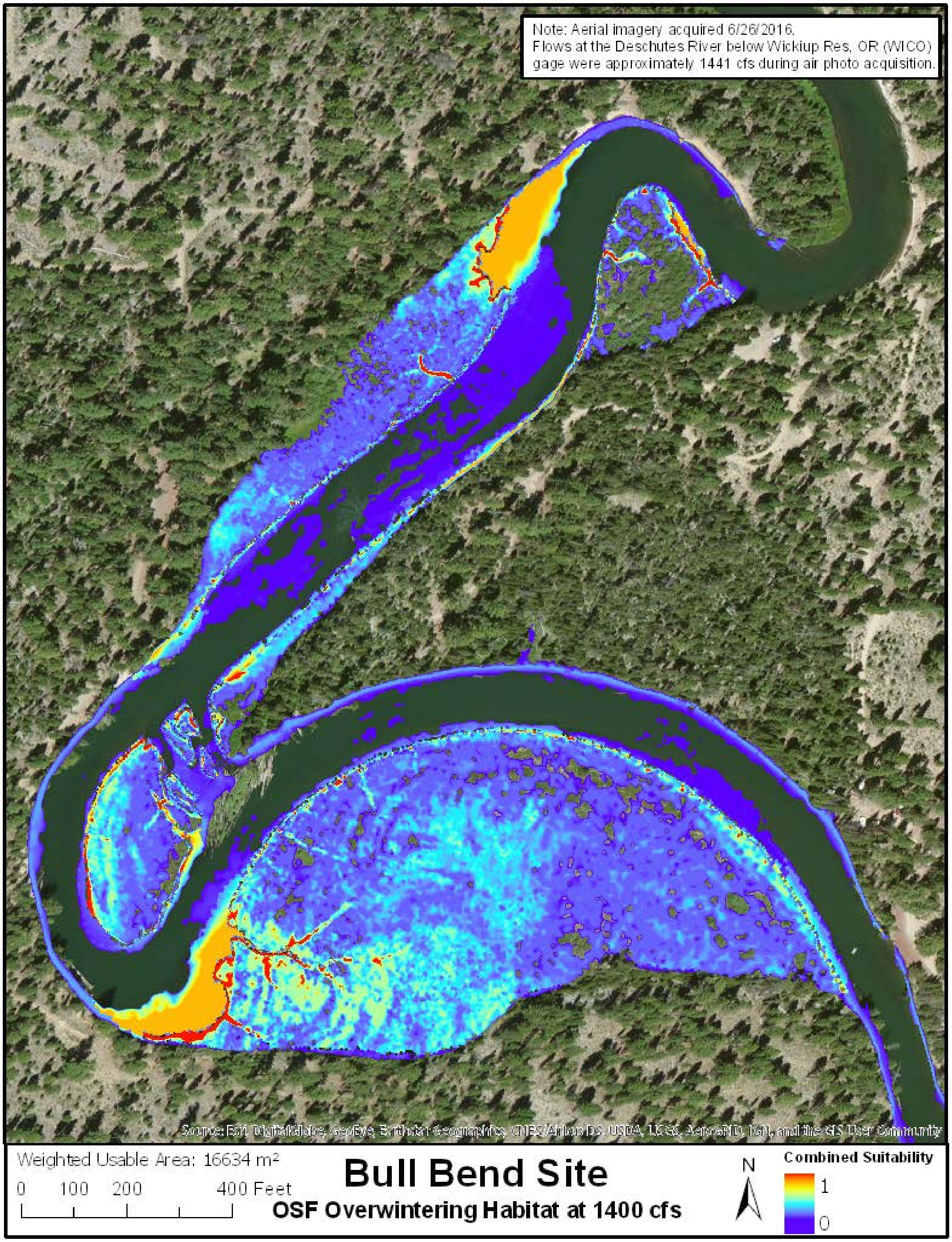

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 7722 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 600 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 7785 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 700 cfs
N
Combined Suitability
1
0

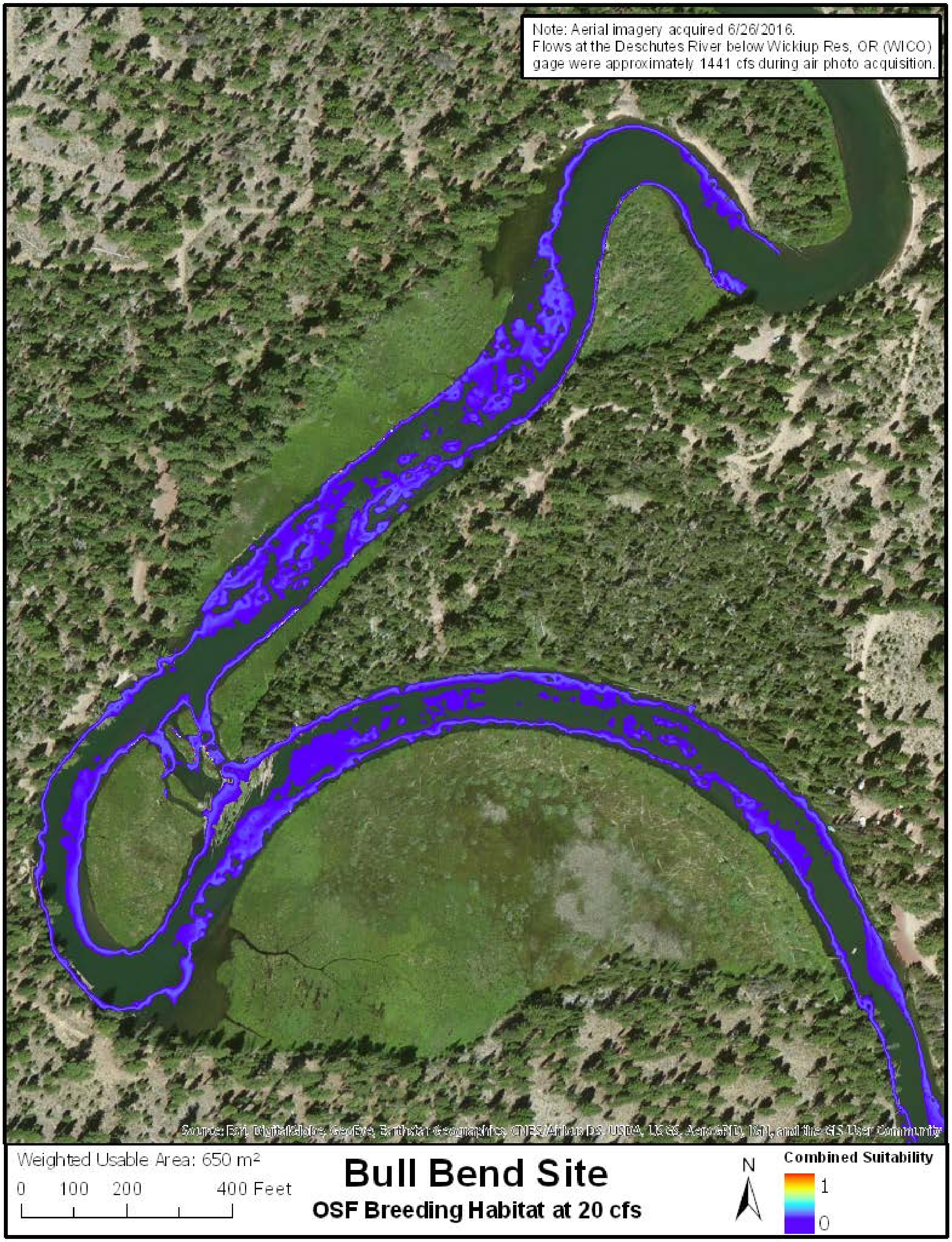

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 7973 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 800 cfs
N
Combined Suitability
1
0

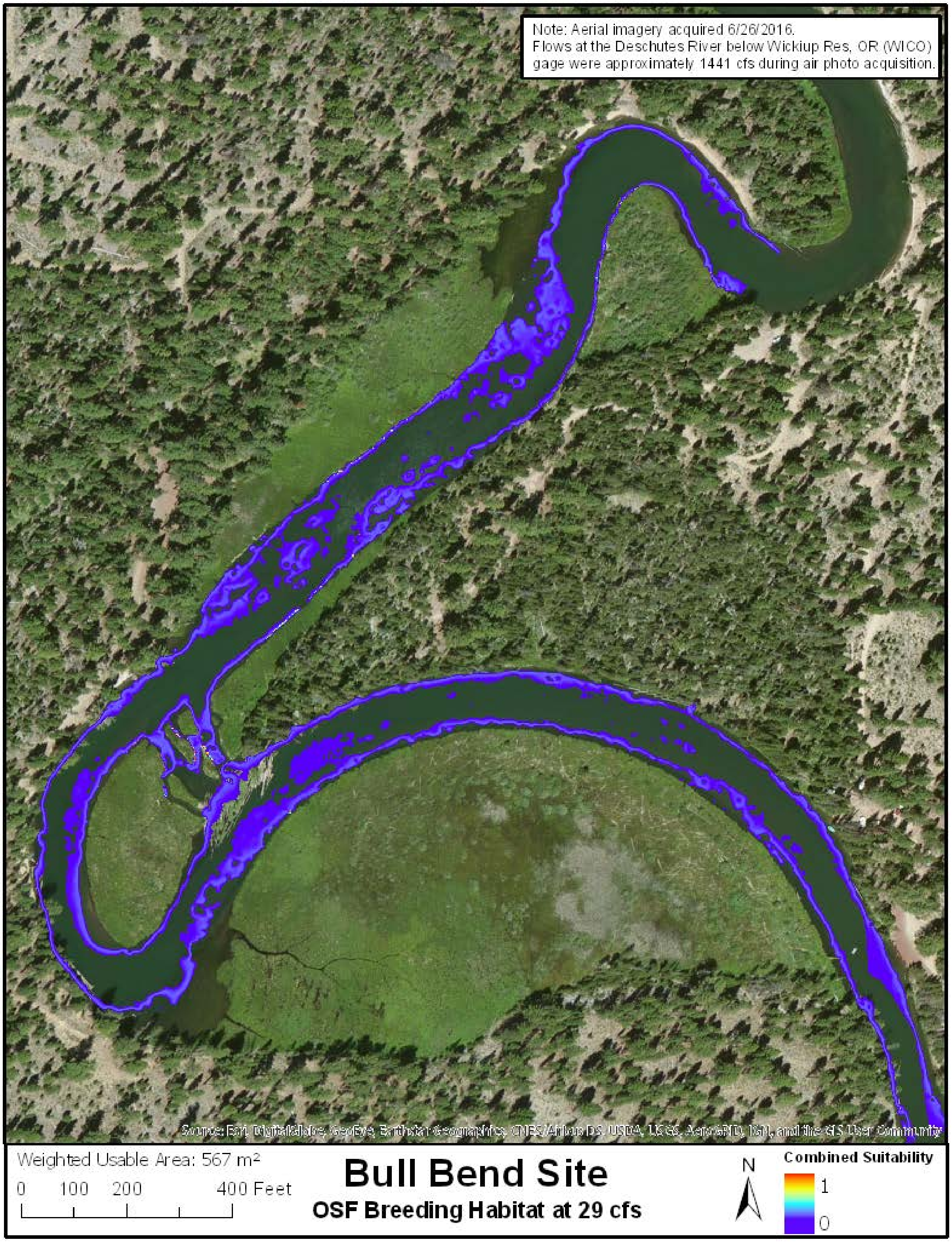

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 8912 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 1000 cfs
N
Combined Suitability
1
0

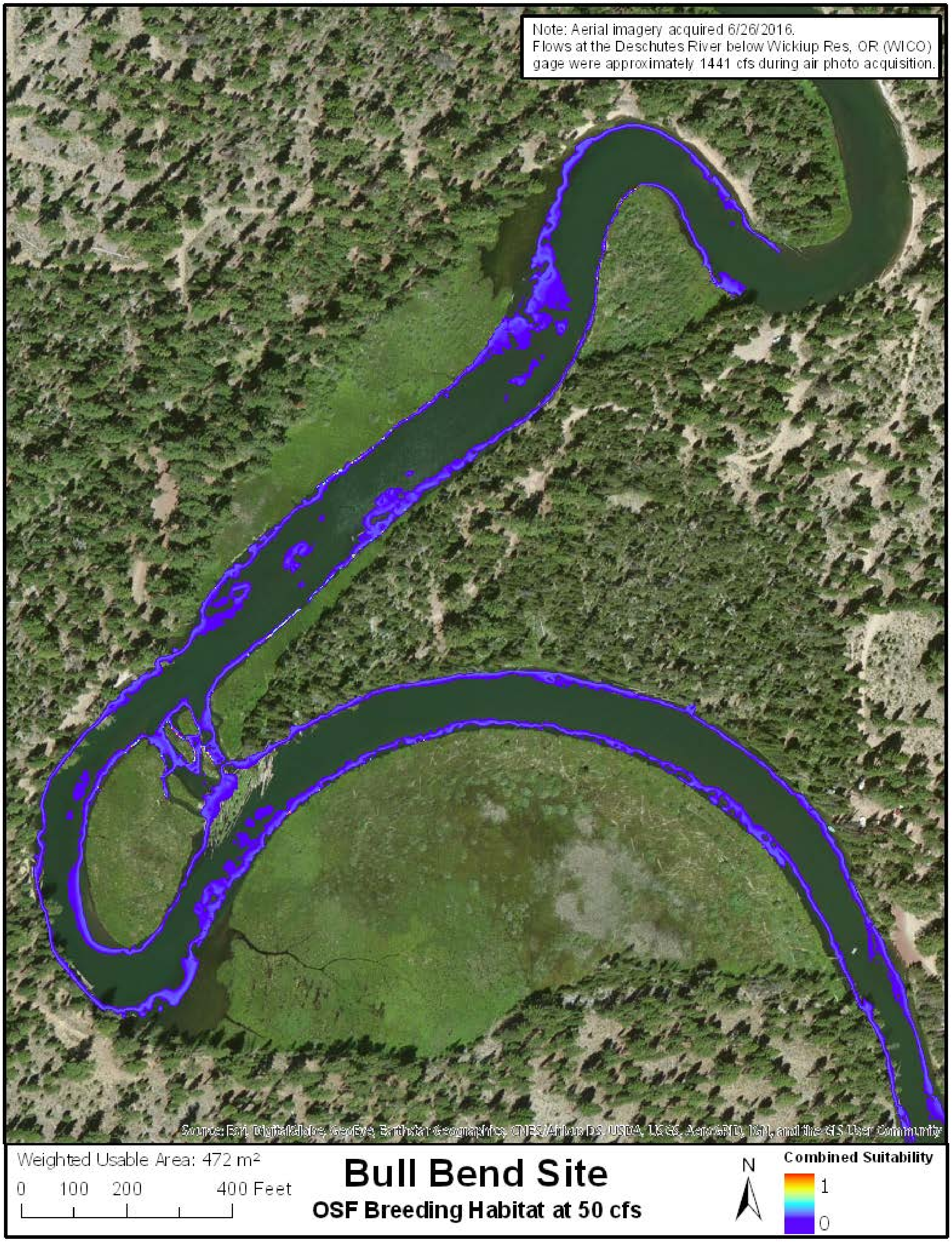

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 11818 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 1239 cfs
N
Combined Suitability
1
0

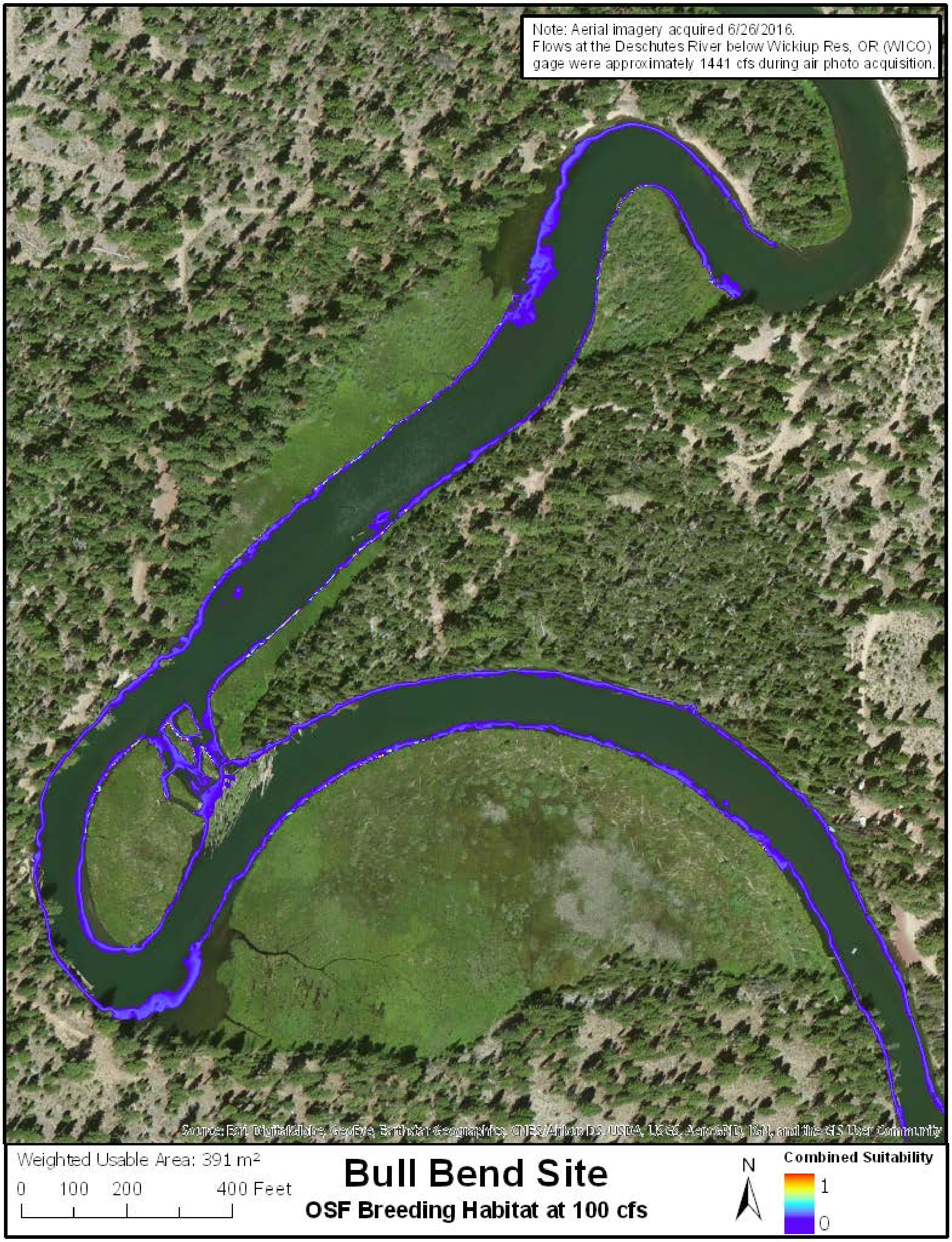

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 16634 m²
0 100 200 400 Feet
Bull Bend Site
OSF Overwintering Habitat at 1400 cfs
N
Combined Suitability
1
0

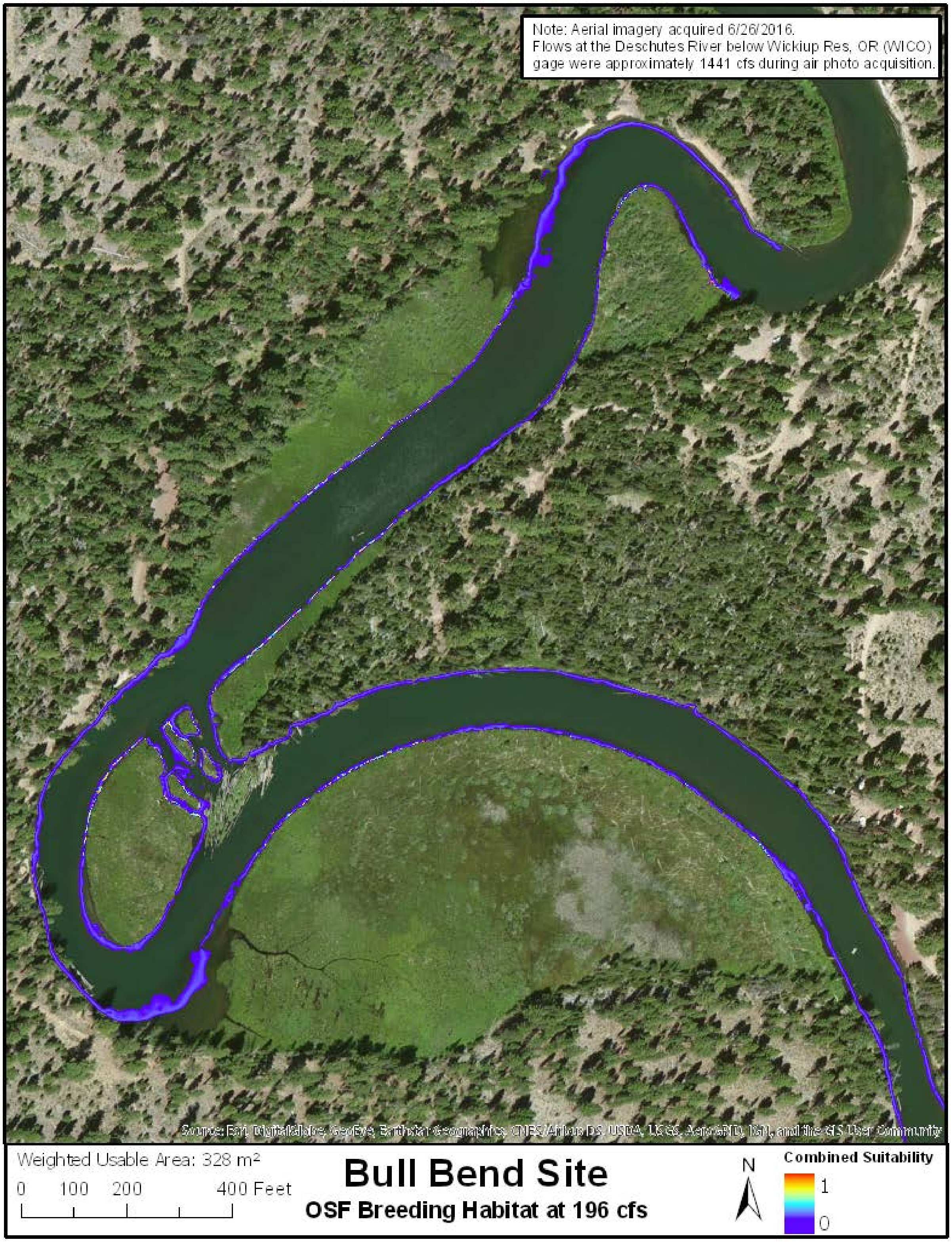
Bull Bend – Oregon Spotted Frog Breeding Habitat



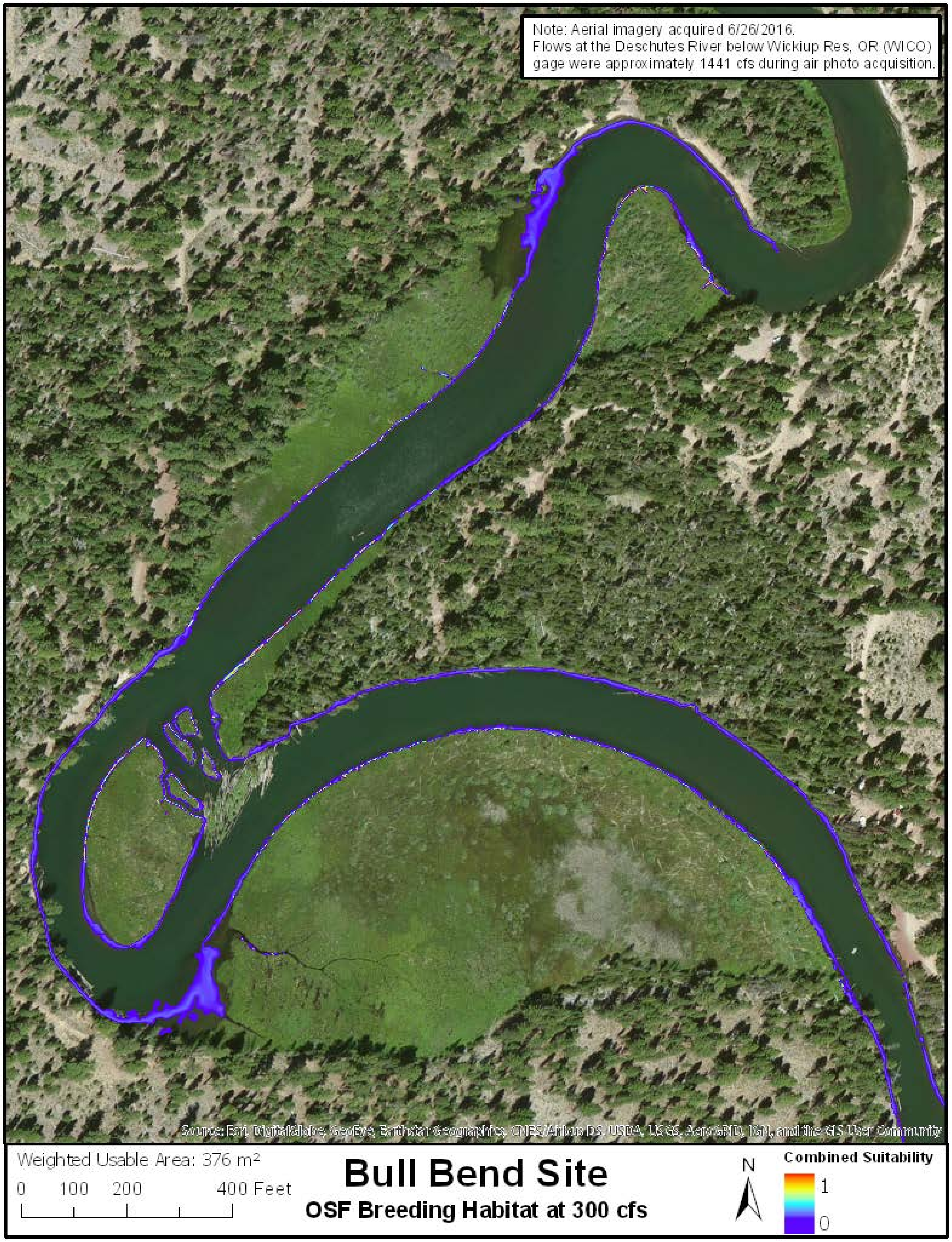

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 567 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 29 cfs
N
Combined Suitability
1
0

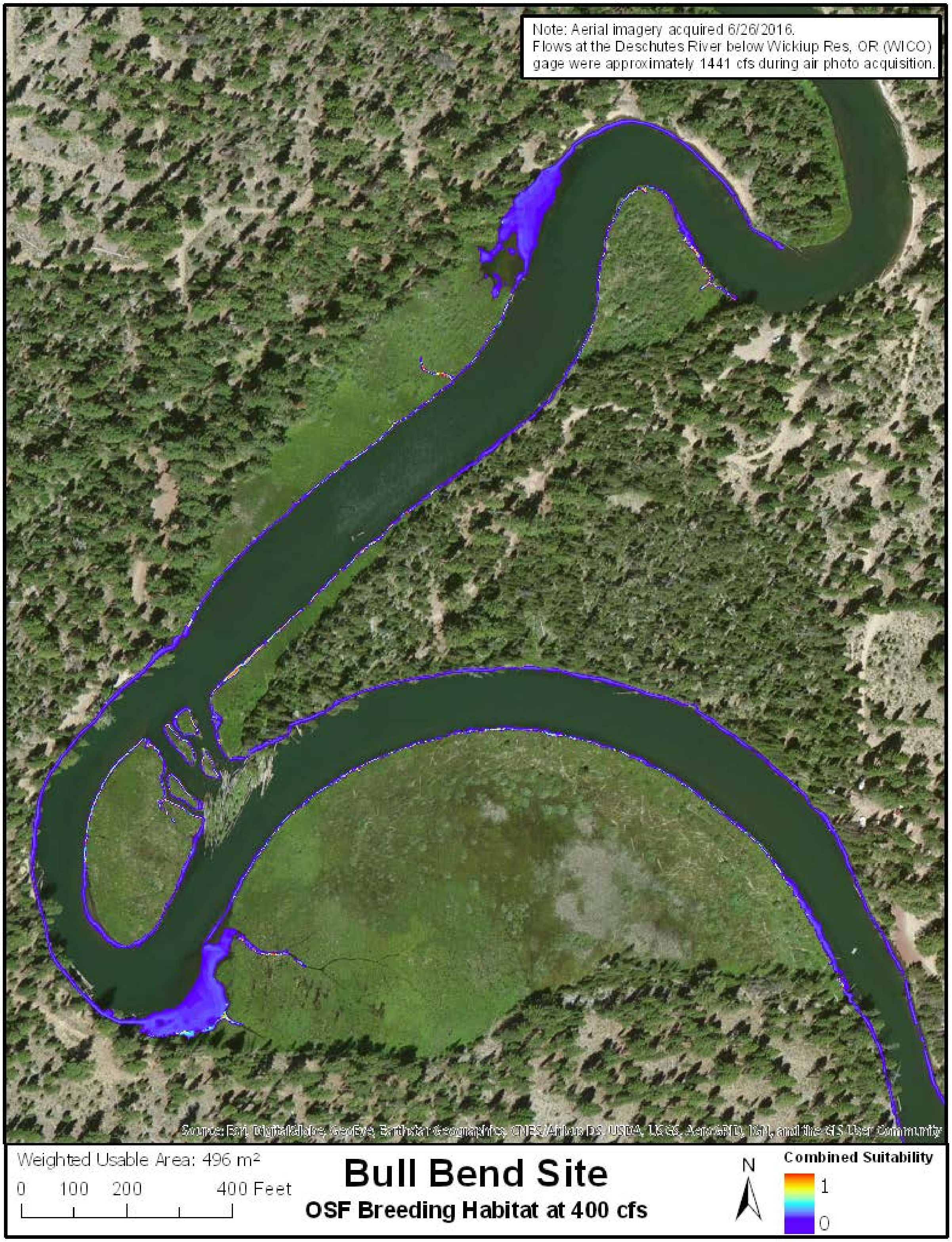

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 472 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 50 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 391 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 100 cfs
N
Combined Suitability
1
0

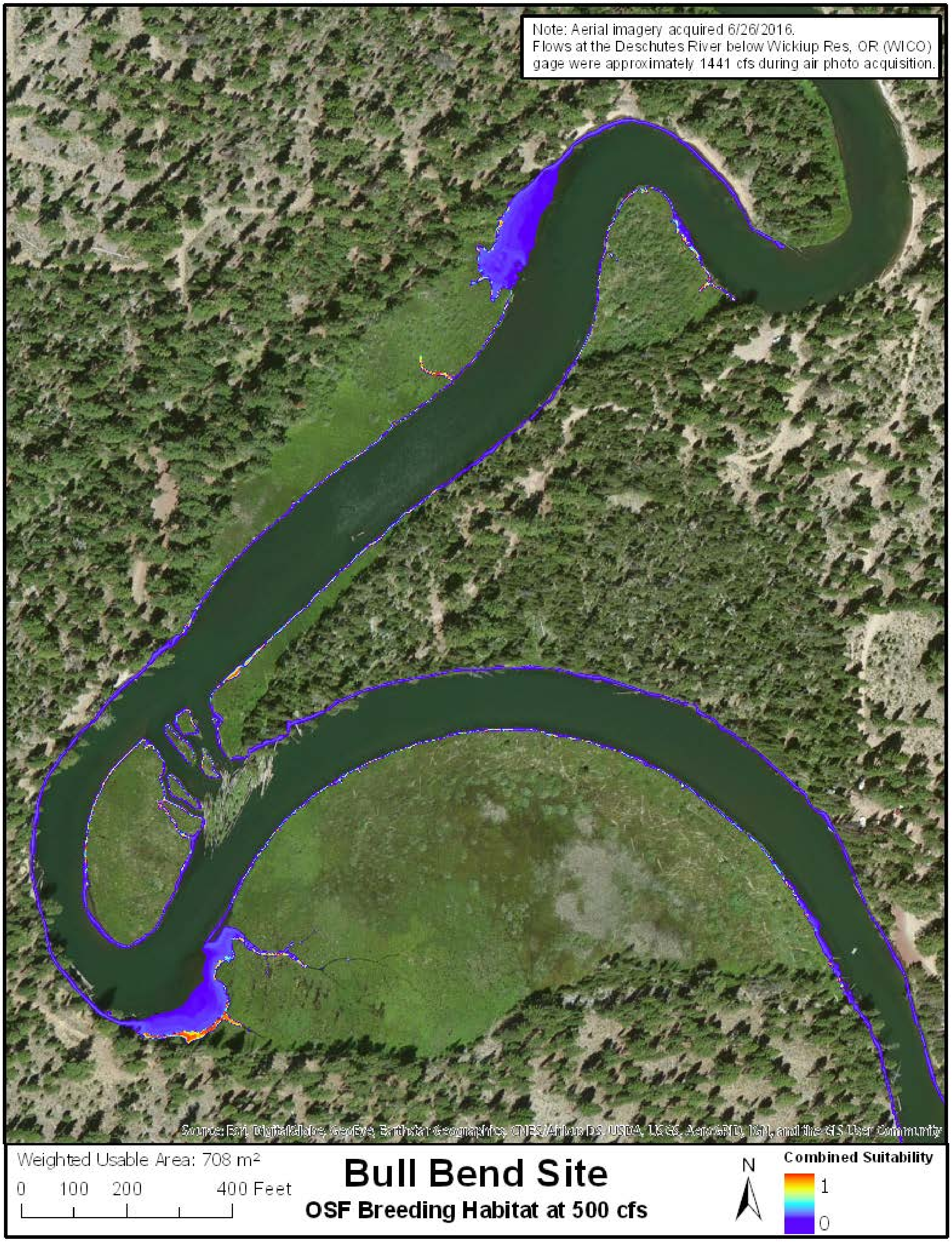


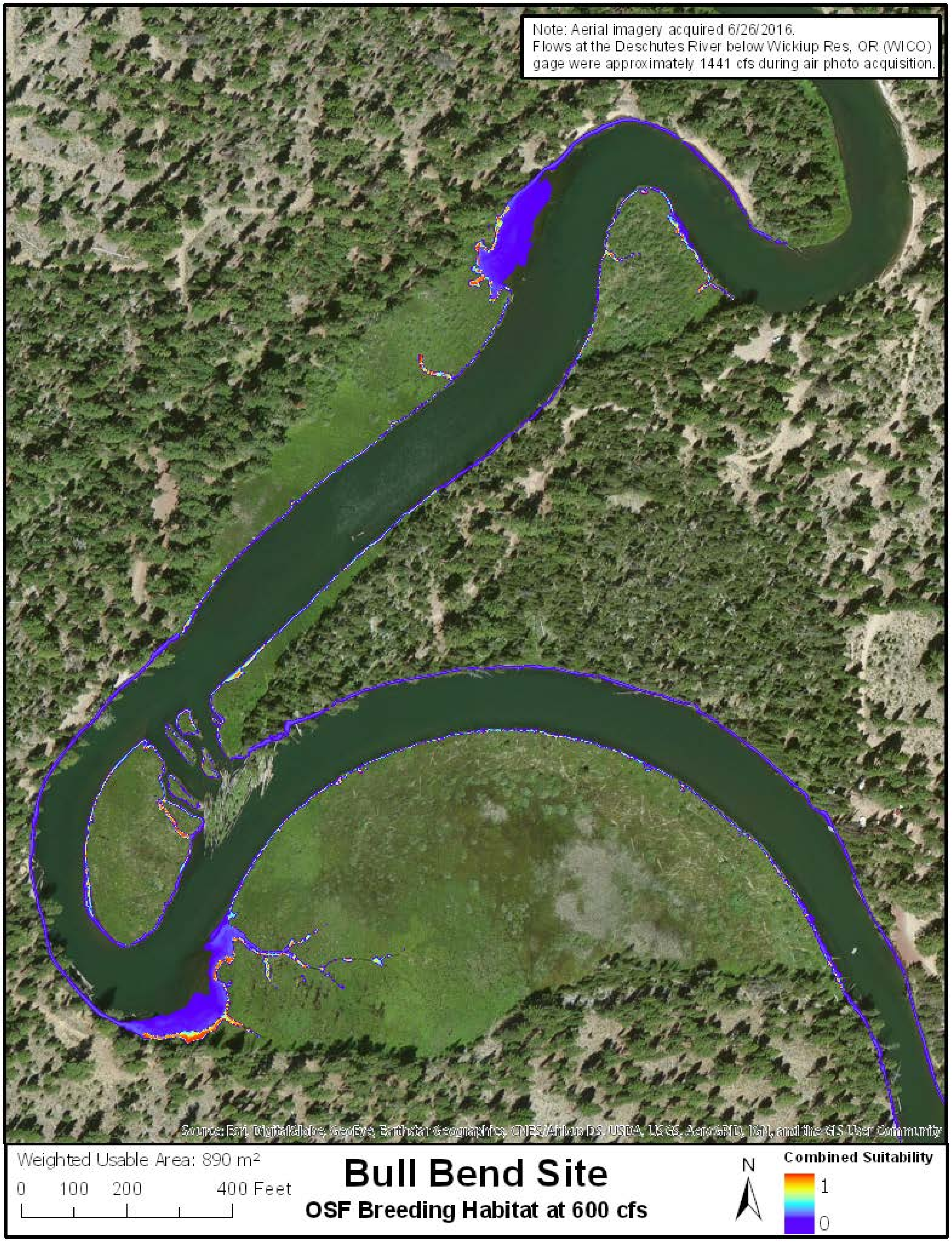
Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 328 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 196 cfs
N
Combined Suitability
1
0

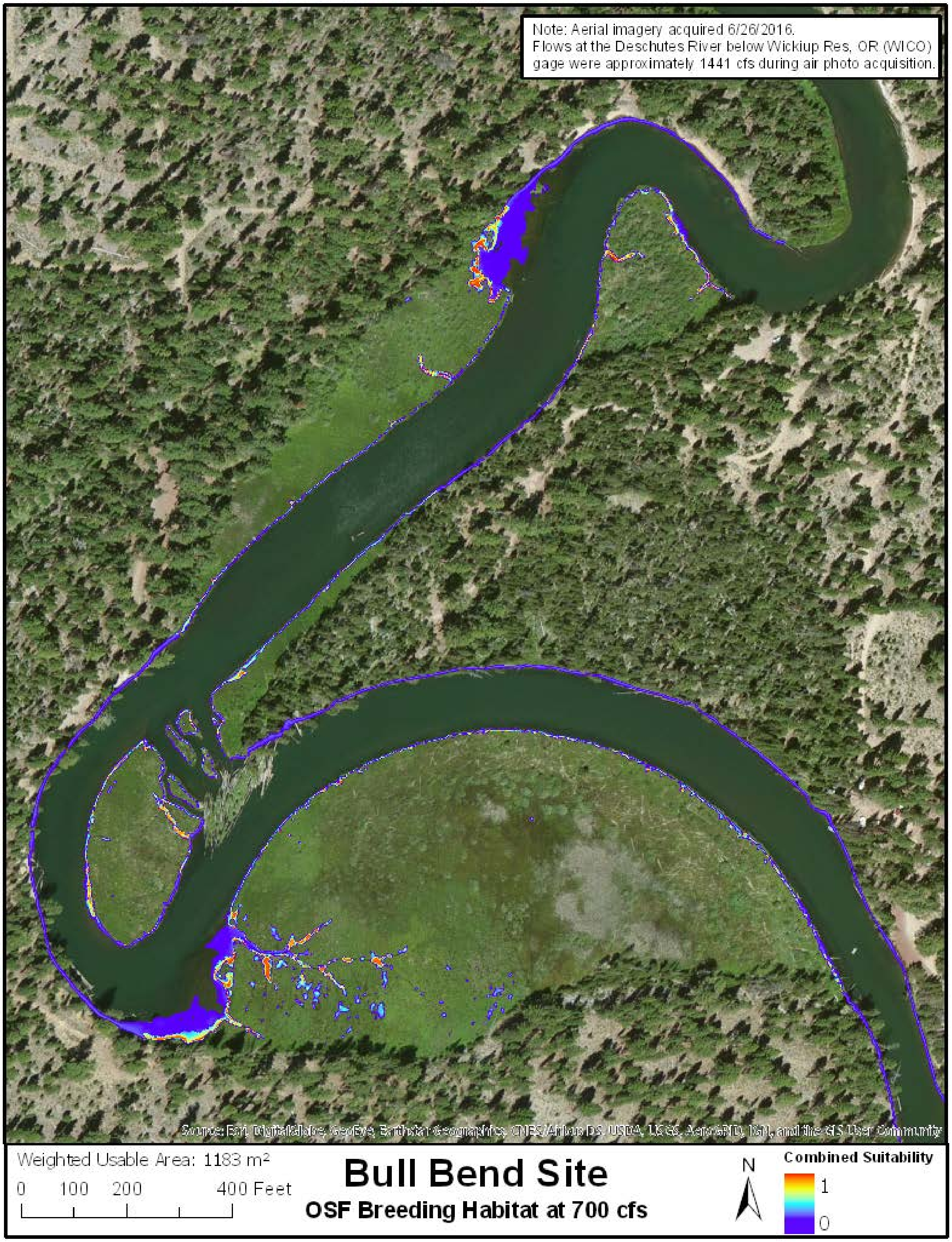

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 376 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 300 cfs
N
Combined Suitability
1
0

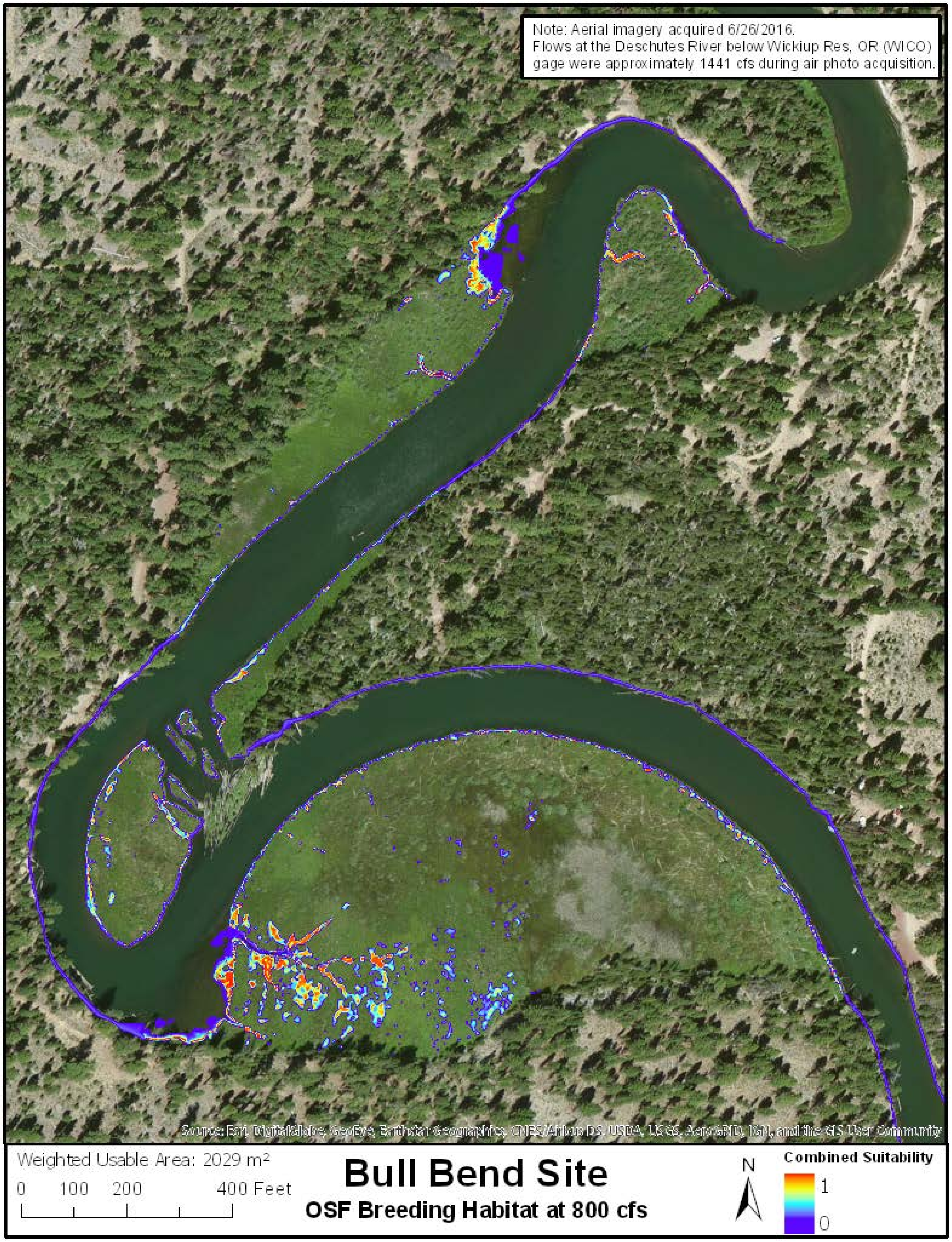


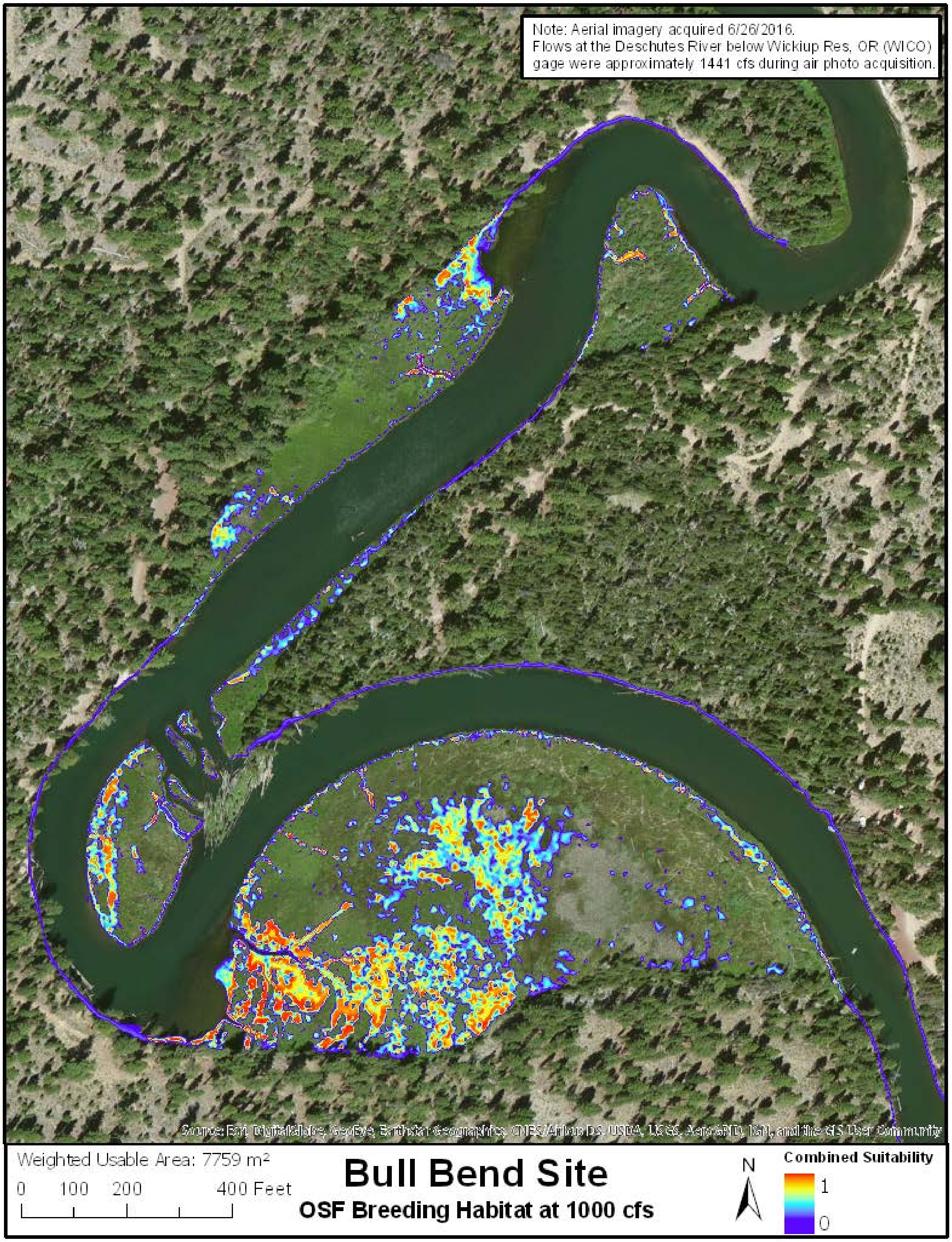
Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 496 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 400 cfs
N
Combined Suitability
1
0

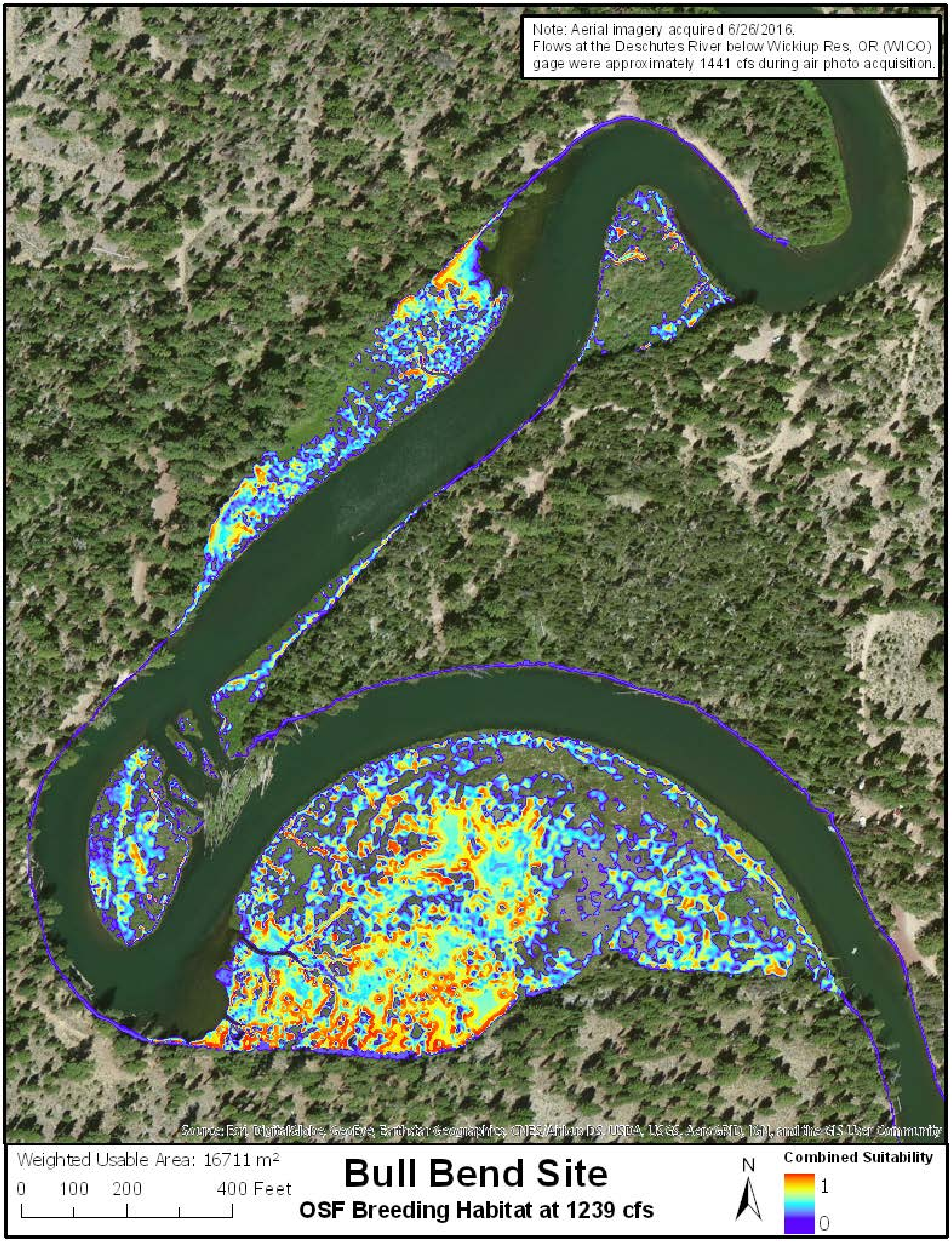

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 708 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 500 cfs
N
Combined Suitability
1
0

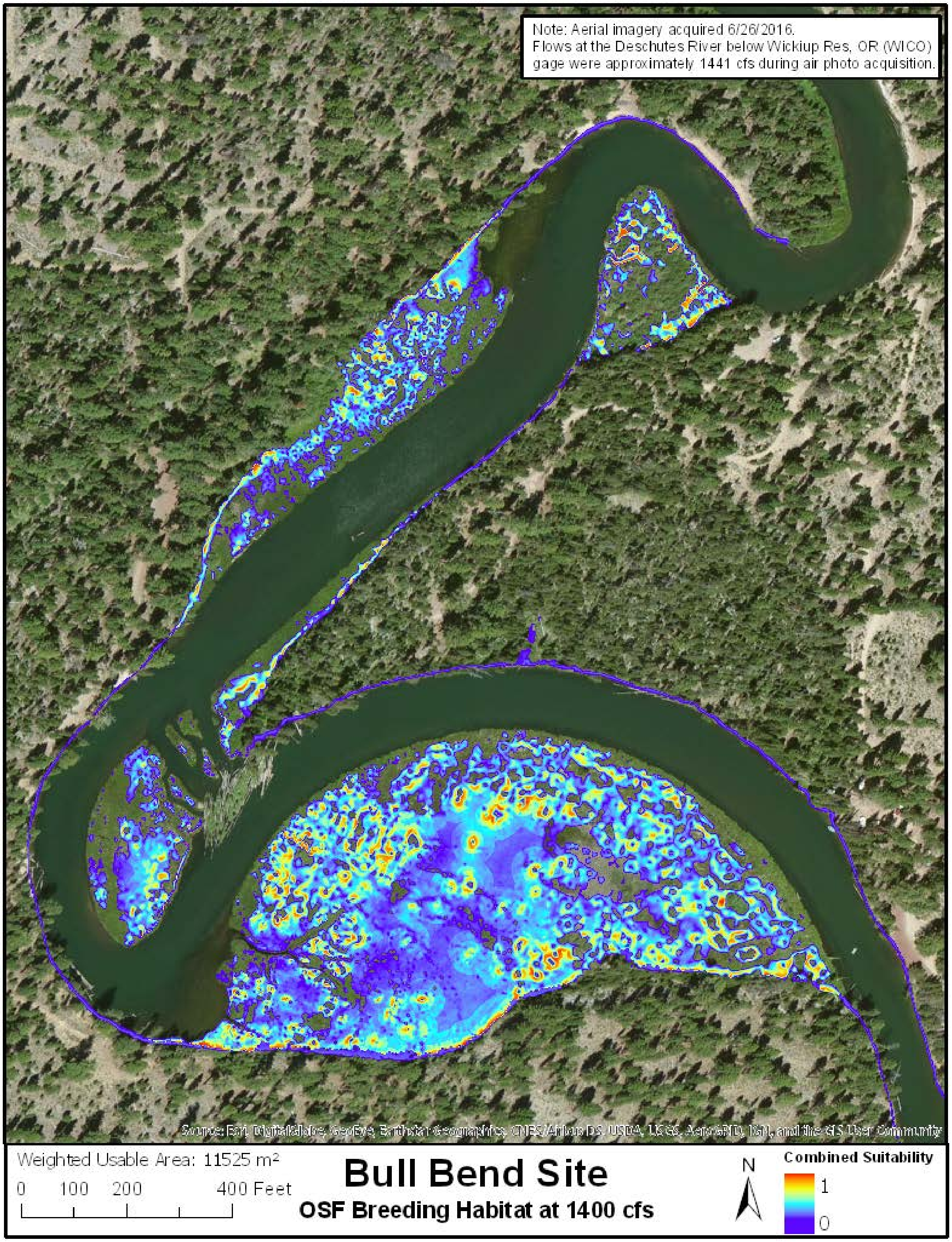

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 890 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 600 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 1183 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 700 cfs
N
Combined Suitability
1
0

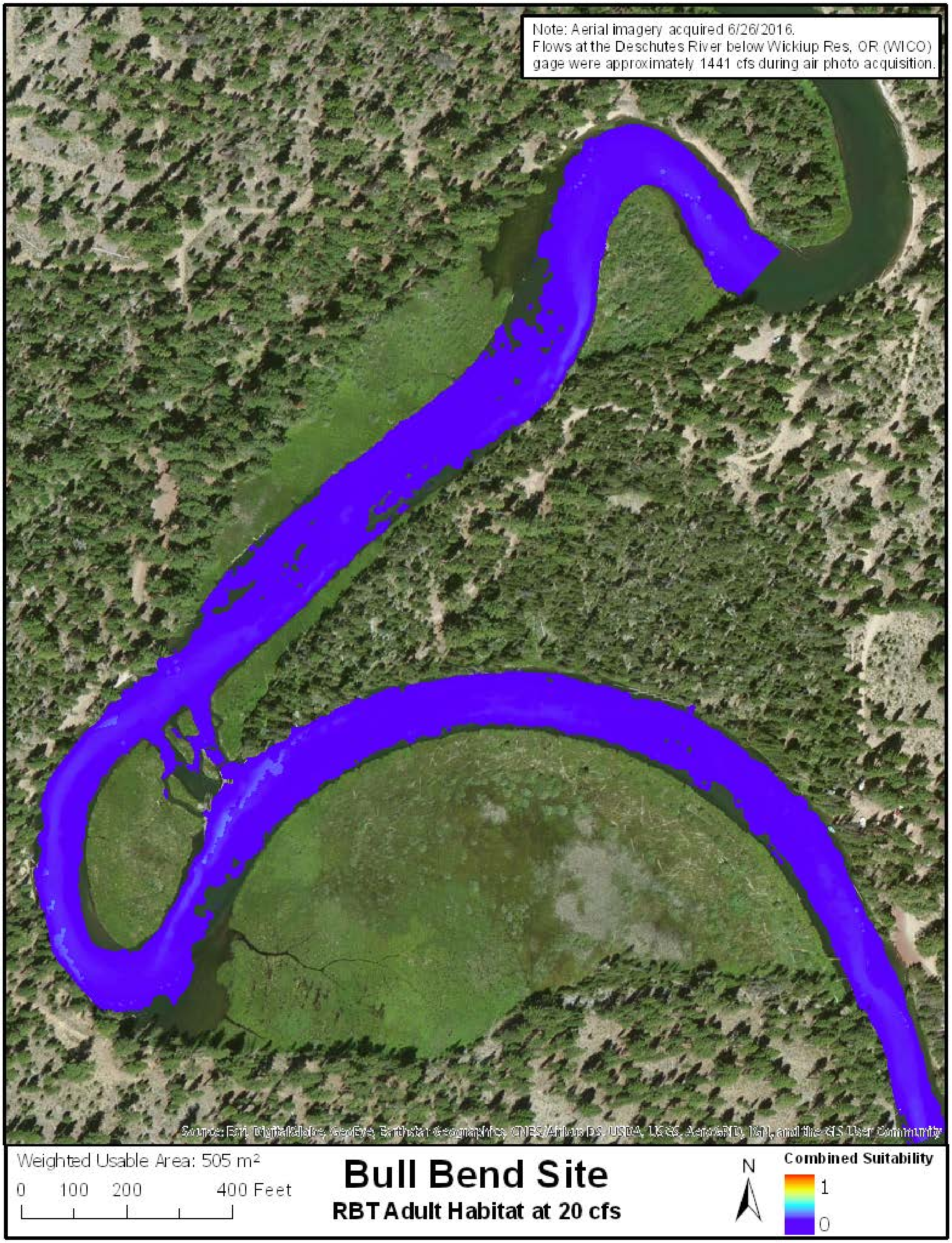

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 2029 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 800 cfs
N
Combined Suitability
1
0

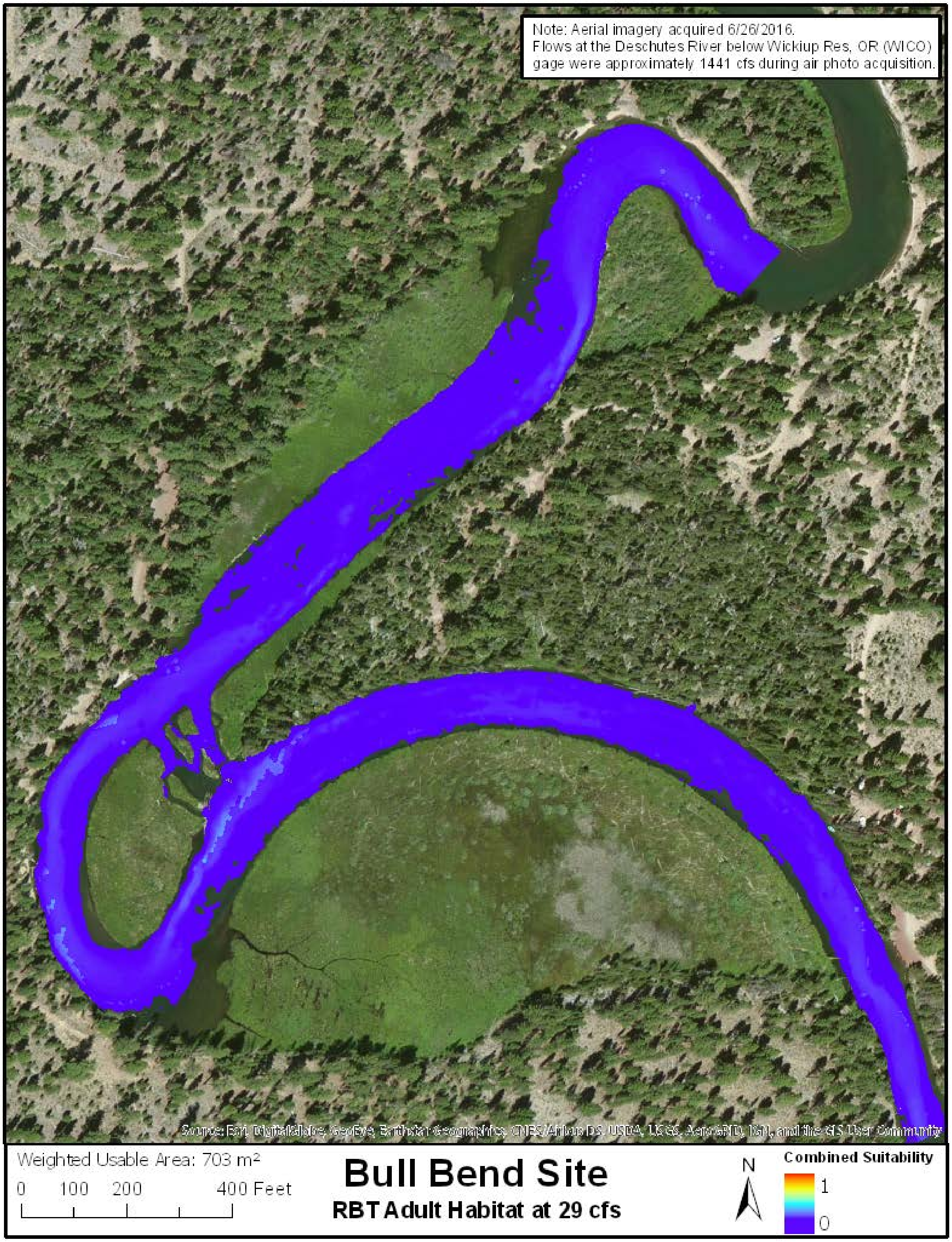

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 7759 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 1000 cfs
N
Combined Suitability
1
0

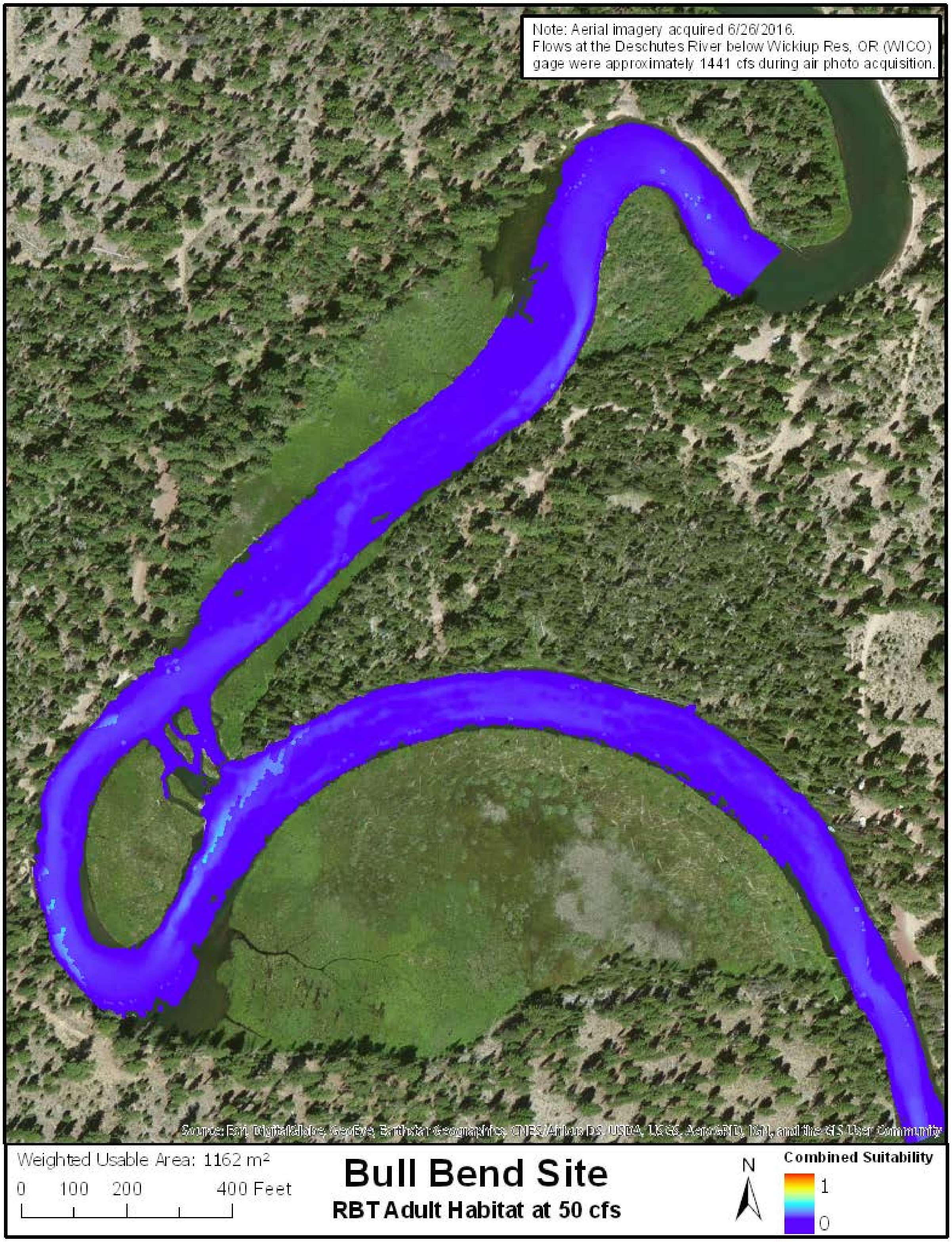

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 16711 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 1239 cfs
N
Combined Suitability
1
0

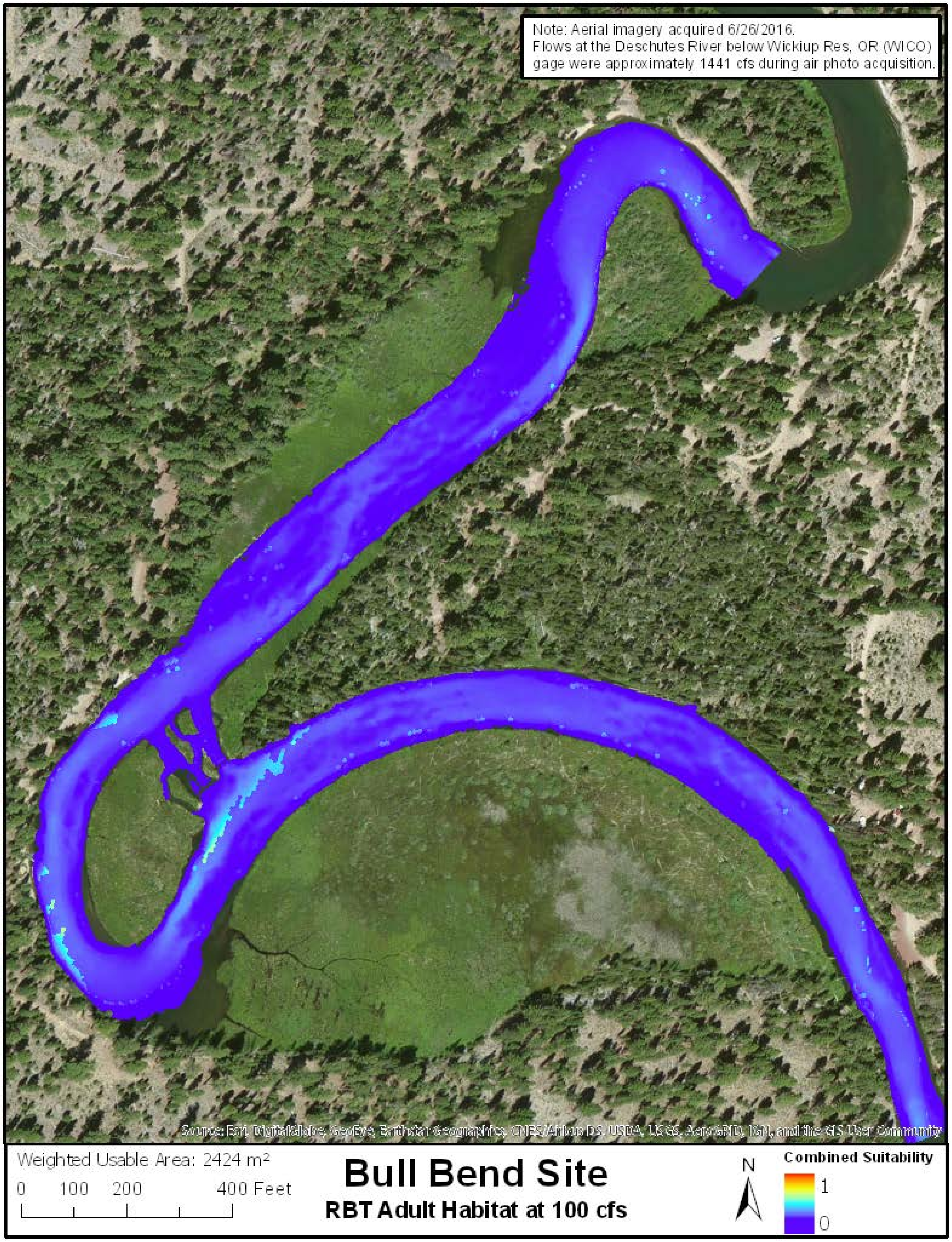

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 11525 m²
0 100 200 400 Feet
Bull Bend Site
OSF Breeding Habitat at 1400 cfs
N
Combined Suitability
1
0

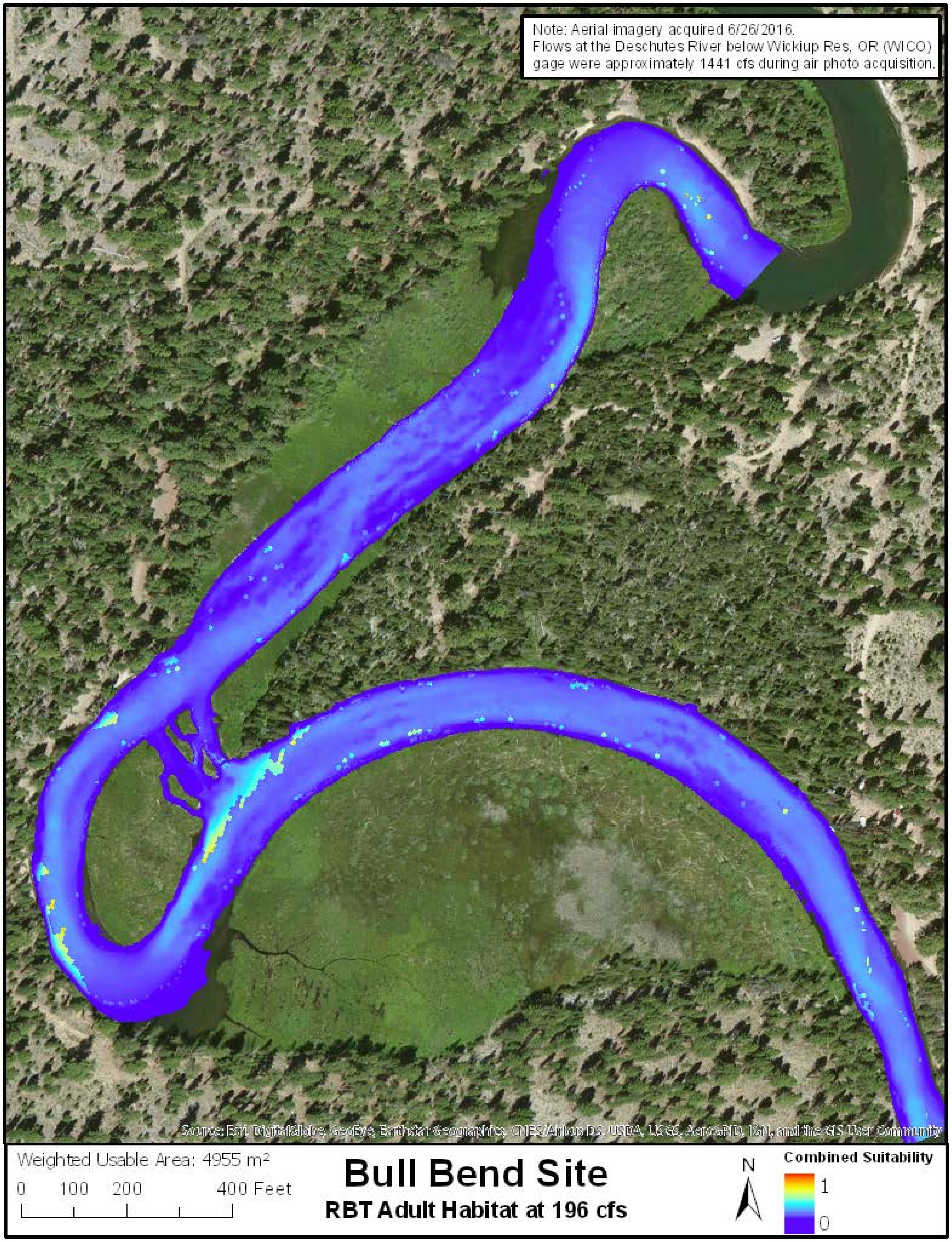
Bull Bend – Redband Trout Adult Holding Habitat

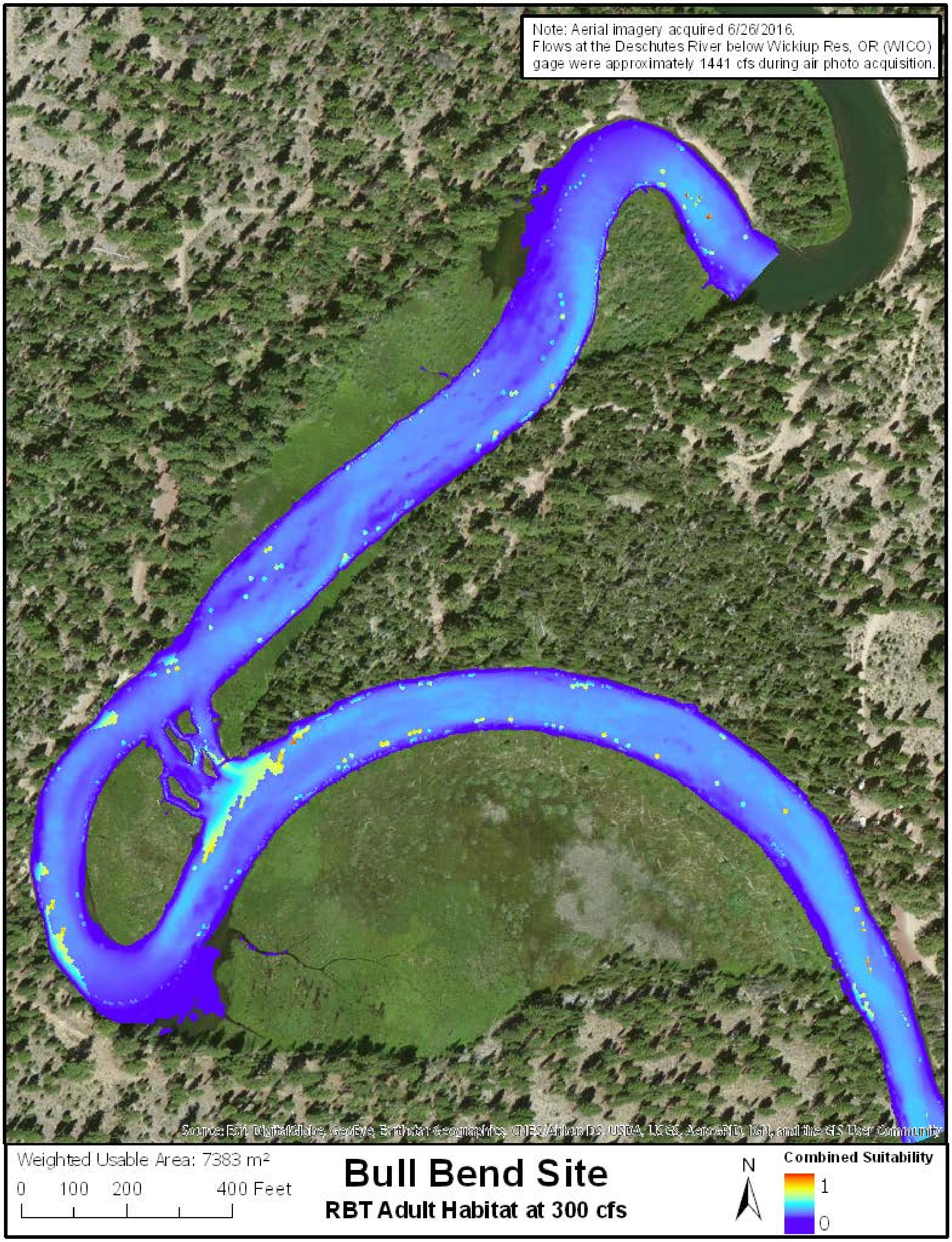


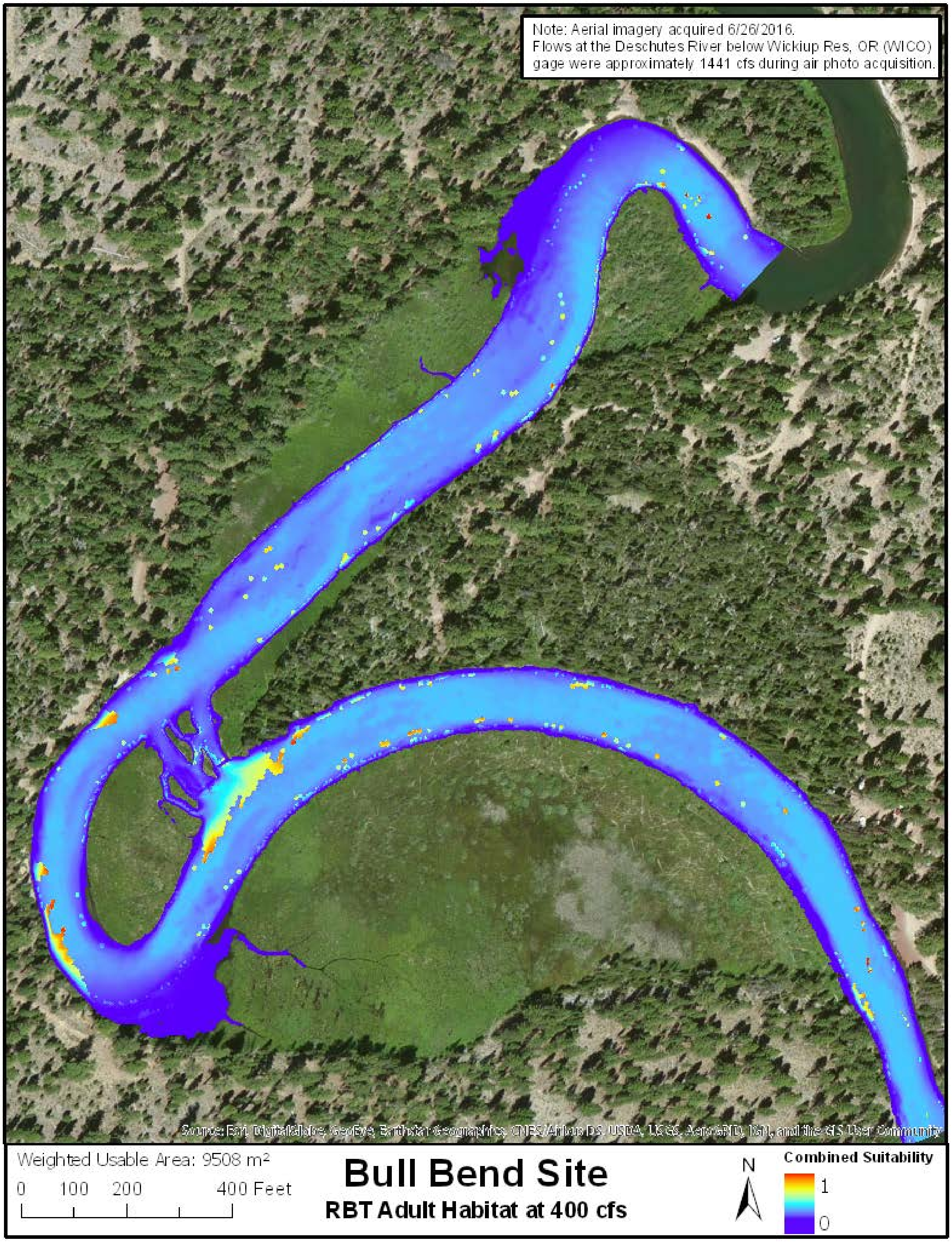

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 703 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 29 cfs
N
Combined Suitability
1
0

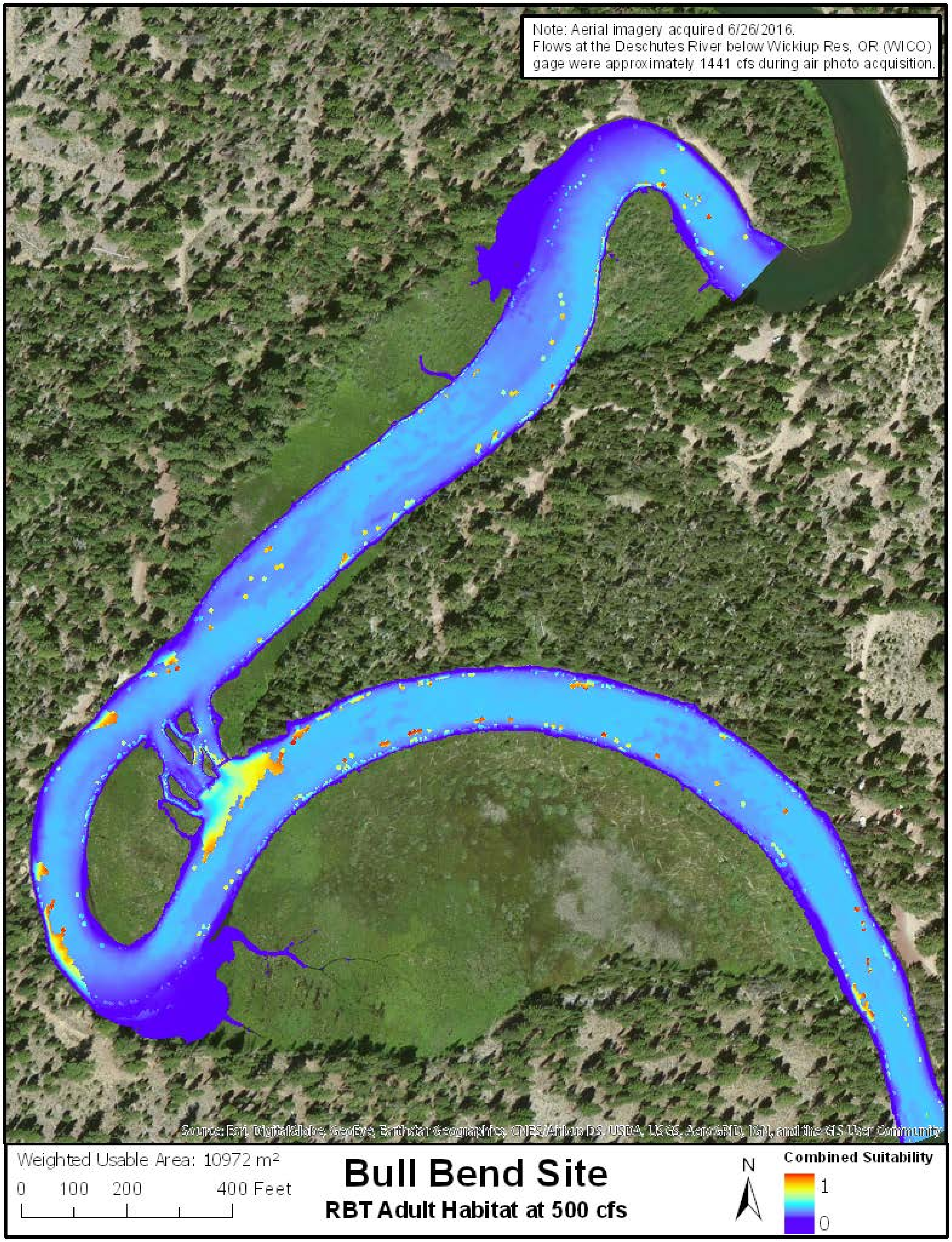

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 1162 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 50 cfs
N
Combined Suitability
1
0

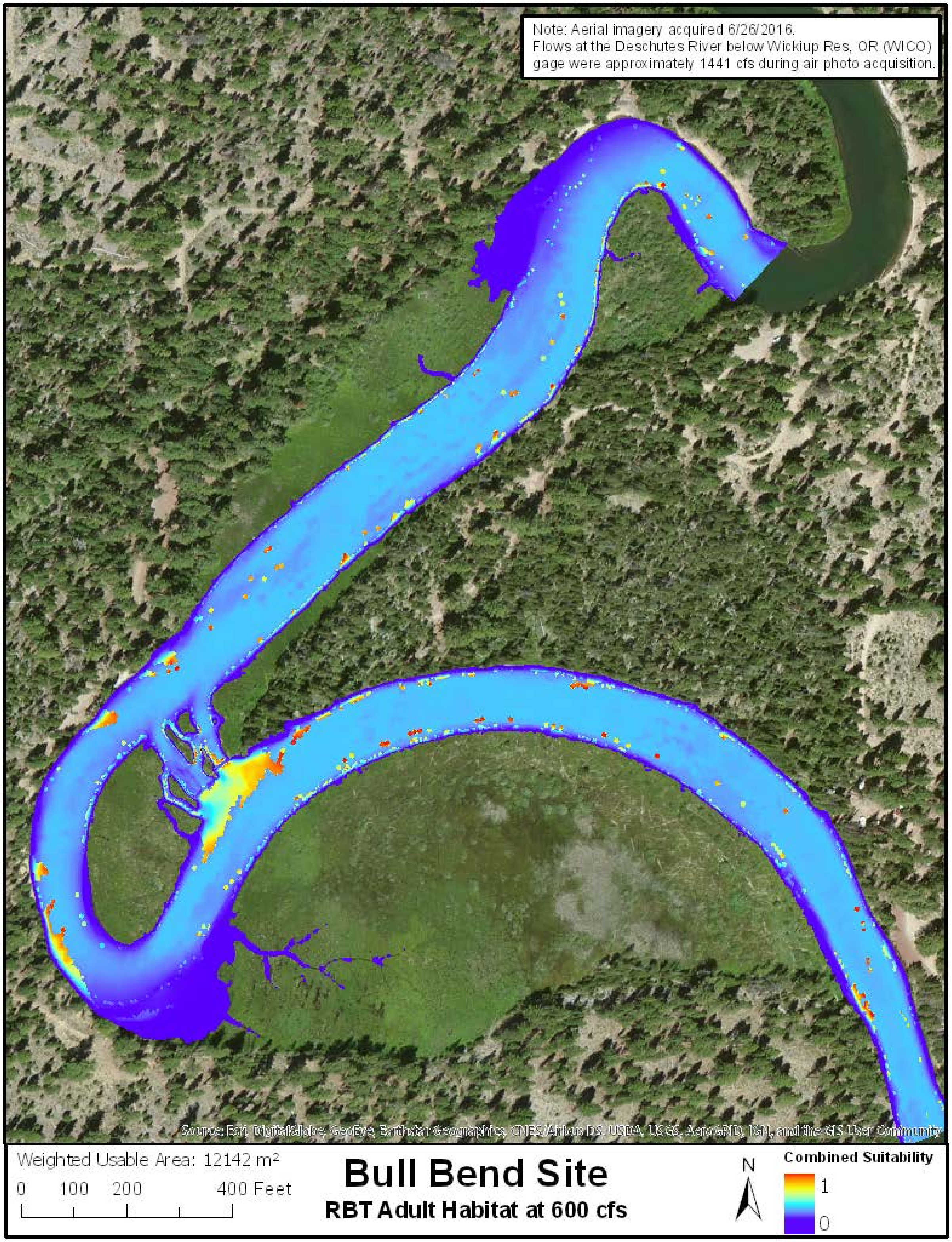

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 2424 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 100 cfs
N
Combined Suitability
1
0

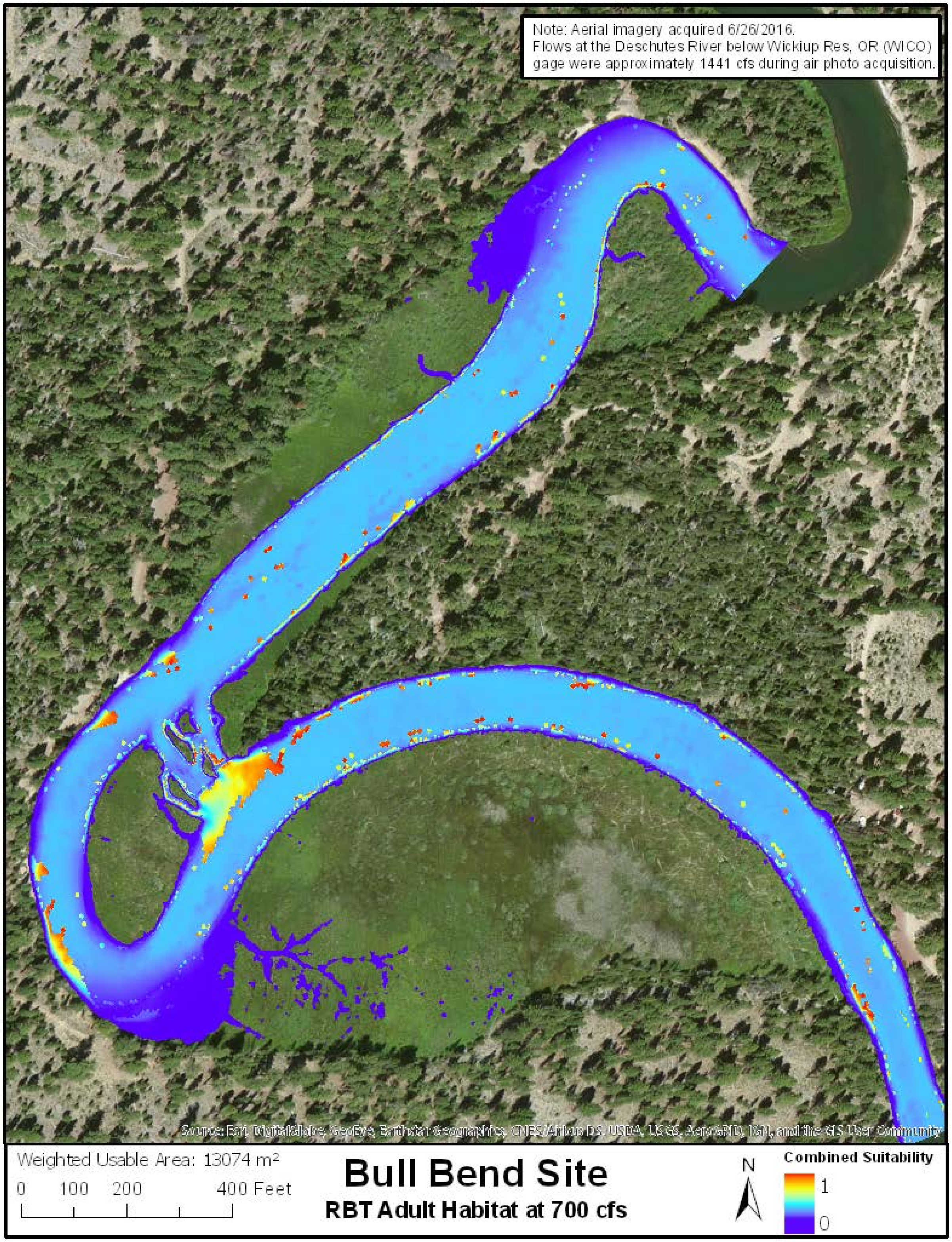

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 4955 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 196 cfs
N
Combined Suitability
1
0

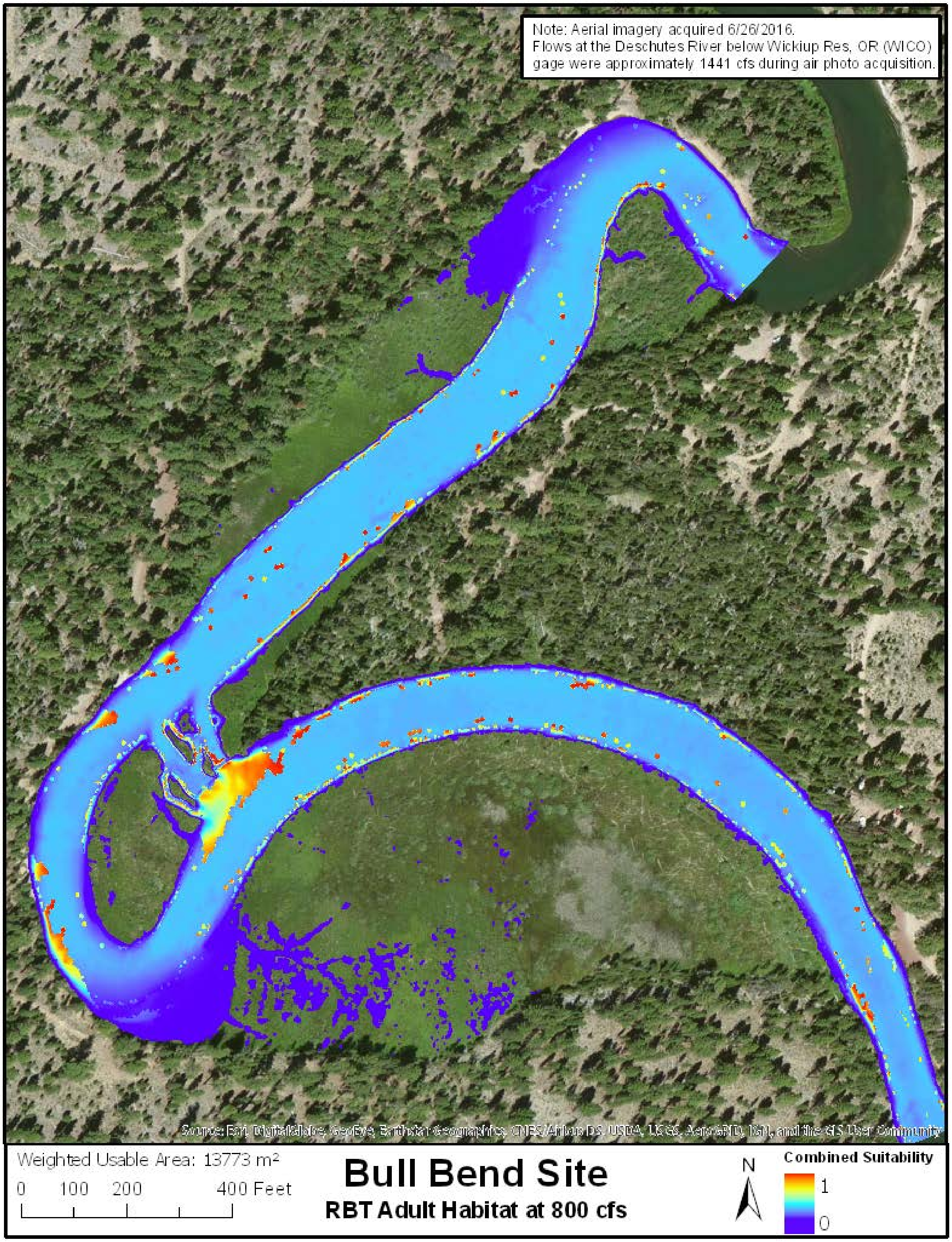

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 7383 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 300 cfs
N
Combined Suitability
1
0

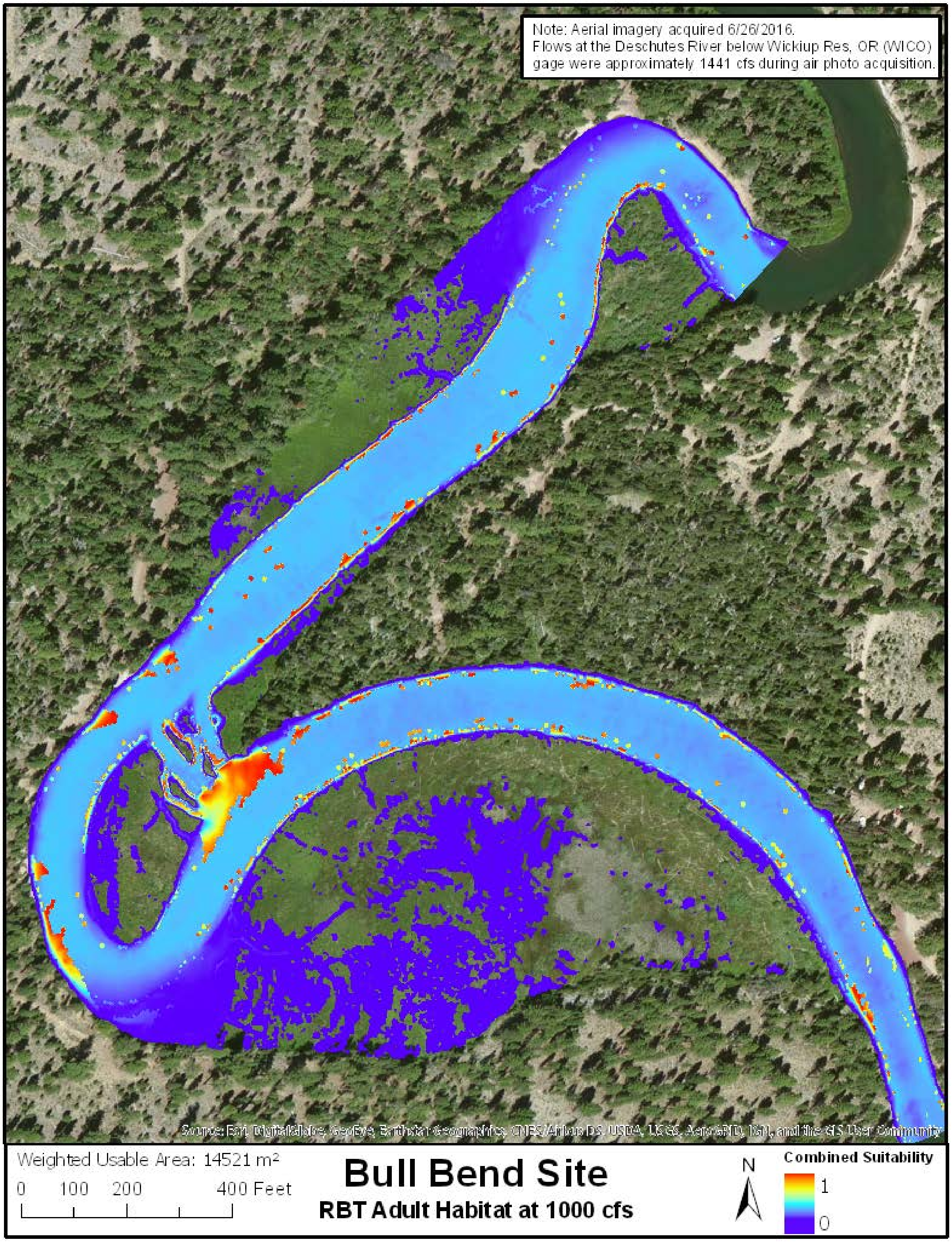

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 9508 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 400 cfs
N
Combined Suitability
1
0

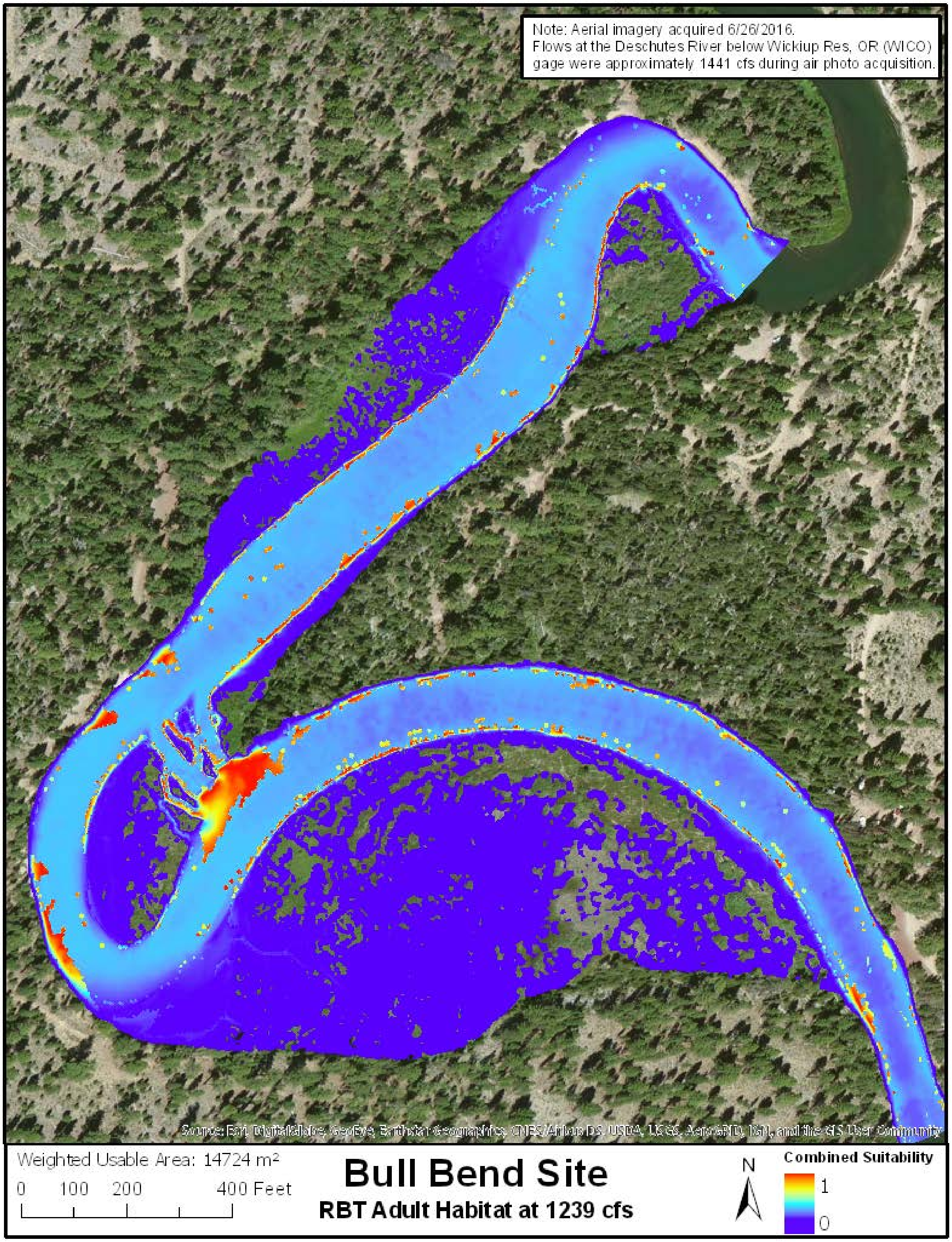

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 10972 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 500 cfs
N
Combined Suitability
1
0

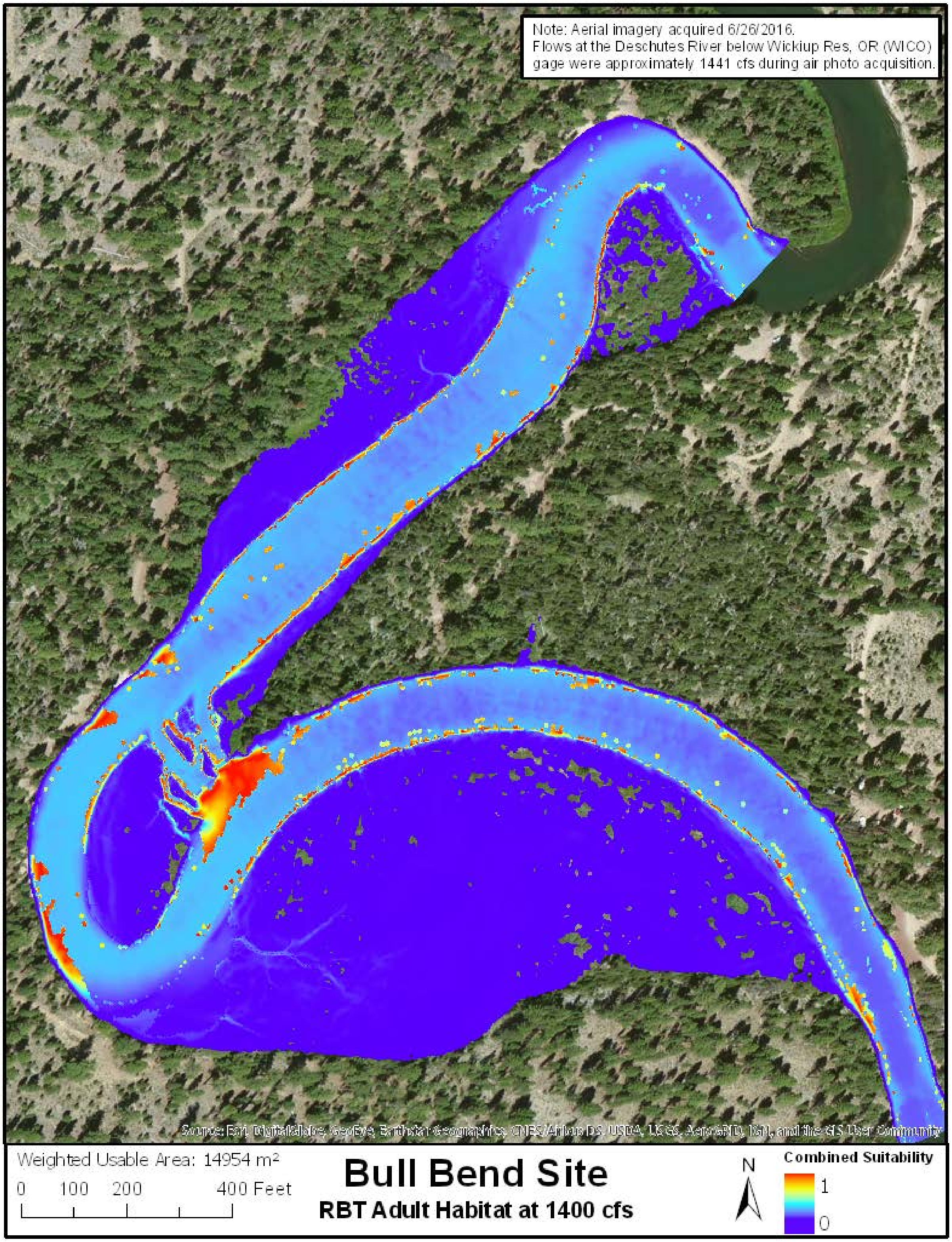

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 12142 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 600 cfs
N
Combined Suitability
1
0

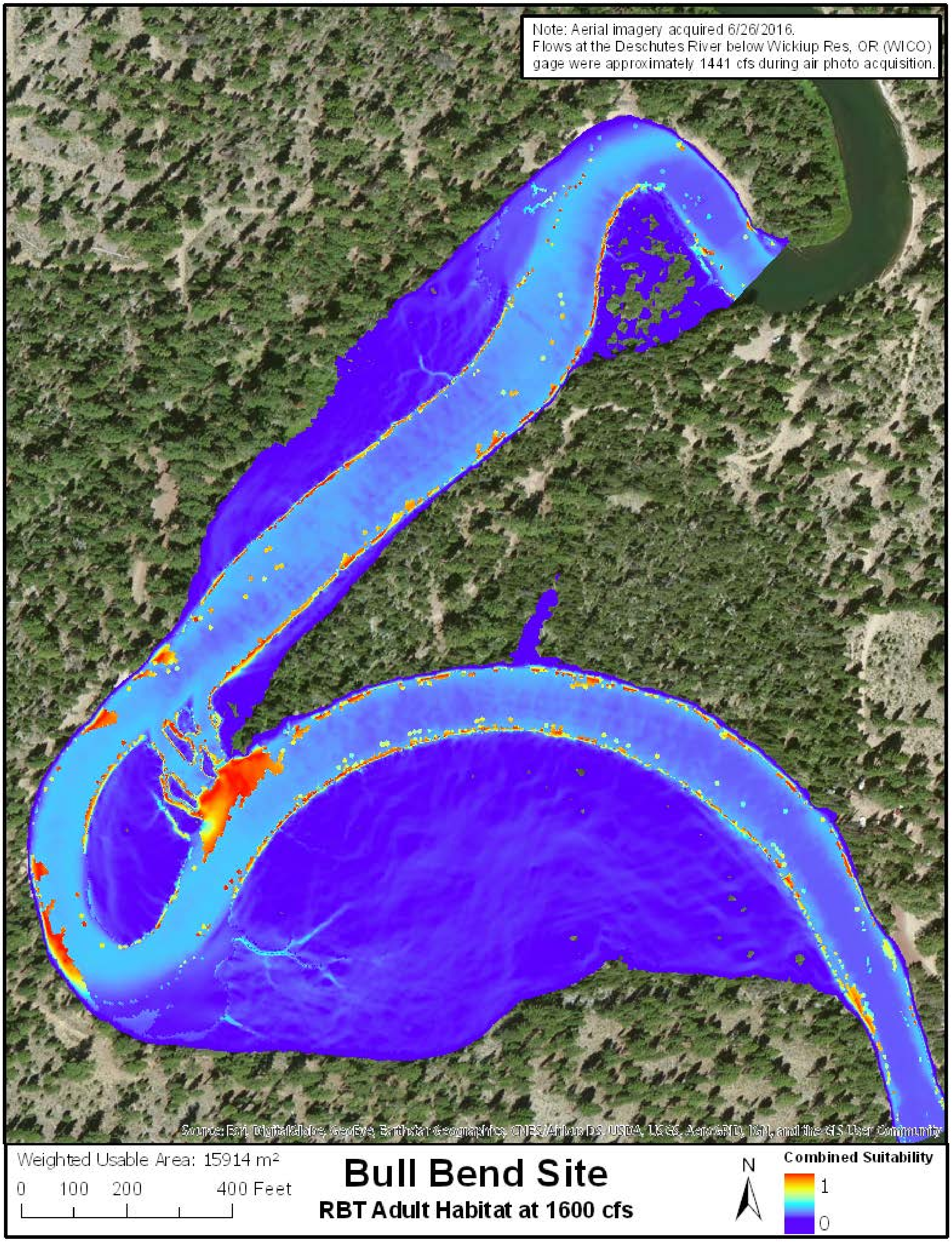

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 13074 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 700 cfs
N
Combined Suitability
1
0

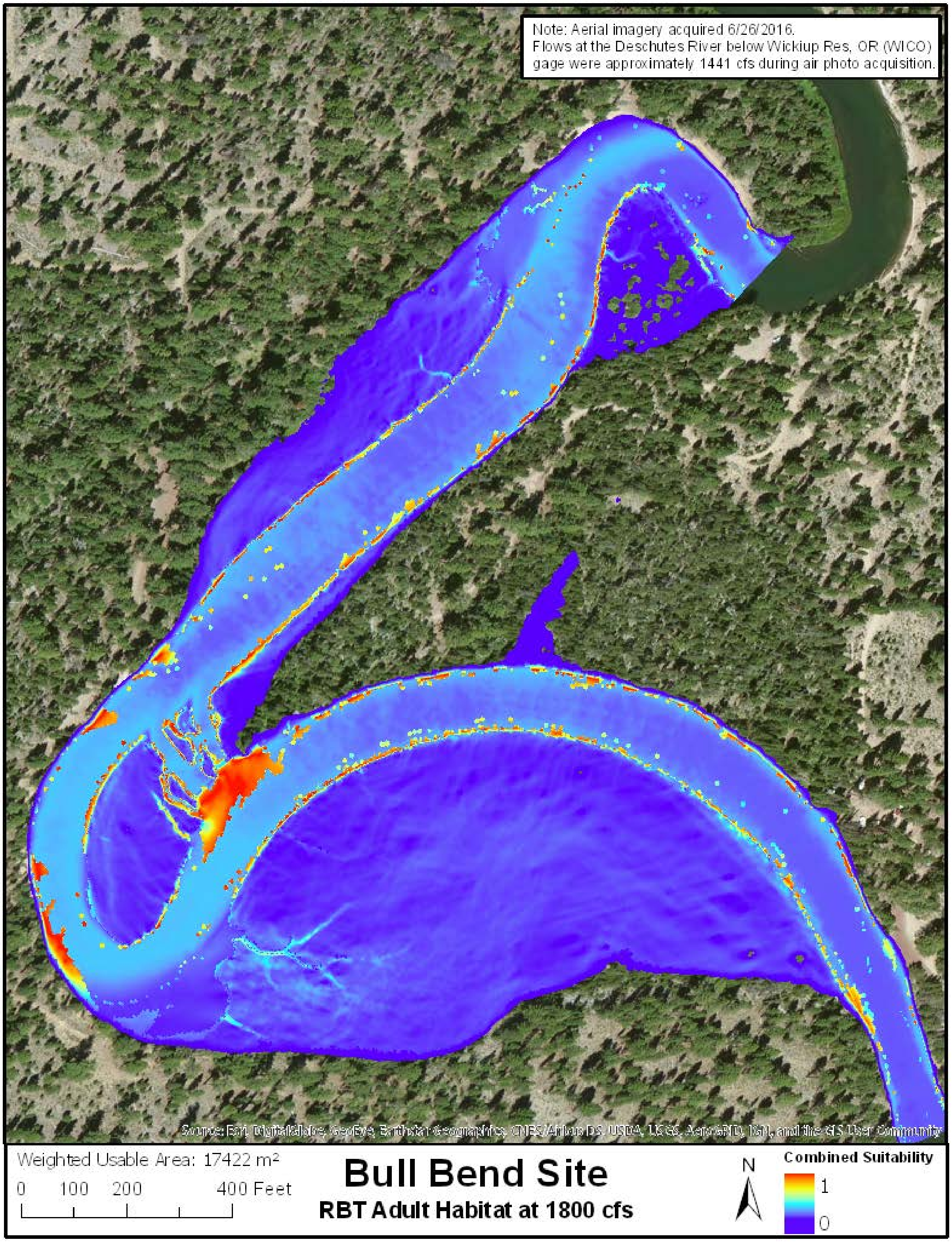

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 13773 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 800 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 14521 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 1000 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 14724 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 1239 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 14954 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 1400 cfs
N
Combined Suitability
1
0

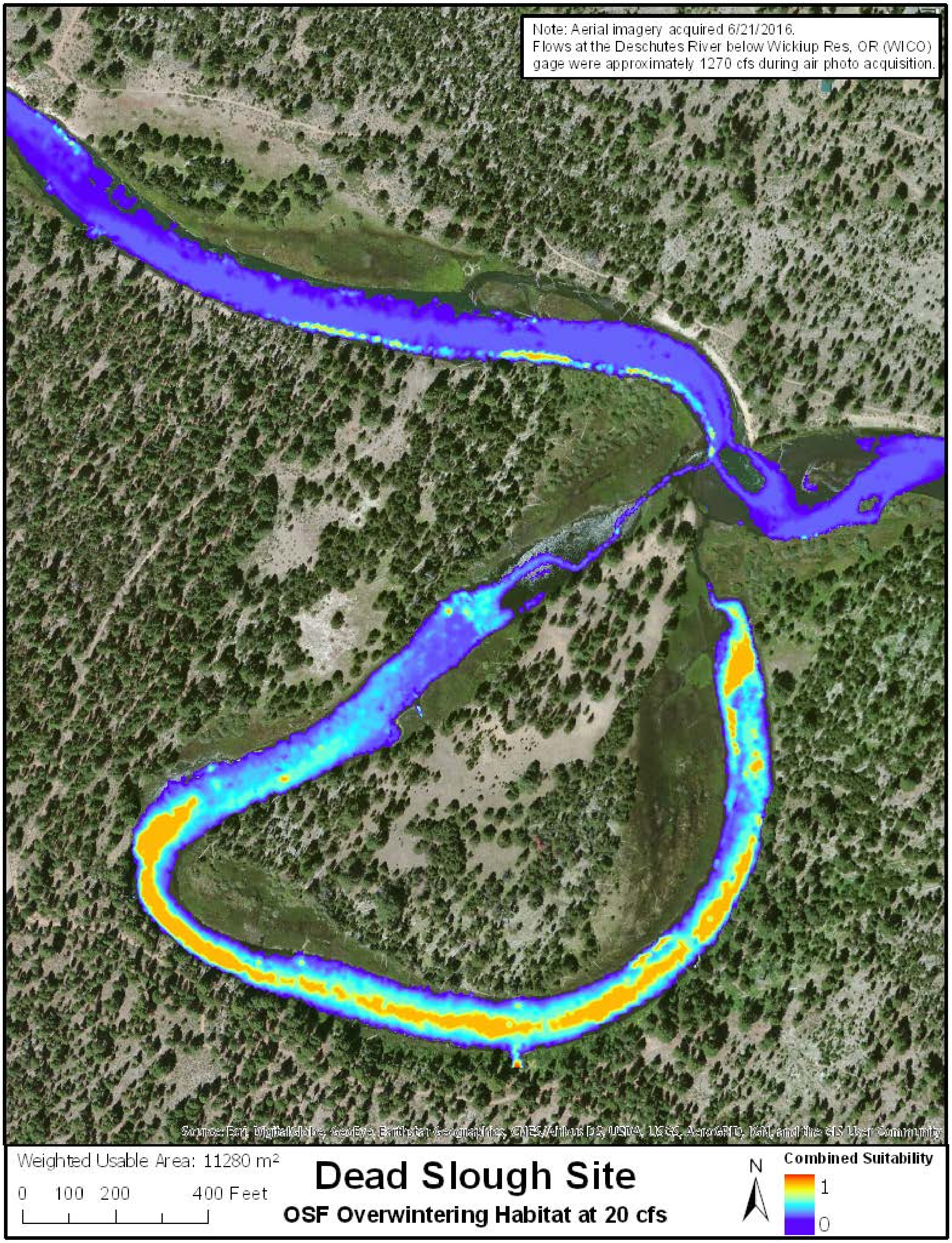

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 15914 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 1600 cfs
N
Combined Suitability
1
0

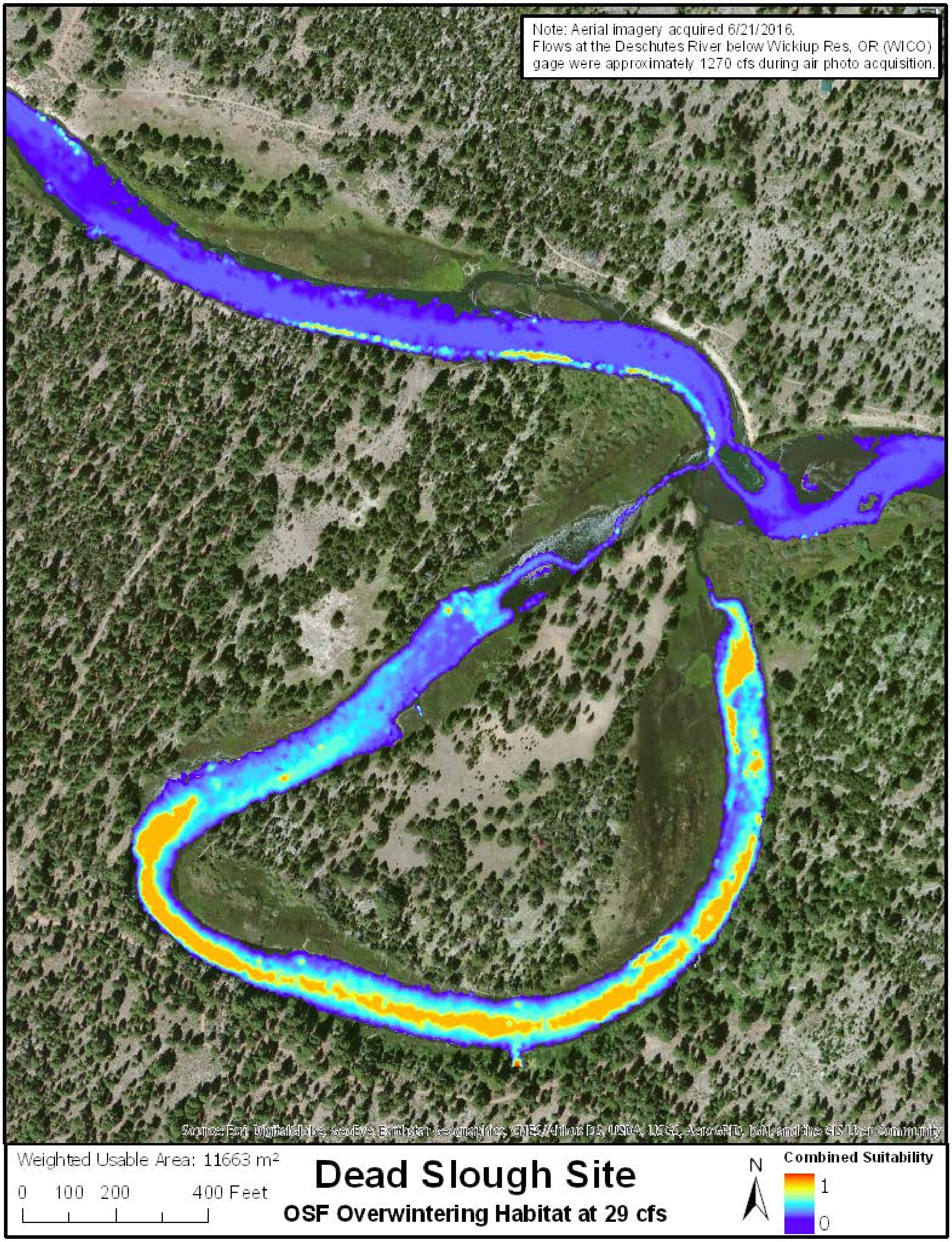

Note: Aerial imagery acquired 6/26/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1441 cfs during air photo acquisition.
Weighted Usable Area: 17422 m²
0 100 200 400 Feet
Bull Bend Site
RBT Adult Habitat at 1800 cfs
N
Combined Suitability
1
0

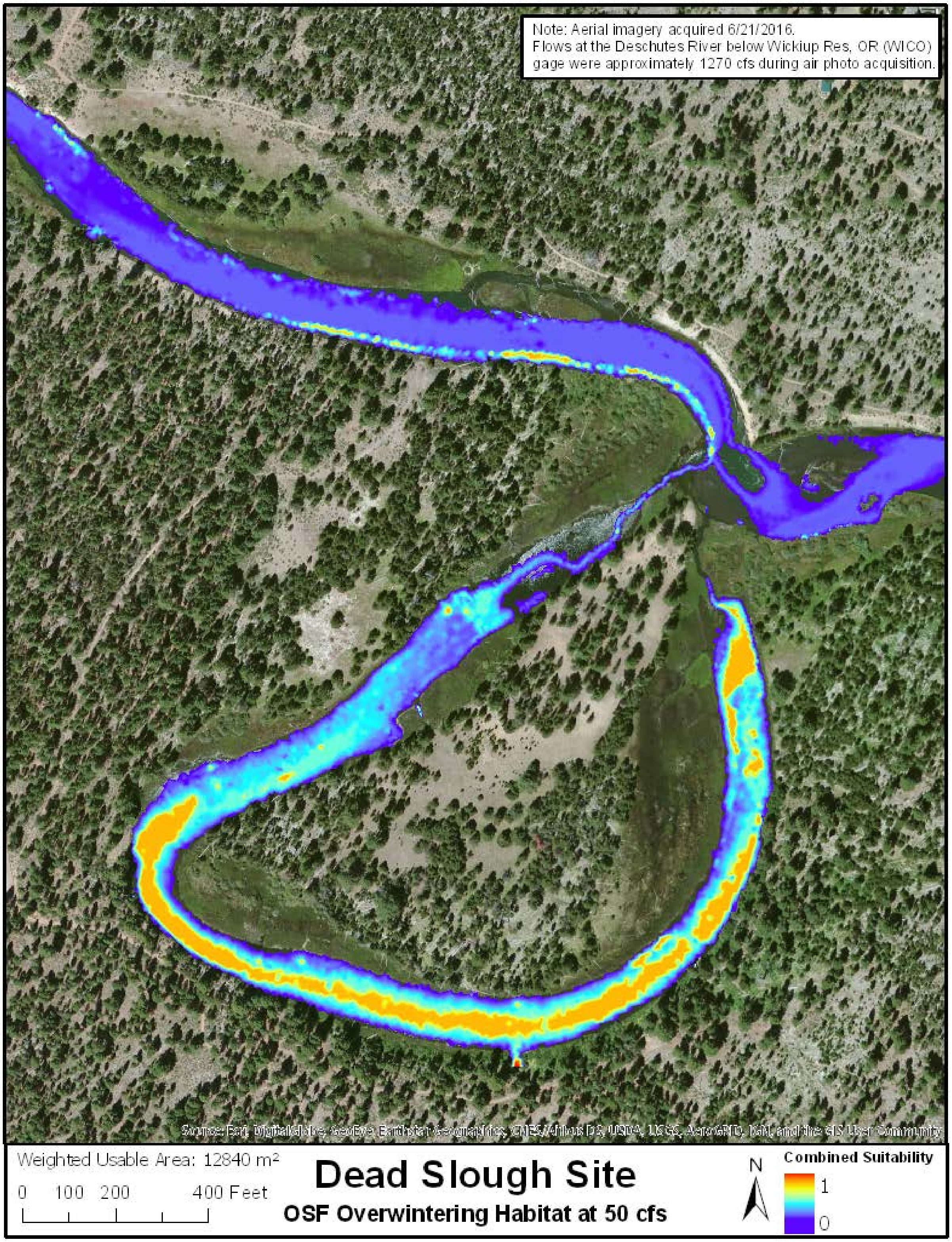
Appendix B

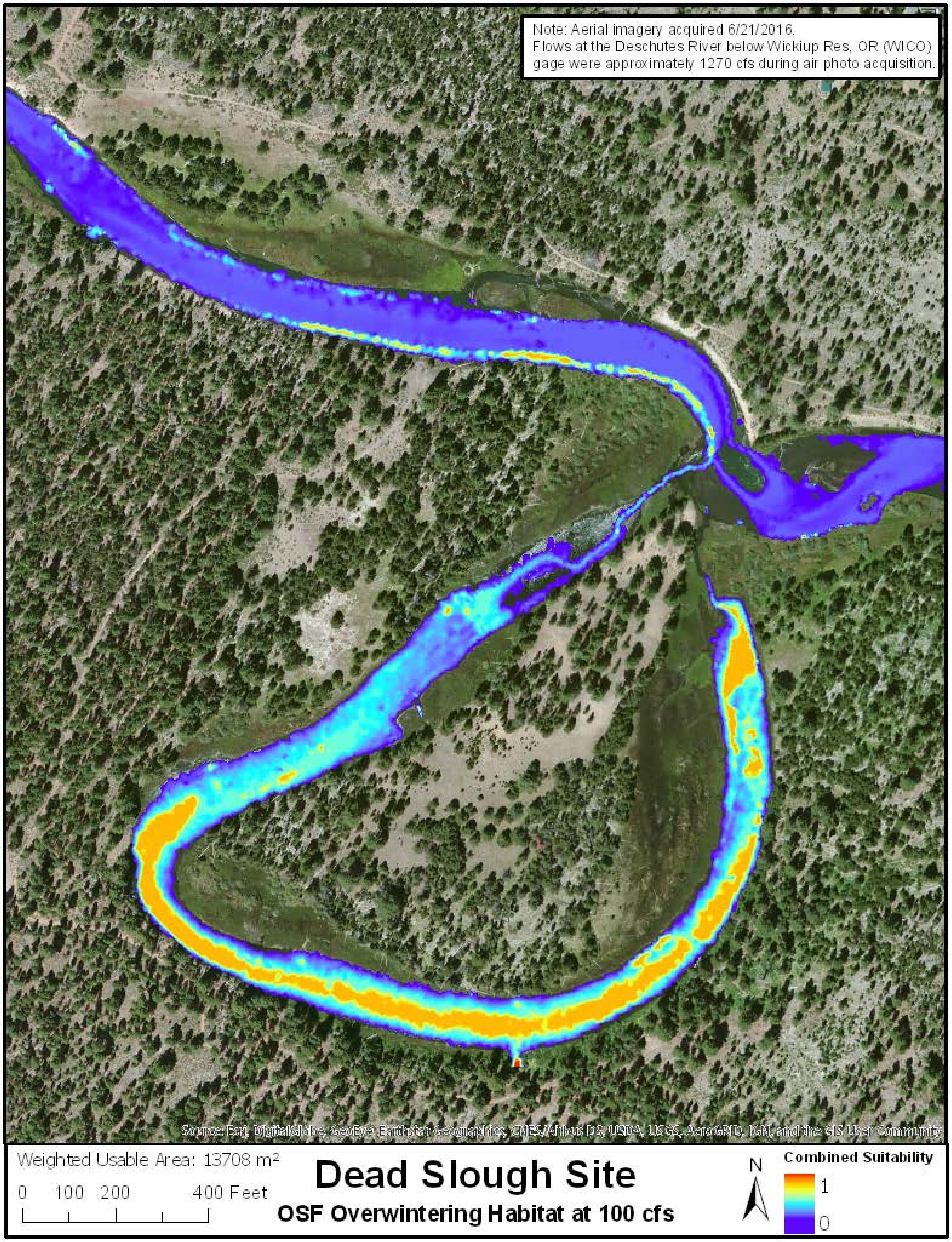
Habitat Suitability Maps - Dead Slough

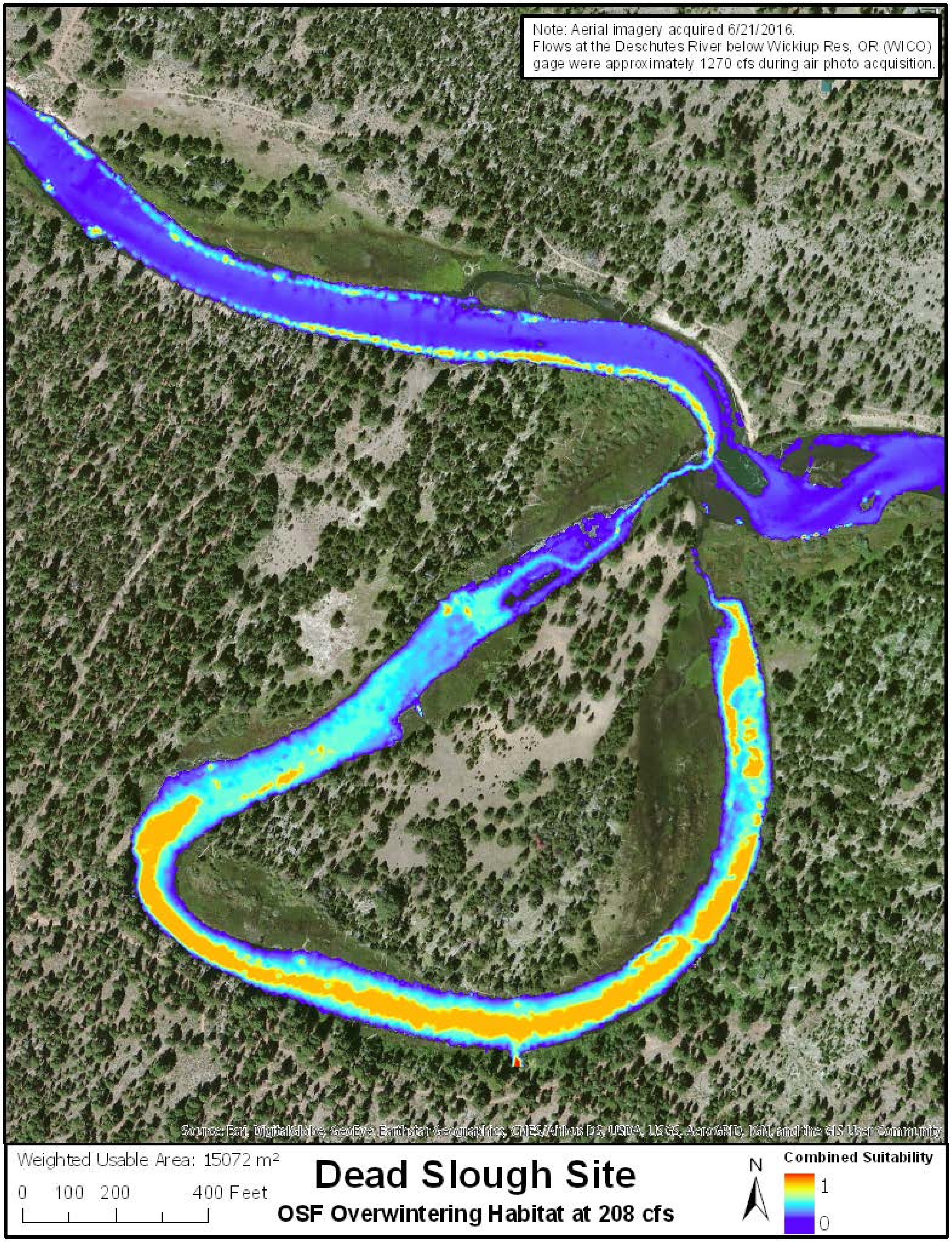
Dead Slough – Oregon Spotted Frog Overwintering Habitat

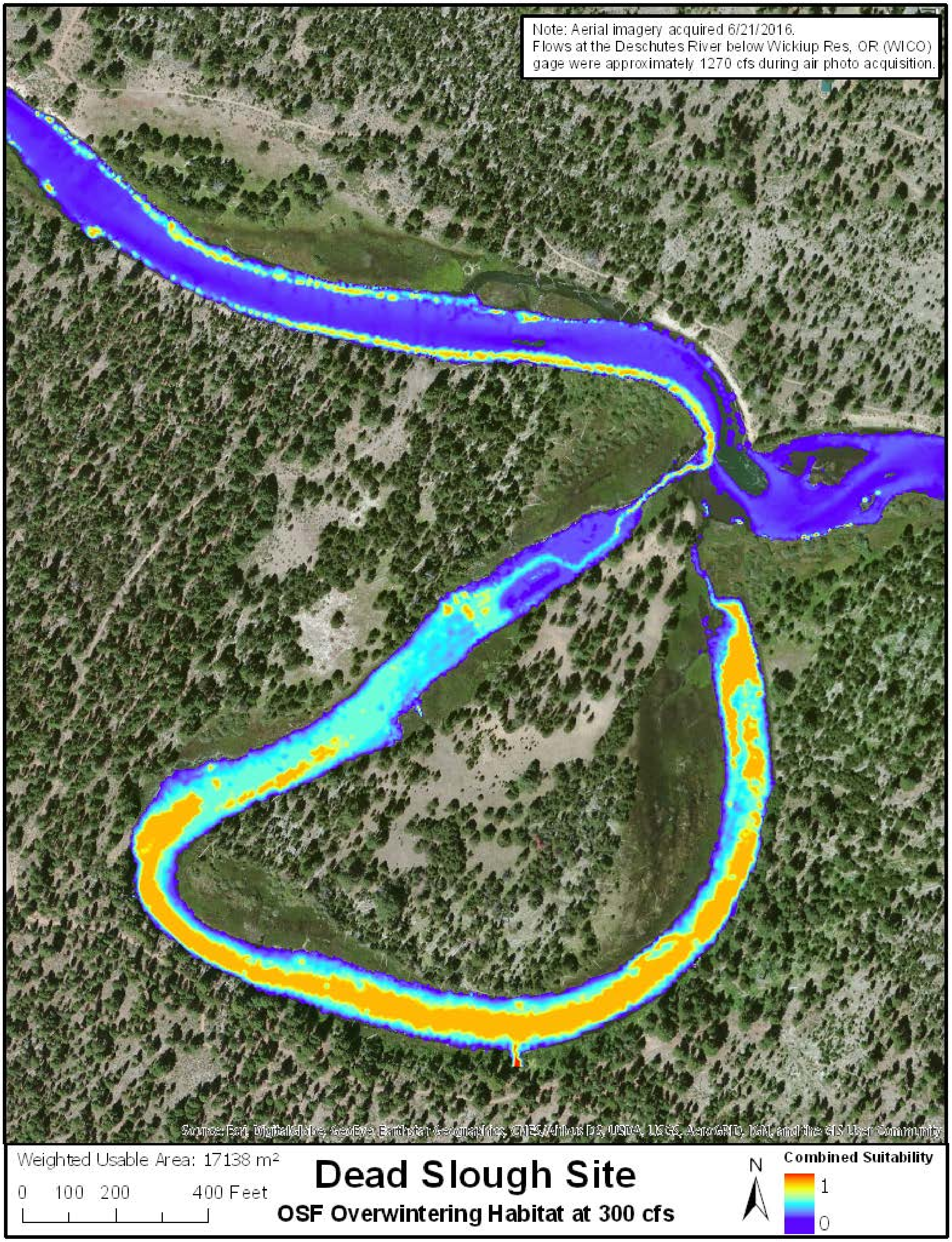


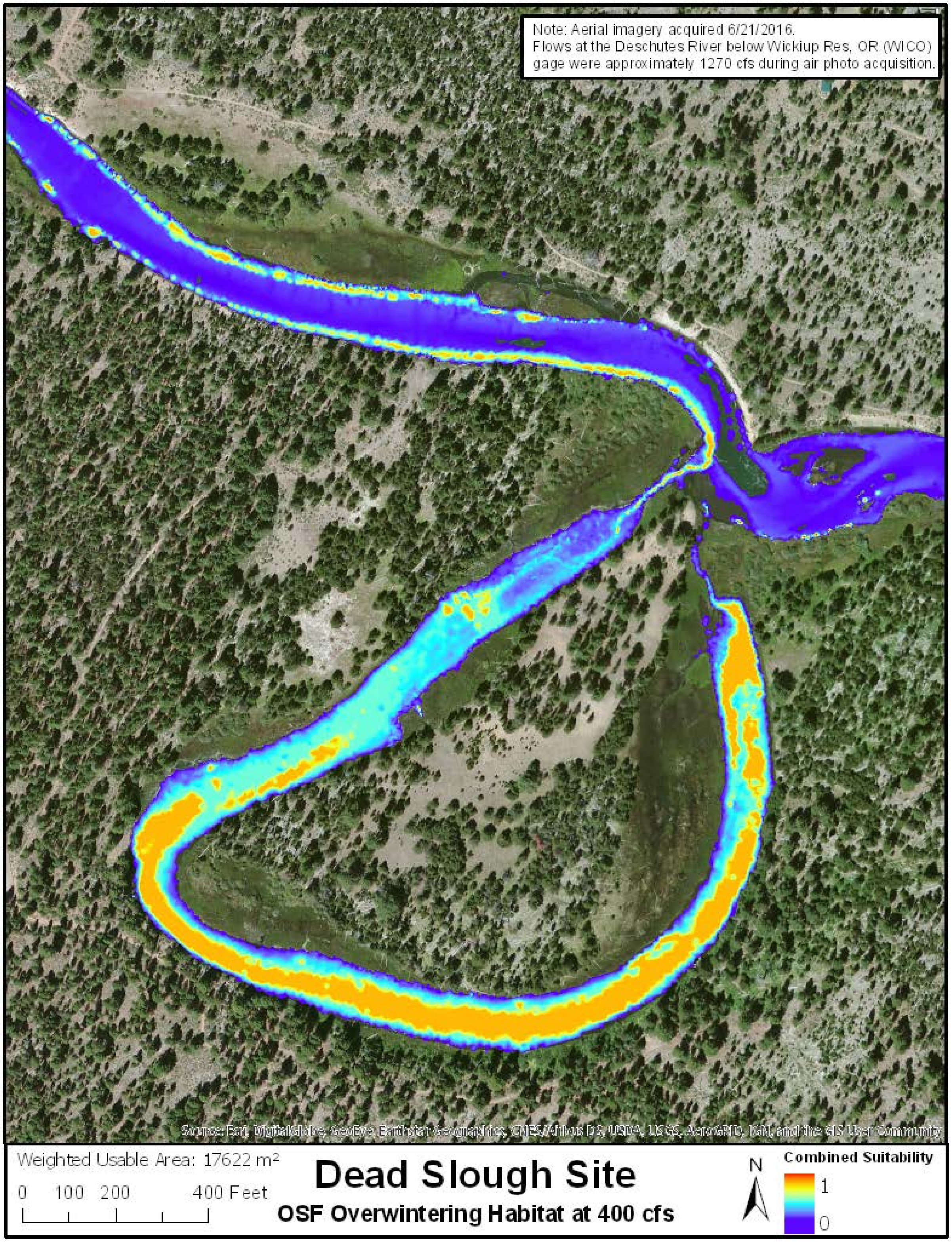

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 11663 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 29 cfs
N
Combined Suitability
1
0

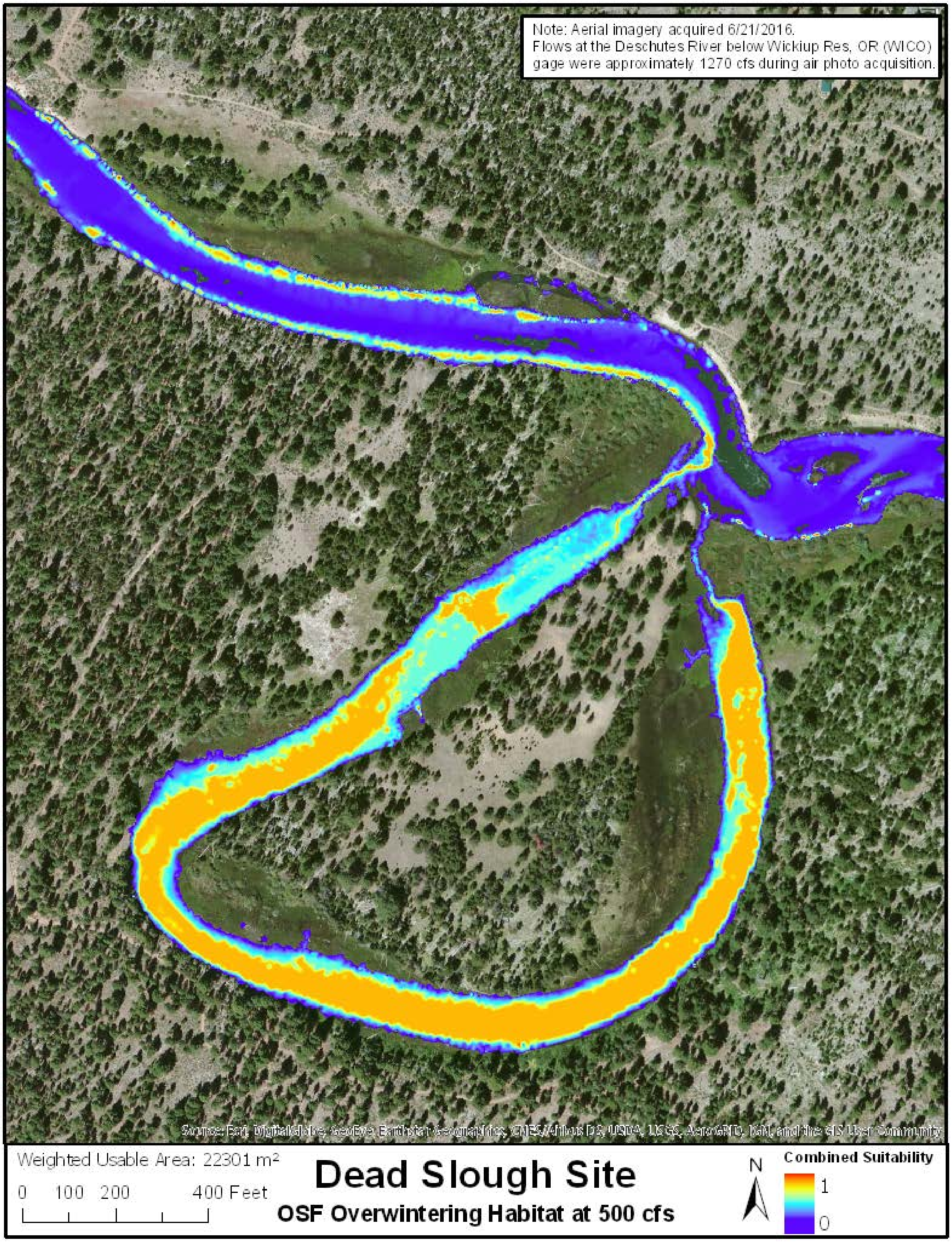

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 12840 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 50 cfs
N
Combined Suitability
1
0

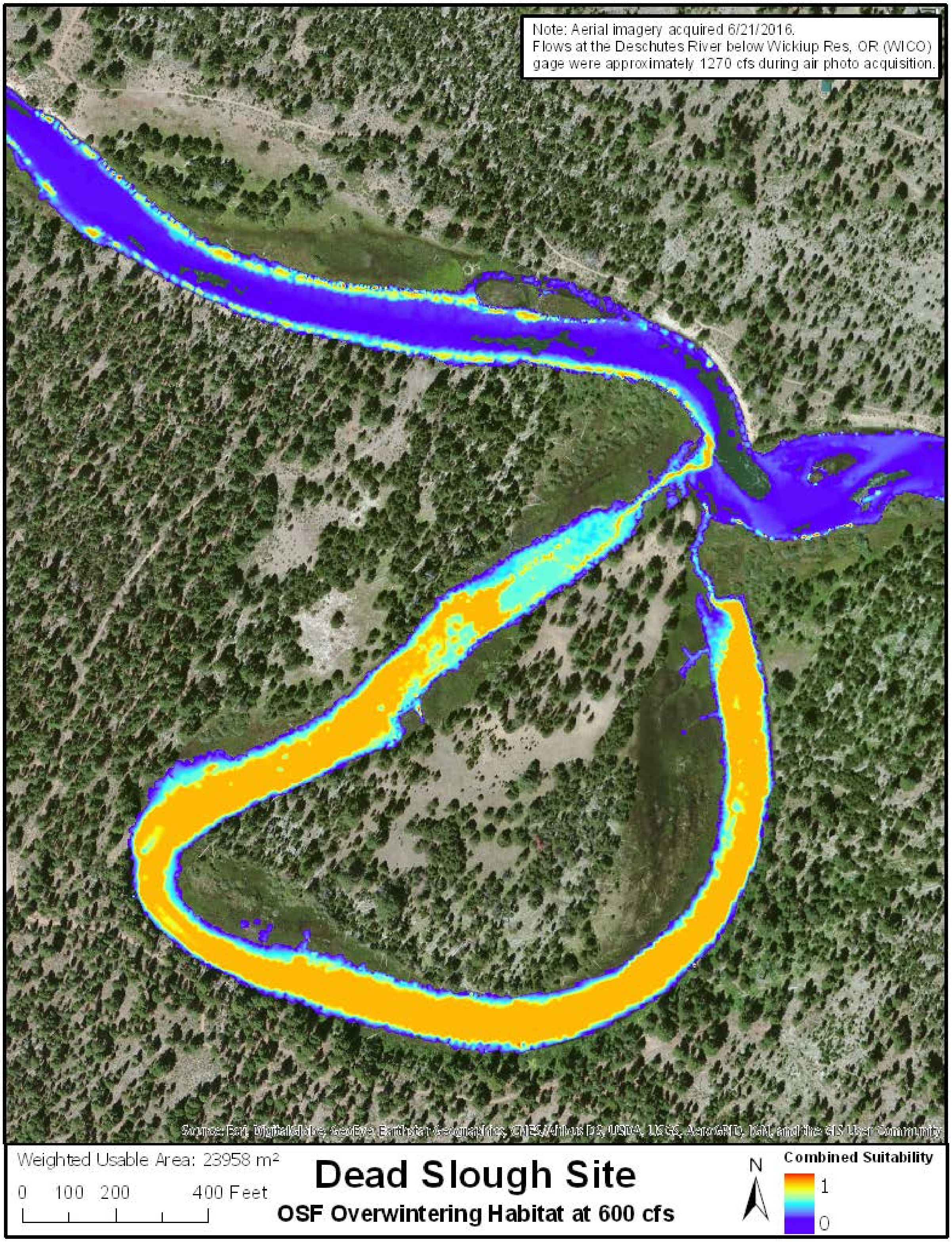

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 13708 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 100 cfs
N
Combined Suitability
1
0

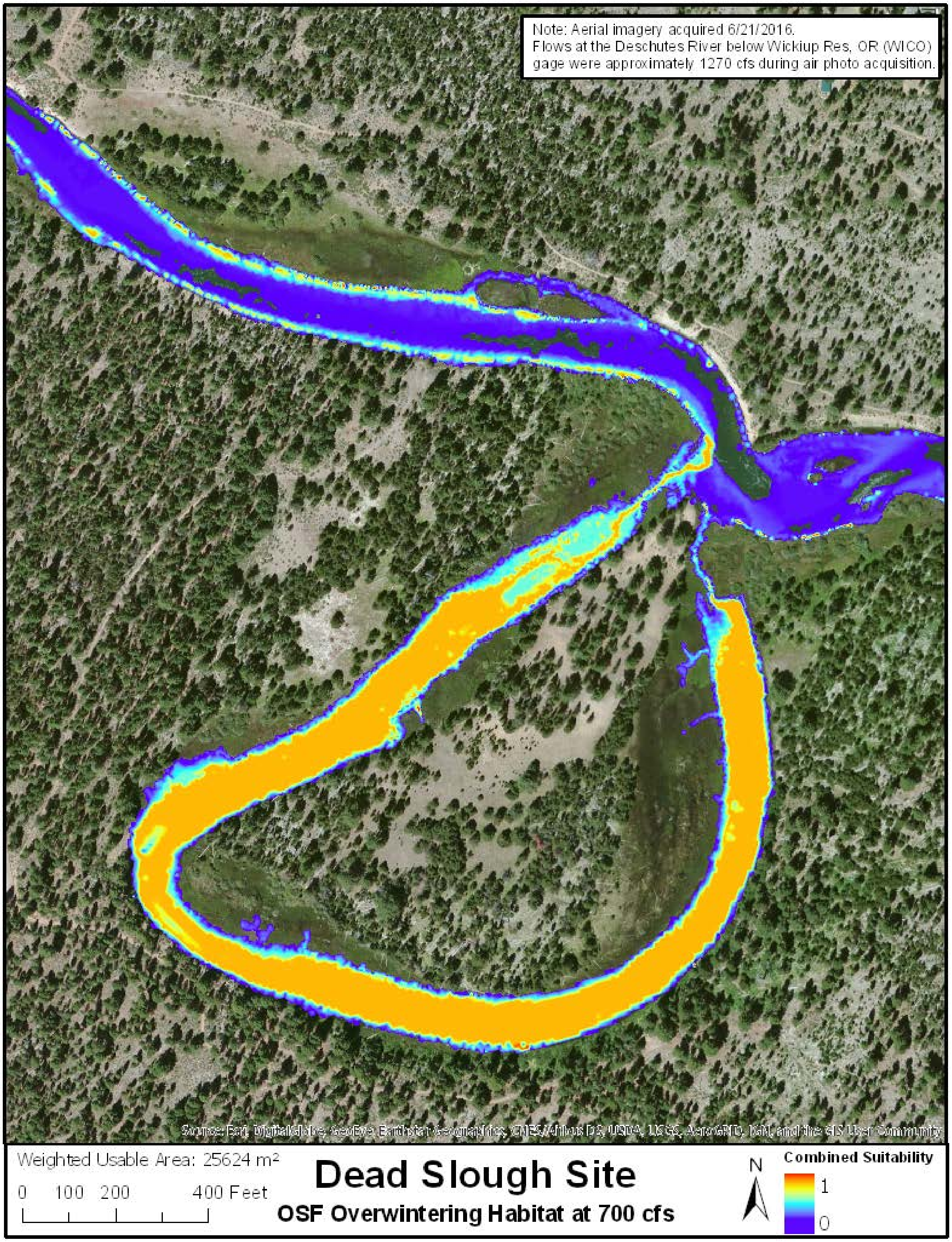

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 15072 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 208 cfs
N
Combined Suitability
1
0

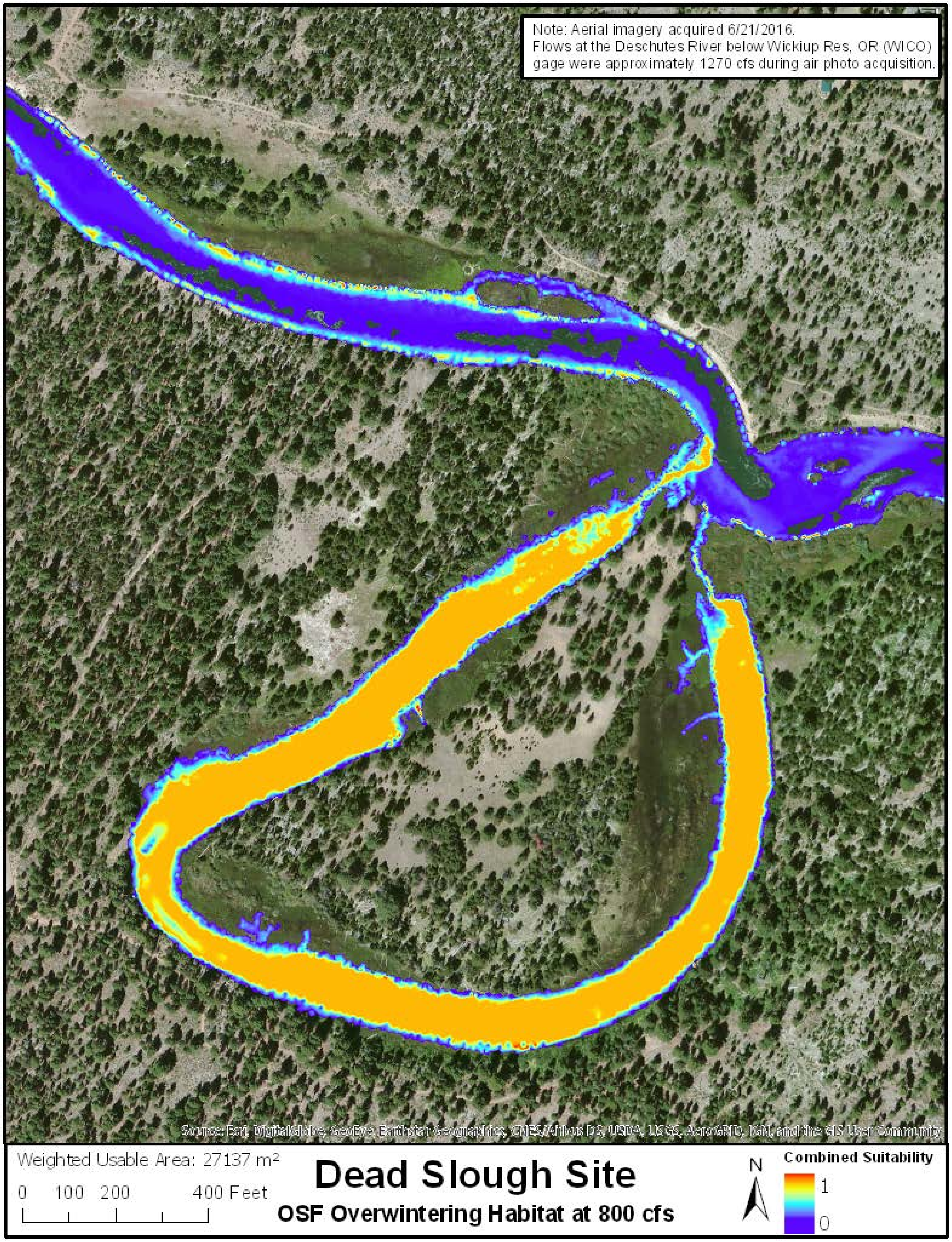

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 17138 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 300 cfs
N
Combined Suitability
1
0

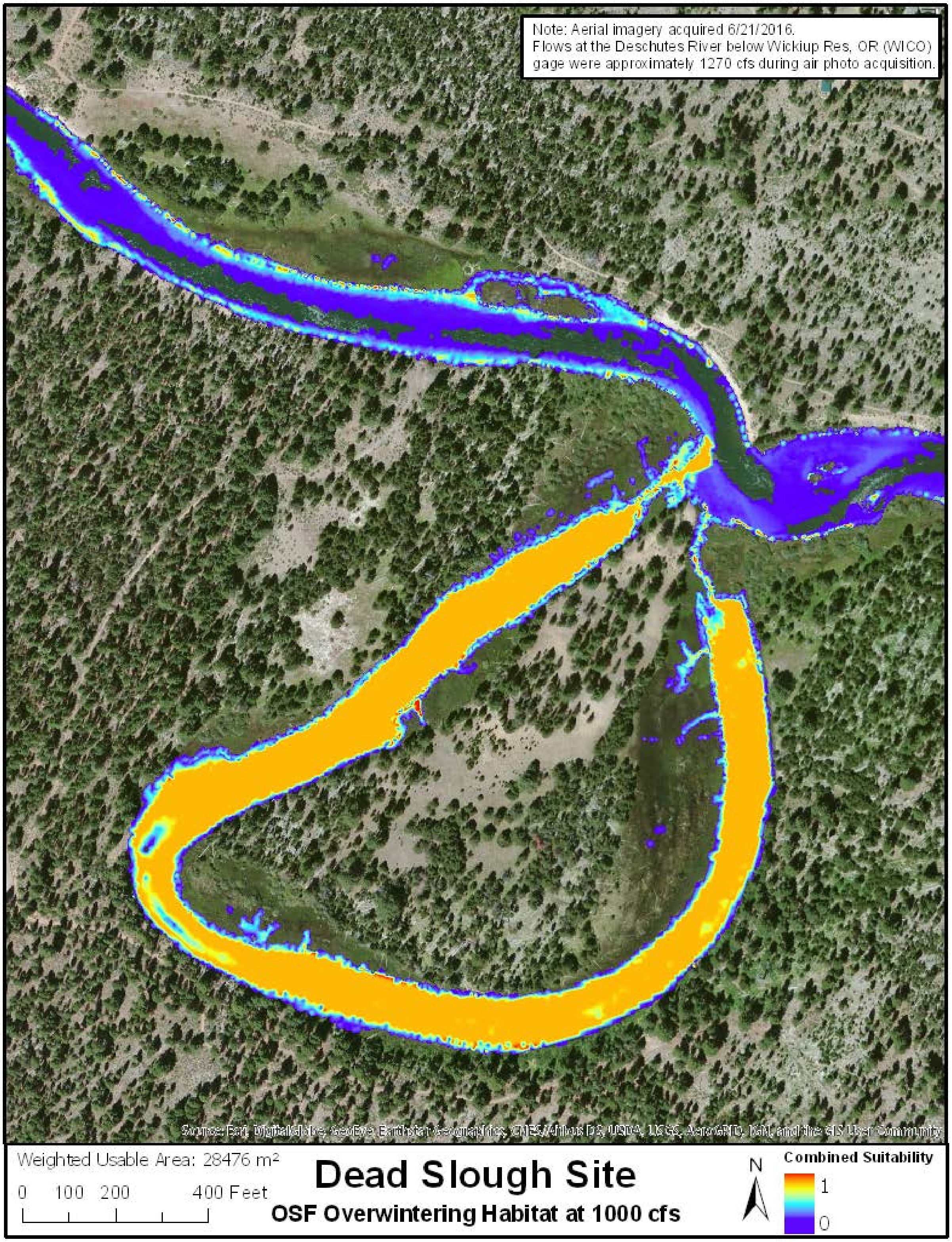

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 17622 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 400 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 22301 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 500 cfs
N
Combined Suitability
1
0

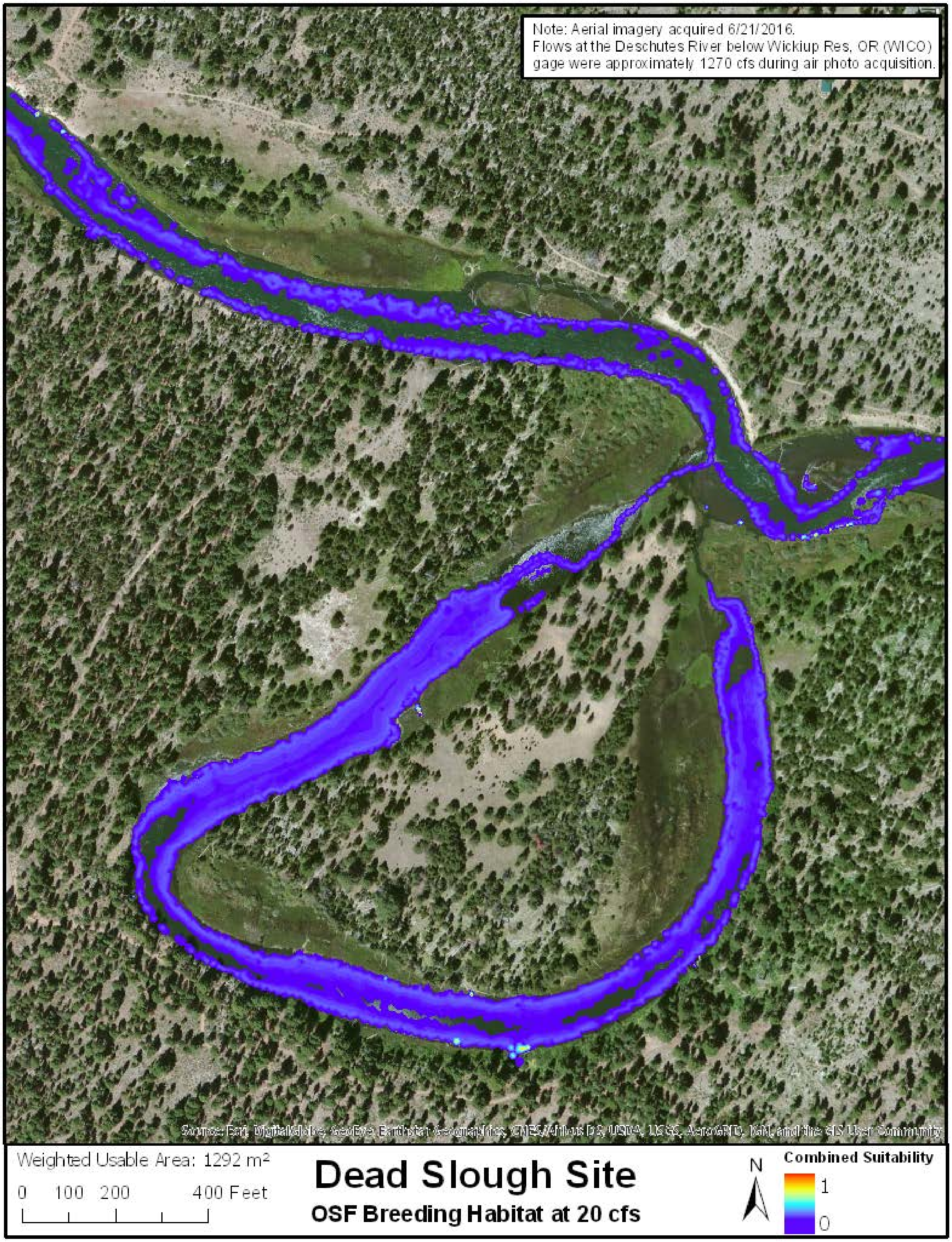

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 23958 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 600 cfs
N
Combined Suitability
1
0

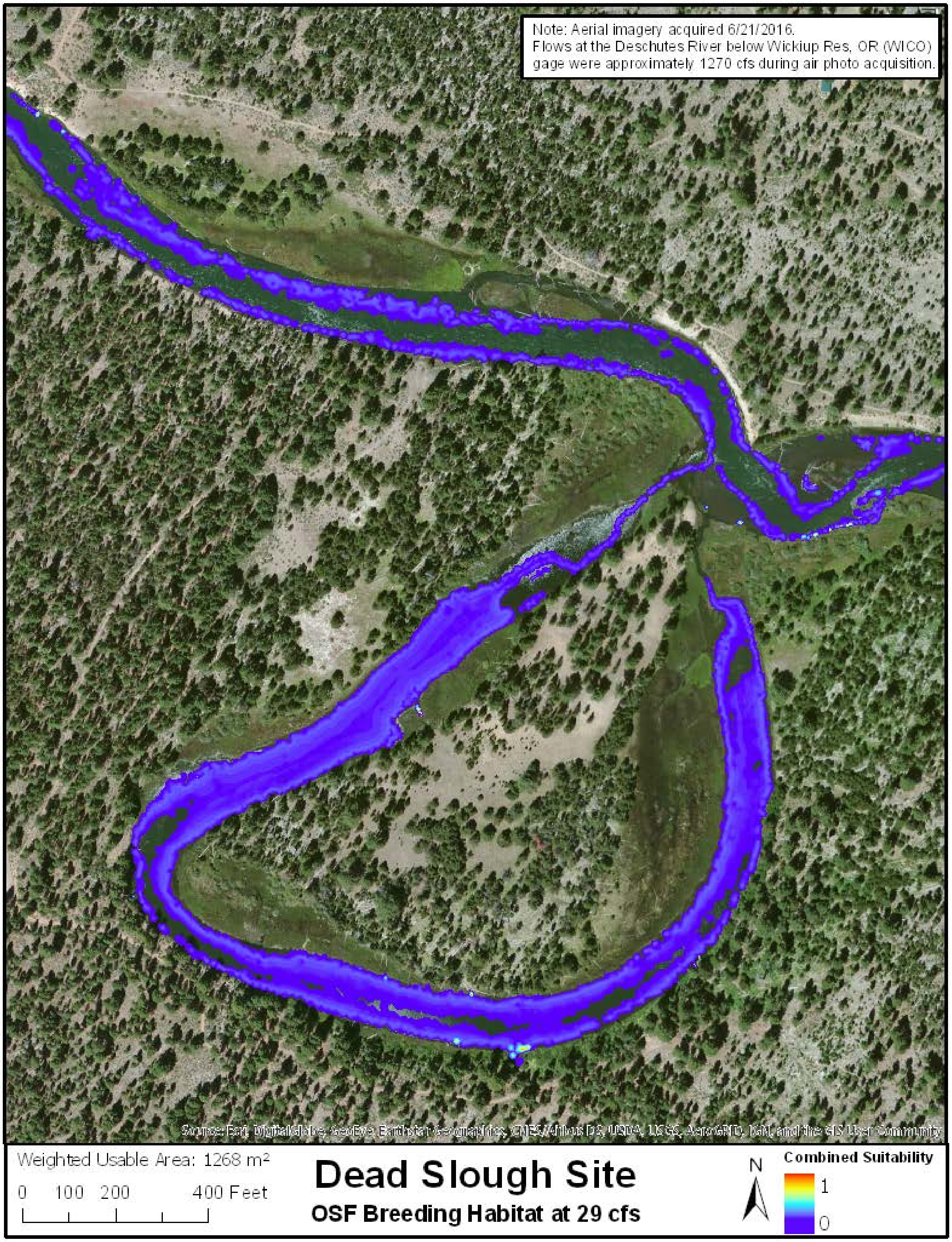

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 25624 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 700 cfs
N
Combined Suitability
1
0

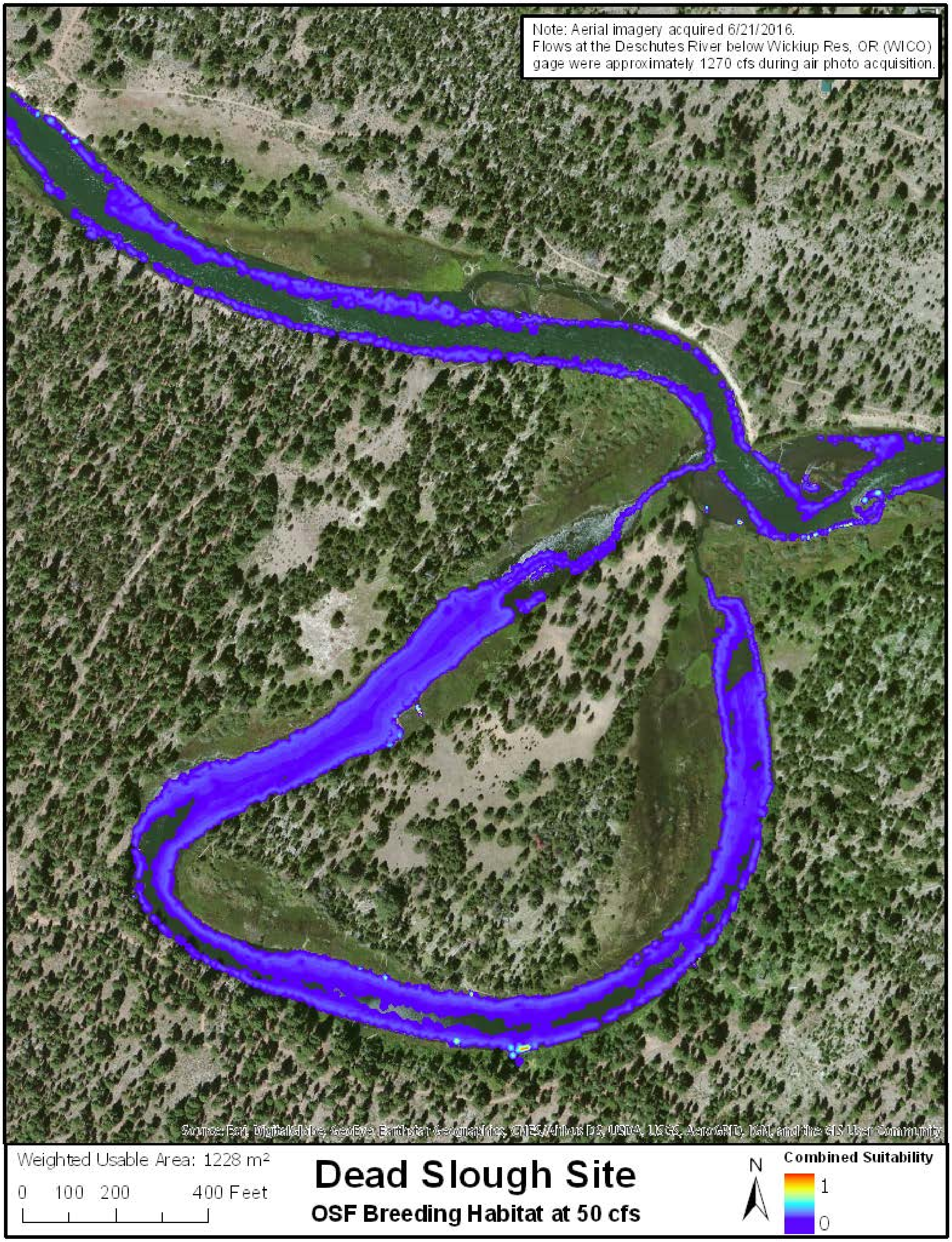

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 27137 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 800 cfs
N
Combined Suitability
1
0

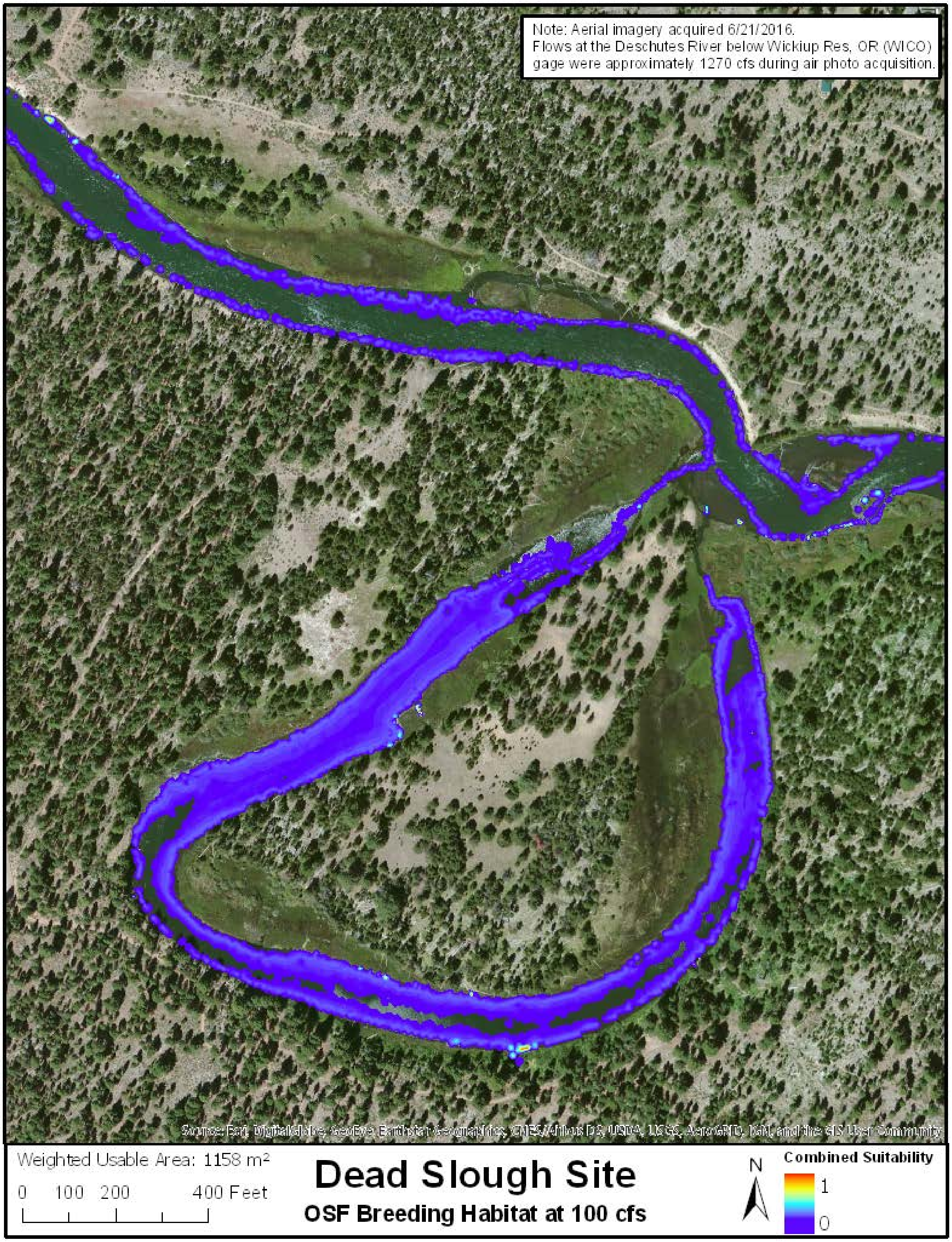

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 28476 m²
0 100 200 400 Feet
Dead Slough Site
OSF Overwintering Habitat at 1000 cfs
N
Combined Suitability
1
0

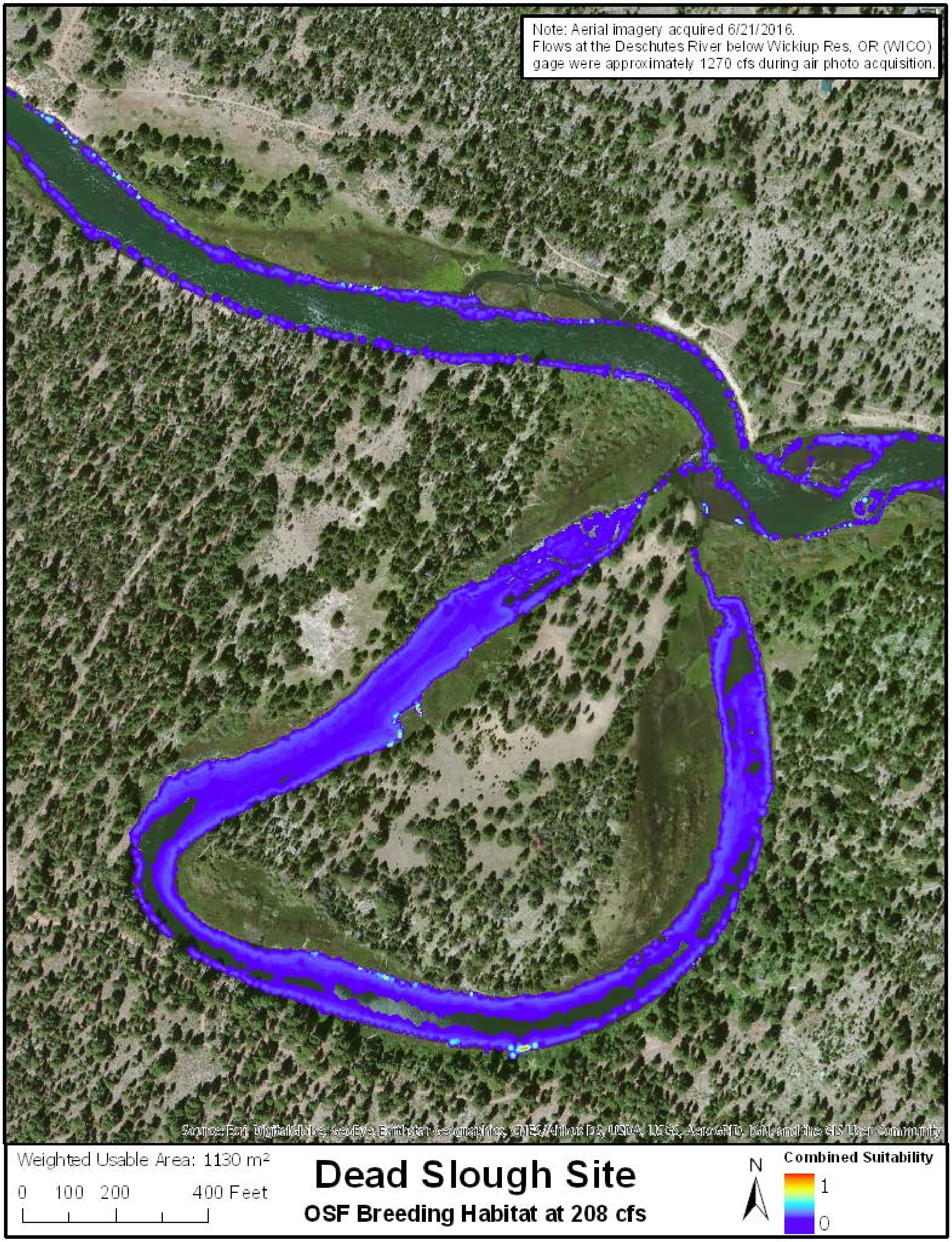
Dead Slough – Oregon Spotted Frog Breeding Habitat

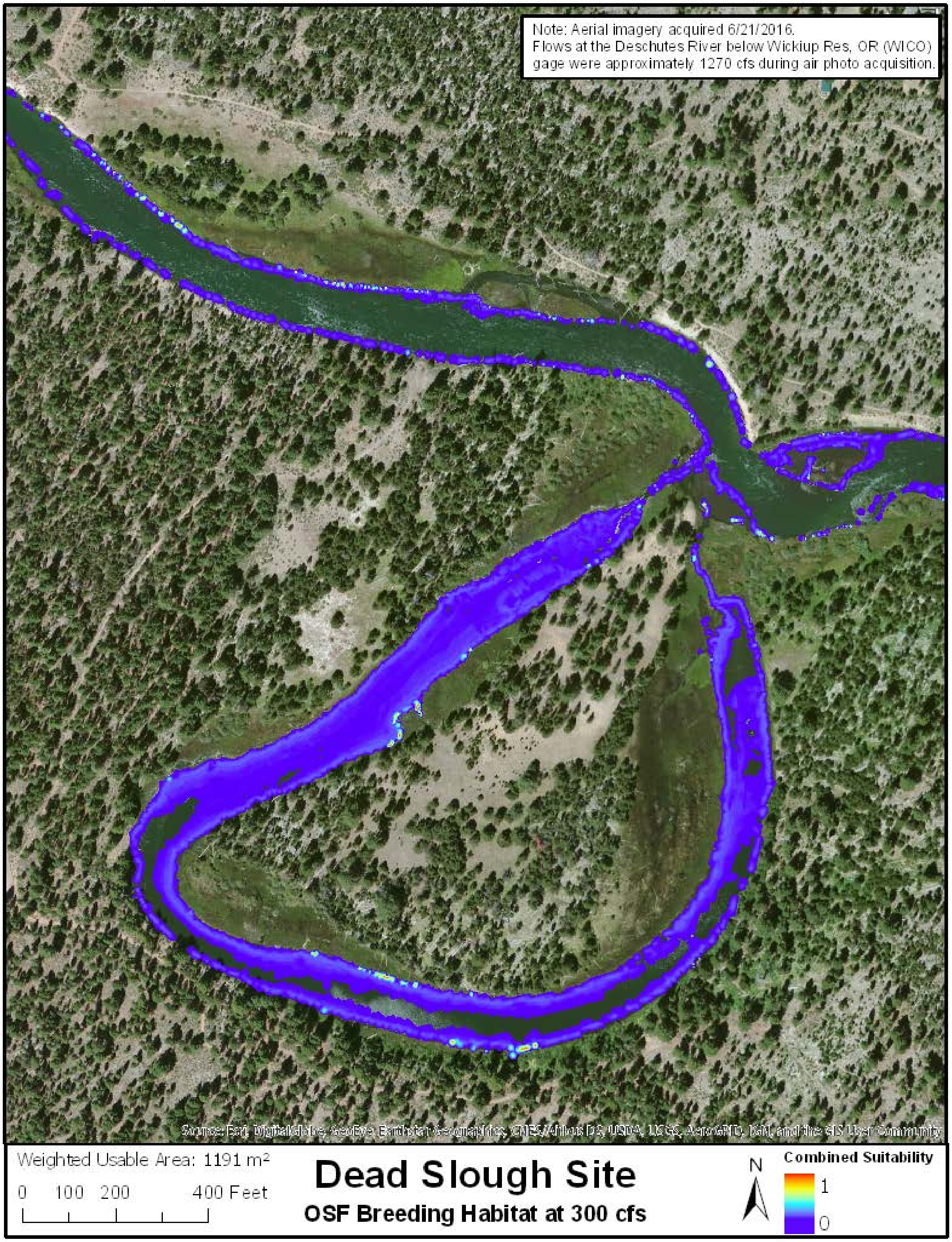


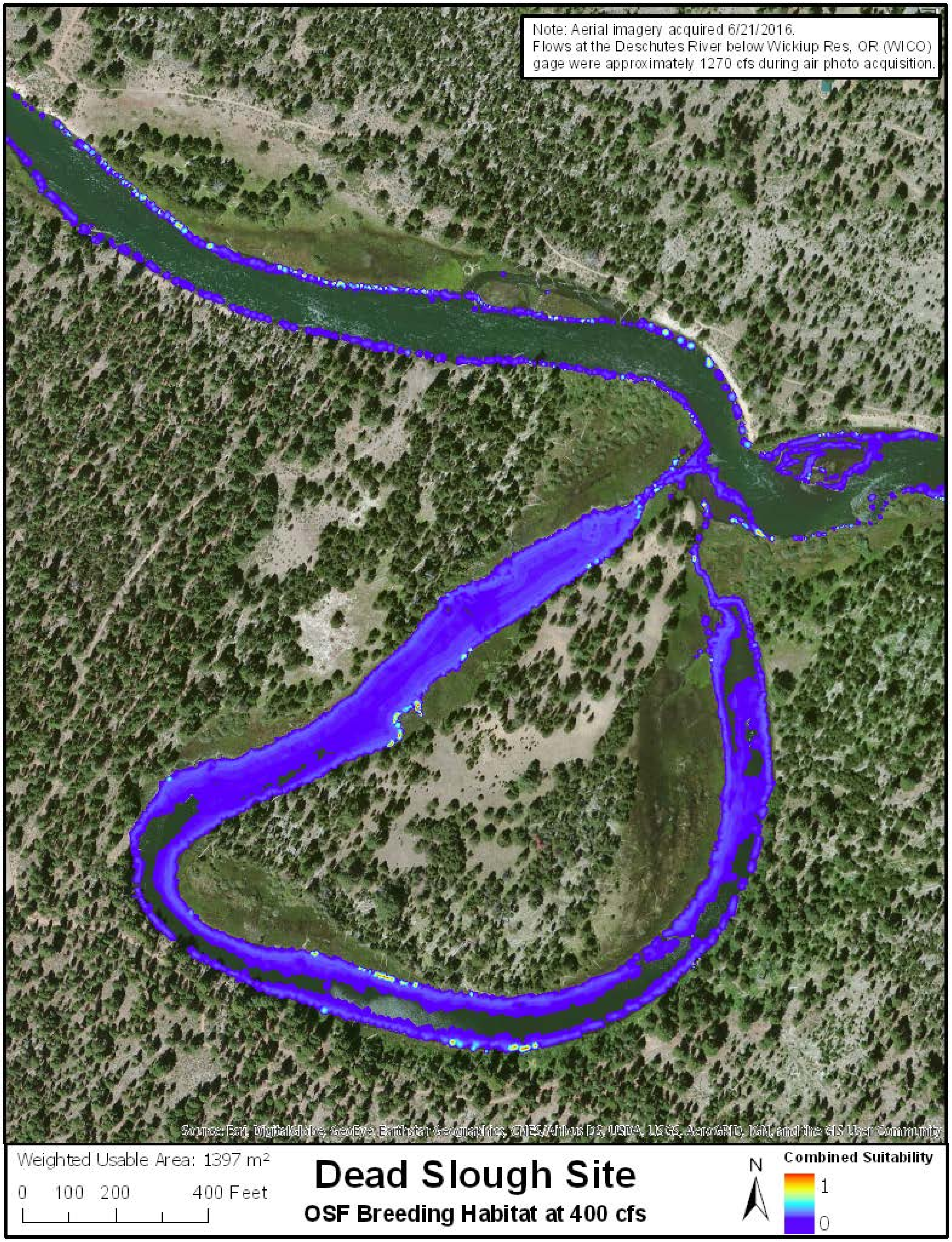

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 1268 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 29 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 1228 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 50 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 1158 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 100 cfs
N
Combined Suitability
1
0

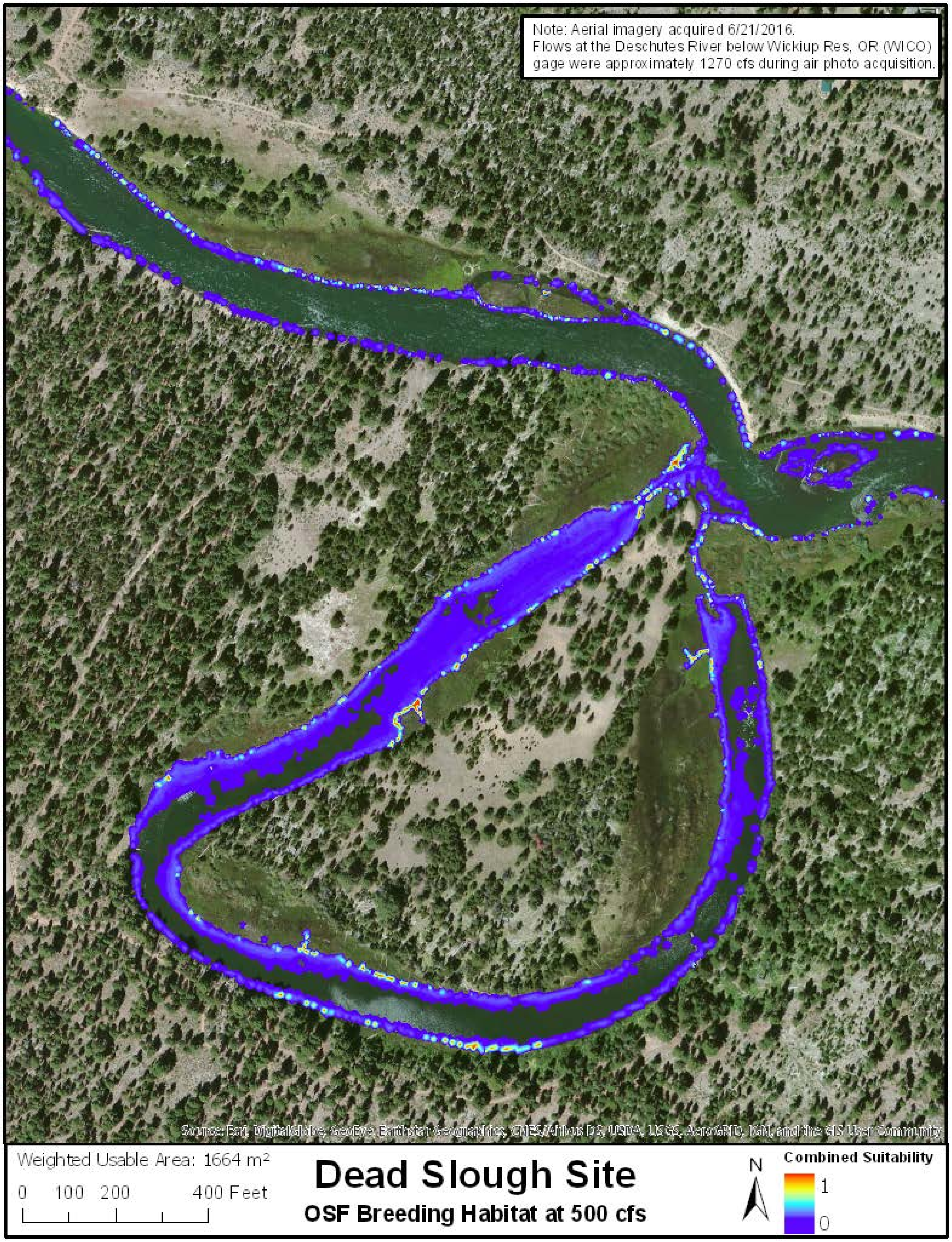

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 1130 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 208 cfs
N
Combined Suitability
1
0

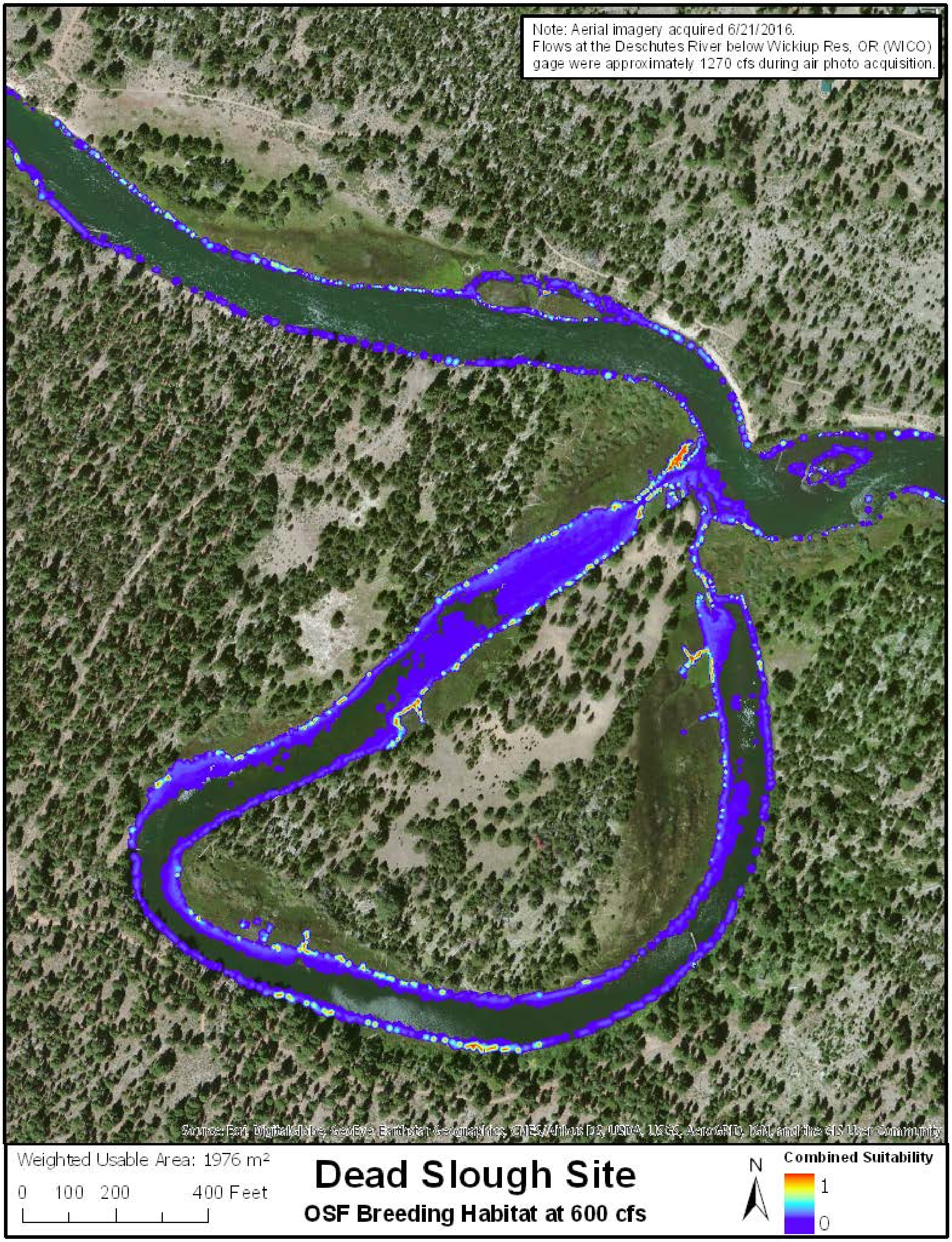

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 1191 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 300 cfs
N
Combined Suitability
1
0

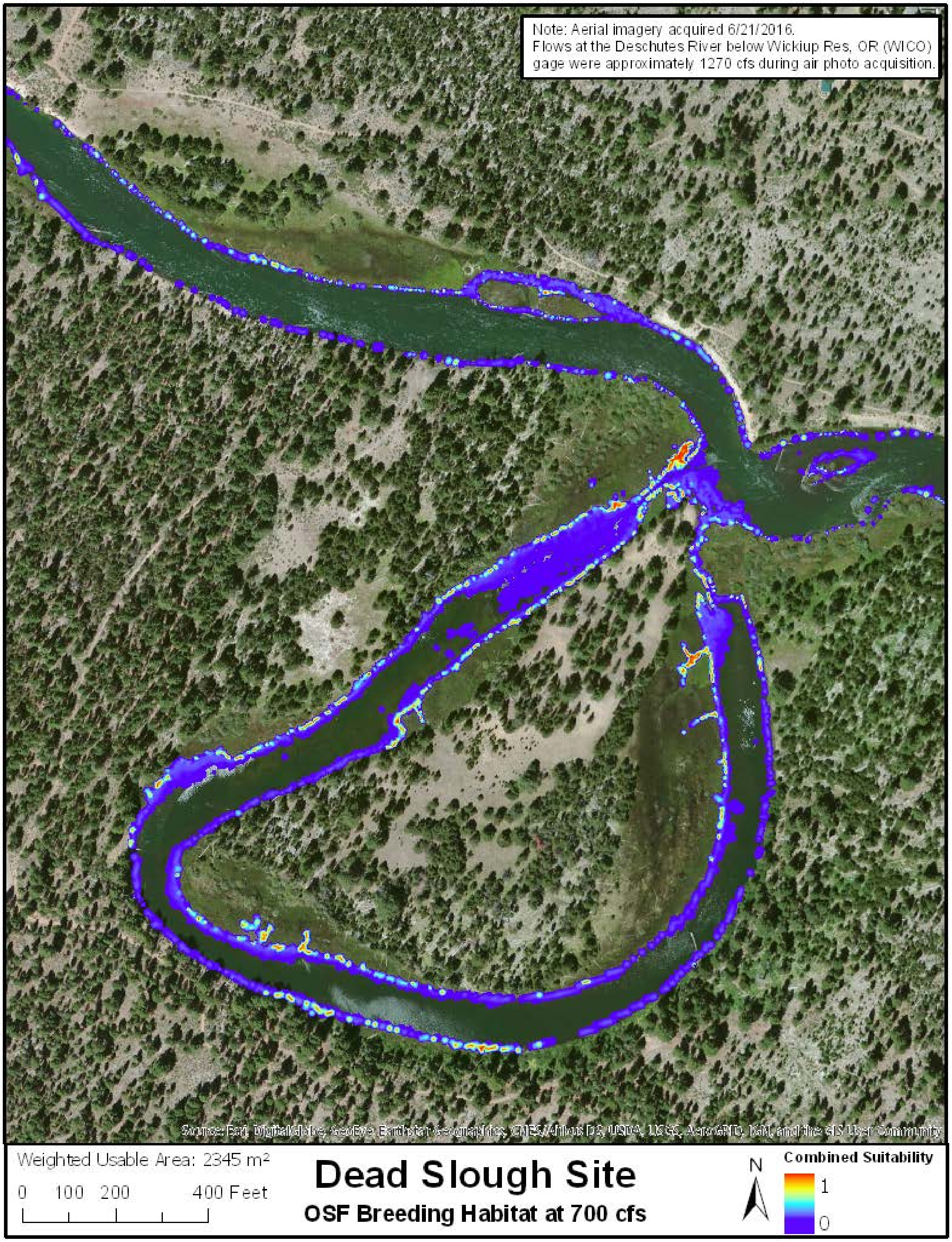


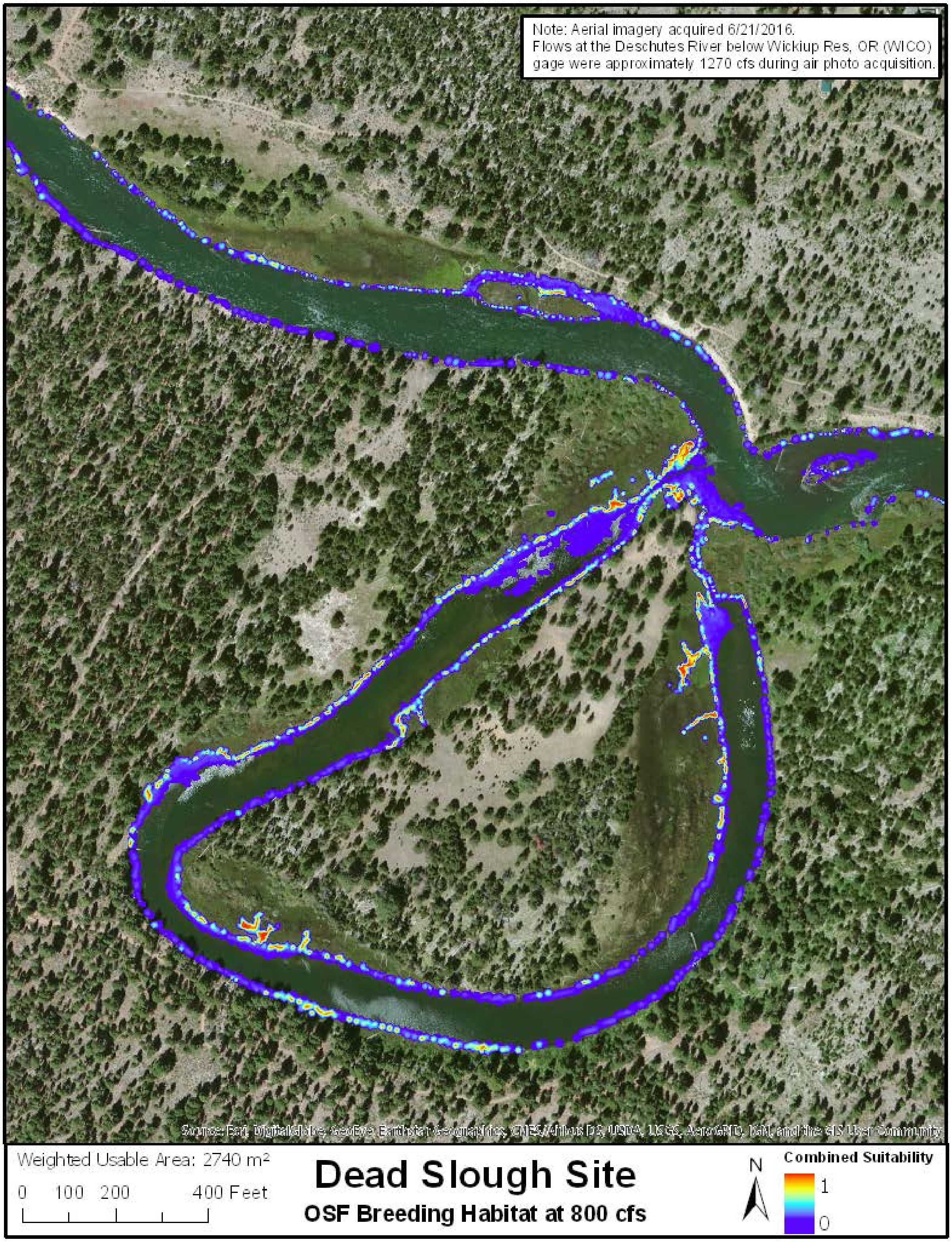
Dead Slough Site

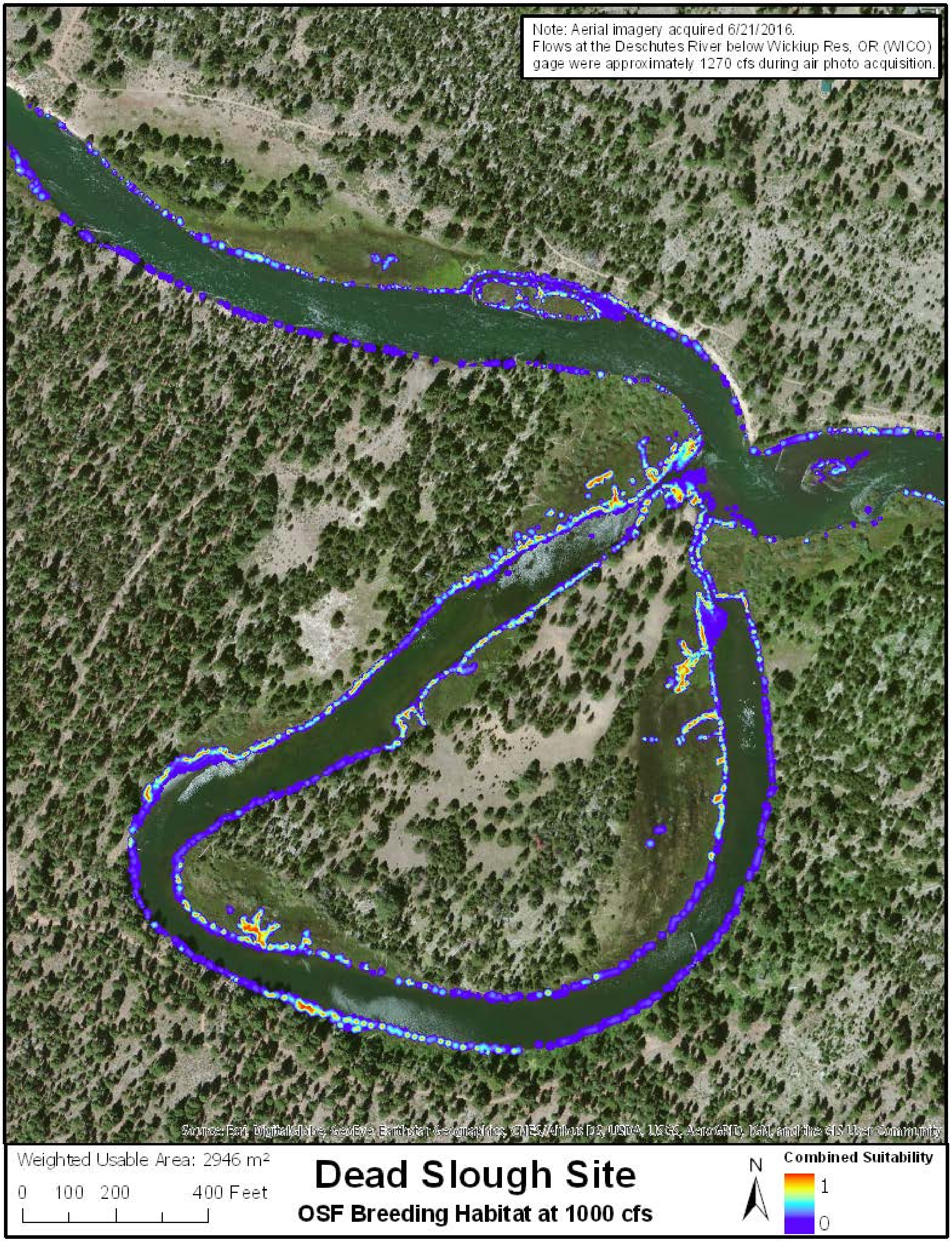
OSF Breeding Habitat at 400 cfs

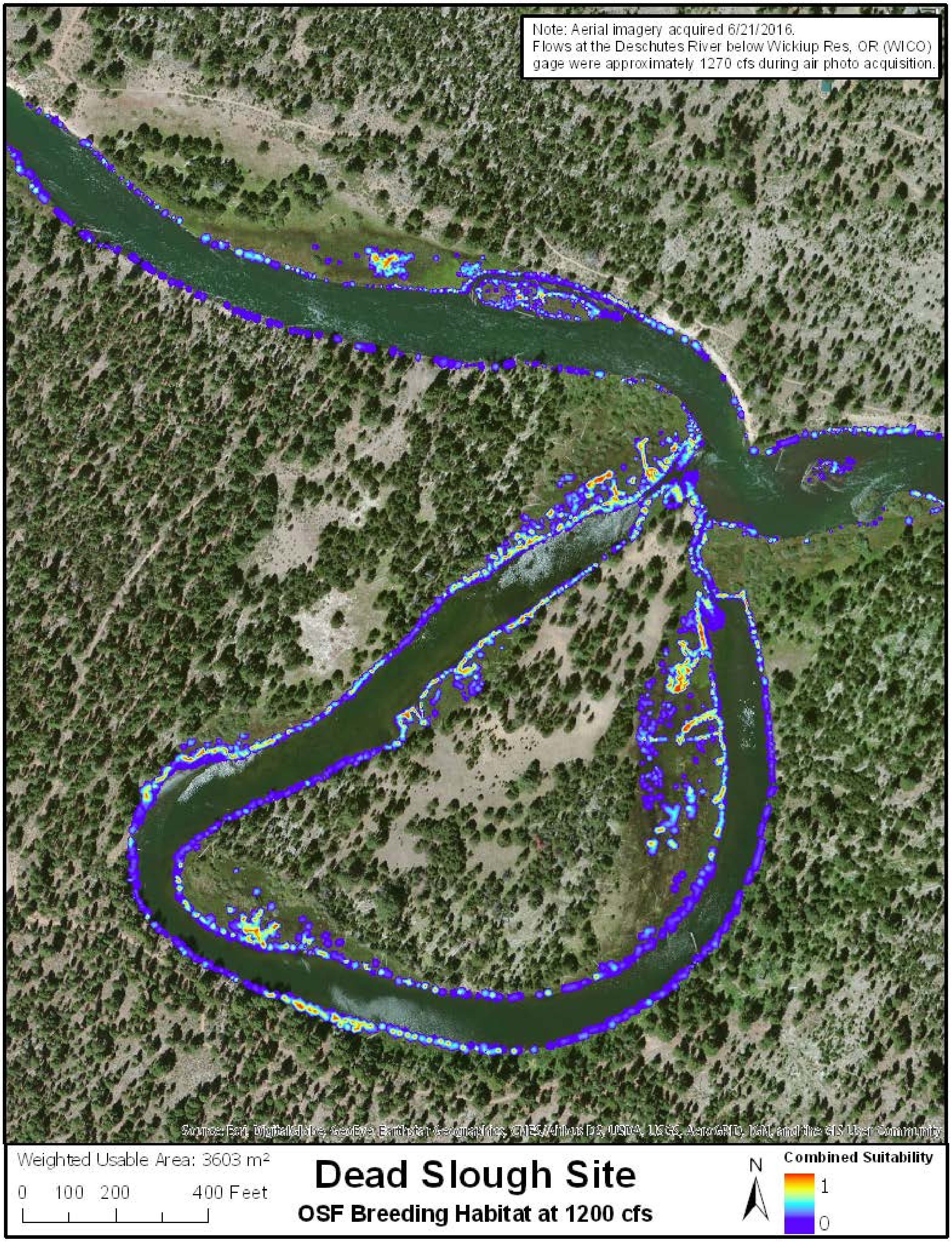

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 1664 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 500 cfs
N
Combined Suitability
1
0

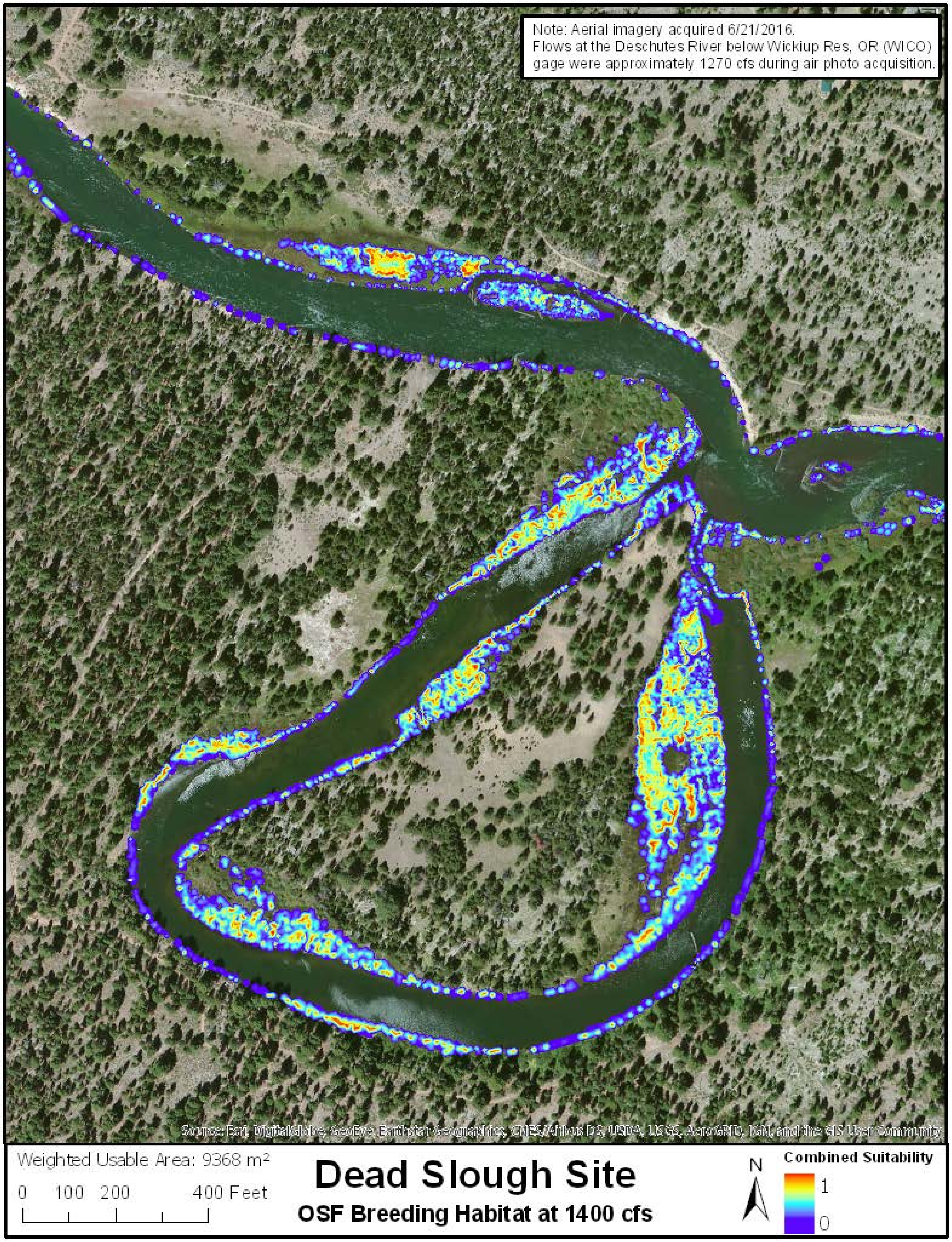

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 1976 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 600 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 2345 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 700 cfs
N
Combined Suitability
1
0

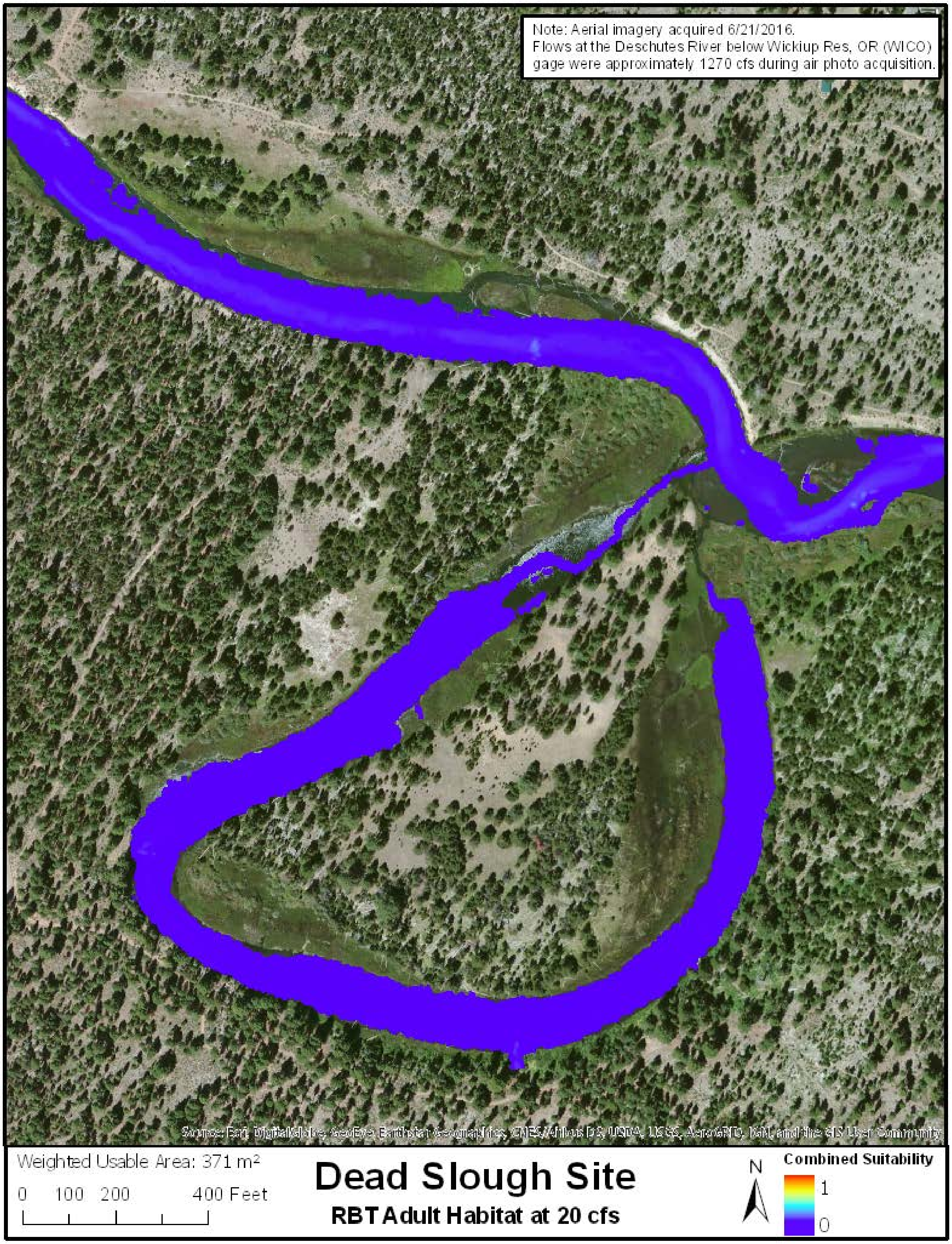

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 2740 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 800 cfs
N
Combined Suitability
1
0

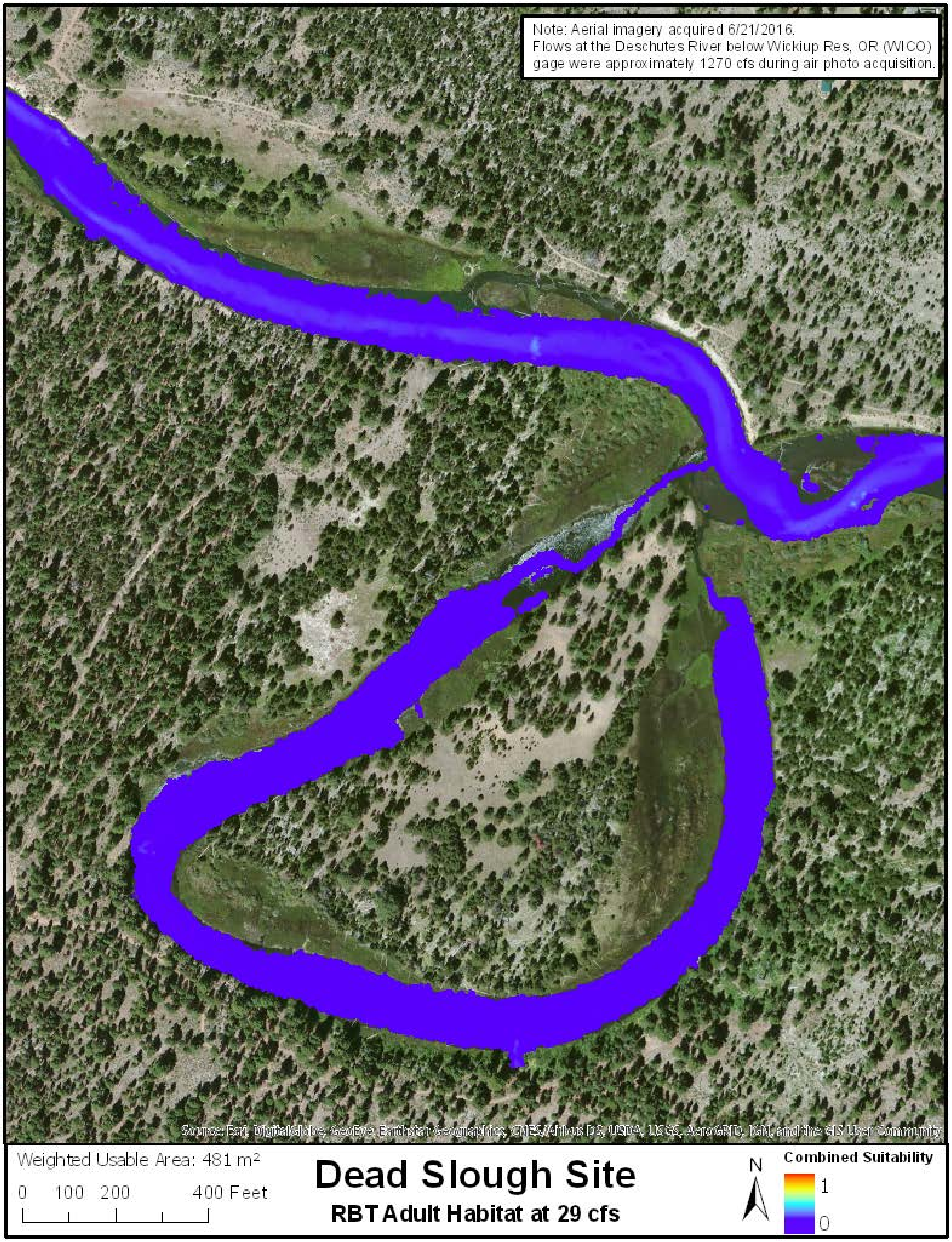

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 2946 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 1000 cfs
N
Combined Suitability
1
0

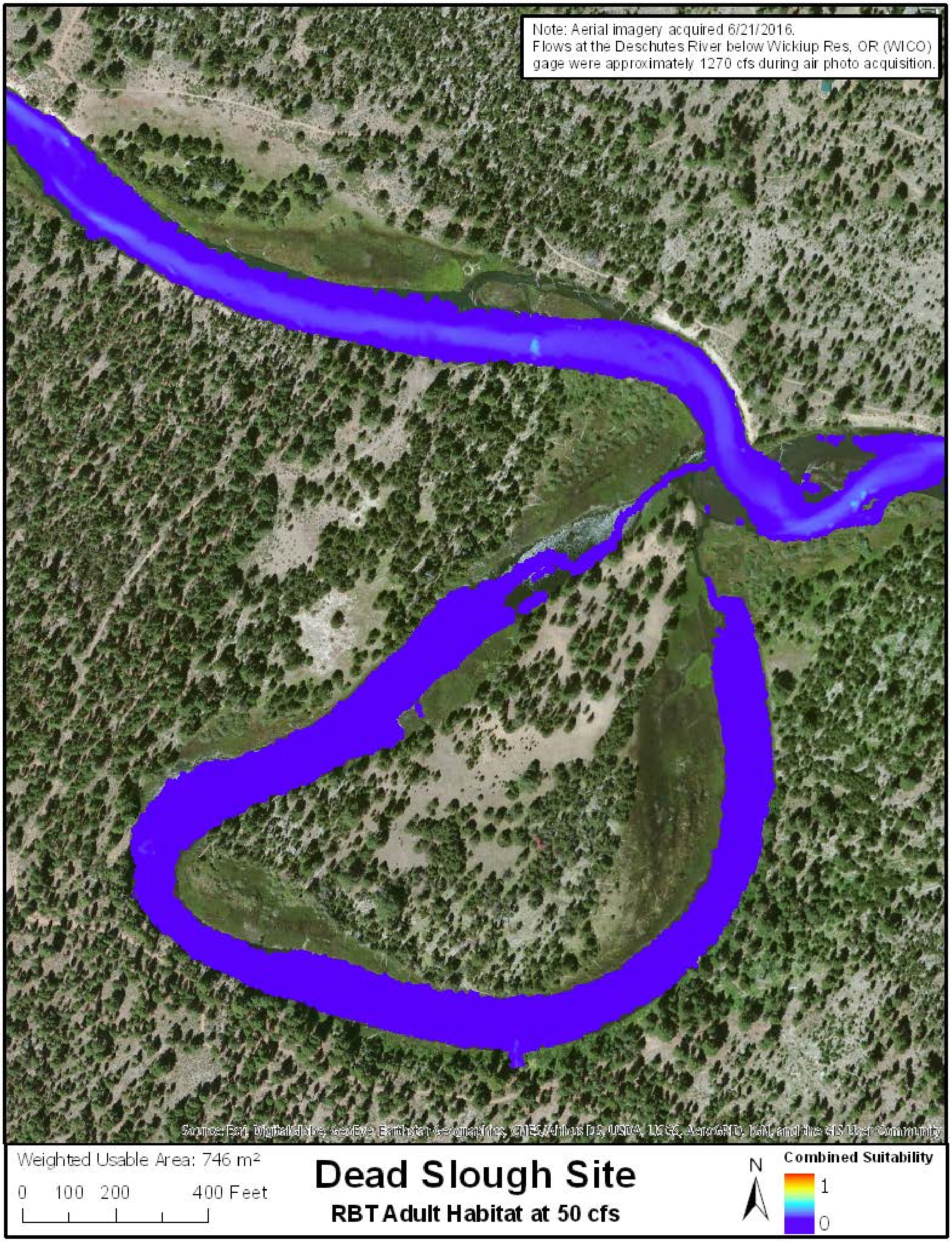

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 3603 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 1200 cfs
N
Combined Suitability
1
0

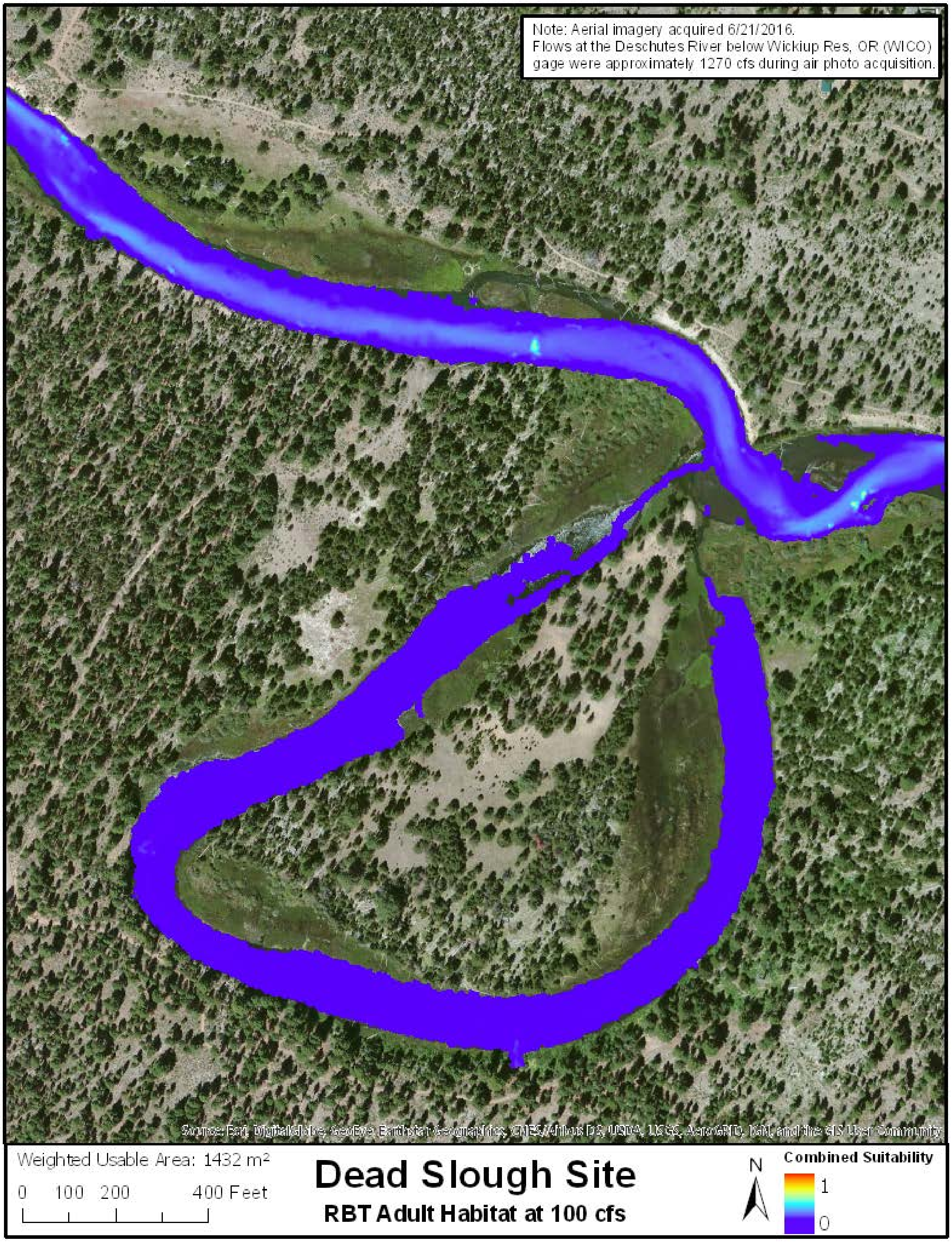

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 9368 m²
0 100 200 400 Feet
Dead Slough Site
OSF Breeding Habitat at 1400 cfs
N
Combined Suitability
1
0

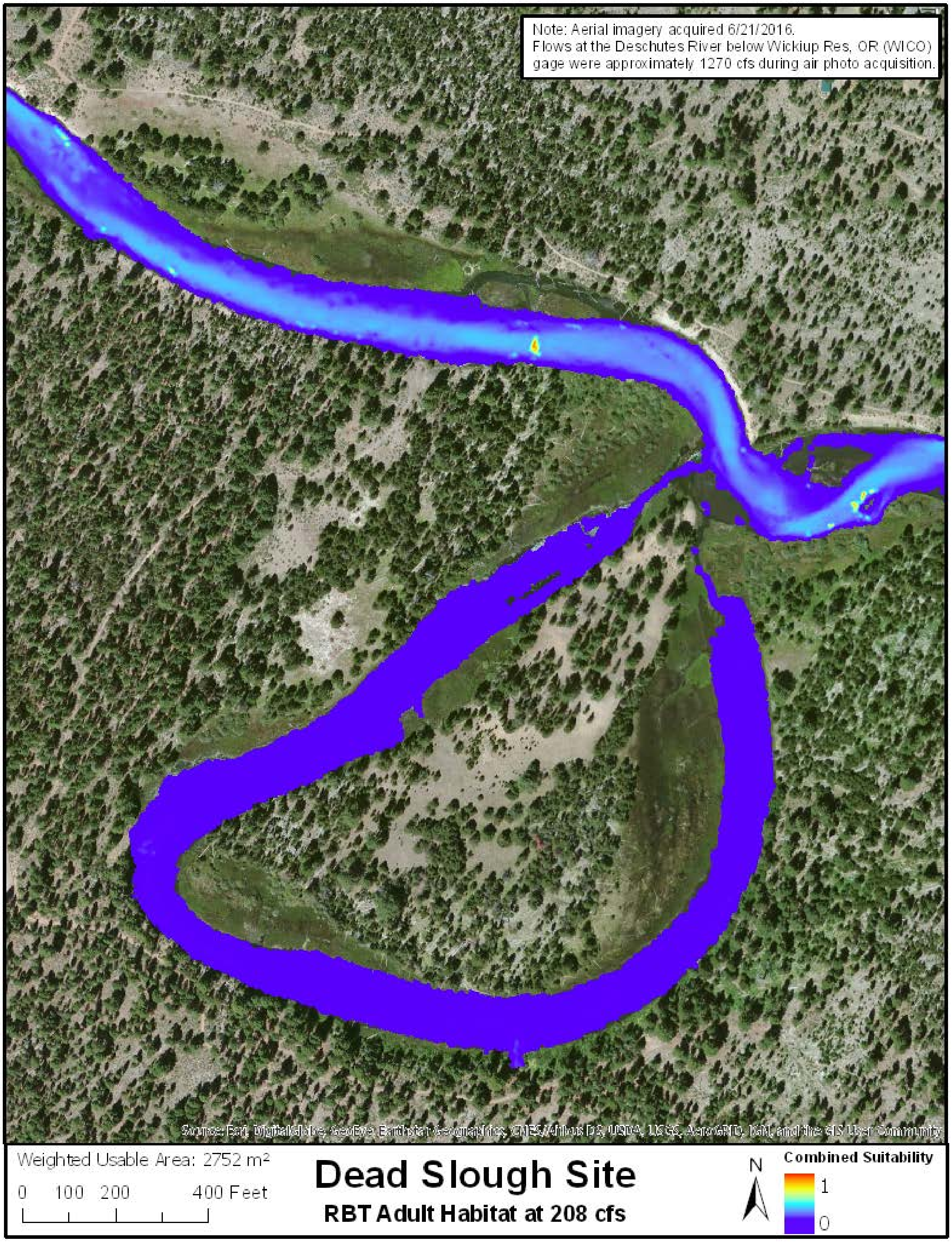
Dead Slough – Redband Trout Adult Holding Habitat

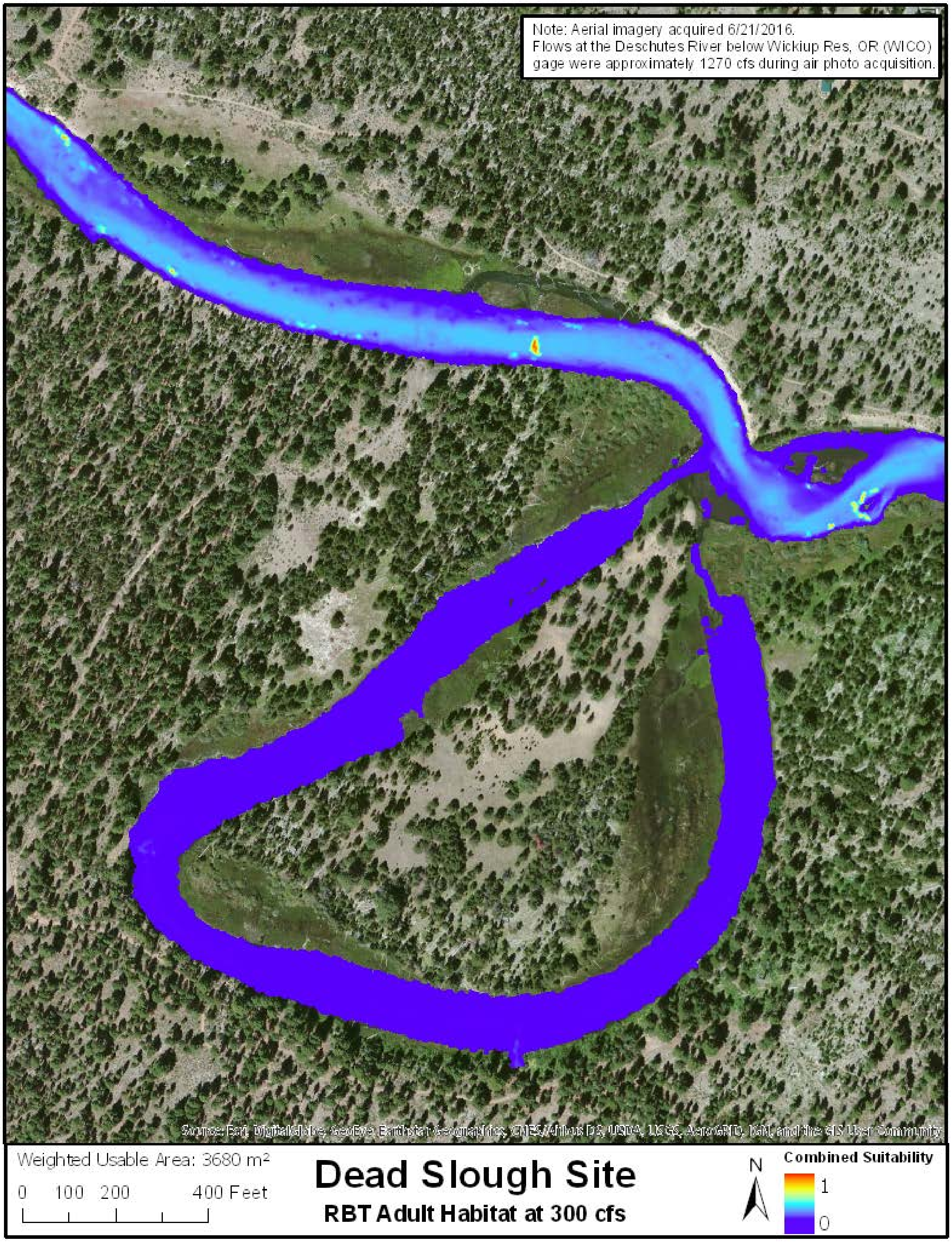


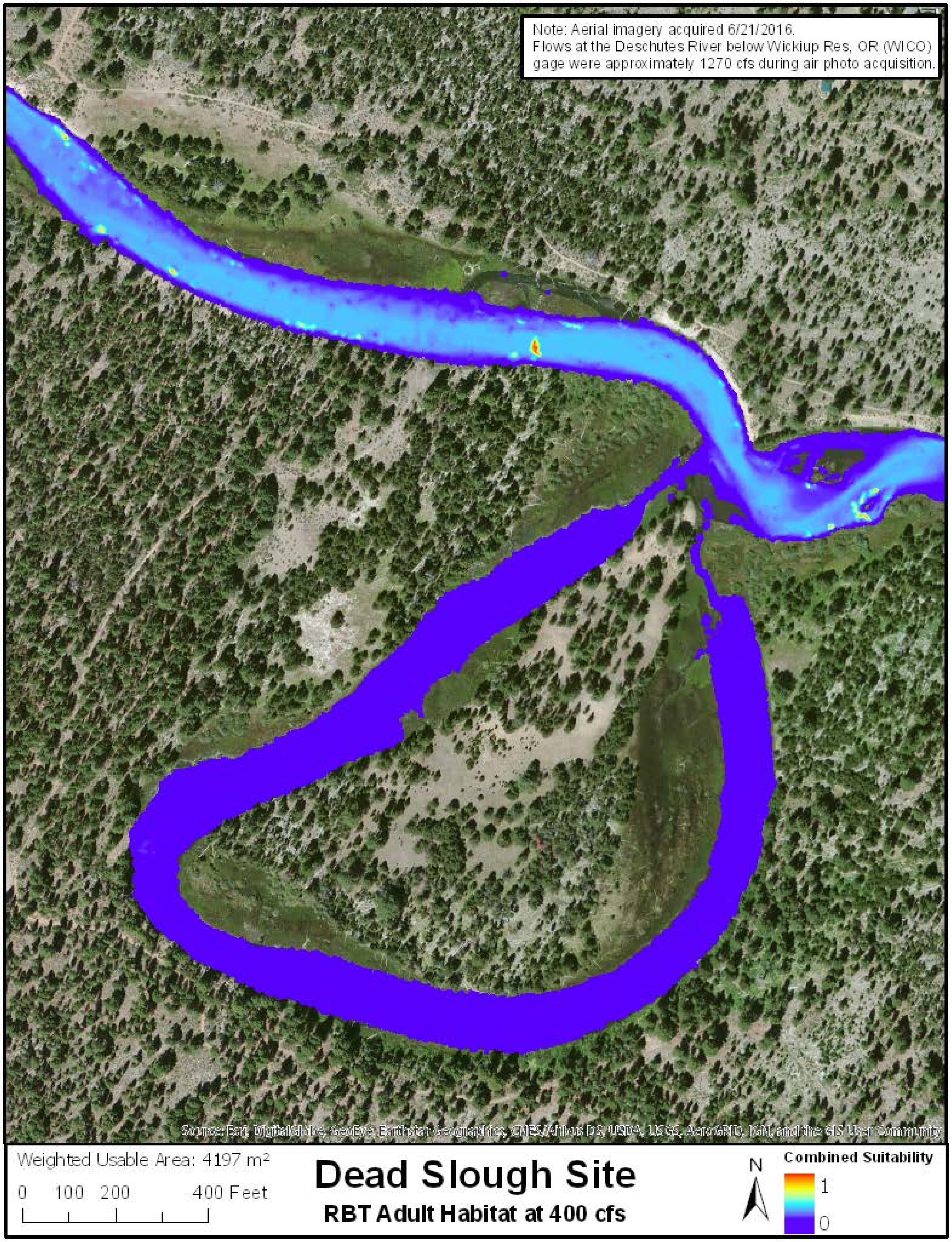

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 481 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 29 cfs
N
Combined Suitability
1
0

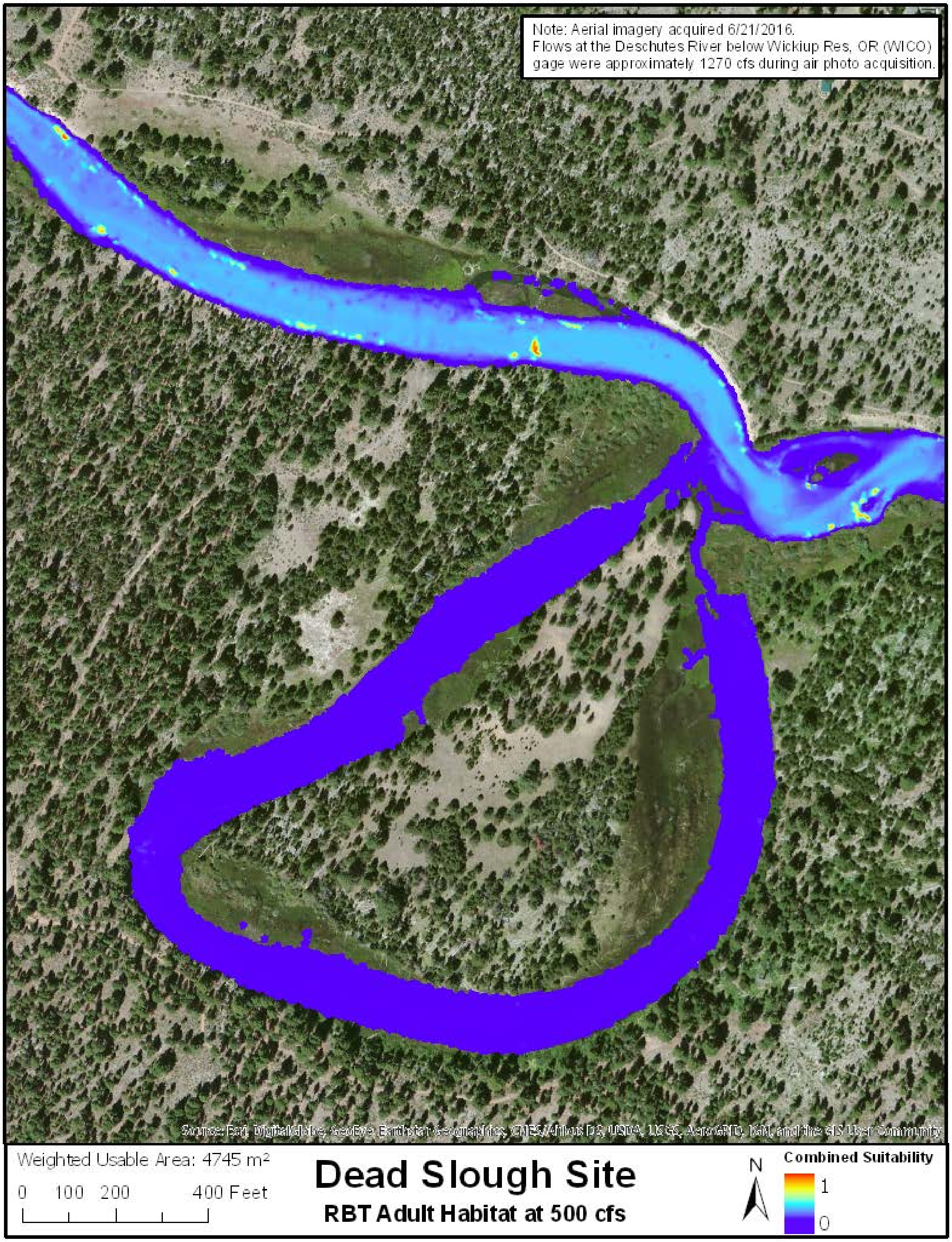

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 746 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 50 cfs
N
Combined Suitability
1
0

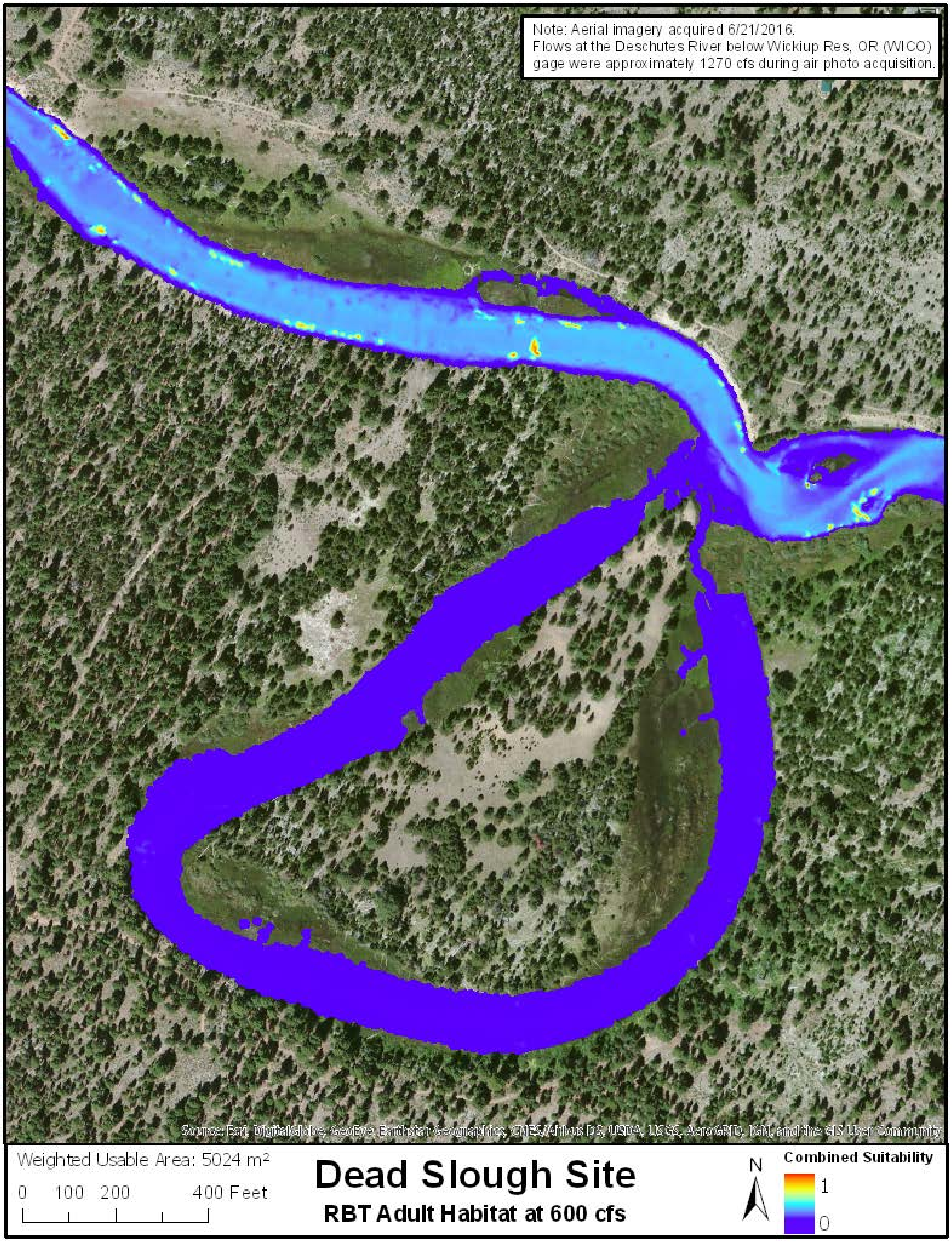

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 1432 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 100 cfs
N
Combined Suitability
1
0

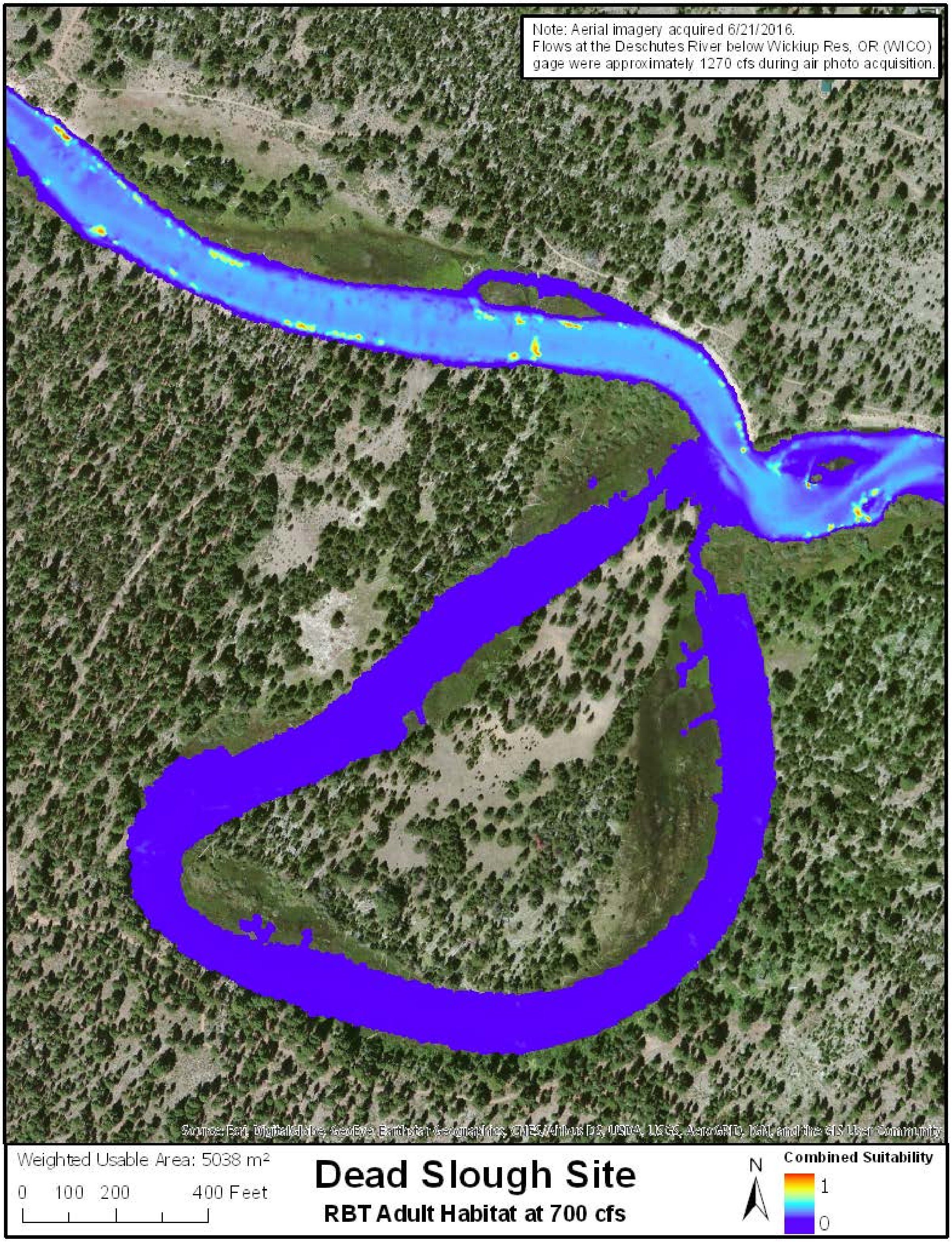

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 2752 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 208 cfs
N
Combined Suitability
1
0

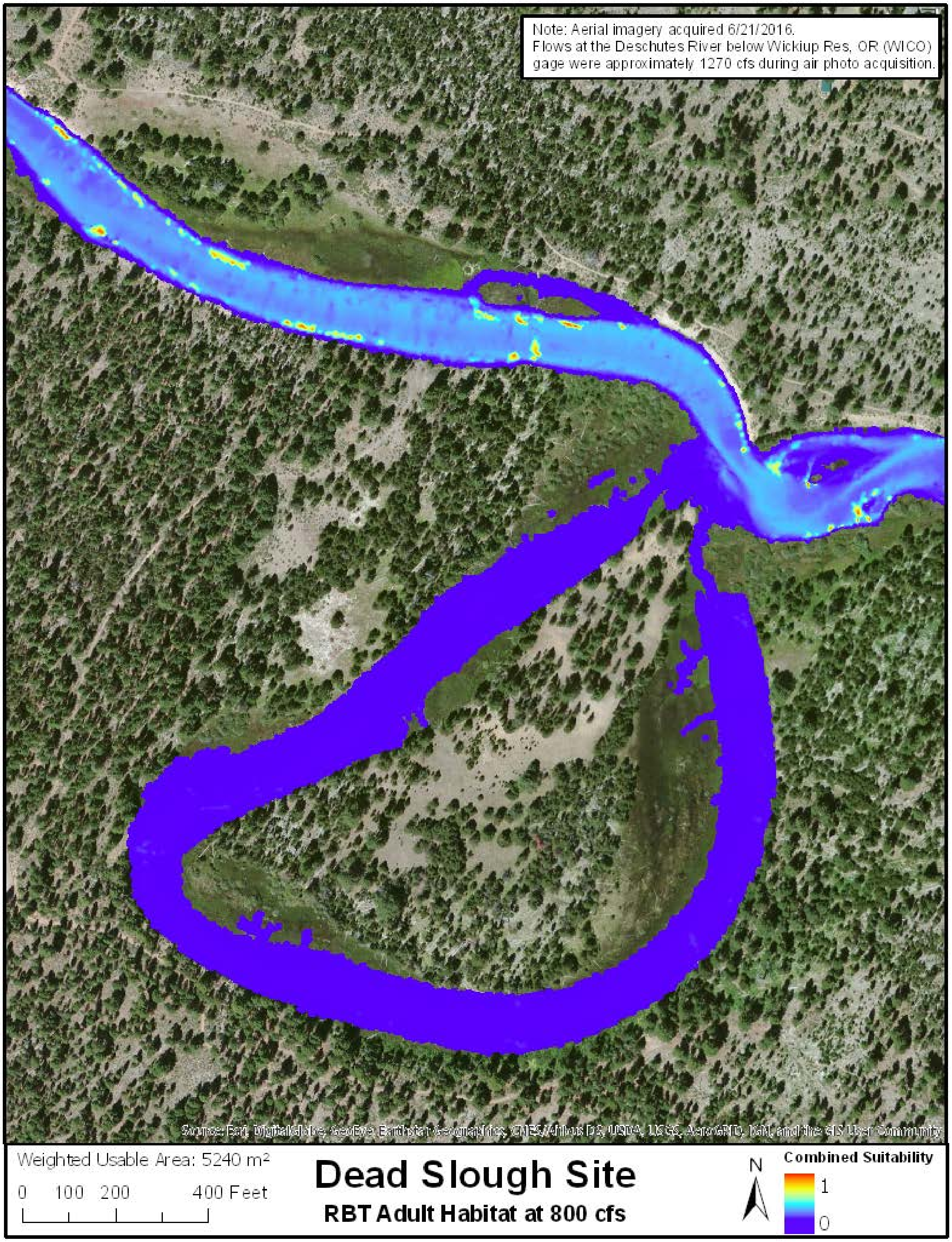

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 3680 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 300 cfs
N
Combined Suitability
1
0

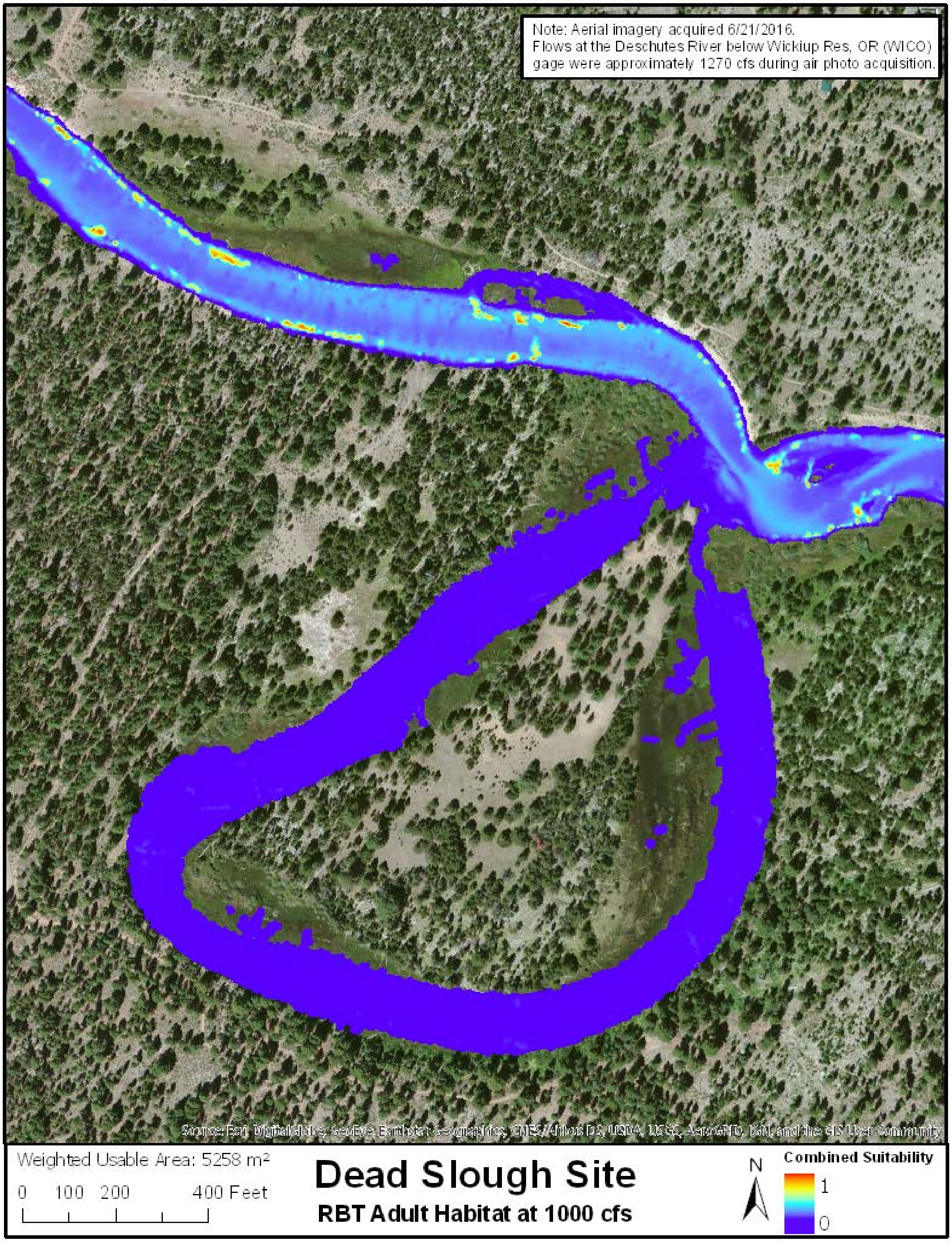

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 4197 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 400 cfs
N
Combined Suitability
1
0

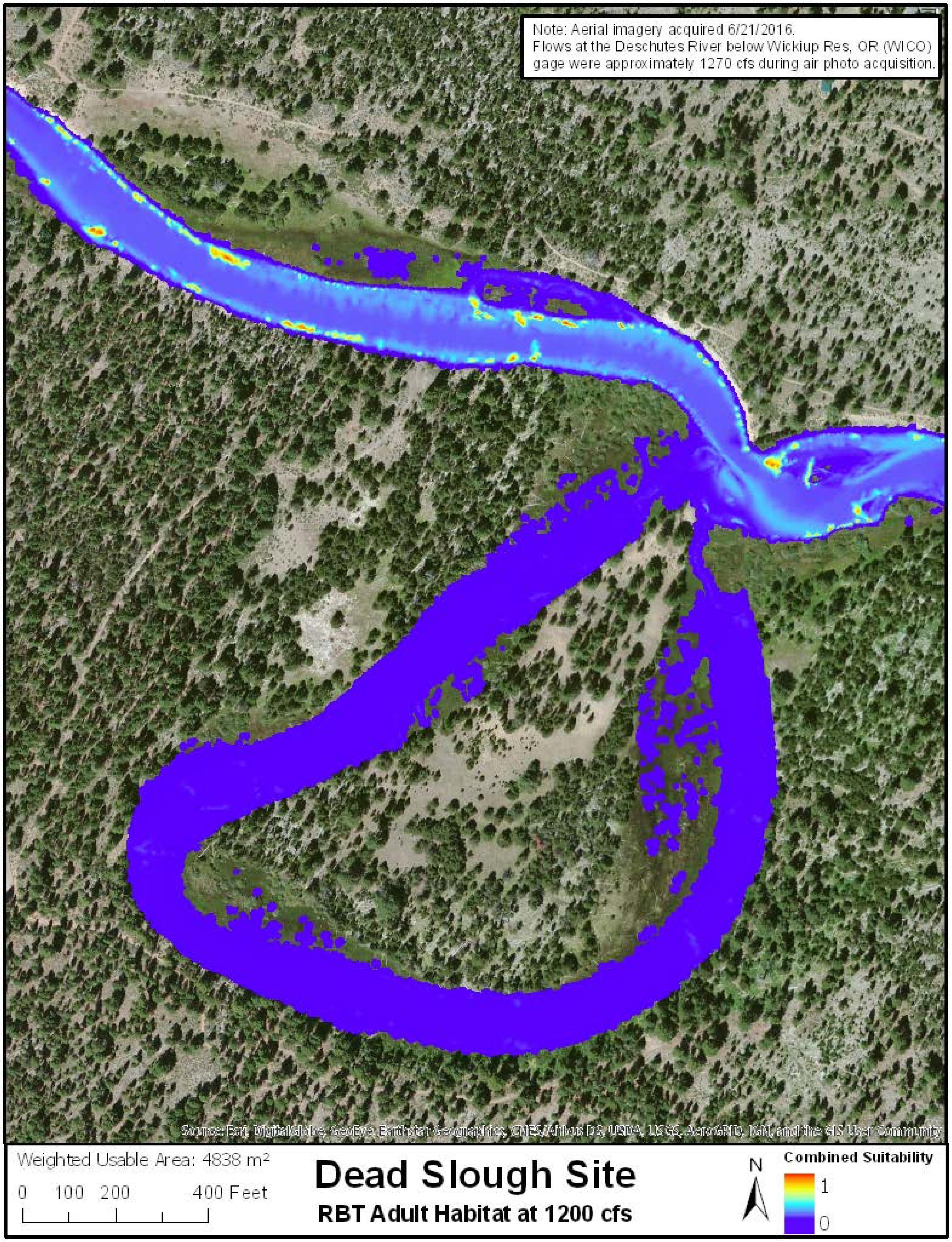

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 4745 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 500 cfs
N
Combined Suitability
1
0

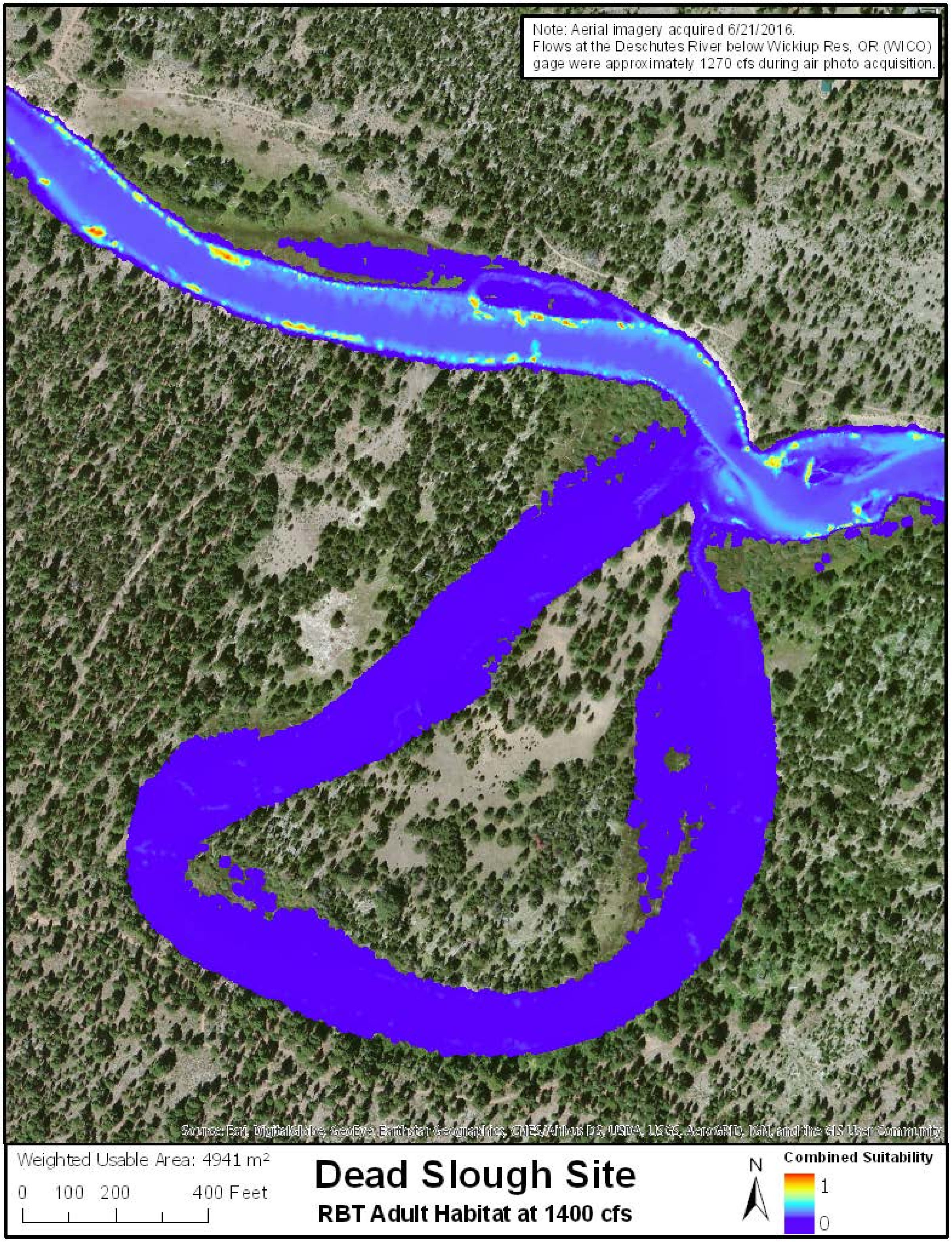

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 5024 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 600 cfs
N
Combined Suitability
1
0

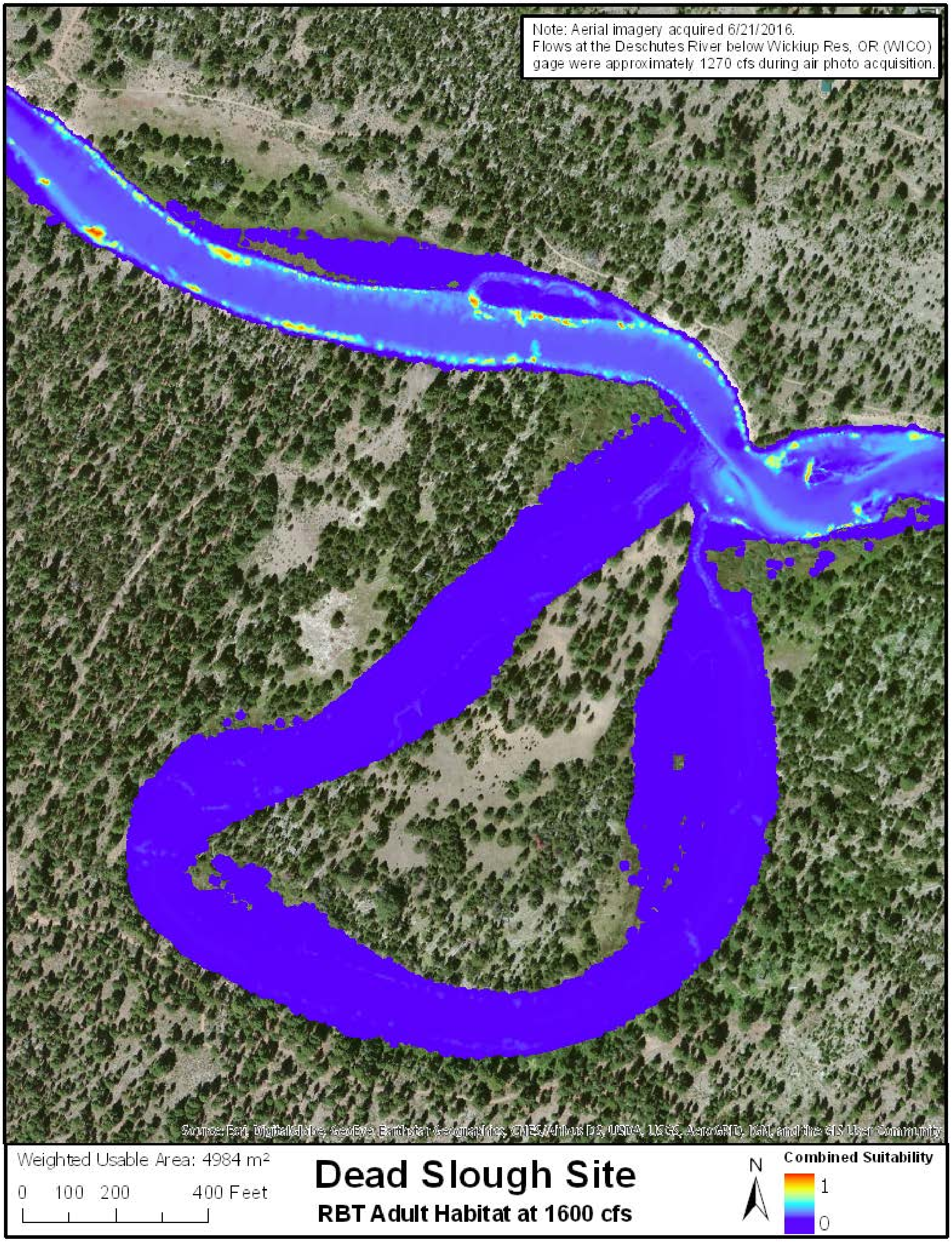

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 5038 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 700 cfs
N
Combined Suitability
1
0

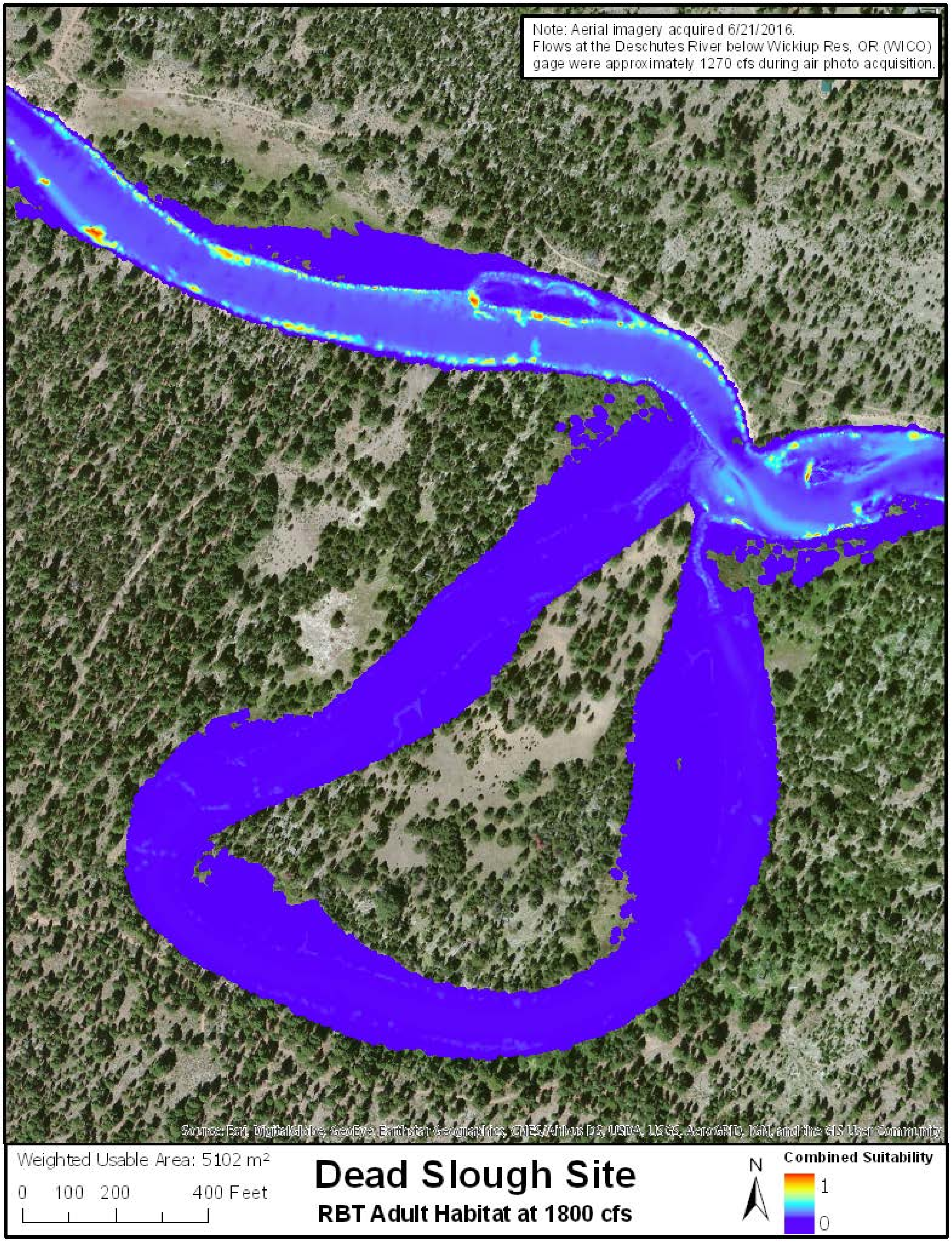

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 5240 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 800 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 5258 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 1000 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 4838 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 1200 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 4941 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 1400 cfs
N
Combined Suitability
1
0

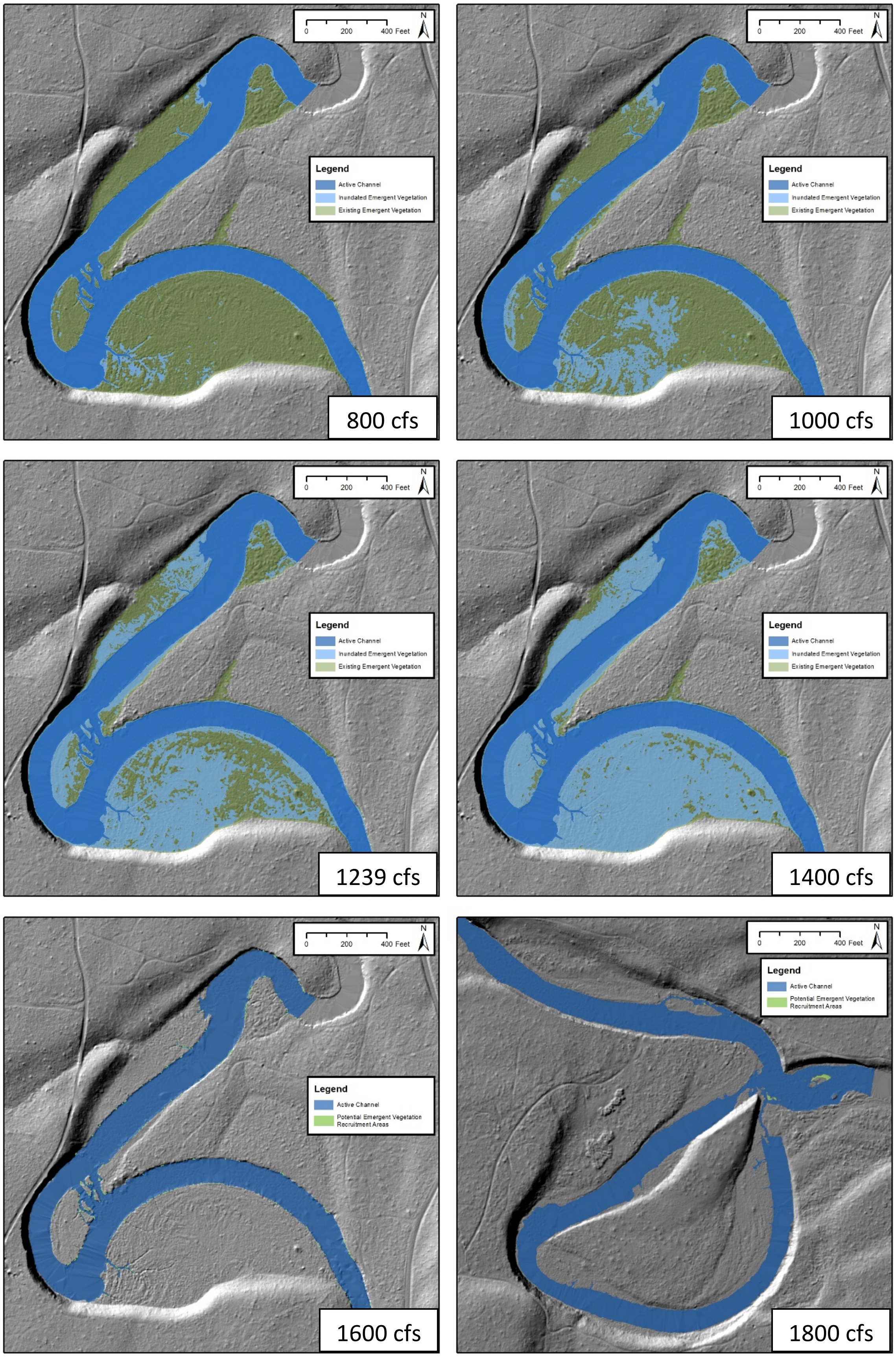

Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Weighted Usable Area: 4984 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 1600 cfs
N
Combined Suitability
1
0


Note: Aerial imagery acquired 6/21/2016.
Flows at the Deschutes River below Wickiup Res, OR (WICO) gage were approximately 1270 cfs during air photo acquisition.
Weighted Usable Area: 5102 m²
0 100 200 400 Feet
Dead Slough Site
RBT Adult Habitat at 1800 cfs
N
Combined Suitability
1
0

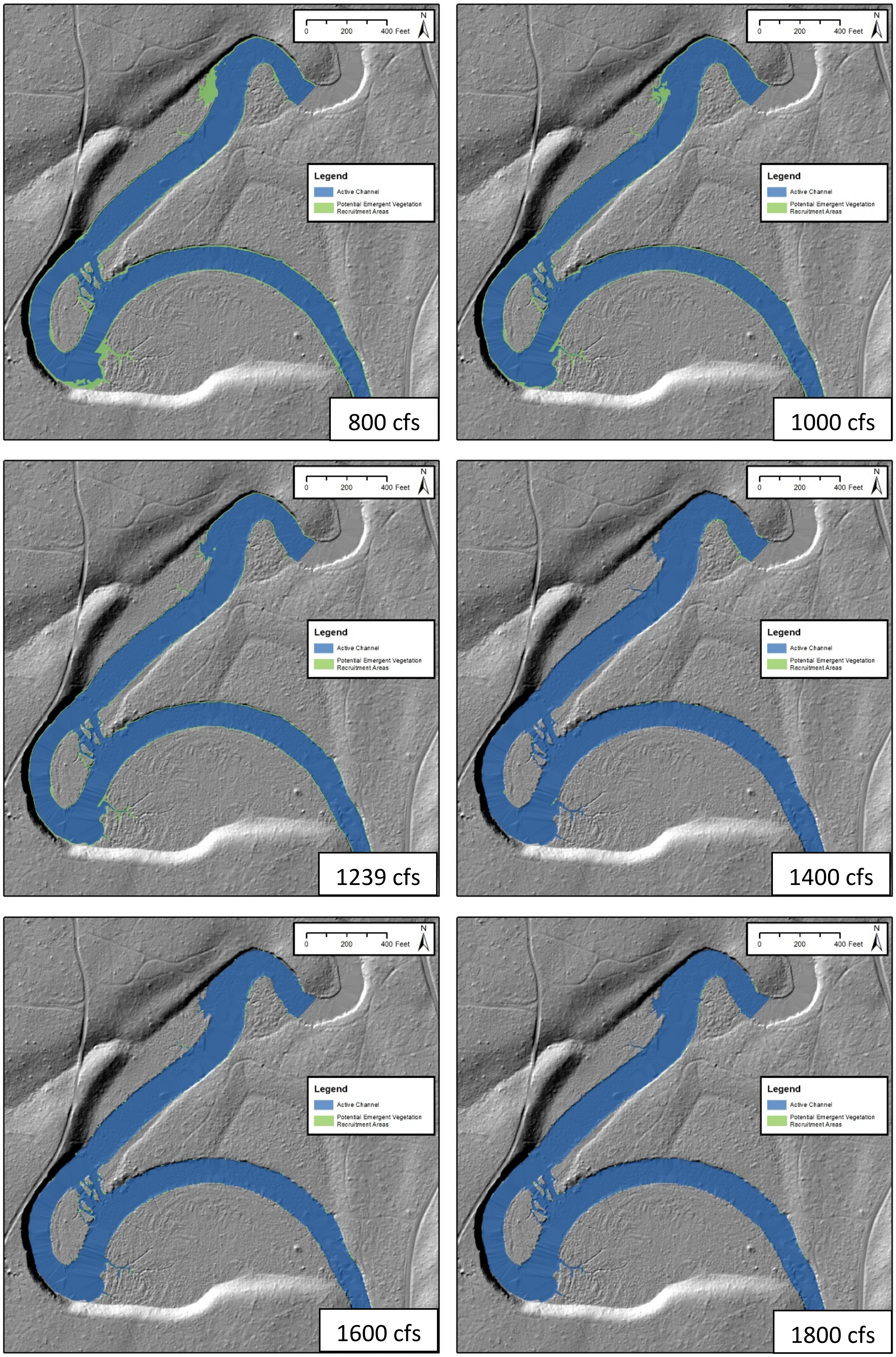
Appendix C

Riparian Analysis Maps

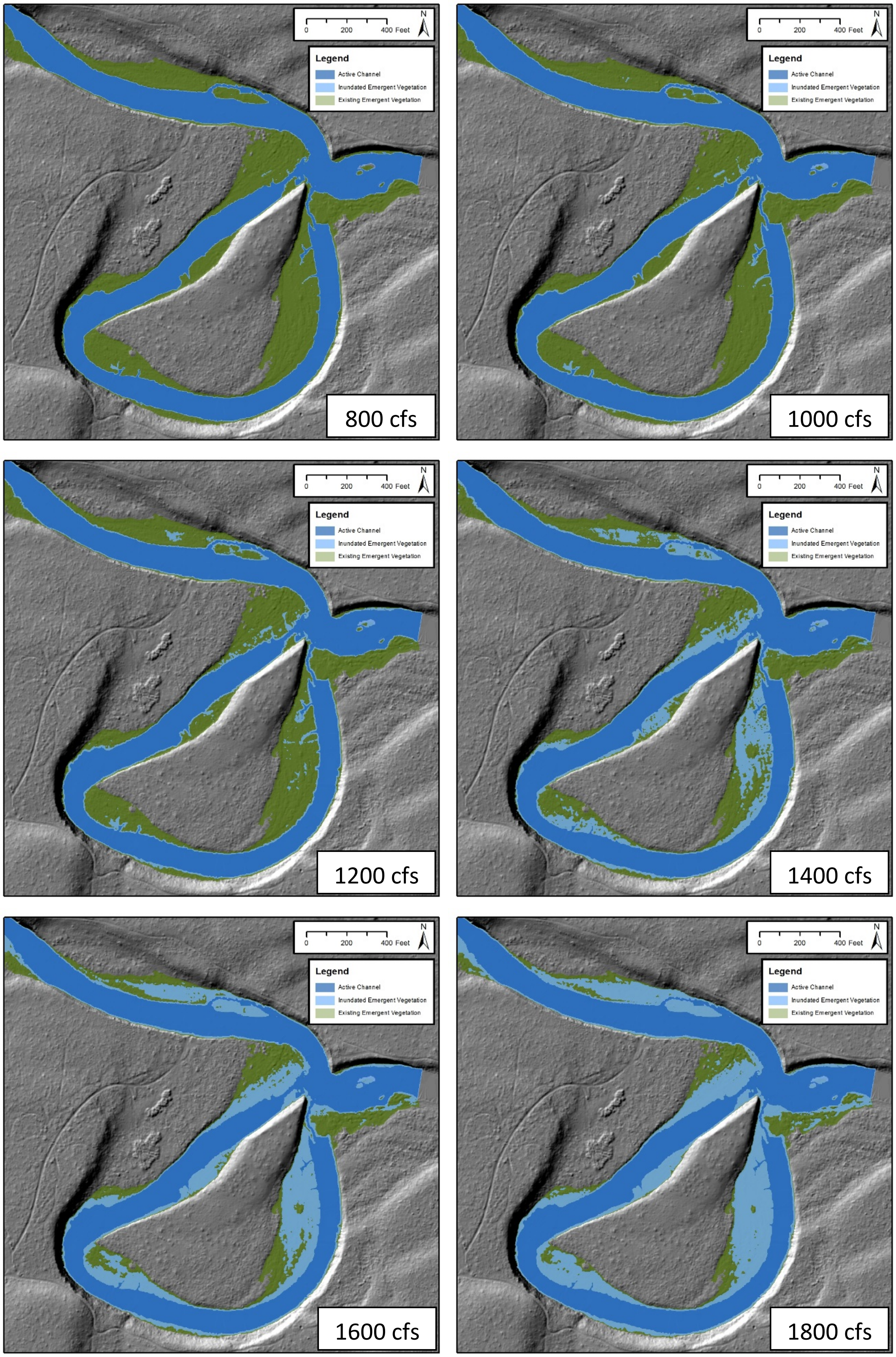
Bull Bend – Existing Emergent Vegetation Inundation



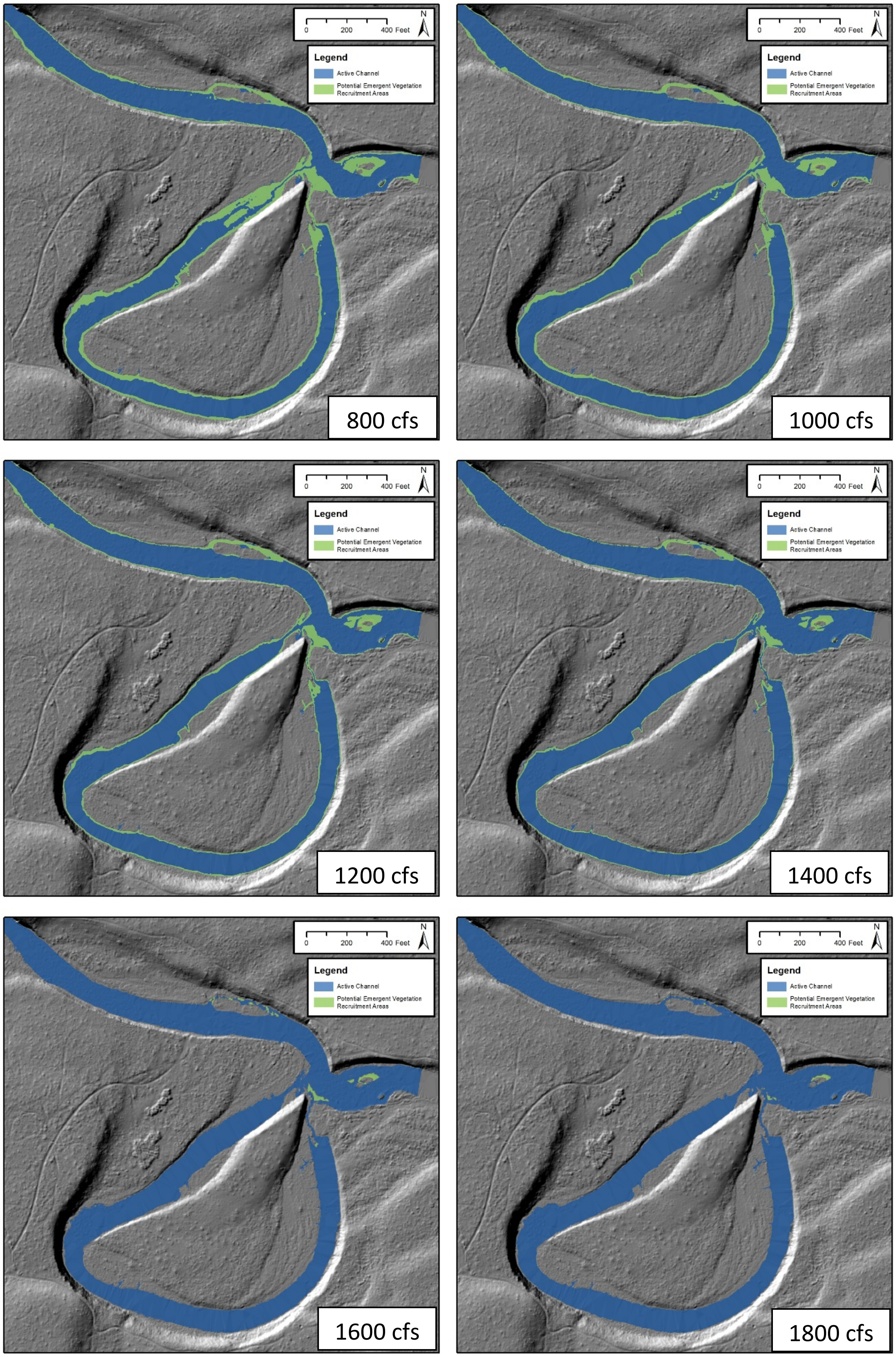
Bull Bend – Potential Emergent Vegetation Recruitment



Dead Slough – Existing Emergent Vegetation Inundation



Dead Slough – Potential Emergent Vegetation Recruitment



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