Herrera Environmental Consultants, Inc.

Final Memorandum

To	Kimberlie Gridley, South Puget Sound Salmon Enhancement Group
cc	Florian Leischer, Nisqually Indian Tribe
From	Chris Brummer and Ian Mostrenko, Herrera Environmental Consultants
Date	October 23, 2008
Subject	Hazard and Risk Assessment, Mashel River Phase II Restoration Analysis and Design

Introduction

This technical memorandum presents the results of a hazard and risk assessment completed for the second phase (Phase II) of a habitat restoration project proposed by the South Puget Sound Salmon Enhancement (SPSSEG) on the Mashel River near Eatonville, Washington. The proposed measures are being implemented to restore habitat for fall Chinook, winter steelhead, and coho. The Phase II project extents include two discontinuous reaches designated as Reach 4 and Reach 7 (Figure 1), as modified herein from the reach designations defined by Watershed Professionals Network (2004). Reach 4 is approximately 1,900 feet long and extends from the former Weyerhaeuser haul road bridge to the State Route (SR) 161 bridge. Reach 7 is approximately 2,300 feet long and extends from approximately 1,300 feet upstream of the confluence with the Little Mashel River to approximately 1,000 feet downstream of the confluence. The SPSSEG proposes to construct several engineered logjams (ELJs) and other habitat structures in both these reaches as part of the Phase II restoration.

Previous habitat restoration activities completed during Phase I within the vicinity of this project included the construction of several ELJs in Mashel River Reaches 1, 2, and 4 during 2006 and 2007 by the SPSSEG. A total of three bank ELJs and one smaller deflector ELJ were constructed on the left bank in the vicinity of Smallwood Park within Reach 4. No ELJs or other successful habitat restoration activities have been completed in Reach 7. A small riparian planting was done by the Pierce Conservation District in Reach 7 during 2002, but failed due to consistently dry soil conditions.

Purpose and Scope

The purpose of this study is to identify existing flood and erosion hazards within Reaches 4 and 7 of the Mashel River and to evaluate any potential increases in these risks as a result of the proposed habitat restoration measures. The scope of this study is limited to the identification of

existing geomorphic hazards and the risks the proposed measures may pose to existing property and infrastructure through the hydraulic modeling of existing and proposed conditions and an assessment of changes in existing risk to property and infrastructure as a result of the project. The scope of this study is limited to the assessment of risk within the extents of Reaches 4 and 7, as defined above.

The proposed habitat restoration measures will increase the hydraulic roughness of the channel in the immediate vicinity of the proposed ELJs. This local effect on the channel hydraulics is necessary to achieve the desired habitat effects of creating pools and sorting spawning gravels. Because the channel must still convey the same amount of water under the proposed conditions as it does under existing conditions, habitat restoration measures that add hydraulic roughness and decrease the average flow velocity have the potential to increase the water-surface elevation relative to existing conditions.

FEMA typically prohibits encroachments in regulated floodways unless provided with an analysis showing no net rise in the 100-year, base flood elevation. In the past, FEMA Region 10 has made exceptions to the no-rise standard for fish-enhancement projects by encouraging project designers to keep any rise in the base flood elevation to as close to zero as possible and by requiring that existing property and infrastructure not be impacted by a potential rise. Additionally, FEMA Region 10 encourages any rise in the base flood elevation to be offset by compensatory storage, channel alteration, or removal of existing encroachment. FEMA Region 10 has deferred to local officials to make these determinations for fish-enhancement projects. This risk assessment addresses the potential impacts to existing property and infrastructure as a result of the proposed habitat restoration measures and also considers some offsets recommended by FEMA for the proposed measures that might constitute a floodway encroachment.

This hazard and risk assessment was performed by reviewing existing background information, assessing existing geomorphic conditions, identifying potential restoration opportunities and construction constraints, performing hydraulic modeling of existing and proposed conditions, and evaluating the anticipated changes in flood elevations and flow velocities.

Background

Several reports and data sets were reviewed during the development of this study:

Mashel River Restoration Design Technical Memorandum prepared for the Pierce Conservation District (Watershed Professionals Network 2004). This report includes a discussion of land use, geology, riparian vegetation, hydrology, disturbance, and existing conditions for the watershed.

Mashel Watershed Analysis: Resource Assessment Report prepared by the Washington Department of Natural Resources (Bohle et al. 1996).

Flood Insurance Mapping Study for the Mashel River near Eatonville, Washington, Pierce County, WA and Incorporated Areas, Community Number – 530138 prepared for the Federal

Emergency Management Agency (FEMA) by Northwest Hydraulic Consultants (NHC 2003). This report includes the updated FEMA flood map for the Mashel River from the confluence with the Little Mashel River to the railroad bridge (approximately 2.4 miles) and supporting documentation for this study.

PCD (Pierce Conservation District). 2002. Lidar digital elevation model and color digital orthophotographs. Data acquired September 16, 2002.

Existing Geomorphic Conditions

The assessment of existing geomorphic conditions is based primarily on information compiled by Watershed Professionals Network (2004), geomorphic mapping of Reaches 4 and 7 conducted by Herrera on October 30, 2007, and prior hydraulic modeling and construction experience in Reaches 1, 2, and 4.

Watershed Conditions

The Mashel River drains an area of approximately 56 square miles upstream of the confluence with the Little Mashel River. The Little Mashel River drains an area of approximately 20 square miles. Both rivers drain the southwestern flank of Mount Rainier. Most of the basin was heavily logged as early as the late 1800s and is now managed as an industrial forest. The project reach is impacted by artificially high sediment loading from landslides associated with road construction and timber harvest. Logging has also reduced instream wood through the clearing of riparian forests.

Site Geology

Geologic conditions at the project site are dominated by Pleistocene age (less than 1.5 million years old) glacial sediments underlain by Miocene age (5 to 15 million years) continental sedimentary rocks of the Mashel Formation (interbedded sandstone, siltstones, conglomerates derived from volcanic source rocks). The active floodplain of the Mashel River is mapped as recent alluvium (DNR 2005). Rocks of the Mashel formation are exposed in the upstream extent of Reach 4 and at the base of the recent landslide in Reach 7. Glacial sediments are exposed in terraces and the upper portion of the recent landslide in Reach 7.

Existing Site Conditions

Existing geomorphic conditions in Reaches 4 and 7 are described in the following sections. Results of the hydraulic modeling of existing conditions are described later in this memo.

Reach 4

The active channel in Reach 4 ranges in width from approximately 80 to 150 feet and consists of three prominent meander bends confined within the floodplain (Figure 2). Reach 4 exhibits a classic pool-riffle morphology, with prominent riffles located between meanders. Side channels split from the mainstem channel and occupy the inside of each meander bend. Most of Reach 4 is incised and disconnected from the floodplain as a result of the historical removal of the riparian forest and the loss of instream wood. ELJs 4-1 through 4-4 were constructed in 2006 along the left bank of the middle meander bend within Smallwood Park.

The upstream extent of Reach 4 is confined by the former bridge crossing and bedrock exposed in the channel and along the banks. Bedrock was not encountered in Reaches 1, 2, and 4 at the depth of the previous excavations, which ranged from 10 to 15 feet below the channel bed. Downstream of the bedrock constriction, the channel is artificially confined by an intermittent riprap revetment on the right bank. Approximately 300 feet of the right bank (downstream of the Eatonville water treatment plant) is unprotected by riprap and is actively eroding. Most of the riprap on the right bank consists of concrete debris placed in an ad-hoc manner to inhibit bank erosion. However, sparse bank coverage by the riprap and concrete debris observed within the channel provide evidence that the ad-hoc revetment is unstable and will continue to fail if left untreated. The one exception is the riprap revetment constructed along right bank to protect the Eatonville water treatment plant. The facing on this revetment consists of granite boulders up to 6 feet in diameter.

The left bank across from the water treatment plant is armored with large boulders but lacks any apparent riprap. Relic side channels within the southern floodplain across from the treatment plant and upstream of Smallwood Park are currently disconnected from the mainstem except during exceptionally large flood events. For instance, the southern floodplain does not appear to have been activated during the November 2006 flood, but should have been inundated during the December 2007 flood based on the results of the HEC-RAS modeling presented later in this memo. Based on data provided by the Nisqually Indian Tribe from the USGS gage at La Grande (approximately 1 mile downstream of the confluence with the Little Mashel River), the recurrence intervals of these events were approximately 10 and 90 years, respectively. The recurrence intervals in Reach 4 (upstream of the influence of the Little Mashel River) may have been different. By comparison, the 1996 event had a recurrence interval of approximately 25 years.

Aerial photographs indicate that a branch of the mainstem Mashel River flowed through the left bank floodplain area and Smallwood Park sometime between 1955 and 1965 but migrated northward and abandoned the floodplain before 1978. The channel subsequently filled with sediment and/or the channel became incised since abandonment of the floodplain. The remnant side channels were reportedly excavated to divert water to the trout pond in Smallwood Park.

The mainstem widens downstream of the upper meander to include a vegetated bar separating the mainstem from a secondary channel on the left bank. This secondary channel remains wetted at base flow and joins back with the mainstem at the end of the riffle immediately upstream of

ELJ 4-1. The side channel on right bank across from the park was dry during the site visit and is only activated during high flows. The third major side channel on the left bank downstream of ELJ 4-4 was activated during the November 2006 flood.

Downstream of the park, the prominent riffle drops into a pool that has formed along right bank adjacent to the Mill Pond. Here, the right bank is a near-vertical, earth embankment containing sparse accumulations of concrete blocks and woody debris at the toe. Several pieces of concrete and a single rootwad are fortuitously located where flow currently impinges on the bank and appear to be inhibiting further bank erosion at this time. Based on a comparison of historical aerial photographs and examination of the lidar, the channel migrated approximately 80 feet north by eroding the toe of the embankment between 1965 and 1978. The embankment separating the river from the Mill Pond is now only 30 feet wide at this location. Based on the lidar, the elevation of the water surface in the mill pond is approximately 14 feet above the water surface of the river at base flow.

The point bar on the left bank across from the Mill Pond appears to be inundated on an annual basis. A large cottonwood (115 feet long, 28-inch diameter) recently fell to the north and extends out to the edge of the low-flow channel. Riprap and other concrete debris were observed in the channel downstream of the Mill Pond and were presumably eroded from the Mill Pond revetment. Downstream of the Mill Pond, the river is deflected to the northwest under the SR 161 bridge by a rock revetment on the left bank. A deep scour hole has formed on the left bank upstream and adjacent to the southern abutment of the SR 161 bridge.

Based on the assessment of existing conditions, Reach 4 includes several areas that are currently at risk of flooding or bank erosion:

- Erosion of the right bank downstream of the Eatonville water treatment plant.
- Flooding in Smallwood Park.
- Erosion and breaching of the earth embankment (right bank) at the southwest corner of the Mill Pond. Breaching of the Mill Pond would adversely impact water quality and spawning habitat in the downstream reach of the Mashel River. Breaching of the Mill Pond may also pose a public safety hazard to downstream properties.
- Scour and wood accumulation at the SR 161 bridge.

Reach 7

Reach 7 exhibits complex geomorphic conditions in relation to Reach 4. The mainstem of the Mashel River rapidly transitions from a relatively confined bedrock/alluvial channel at the upstream extent of Reach 7 to unconfined conditions immediately upstream of the confluence with the Little Mashel River (Figure 2). Reach 7 consists of the mainstem channel, several side channels, and an active floodplain inset within a wide canyon and a series of ancient terraces that

likely records the late Pleistocene or early Holocene incision of outwash deposits during post-glacial downcutting of the Mashel River. The width of the low-flow channel ranges from approximately 85 to 125 feet. Additionally, bedrock is exposed at several locations in the upstream portion of the reach and at the toe of the active landslide.

The channel and floodplain are incised 50 to 90 feet into the surrounding sedimentary rocks of the Mashel Formation and overlying glacial sediments. The Mashel Formation forms a steep bluff on the north side of the valley and is prone to deep-seated slope failures. Based on field observations and an interpretation of the lidar topography, the base of the bluff along the entire project reach is mantled with recent and ancient landslide deposits. Additional water and sediment from the Little Mashel River enters on the left bank of the mainstem near the middle of the project reach. Convergent flow at the confluence has created a deep pool at this location. The width of the active floodplain ranges from 400 to 700 feet downstream of the confluence.

The mainstem consists of two prominent meander bends located on either side of the Little Mashel confluence. The upper meander (upstream of the Little Mashel confluence) currently flows along the toe of the recent landslide at the base of the steep bluff. The landslide was reportedly last activated either in 1990 or in 1996 (or both dates) during intense storms and peak flows with estimated recurrence intervals of approximately 50 and 25 years, respectively (Watershed Professionals Network 2004). Although the site was not visited after the December 2007 flood (an estimated 90-year recurrence event downstream of the Little Mashel confluence at the La Grande gage), reactivation of the landslide has not been reported. The flood of record occurred in 1946. Based on a comparison of historical aerial photographs, widening of the upper meander bend and straightening of the lower meander bend occurred between 1989 and 2002. Conversations with property owners indicate that the straightening in the lower meander occurred during the 1996 flood and involved an avulsion during the failure of a riprap revetment that had maintained flows through the historical meander alignment to the north.

Following the 1996 event, additional riprap was reportedly placed by local landowners to protect the left bank and floodplain adjacent to the confluence (Figure 3). The southern floodplain protected by this riprap contains an 800-foot-long, wall-based channel (a secondary channel formed on a floodplain near the base of a valley wall or terrace, often created by channel migration and fed by hillslope seepage, shallow groundwater, or hyporheic flow). Based on the hydraulic modeling presented below, this wall-based channel is apparently inundated by flows with a 1- to 2-year recurrence. Lidar topography and aerial photos suggest that the upstream extent of this side channel has been filled and the channel widened to create an artificial pond. Although the previous bank and floodplain modifications have disconnected this side channel (and associated spawning, rearing, and refuge habitat) from mainstem flows, a partial or full avulsion through this floodplain would provide limited habitat value because the upstream half of this floodplain area currently lacks significant riparian vegetation.

Based on the assessment of existing conditions, Reach 7 includes several areas that are currently at risk of flooding, bank erosion, or bank failure:

- Re-activation of the active landslide at the upper meander

- Erosion of the left bank at the confluence of the Little Mashel River and avulsion of the river into the wall-based channel

- Flooding on the left bank floodplain south of the abandoned meander.

Proposed Restoration Measures

The proposed restoration measures are based on the success of previous measures in Reaches 1, 2, and 4, construction feasibility and site constraints, the project goal of maximizing habitat gain versus construction cost, and maintaining or decreasing the existing risk of flooding and bank erosion to adjacent property and infrastructure. For purposes of hydraulic modeling, all ELJs were assumed to be 40 feet by 40 feet in dimension.

Reach 4

The proposed restoration measures in Reach 4 include the construction of six ELJs, stream bank and floodplain grading, revegetation, and floodplain roughening to deflect flow and reduce existing flood hazards in Smallwood Park (Figure 2). The restoration measures in Reach 4 are proposed at two locations:

- **Right bank between the Eatonville water treatment plant and Mill Pond:** Two bank ELJs (ELJs 4-5 and 4-6) are proposed along the unprotected and eroding bank downstream of the Eatonville water treatment plant. The ELJs would protrude 20 to 30 feet into the channel from the edge of the existing right bank. The purpose of the ELJs is to create complex pool habitat and cover and to sort spawning gravels. The ELJs will also reduce flow velocities, dissipate energy, and inhibit further bank erosion toward the mill pond. The constriction and added hydraulic roughness created by these bank ELJs would divert additional flows into the secondary channel along the left bank. As a result of this effect, additional woody debris could accumulate on the large boulder at the head of the vegetated bar to form a natural apex jam and further constrict the channel. Model results suggest that the backwater created by this constriction would reduce erosive forces on the right bank upstream of ELJ 4-5 but slightly increase the potential for scour and bank erosion on the left bank of the secondary channel due to increased flows. The upstream extent of the backwater from these ELJs is not expected to be sufficient to reactivate any of the existing side channels on the left bank floodplain upstream of Smallwood Park. The hydraulic modeling of ELJ placements further upstream on the right bank (adjacent to the water treatment plant) also resulted in insufficient conditions for the reactivation of the side channels on the left bank floodplain upstream of Smallwood Park.

- **Right bank adjacent to the Mill Pond and left bank floodplain:** Three bank ELJs (ELJs 4-7, 4-8, and 4-9) are proposed on the right bank, and one apex ELJ (ELJ 4-10) is proposed on the existing point bar in the left bank floodplain. The three ELJs constructed on the right bank will protrude 20 to 40 feet into the existing channel. Although ELJ 4-7 and ELJ 4-9 will be partially keyed into the right bank, ELJ 4-8 would be constructed at the thinnest and most vulnerable segment of the Mill Pond levee and should be constructed so as to not require excavation of the existing levee. ELJ 4-10 would be designed to function in concert with ELJ 4-7 to deflect flows toward the left bank floodplain. Ballast material for these ELJs would be obtained from side-channel excavation on the left bank and from the ELJ excavations.

Reach 7

The proposed restoration measures in Reach 7 include the construction of up to ten ELJs, bank roughening with a continuous wood crib wall, floodplain grading, and revegetation (Figure 3). The restoration measures in Reach 7 are proposed at three key locations:

- **Upstream meander bend:** Two bank ELJs (ELJs 7-1 and 7-2) are proposed on the right bank, and one apex ELJ (ELJ 7-3) is proposed on the left bank downstream of the inlet to the existing side channel. The purpose of these ELJs is to divert a portion of the flow into the side channels on the left bank to increase available habitat where riparian vegetation already exists. These ELJs will also divert a portion of the mainstem flow away from the toe of the active landslide. Bank roughening, consisting of logs with attached rootwads and held in place with pin piles, is proposed at the toe of the landslide downstream of ELJ 7-2. Excavation to lower the inlet of the side channel is proposed near ELJ 7-3 at the inlet to the side channel. Because ELJ 7-1 would be constructed on bedrock, conventional piles may not be feasible in its construction. Instead, ELJ 7-1 would be designed as a gravitational structure, whereby structural stability is achieved by the placement of rock ballast in the core of the structure and not by the use of driven piles. Alternatively, a pile-based structure could be constructed by drilling shallow (3- to 5-foot-deep) sockets into the bedrock).

- **Little Mashel confluence:** Two apex ELJs (ELJ 7-4 and 7-5) are proposed within the left-bank floodplain upstream of the confluence with the Little Mashel River, and two bank ELJs (ELJs 7-6 and 7-7) are proposed on the left bank downstream of the confluence. The existing riprap should be incorporated into ELJs 7-6 and 7-7 to provide a measure of redundancy against bank erosion. The purpose of these ELJs is to deflect flows originating from the mainstem and the left bank

side-channels away from the unvegetated (left) bank downstream of the confluence and into the old channel alignment to the north. By reducing the risk of property loss from an avulsion through the southern floodplain, ELJs 7-6 and 7-7 would eliminate opportunities to reconnect flows in the wall-based channel; however, rearing and refugia habitat could be restored in this channel with the cooperation of property owners if further investigations find that hyporheic flows are sufficient for this purpose. ELJs 7-6 and 7-7 will be bridged by additional bank roughening consisting of logs with attached rootwads embedded into the riprap and held in place with pin piles. Additionally, ELJ 7-4 must be designed to accommodate incident flow approaching from any angle ranging between the north-northeast and the south.

- **Downstream meander bend:** Excavation of the former meander bend is proposed in order to initiate reoccupation of this alignment as a secondary channel. One apex ELJ (ELJ 7-8) is proposed on the right bank of the existing main stem to divert flow into the excavated channel. This ELJ would work in concert with ELJs 7-7 and 7-6 on the opposite bank. Additionally, two bank ELJs (ELJs 7-9 and 7-10) are proposed on the right bank of the excavated channel to provide pool habitat and deflect flows away from the eroding bank at the toe of the ancient landslide deposits. The existing alder trees growing along the right bank adjacent to the abandoned orchard should be adequate to inhibit bank erosion if only a portion of the flow is diverted to this side channel, as this channel formed previously from the entire flow of the mainstem.

Hydraulic Modeling

Existing and proposed hydraulic conditions were evaluated in Reaches 4 and 7 using two separate hydraulic models. The following sections describe the model assumptions and results for both existing and proposed conditions.

Reach 4

Reach 4 was evaluated for the 100-year flow using the HEC-RAS model developed for FEMA by NHC (2003). The proposed conditions in Reach 4 were modeled by modifying the appropriate cross-sections to simulate the proposed restoration measures. The model predicts the water-surface elevation and the cross-sectional average velocity. Limitations with the HEC-RAS model arise from the accuracy of the cross-sections. For instance, only 5 of the 32 cross-sections used by the model through Reach 4 were derived from topographic surveys. The remaining 27 cross-sections were interpolated between the original 5 surveyed cross-sections. To verify elevations, the results of the model simulations were checked against the 2002 lidar, which was not available when the HEC-RAS model was developed. Results of the HEC-RAS modeling for Reach 4 are summarized in Table 1.

Table 1. Results of the HEC-RAS model for existing and proposed conditions at selected locations in Reach 4 for the 100-year flow.

Location	HEC-RAS Cross-Section Location (RM upstream of Little Mashel confluence)	Water Surface Elevation (feet, NGVD29)		Water Velocity (ft/sec)	
		Existing	Proposed (net change)	Existing	Proposed (net change)
Cross-Section "Q" approx. 75' upstream of former bridge crossing	1.280	800.1	800.1	12.1	12.1
Former bridge crossing	1.249	797.9	798.1 **(+0.2)**	12.0	11.5 **(-0.5)**
Upstream of Eatonville Water Treatment Plant	1.196	792.7	793.5 **(+0.8)**	13.4	11.0 **(-2.4)**
Cross-section "P" downstream of Eatonville Water Treatment Plant	1.188	792.1	792.3 **(+0.2)**	13.2	13.0 **(-0.2)**
Proposed ELJ 4-6 on right bank downstream of side channel inlet	1.152	788.9	789.1 **(+0.2)**	11.3	14.0 **(+2.7)**
Cross-Section "O" upstream of Smallwood Park	1.106	786.4	786.4	6.2	6.2
Cross-section "N" upstream of Existing ELJ 4-4 at Smallwood Park	0.995	780.5	781.1 **(+0.6)**	5.7	5.0 **(-0.7)**
Proposed ELJ 4-10 on right bank near Mill Pond	0.938	776.8	779.6 **(+2.8)**	7.8	5.1 **(-2.7)**
Proposed ELJ 4-8 on right bank near Mill Pond	0.929	776.4	778.8 **(+2.4)**	7.8	7.4 **(-0.4)**
Upstream of proposed ELJ 4-9 on right bank	0.9197	776.0	776.4 **(+0.4)**	8.0	12.7 **(+4.7)**
Cross-section "M" at SR 161 Bridge	0.882	774.5	774.5	8.4	8.4

Note: Vertical datum for the HEC-RAS model is NGVD29. Add 3.46 ft to convert NGVD29 to NAVD88.

Results of the HEC-RAS model show that the proposed measures in Reach 4 would result in an increase in the existing 100-year base flood elevation and changes in flow velocity within the immediate vicinity of the ELJ placements. Most of the changes in flow velocity involve decreases; however, local increases in velocity would occur at ELJ 4-6 and immediately upstream of ELJ 4-9 due to the constrictions created by these structures. No net change in either the base flood elevation or average flow velocity is expected at the upstream and downstream boundaries of the project defined by the former bridge crossing upstream of the Eatonville water treatment plant and at the SR 161 bridge.

Under proposed conditions, the 100-year base flood elevation at the water treatment plant would still be approximately 3 feet below the top of the revetment. At the Mill Pond, the proposed 100-year base flood elevation would be approximately 7 feet below the top of the embankment.

Reach 7

Because the existing HEC-RAS model only extends as far downstream as the Little Mashel River, hydraulic conditions in Reach 7 were evaluated using the two-dimensional model FLO-

2D. The FLO-2D model uses the new lidar topography and is well-suited for the complex geomorphic conditions and the convergent and divergent flow that occurs in this reach. The two-dimensional model of Reach 7 was developed using a grid size of 15 feet. FLO-2D was used to calculate the flow depth and velocity in each grid cell under both existing and proposed conditions for the 2-year and 100-year flows. Based on the precision of the model, the level of significance was set at +/- 0.1 feet and +/- 0.5 feet per second. Results of the FLO-2D modeling for Reach 7 are presented in Figures 4 through 11 and are summarized below in Table 2.

Table 2. Results of the FLO-2D model for existing and proposed conditions at selected locations in Reach 7 for the 100-year flow.

	Water Depth (feet)		Max. Water Velocity (ft/sec)	
Location	Existing Conditions	Net Change Under Proposed Conditions	Existing Conditions	Net Change Under Proposed Conditions
Upstream of ELJ 7-1	8 to > 9	0.1 to 0.5	13 to 15	-3.0 to -0.5
Upstream of active landslide near side channel inlet (ELJs 7-1 through 7-3	6 to 9	0.5 to 2.0	13 to 15	> 3
Right bank along active landslide toe	5 to 6	-0.1 to 0.1 (not significant)	9 to 10	-3.0 to -0.5
Right bank immediately downstream of active landslide	4 to 5	0.1 to 0.5	8 to 9	-3.0 to -0.5
Left bank of Little Mashel at confluence	> 9	0.1 to 0.5	11 to 12	1.0 to 2.0
Left bank of Mashel immediately downstream of Little Mashel confluence	> 9	-1.0 to -0.1	13 to 15	-8.0 to -5.0
Right bank along abandoned orchard (old channel alignment)	5 to 6	0.1 to 1.0	5 to 6	> 3
Left bank floodplain and side channel near lower meander.	3 to 4	-0.5 to -0.1	8 to 9	-0.5 to 0.5 (not significant)

Results of the FLO-2D model show that the proposed measures in Reach 7 would not increase flow depths and would slightly reduce flow velocities along the toe of the active landslide. Model results also show that the proposed restoration measures would increase the frequency of inundation of the side channel within the active floodplain on the left bank of the upper meander and within the abandoned side channel in the lower meander. Splitting the flow between the active channel and the abandoned (lower) meander would result in a considerable reduction in flow velocity along the left bank immediately downstream of the confluence, with no significant increase in flooding within the left bank floodplain.

Geomorphic Risk Assessment

The anticipated geomorphic changes associated with the proposed habitat restoration measures include reduced bank erosion, sorting and retention of spawning gravels, increased pool habitat, the reconnection of floodplain and side-channel habitat, and the overall increase in instream habitat complexity. The relative change in the level of risk associated with these measures is summarized below in Table 3.

Table 3. Summary of existing and anticipated conditions under the proposed restoration measures.

Location	Feature	Existing conditions	Anticipated conditions under the proposed measures
Reach 4, right bank at Eatonville, water treatment plant	Riprap revetment along Eatonville, water treatment plant	HEC-RAS predicts a flood elevation within approximately 3 feet of the top of the riprap revetment during the 100-year event.	HEC-RAS predicts an increase of 0.2 to 0.6 feet in water-surface elevation. The base flood elevation could be reduced during design development.
Reach 4, right bank, downstream from the Eatonville water treatment plant	New ELJs	The existing bank is unprotected and eroding toward the Mill pond.	HEC-RAS predicts a net increase of 0.2 ft in water-surface elevation and a local increase of 2.7 ft/sec in the velocity at ELJ 4-6. The base flood elevation could be reduced during design development.
Reach 4, left bank at Smallwood Park	New ELJs at Smallwood Park	HEC-RAS predicts flooding of Smallwood Park during the 100-year event	HEC-RAS predicts an increase of 0.0 to 0.6 ft along the park and a minor reduction in flow velocity due to backwater from the proposed downstream ELJs.
Reach 4, right bank along the Mill Pond	Earth revetment containing the Mill Pond	The eroding revetment is at risk of becoming breached, which would drain the pond and adversely impact water quality in the downstream reach of the Mashel River.	HEC-RAS predicts an increase of up to 2.8 feet in the 100-year base flood elevation, reductions in flow velocity, and no increase in inundation area. The base flood elevation would be 7 feet below the top of the embankment and 5 feet below the top of the left bank. The ELJs would substantially reduce the risk of a levee breach by deflecting the thalweg to the south.
Reach 4, Both Banks	SR 161 Bridge abutments	The bridge is an artificial constriction. Scour is occurring along the left bank abutment.	HEC-RAS predicts no change in the 100-year base flood elevation and velocity. The upstream ELJs would collect woody debris and reduce the risk of wood accumulation on the bridge abutments.
Reach 7, left bank along upper meander	Left bank floodplain and side channels	Inundation during 2-year flow with shallow water depths and low velocities.	FLO-2D predicts increased flow depths and velocities required for spawning habitat.
Reach 7, right bank along upper meander	Active landslide	The Mashel River flows along the unprotected toe of the active landslide. Sediment from the eroding landslide impairs habitat.	FLO-2D predicts reduced velocity along the right bank due to proposed log revetment and diversion of flow to left bank side-channels and floodplain. Overall reduction in risk of landslide activation.
Reach 7, left bank at confluence	Eroding bank and floodplain area	Highly erosive banks are armored with riprap and impair habitat. Floodplain inundated during 2-year event.	Proposed ELJs will reduce erosion hazard and deflect flows north into abandoned side-channel to create additional spawning habitat under base-flow conditions. Flow deflection minimizes increase in 100-year base flood elevation to < 0.5 feet.
Reach 7, right bank at confluence	Abandoned side channel	Abandoned side channel has filled with sediment and lacks sufficient flows at 2-year event to sustain spawning habitat.	The ELJs proposed at the confluence and the excavation of the side channel will increase the frequency of inundation and improve spawning habitat.
Reach 7, right bank in abandoned side channel	Abandoned orchard	Slight risk of channel migration into the unvegetated floodplain.	FLO-2D predicts a reduction in flow velocity along this bank due to proposed measures.
Reach 7, left bank	Left bank floodplain	Inundation during the 2-year flood event.	FLO-2D predicts a reduction in flood depth (up to 0.5 feet) for the 100-year base flood due to the diversion of flow into the abandoned side channel.

Proposed Native Vegetation Planting

Plantings completed by the SPSSEG in Reach 4 for the first construction phase have included Douglas fir, cedar, cottonwood, dogwood, and shrubs such as rose and snowberry. The recommendations presented below are based partially on the success of these plantings as observed during site visits. The recommendations apply to the proposed restoration project but should also be considered for the recently constructed ELJs, as applicable. The following are recommendations are for the planting of four areas on the project site:

- Top surfaces of all ELJs
- River-facing sides of the ELJs
- Disturbed banks between ELJs and along bank-roughening logs
- Poorly vegetated floodplain areas in Reach 7.

Site conditions include very rocky and well-drained stream banks and floodplain soils with low soil moisture during the dry season. These conditions require aggressive revegetation techniques to successfully establish a thriving native plant community.

ELJ tops

Immediately following log placement and compaction of ballast material, the top surfaces of the ELJs should be covered with 6 inches of amended topsoil and seeded with a species mix of native grasses that will readily establish and thrive under seasonally dry conditions. Live plantings on this surface should use plants grown in containers at least 14 inches deep so that they are able to access soil moisture during the dry season. These plantings would be installed by hand with the use of an auger or with an excavator-mounted planter. The application of fertilizer packets, including slow-release fertilizers and mycorrhizal inoculum, will support the nutrient needs of the plants and increase water uptake during the dry season. Table 4 includes a species list of recommended for planting on the tops of ELJs.

Table 4. Recommended species plantings for the tops of ELJs.

Trees	Shrubs	Grasses
Picea sitchensis (Sitka spruce)	*Symphoricarpos alba* (Snowberry)	*Deschampsia caespitosa* (Tufted hairgrass)
Tsuga heterophylla (Western hemlock)	*Rosa nootkana* (Nootka rose)	Regreen Hybrid (sterile cover crop)
Pseudotsuga menzeiesii (Douglas fir)	*Amelanchier alnifolia* (Serviceberry)	

Vegetation incorporated into ELJ structures

Vegetation should be incorporated into the ELJs to create bioengineered structures that will retain ballast material and provide long-term stability through the development of root cohesion. Willow fascines (bundles of willow cuttings) wrapped in coir fabric should be installed into the river face of the ELJs during construction. These fascines should be tied to the structure with the

base of the bundle in contact with water or wet soil. Willow cuttings made in late winter or early spring should be tied together with coir twine to create fascines 12 to 18 inches in diameter and 8 to 10 feet long. The bottom two-thirds should be wrapped in several layers of coir fabric and tied securely. Once rooted and established, these bundles would provide overhanging vegetation and roughness on the ELJ surface and would also provide root cohesion for added structural integrity.

Actively growing willows could also be installed projecting from the face of the lower levels of the structures during construction. This technique would incorporate live willows in a growing medium that would sustain the plants until they are established into the matrix of the structure. This method should consist of 6-foot willow cuttings grown into 8- to12-inch by 5-foot coir logs. Coir logs should be ordered with a hole drilled two feet into the end for inserting a willow cutting and a small amount of growing medium. These "logs" should be grown for 3 months in a nursery and delivered with a mass of roots in the log and a growing top of 2 to 5 feet in height. The plants could then be tied into the structure with the bottoms of the coir logs in contact with consistent moisture and the tops protruding out of the face of the ELJs above the water.

Disturbed banks between ELJs and along bank-roughening logs

These areas would be planted with 14-inch-deep container plants by hand or with an excavator-mounted planter. These deep-rooted plants would be able to withstand the overbank flows if planted deeply into the banks. Because these plants may be subject to sediment deposition during high flows, the species list includes plants that would survive if their root collars were buried by sediment. The application of fertilizer packets, including slow release fertilizers and mycorrizal inoculum, would support the nutrient needs of the plants until high-water events deposit sediment and organic matter. The disturbed soils should be seeded with grasses. Table 5 includes a list of species recommended for planting on disturbed banks.

Table 5. Recommended species plantings for disturbed banks.

Trees	Shrubs	Grasses
Populus trichocarpa (black cottonwood)	*Salix hookeriana* (Hookers willow)	*Deschampsia caespitosa* (Tufted hairgrass)
	Salix sitchensis (Sitka willow)	Regreen Hybrid (sterile cover crop)
	Cornus sericea (redosier dogwood	

Floodplain behind ELJs 7-6 and 7-7.

This site is extremely dry and difficult to revegetate. The species mix for this site should be composed of species tolerant of dry conditions. The use of slow release fertilizer packets including mycorrhizal inoculum would support the nutrient needs of the plants and help with water uptake during the dry season. Plants should be grown in containers at least 14 inches deep so they can reach soil moisture during the dry season. These could be installed by hand, with the use of an auger, or with an excavator-mounted planter. Table 6 includes a list of species recommended for planting on the floodplain behind ELJs 7-6 and 7-7.

Table 6. Recommended species plantings for floodplain areas.

Trees	Shrubs
Pseudotsuga menzeiesii (Douglas fir)	*Rosa gymnocarpa* (bald hip rose) *Symphoricarpos albus* (snowberry) *Ribes lacustre* (currant)

Summary and Recommendations

The proposed restoration measures will provide numerous ecological benefits to Reaches 4 and 7 as described within this memo. The proposed measures will reduce the existing level of risk associated with bank erosion and flooding along adjacent properties at several locations within the project reaches. The measures proposed in this memo would result in local increases in the base flood elevation at several locations in order to restore habitat and increase the frequency of side-channel activation. Because most of the Mashel River is confined within artificial levees or within natural terraces, the anticipated increases in base flood elevation are not expected to increase the area of floodplain inundation. The base flood elevation predicted for the proposed measures could be reduced during design development. Based on the results of the hydraulic modeling, the following recommendations are presented:

- Coordinate with Pierce County to discuss the implications of the anticipated increases in flood elevation and areas of floodplain inundation. In order to continue to qualify for FEMA aid, the County may require property owners to grant a flood easement for any rise in the 100-year base flood elevation.

- Obtain easement rights from property owners for access and construction of the proposed ELJs.

- Evaluate the need for ELJ 7-5 during design development, since results of the hydraulic modeling show minimal effects on existing flow conditions.

References

Watershed Professionals Network. 2004. *Mashel River Restoration Design Technical Memorandum* prepared for the Pierce Conservation District.

Bohle, T., C.E. Cupp, R. Denman, R. Jackson, J. Kirtland, J. Metzler, E Salminen, K. Sargent, and T. Whiley. 1996. *Mashel Watershed Analysis: Resource Assessment Report.* Washington Department of Natural Resources, South Puget Sound Region, Enumclaw, WA.

Northwest Hydraulic Consultants (NHC). 2003. *Flood Insurance Mapping Study for the Mashel River near Eatonville, Washington, Pierce County, WA and Incorporated Areas, Community Number – 530138*, prepared for the Federal Emergency Management Agency (FEMA).

Pierce Conservation District (PCD). 2002. Lidar digital elevation model and color digital orthophotographs. Data acquired September 16, 2002.

ATTACHMENT A

Figures

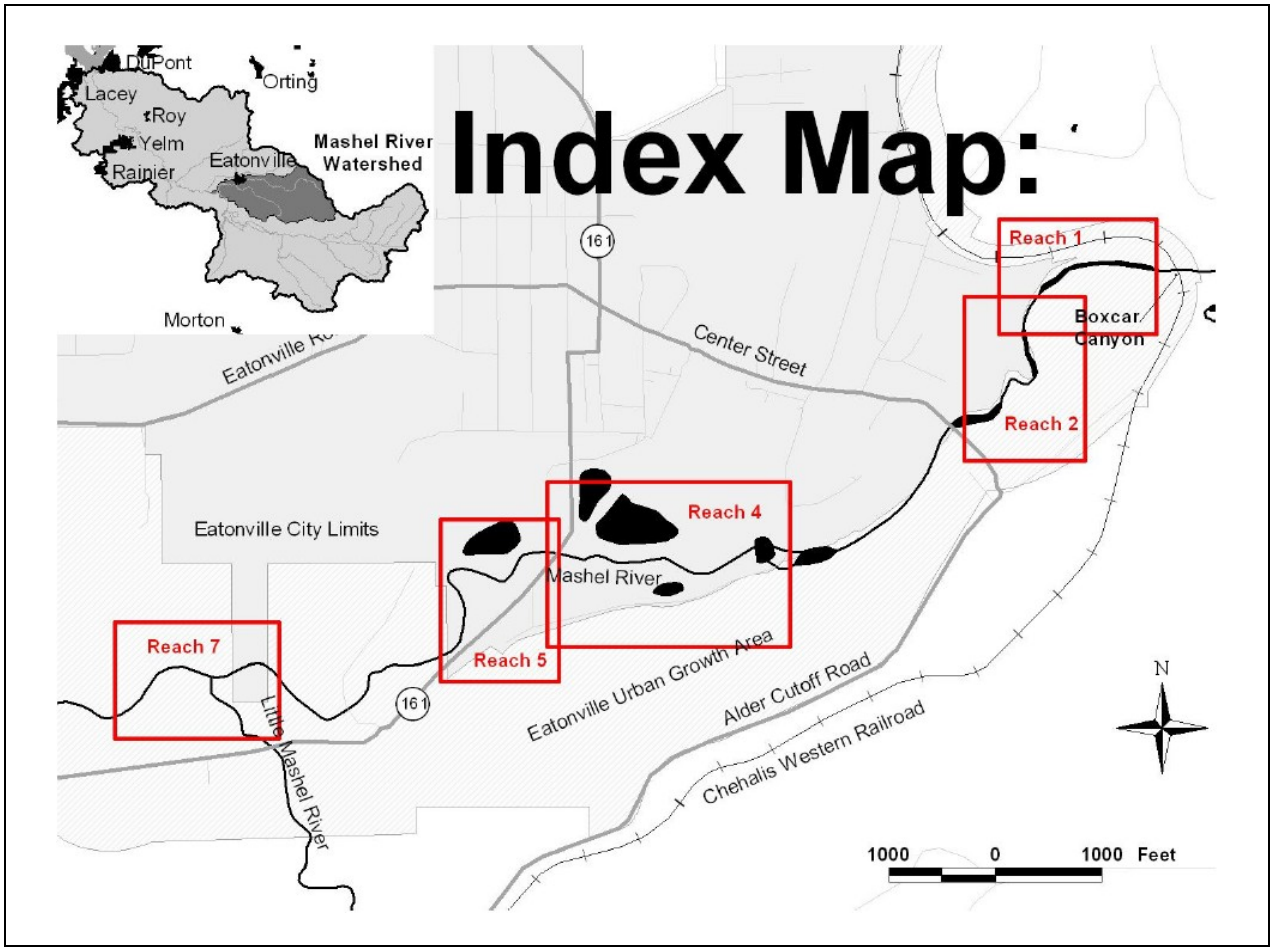

Figure 1. Project overview map.

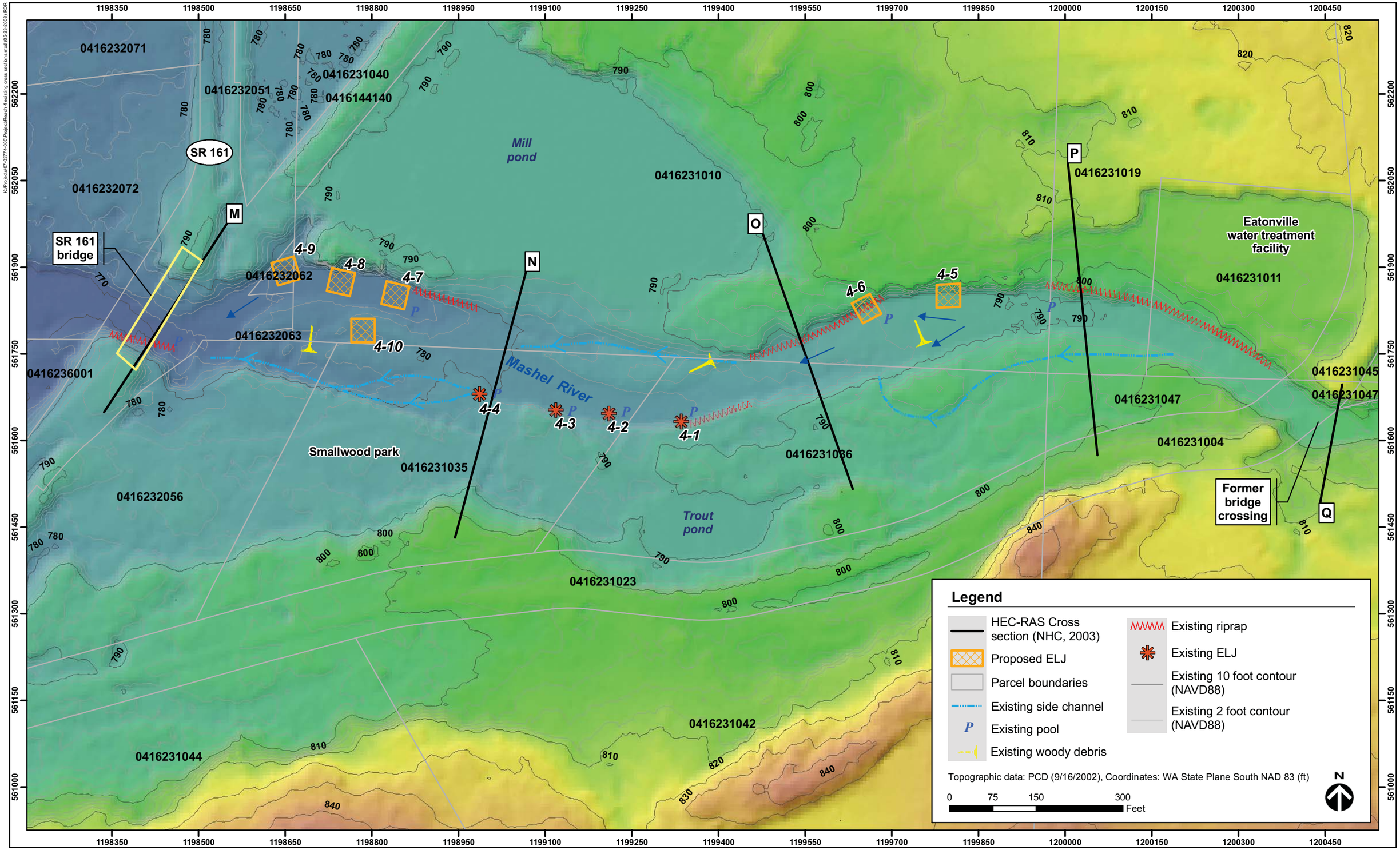

Figure 2. Reach 4 existing conditions and proposed restoration measures.

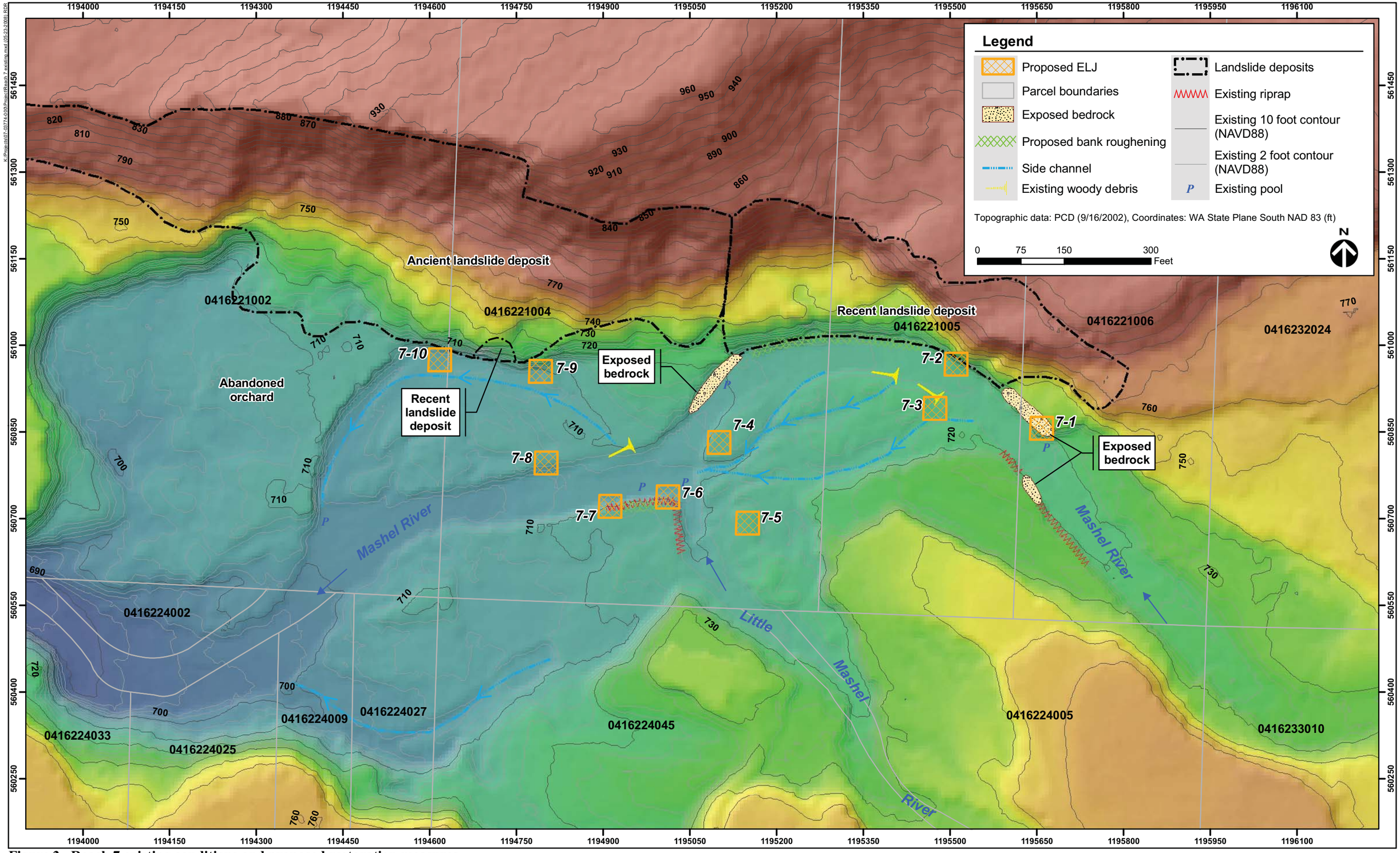

Figure 3. Reach 7 existing conditions and proposed restoration measures.

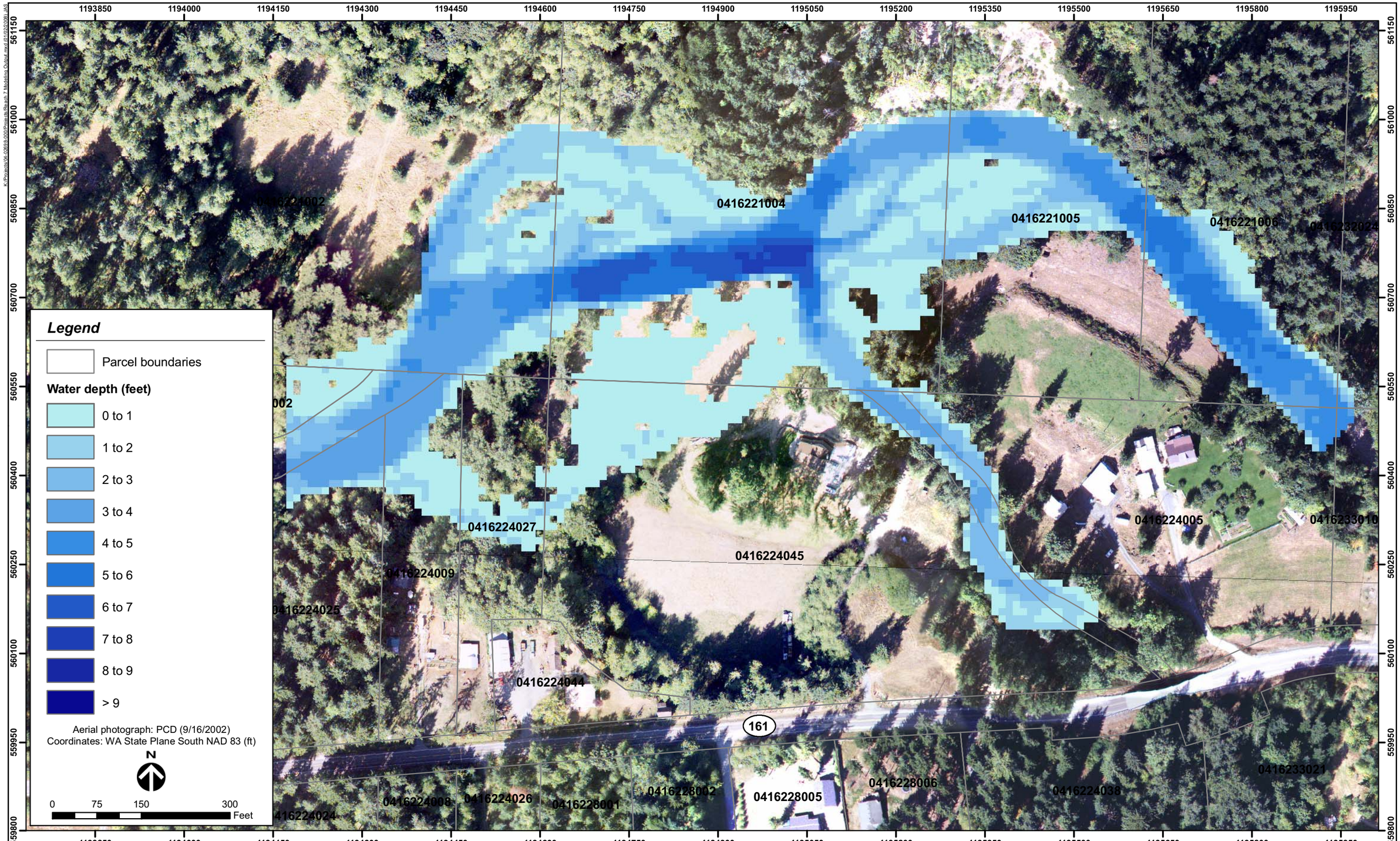

Figure 4. Simulated 2-year flow depths under existing conditions - Mashel River, Reach 7.

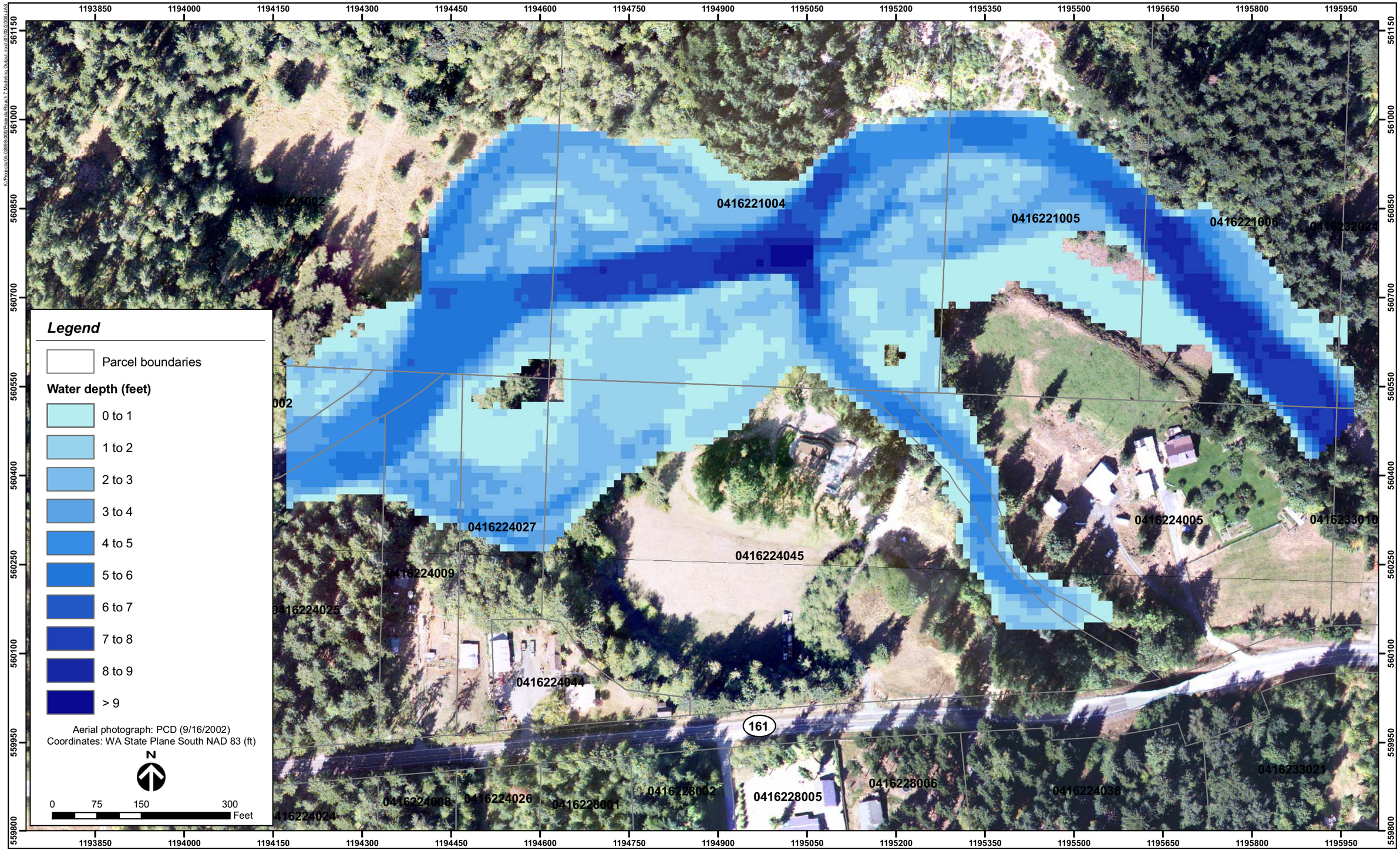

Figure 5. Simulated 100-year flow depths under existing conditions - Mashel River, Reach 7.

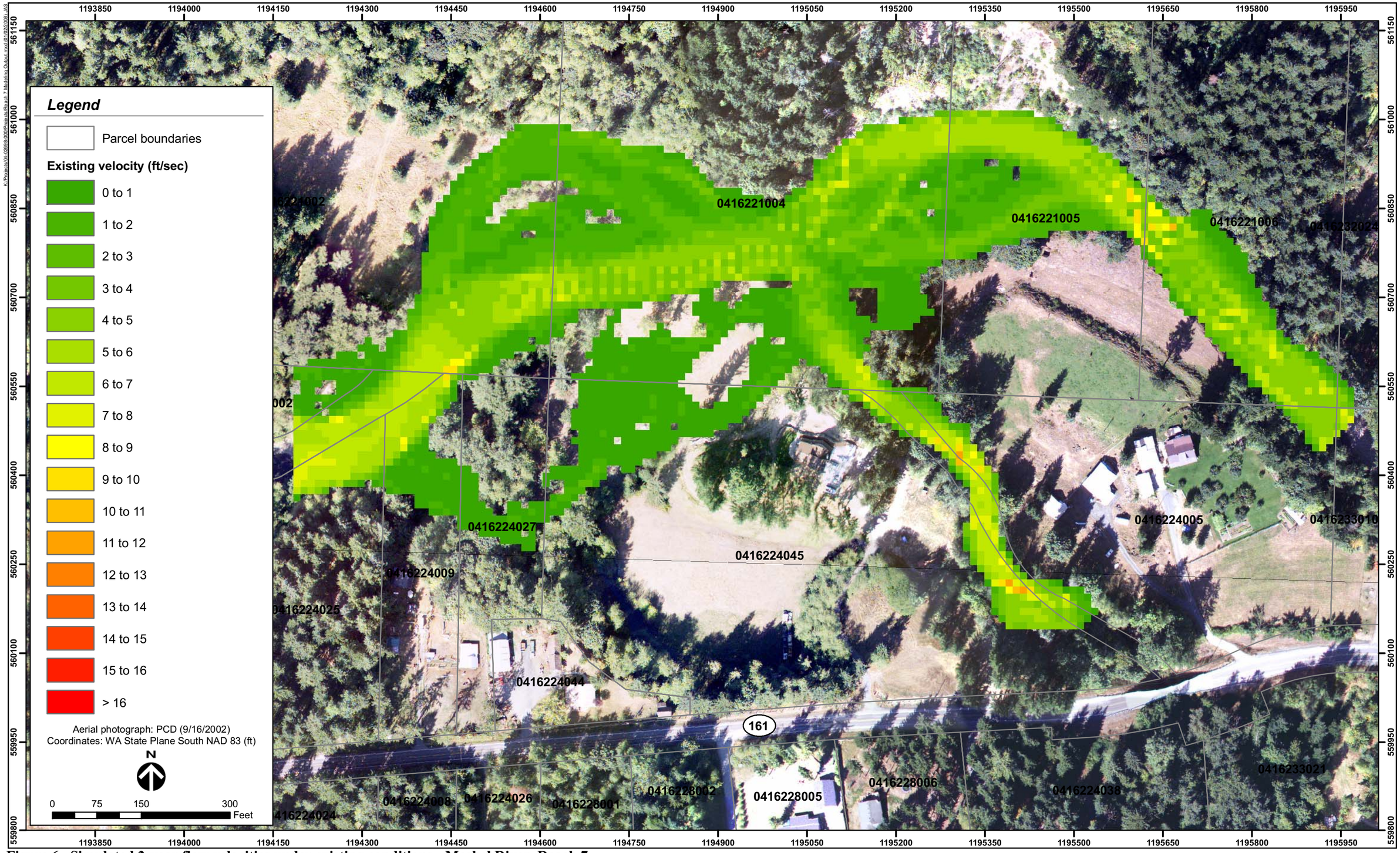

Figure 6. Simulated 2-year flow velocities under existing conditions - Mashel River, Reach 7.

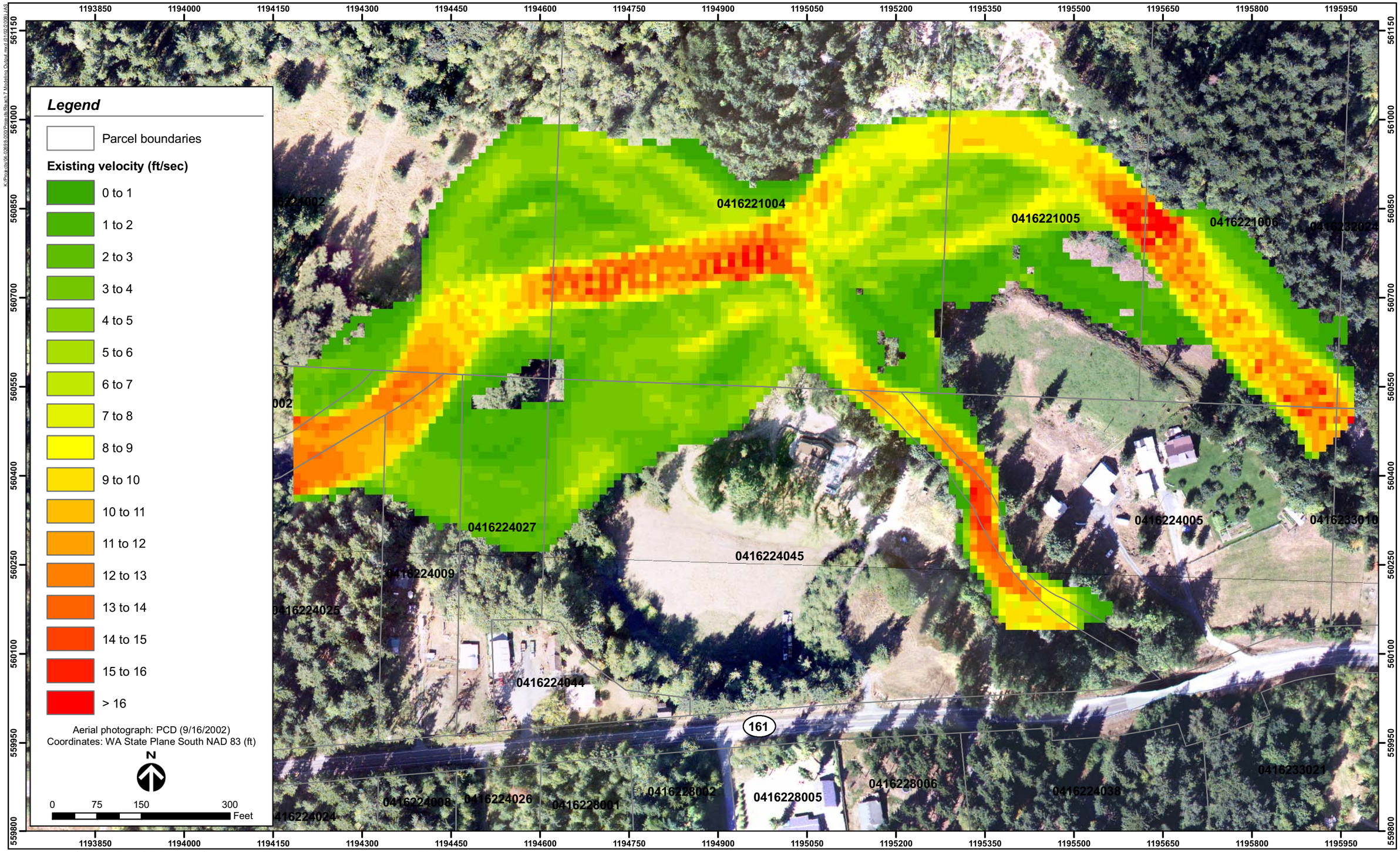

Figure 7. Simulated 100-year flow velocities under existing conditions - Mashel River, Reach 7.

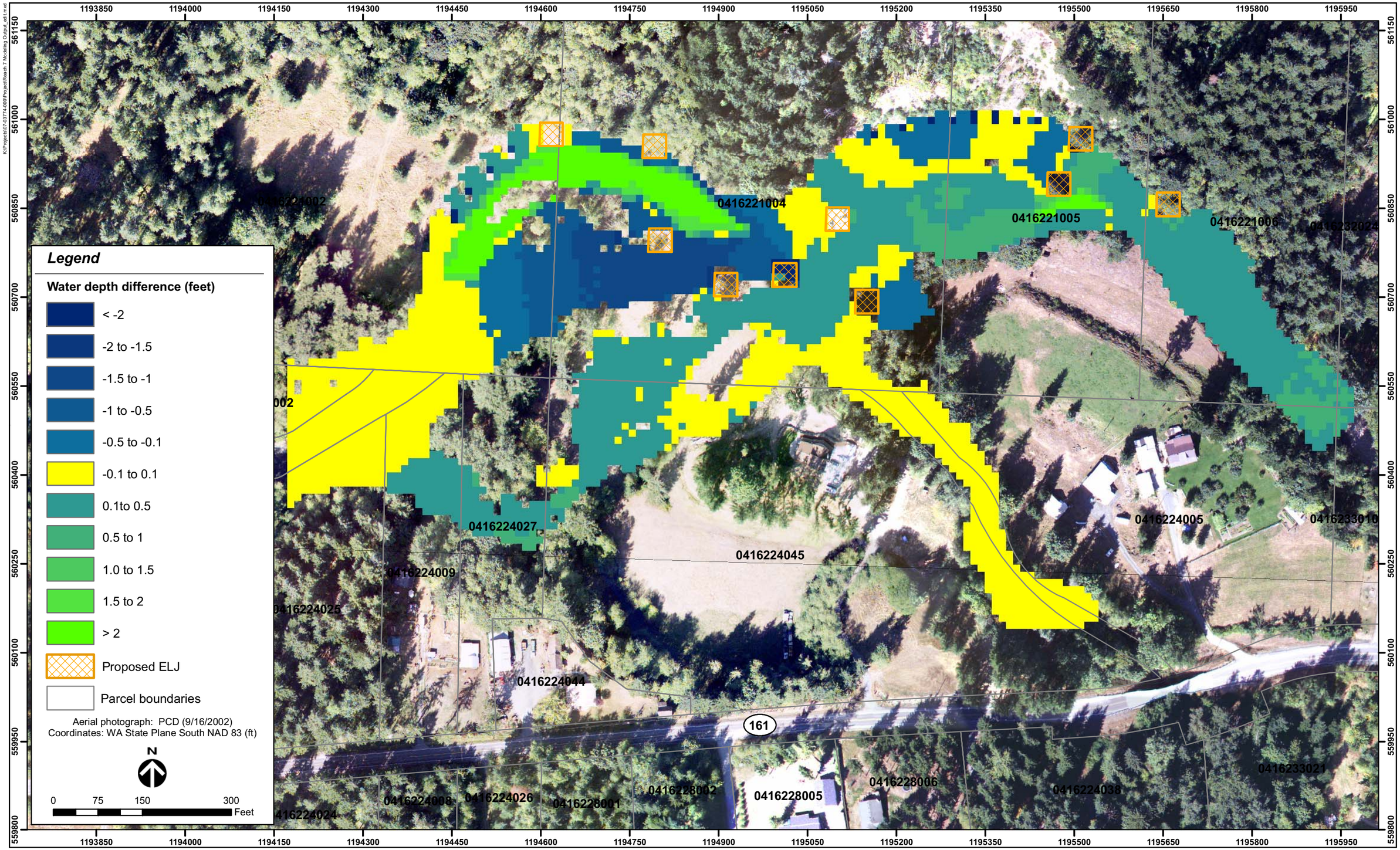

Figure 8. Estimated changes in flow depths for 2-year flow - Mashel River, Reach 7.

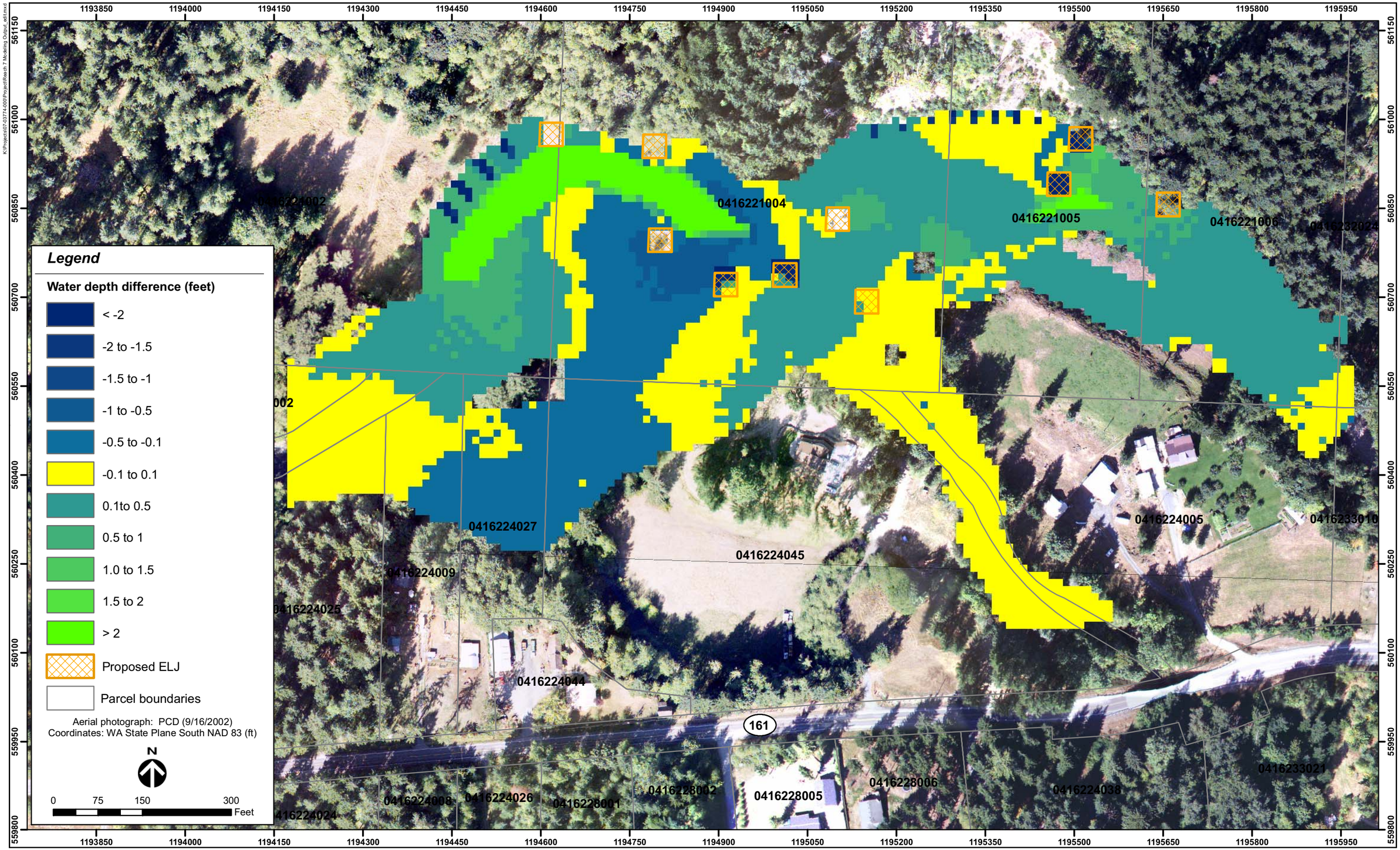

Figure 9. Estimated changes in flow velocities for 100-year flow - Mashel River, Reach 7.

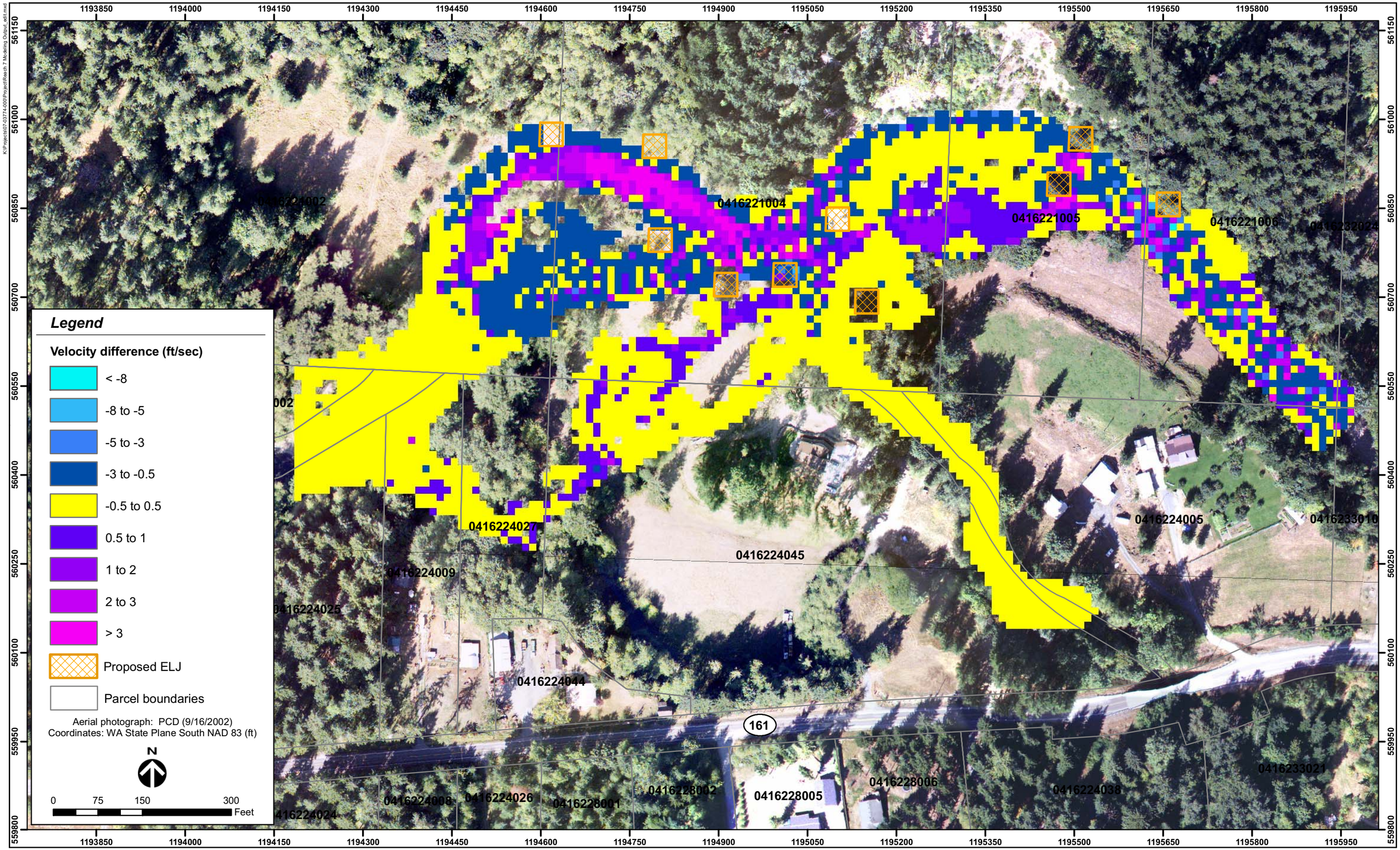

Figure 10. Estimated changes in flow velocities for 2-year flow - Mashel River, Reach 7.

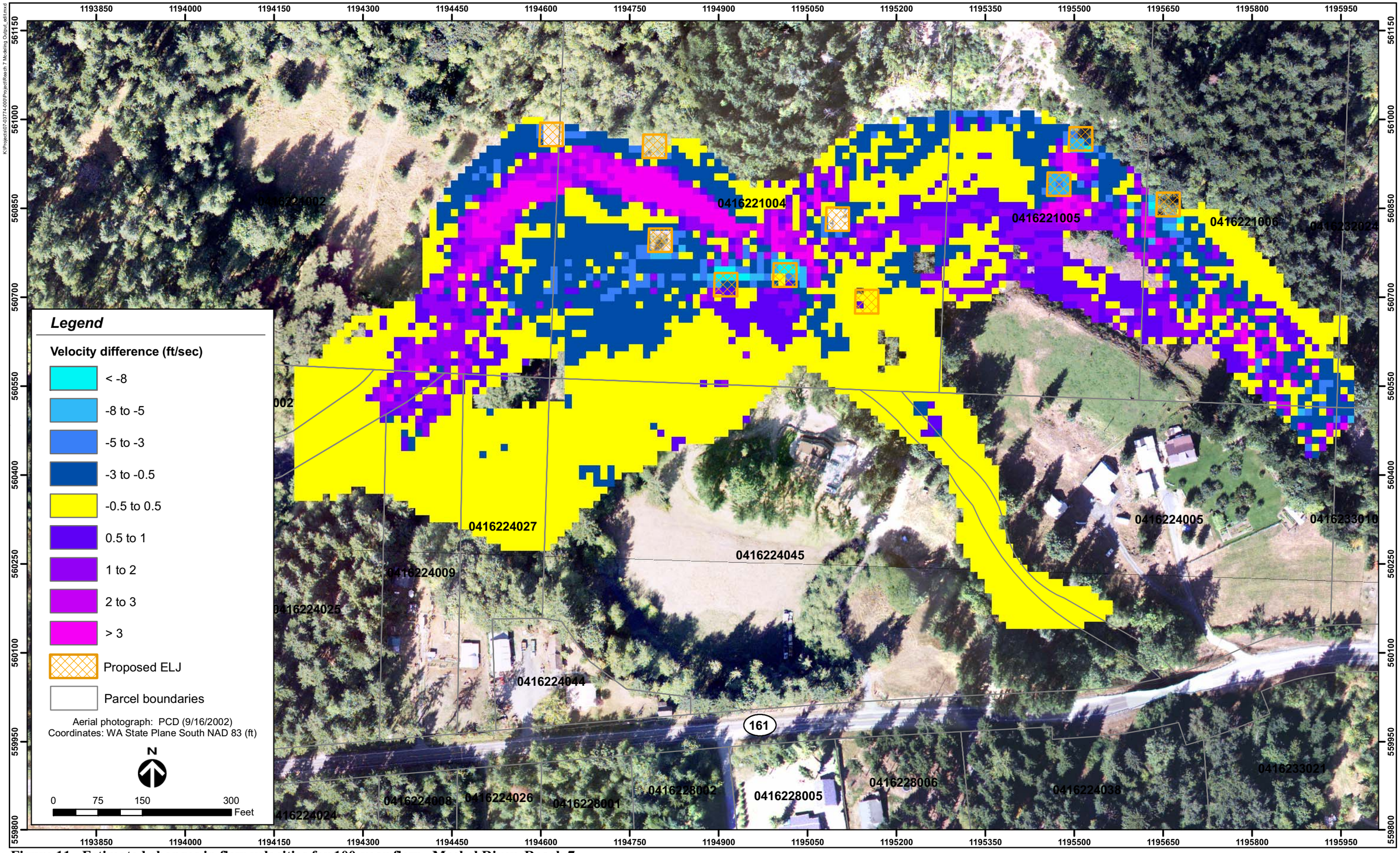

Figure 11. Estimated changes in flow velocities for 100-year flow - Mashel River, Reach 7.