Long Tom River Inundation Mapping Methodology Report

Prepared for

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Executive Summary

River Design Group, Inc. (RDG), was retained by the Long Tom Watershed Council (LTWC) to complete a floodplain inundation analysis for an approximate bankfull discharge on the Long Tom River, near Monroe, Oregon. The inundation mapping was completed to better understand potential floodplain inundation at a relatively frequent flow and to facilitate restoration and flood abatement project planning downstream from the U.S. Army Corps of Engineers flood control dam located at Fern Ridge Reservoir at Alvadore, Oregon.

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Glossary

Flood frequency analysis: An analytical technique that involves using observed annual peak flow data to calculate statistical information, such as mean values, standard deviations, skewness, and recurrence intervals. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedance probability.

Historical floodplain: The land area previously inundated by the Long Tom River during high water events prior to land settlement, road construction, and flood control operations.

Historical or pre-regulation period: The period prior to the onset of flood control dam construction in the Long Tom River watershed. Fern Ridge Dam began operation and water control in 1941.

Hydrograph: A graph showing the rate of flow (discharge) versus time past a specific point in a river, or other channel or conduit carrying flow.

Hydrology: The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground.

LiDAR: An airborne laser system, flown aboard rotary or fixed-wing aircraft, that is used to acquire x, y, and z coordinates of terrain and terrain features that are both manmade and naturally occurring. Light detection and ranging (LiDAR) systems consist of an airborne Global Positioning System with attendant base station(s), Inertial Measuring Unit, and light-emitting scanning laser.

Rating table: A table showing the relation between stream gage height and stream discharge.

Study area: The lower 24 miles of the Long Tom River, from Fern Ridge Dam to the confluence with the Willamette River.

USGS: U.S. Geological Survey is a scientific agency of the U.S. government with the Department of the Interior.

USACE: The United States Army Corps of Engineers is a federal agency and a major Army command.

1 Introduction

River Design Group, Inc. (RDG) was retained by the Long Tom Watershed Council (LTWC) to complete a floodplain inundation analysis for the Long Tom River from Fern Ridge Dam to the confluence with the Willamette River. The inundation mapping of the approximate bankfull flow was completed to better understand floodplain inundation at a relatively frequent flow and to facilitate habitat restoration and flood reduction project planning downstream from the U.S. Army Corps of Engineers (USACE) flood control dam located at Fern Ridge Reservoir.

The Long Tom River Watershed drains 410 square miles of land at the southwestern end of the Willamette Valley. The headwaters of the upper Long Tom River originate on the eastern side of the Coast Range and flow south through forested hills and farms until the town of Noti, where the river turns east and eventually flows into Fern Ridge Reservoir. The lower Long Tom River is a regulated river, with the dominant proportion of discharge contributed by releases from Fern Ridge Dam. Fern Ridge Dam, a USACE facility, was completed in 1941 and impounds the upper Long Tom River watershed to provide water storage for winter flood abatement and for irrigation and recreational purposes throughout the summer. In 1945, USACE also oversaw an extensive channelization effort from Fern Ridge Dam downstream to the Willamette River with the primary purpose to reduce channel complexity and flooding of the surrounding areas.

Below Fern Ridge Dam, several tributaries contribute additional flow to the Long Tom River. Substantial tributary inputs between Fern Ridge Dam and the Willamette River include Bear Creek, Amazon Creek, and Ferguson Creek. Most of the floodplain along the lower Long Tom River has been converted from floodplain forest and valley bottom woodlands to residential and agricultural land uses.

2 Long Tom River Hydrology

2.1 Stream Gages

Two U.S. Geological Survey (USGS) river gages were used to evaluate recent hydrologic conditions in the lower Long Tom River watershed. The USGS gage located at Alvadore, OR (#14169000) is located near river mile (RM) 24 directly below Fern Ridge Dam (shown on Panel 1/5 Appendix A), and provides a reliable measurement of the controlled flow released into the lower Long Tom River from Fern Ridge Reservoir. The Long Tom River at Monroe, OR gage (#14170000) has been operational since 1921 and is located at RM 7.5 near the Highway 99W bridge in the town of Monroe as shown on Panel 5/5 in Appendix A. Flows recorded at the Monroe gage include the contributions from the three major tributaries listed above. Table 2-1 provides summary information for the two gages located in the study area.

Table 2-1. Characteristics for river gages in the Long Tom River study area.

Gage #	Gage Name and Location	Period of Record	Period of Record (years)	Regulated Year	Drainage Area (sq mi)
14169000	LONG TOM RIVER NEAR ALVADORE, OR	1940-2017	77	1941	252
14170000	LONG TOM RIVER AT MONROE, OR	1921-2017	96	1941	391

Prior to the construction of Fern Ridge Dam and the resulting regulated flow regime, peak flows on the Long Tom River at Monroe were often in the 10,000 – 20,000 cfs range. Figure 2-1 includes peak flows from the historical and regulated periods.

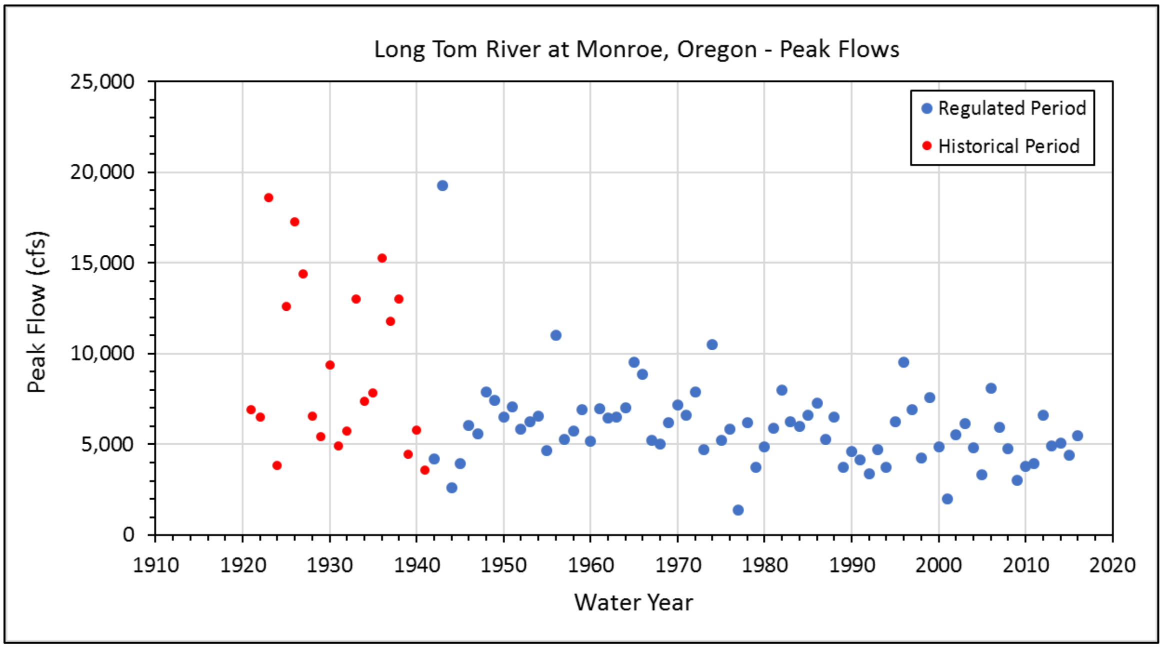

Figure 2-1. Annual peak flows for the historical and regulated periods on the Long Tom River at Monroe, Oregon gage.

Table 2-2 includes summary statistics for historical and regulated period peak flows. The historical period was characterized by higher peak flow values, except the maximum peak flow for the period of record which was recorded in 1943, two years after closure of Fern Ridge Dam.

Table 2-2. Historical and regulated period peak flow statistics.			
	Historical Period (1921-1941)	**Regulated Period (1942 – 2016)**	**Difference**
Minimum Peak Flow (cfs)	3,840	1,380	2,460
Mean Peak Flow (cfs)	9,538	5,939	3,599
Median Peak Flow (cfs)	7,625	5,840	1,785
Maximum Peak Flow (cfs)	18,600	19,300	-700
1 SD (cfs)	4,562	2,377	2,184

Figure 2-2 includes a comparison of mean daily flows for the historical and regulated periods. Compared to the regulated hydrograph, the historical hydrograph typically had higher flows from late winter through spring and lower flows in the fall. Mid-summer mean daily flows are similar between the regulated and historical periods.

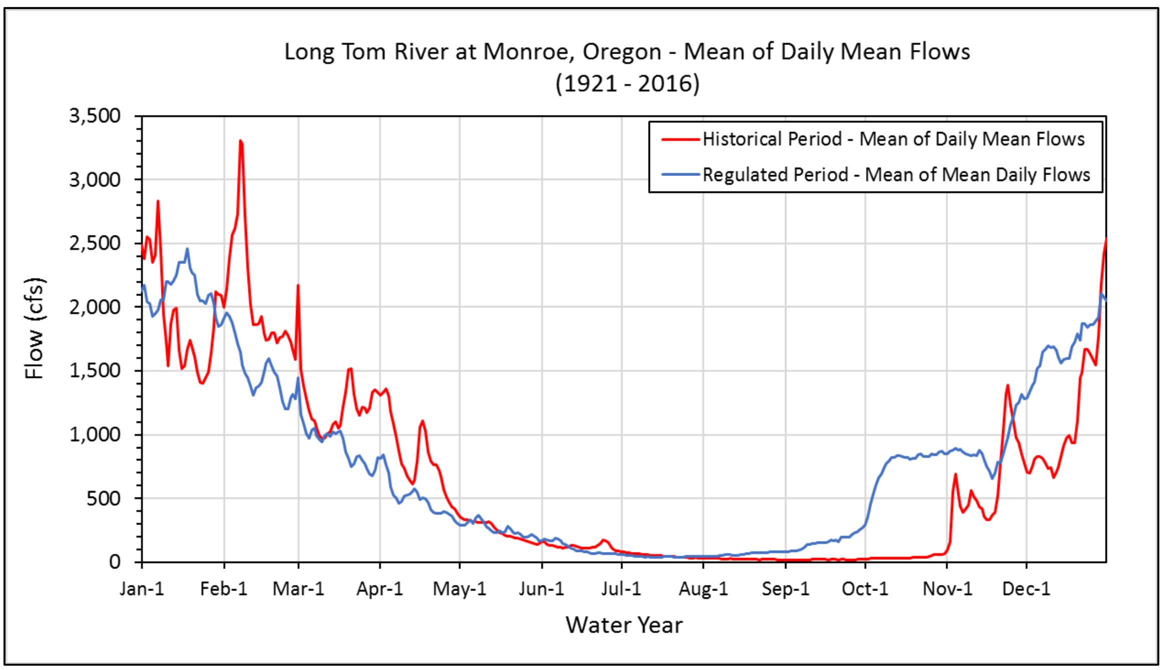

Figure 2-2. Historical period (1921-1941) and regulated period (1942-2016) mean of mean daily flows for the Long Tom River at Monroe, Oregon.

2.2 Flood Frequency Analysis

The Hydrologic Engineering Center (HEC) Statistical Software Package (HEC-SSP) version 2.1 (USACE 2016) was used to update the general flood frequency analysis (FFA) for the Long Tom River at Monroe, OR gage. Since the Long Tom River is heavily regulated and does not meet the requirements for a typical Log Pearson Type III distribution, methods described in USACE 2014 were utilized to evaluate flows associated with flood recurrence intervals. The 1995 to 2014 gage record was selected to reflect current dam and reservoir operations, as well as represent current climatic and hydrologic conditions, and was used for calculating the discharge associated with selected percent chance exceedance values. A locally weighted scatterplot smoothing (LOESS)/graphical fit was used to define the flood frequencies. Tabular results from the analysis are presented in Table 2-3.

Table 2-3. The user-defined flood frequency analysis results based on the 1995 to 2014 period.

			Confidence Limits	
User-defined Curve (cfs)	Percent Chance Exceedance (%)	Return Period (years)	0.05 (cfs)	0.95 (cfs)
40,000	0.2	500	119,568	13,382
16,000	1	100	48,482	6,638
12,802	2	50	25,254	6,638
9,874	5	20	14,724	6,638
8,390	10	10	10,612	6,638
7,194	20	5	8,816	5,870
5,000	50	2	6,299	4,747
4,800	66	1.5	6,299	4,166
3,966	75	1.33	4,838	3,408
3,800	80	1.25	4,838	3,249
3,000	90	1.11	4,000	2,250

2.3 Inundation Mapping Flow

Prior to updating the FFA, a 2-year flood discharge at Monroe of approximately 6,000 cfs, obtained from USACE 2014, was used to produce draft inundation maps. Upon initial review from the project steering committee and stakeholders, it was determined that at flows of 6,000 cfs most of the floodplain downstream of Monroe was inundated, and it was difficult to distinguish localized overbank connection points and patterns of floodplain inundation. Further, after review of recent peak flow events on the Long Tom River as measured at the USGS Monroe gage it was determined that flows of 6,000 cfs or greater have only occurred 7 times in the last 22 years.

After completing the hydrology statistical analysis update described in section 2.2, the steering committee agreed to use a 1.5-year flow of 4,800 cfs to represent an approximate bankfull flow on the Long Tom River as measured at the USGS Monroe gage. Flows of 4,800 cfs or higher have occurred 14 years out of the last 22 years, and represent a moderate flood event that inundates low elevation portions of the floodplain. A final mapping flow of 4,790 cfs was selected for inundation mapping, rather than 4,800 cfs, because of availability of field measurements at this flow. This 10 cfs difference is not within the sensitivity of the mapping effort but accurately relates field data to the hydraulic model and mapping for calibration purposes.

A normal maximum release (NMR) value of 3,000 cfs was used as the portion of the mapping discharge that is released from Fern Ridge Dam as measured at the USGS stream gage at Alvadore, OR. For modeling purposes, the discharge contribution of each tributary downstream of Fern Ridge Dam was determined by calculating the difference between the discharge at the USGS Monroe gage and the USGS at Alvadore gage and then multiplying by the percentage of contributing watershed area of each tributary (Table 2-4). Tributary flow contributions were used to develop the inundation mapping flows for the Long Tom River from Fern Ridge Dam downstream to the Long Tom River confluence with the Willamette River (Table 2-5).

Table 2-4. Flow contributions of the three primary tributaries to the lower Long Tom River.

Tributary	Flow Contribution (%)	Discharge (cfs)
Bear Creek	16	290
Amazon Creek	56	1,000
Ferguson Creek	28	500

Table 2-5. Final mapping flows determined for the reaches of the Long Tom River downstream of Fern Ridge Dam.

Location	Inundation Mapping Flow (cfs)
Long Tom Below Fern Ridge Dam	3,000
Long Tom Below Bear Creek	3,290
Long Tom Below Amazon Creek	4,290
Long Tom Below Ferguson Creek	4,790
Long Tom at Monroe, Oregon	4,790

2.4 Observed Water Surface Elevations

Onset Hobo pressure transducers were installed along the Long Tom River and tributaries by USACE during the summer of 2013 to accurately measure water stage height associated with varying discharges. The pressure transducers recorded stage data continuously at 15-minute intervals between August 14, 2013 and August 28, 2015. Barometric pressure was also recorded during the same period to provide barometric pressure correction to the transducer data. RDG used real-time kinematic (RTK) GPS to survey the pressure transducers elevations to relate water surface elevations to topographic data used for inundation mapping. Table 2-6 contains the flows used for modeling at the two USGS gages, and the water surface elevations recorded at two pressure transducers used for model calibration in the study area.

Table 2-6. Gage and pressure transducer locations, flows, and water surface elevations used to develop water surface profiles for the approximate bankfull flow.

USGS Gage #	Gage or Pressure Transducer (PT) Name and Location	Location (~RM)	Flow (cfs)	2/19/14 Water Surface Elevation (ft)
14169000	LONG TOM RIVER NEAR ALVADORE, OR	24	3,000	-
-	PT HIGH PASS RD	16	-	315.45
14170000	LONG TOM RIVER AT MONROE, OR	7.5	4,790	-
-	PT OLD RIVER RD	2	-	264.59

Water surface elevations recorded at the pressure transducers on February 19, 2014 during a flow event of 4,790 cfs were used to complete hydraulic model calibration as described in Section 3 and this flow coincides with the highest recorded stage during the 2013-2015 pressure transducer time period.

3 Hydraulic Model

3.1 Model Background

An unsteady, one-dimensional HEC-RAS hydraulic model was developed by Jim Crain, PE (USACE-Portland District) to evaluate channel capacity of the lower Long Tom River. The model extents are bounded by Fern Ridge Dam at the upstream end and the Long Tom River confluence with the Willamette River at the downstream, and laterally by the floodplain extents of the Long Tom River. This model was used in our analysis and modified as described below.

Model geometry was developed by USACE from ground surveys, remote sensing, and as-built dimensions of infrastructure and hydraulic structures on the Long Tom River. Substantial hydraulic structures on the Long Tom River include three concrete hydraulic drop structures: Cox Butte Drop Structure, Stroda Drop Structure, and Monroe Drop Structure (Figure 3-1). The drop structures are low head dams installed to control the channel elevation of the Long Tom River, and have approximately 6 to 10 feet of head across each structure. The drop structures influence water surface profiles at the mapped flow.

Figure 3-1. The Monroe Drop Structure at high winter flow.

Several bridges over the Long Tom River are represented in the hydraulic model and include Cox Butte Road, Ferguson Creek Road, Franklin Road, High Pass Road, State Highway 36, Highway 99W at Monroe, Stowe Pit Road, Hubbard Road, Old River Road, and Bundy Road. For the magnitude of flood mapped in this effort, the water surface falls below the bridge deck elevation at all bridges except Stowe Pit Road. The Stowe Pit Road bridge influences water surface elevations at the mapped flow (4790 cfs), but the other bridges do not influence the water surface for flows of this magnitude.

The existing USACE HEC-RAS model was modified to run as a steady-flow model to simulate the selected mapping flow. Levee points and storage areas used for unsteady flow routing were removed from the existing model. Model roughness was left as previously assigned in the USACE channel capacity model but was evaluated in the calibration process.

Many of the storage areas represent low elevation areas in fields adjacent to the river, and these areas are frequently inundated during precipitation events and by drainage culverts installed in the levees along the Long Tom River. The drainage culverts allow water impounded on fields to drain back to the river as river stage decreases, but also provide a hydraulic connection to the river at high stages and allow a limited amount of river water to flood onto fields. Culverts were not included in the model, and the model assumes fully connected overbank regions as would be present under several days of high discharge. This type of arrangement represents flooding conditions similar to anecdotal accounts of flooding along the Long Tom River's low elevation floodplain areas.

3.2 Model Boundary Conditions

The hydraulic model was developed to use a normal depth downstream boundary condition, with a representative reach slope of 0.0002 ft/ft. The lower reaches of the Long Tom River can be greatly influenced by backwater from the Willamette River, but this boundary condition isolates the Long Tom River modeling from influence of the Willamette River. Conceptually, this arrangement simulates the Long Tom River flood conditions when the Willamette River is at a low to moderate stage. If the same inundation mapping flow on the Long Tom River occurred at a higher Willamette River stage, broader flooding would be observed in the lower reaches of the Long Tom River downstream of Monroe, OR.

The Long Tom River and the Willamette River share the same floodplain surface near the confluence of the rivers. Floodplain inundation in this area may be attributed to either or both rivers depending on stage and timing of coincident high flows. In floodplain mapping, FEMA guidance recommends mapping of coincident peak discharges if the ratio of drainage areas are between 0.6 and 1.4 (FEMA 2016). The Willamette River basin is approximately 10 times the size of the Long Tom basin at the confluence, and mapping a coincident peak would not be recommended, and a normal depth boundary condition to isolate modeling of the Long Tom River is correct. However, given the frequency of the mapping flow discharge (66% annual exceedance) and because the types of conditions that produce high discharge on the Long Tom River also increase flow in the Willamette, it is possible that the Willamette River could also be at high stage during the mapping flow and backwater effects could cause even more inundation. A consideration when viewing model results is that low elevation areas near the confluence could be inundated more frequently and to a greater depth than indicated because of the multiple modes of inundation.

3.3 Hydraulic Model Calibration

Observed water surface elevations recorded at pressure transducers located at High Pass Road and Old River Road were used to calibrate the model. The pressure transducers recorded water surface elevations during a flow event of 4,790 cfs as measured at the USGS Monroe gage on February 19, 2014. Modeled and observed water surface elevations were in close agreement between 0.1 and 0.3 feet, and no major changes to model roughness were made.

Table 3-1 contains the difference between the observed and modeled water surface elevations recorded at two pressure transducers in the study area during a 4,790 cfs flow event as measured at the Long Tom River at Monroe, OR gage.

Table 3-1. Modeled versus observed water surface elevations at two pressure transducers in the study area at the modeled discharge.

Pressure Transducer Location	Modeled Discharge	Observed WSE (ft)	Modeled WSE (ft)	Difference (ft)
High Pass Road	3,000	315.45	315.52	-0.07
Old River Road	4,790	264.59	264.28	0.31

3.4 Water Surface Profiles

A water surface profile (Figure 3-2) representing the approximate bankfull flow was generated from the calibrated HEC-RAS model at the approximate bankfull flow (4,790 cfs) used for mapping purposes. The resulting station and water surface elevation cross-section data was exported from HEC-RAS to be used in ArcGIS post processing to complete the inundation mapping.

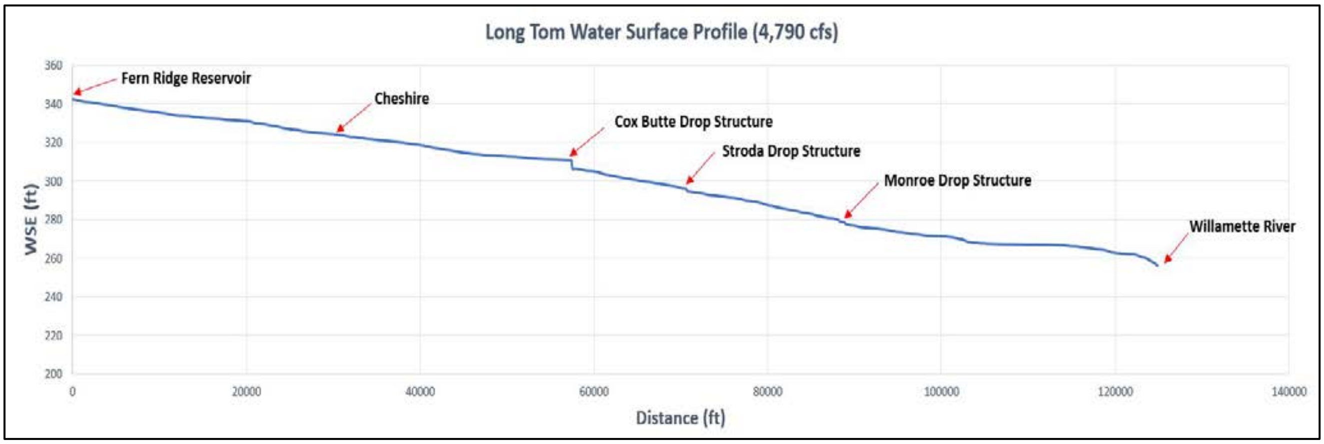

Figure 3-2. Plotted water surface profile for the approximate bankfull flow of 4,790 cfs.

4 Inundation Mapping

4.1 Methods

Cross-section geometry were exported from the modified HEC-RAS model and imported to ArcGIS. The cross-section lines were extended to accommodate the broader floodplain area of the Long Tom River. A clipping boundary was created using the FEMA 100-year boundary to constrain the inundation model to the east, and high topography or infrastructure that separates Long Tom River flow from Willamette River flow to the west. Figure 4-1 depicts the modified model boundary, the existing USACE HEC-RAS cross-sections, and the extended RDG valley cross-sections used in the mapping process.

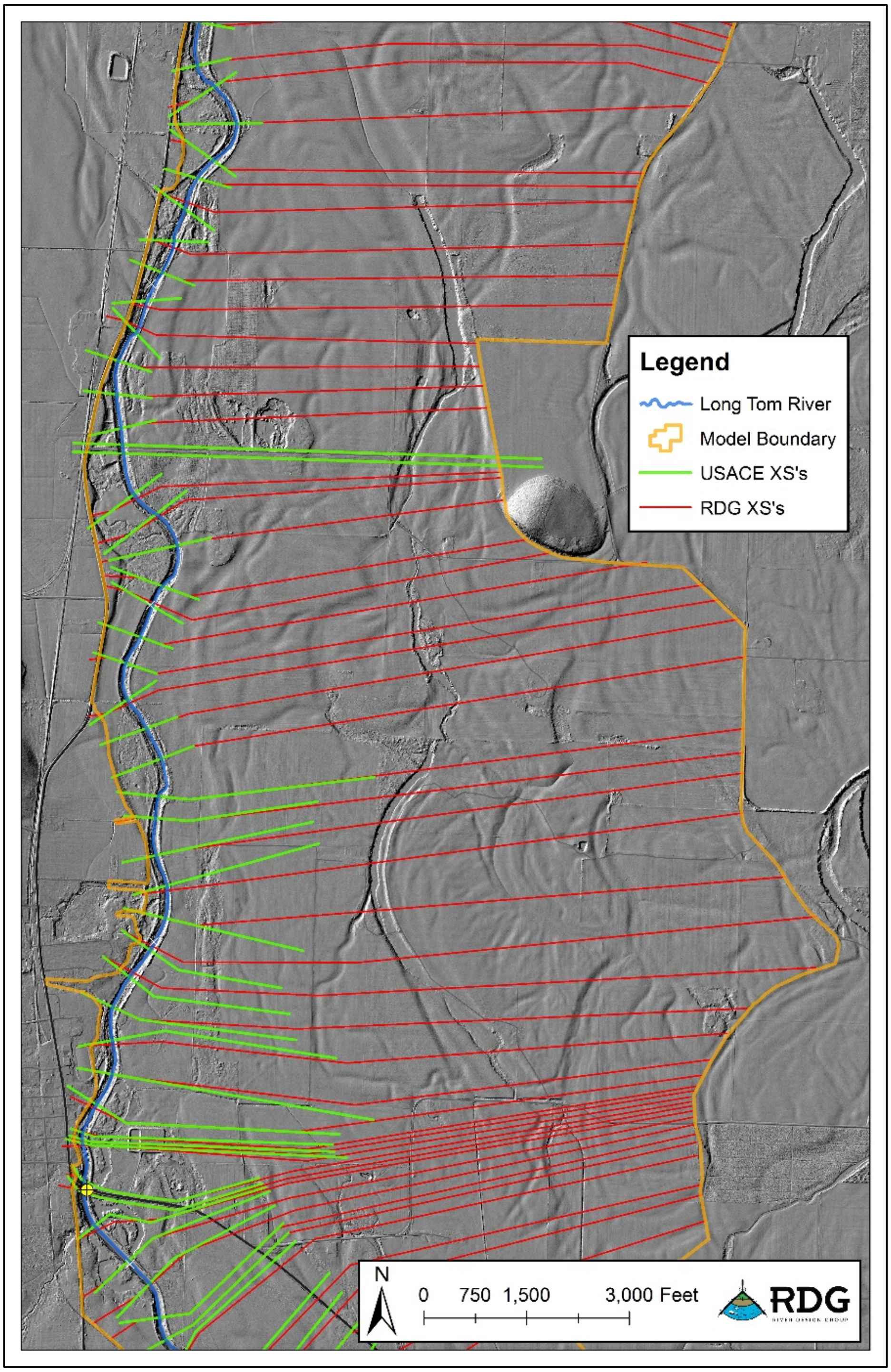

Figure 4-1. Modifications to the existing USACE HEC-RAS model geometry were developed by extending the cross-sections to include the broader Long Tom River-Willamette River floodplain area. The revised model boundary is defined by the FEMA 100-year floodplain to the west and by the topography that defines the flow separation between the Willamette River and Long Tom River to the east.

The water surface profile generated from HEC-RAS for the 4,790 cfs mapping flow was joined to the modified cross-section geometry and then converted to a triangulated irregular network

(TIN) using ArcGIS tools. The bankfull water surface TIN was then converted to raster data as an ESRI grid and then overlaid with the combined topographic – bathymetric surface model. ArcGIS tools were used to calculate the difference between the water surface grid and the underlying elevation surface model to create the inundation depth grid.

4.2 Results

The resulting bankfull inundation layer represents theoretical conditions, as the resulting inundation depths are based solely on the difference between the modeled water surface elevations and the combined bathymetric-LiDAR topographic surface model. The resulting inundation does not account for obstructions that can impede water from flowing from the river into low lying areas of the floodplain such as berms, levees, revetments, etc. Figure 4-2 depicts examples of channels that appear to be inundated in the resulting inundation layer, but may not have surface water connections to the river at the modeled discharge. Furthermore, some of these lower elevation portions of the floodplain may be frequently inundated due to precipitation events, overland runoff, and elevated water table but still lack surface connections to the river, which are important for ecological function of floodplain habitats.

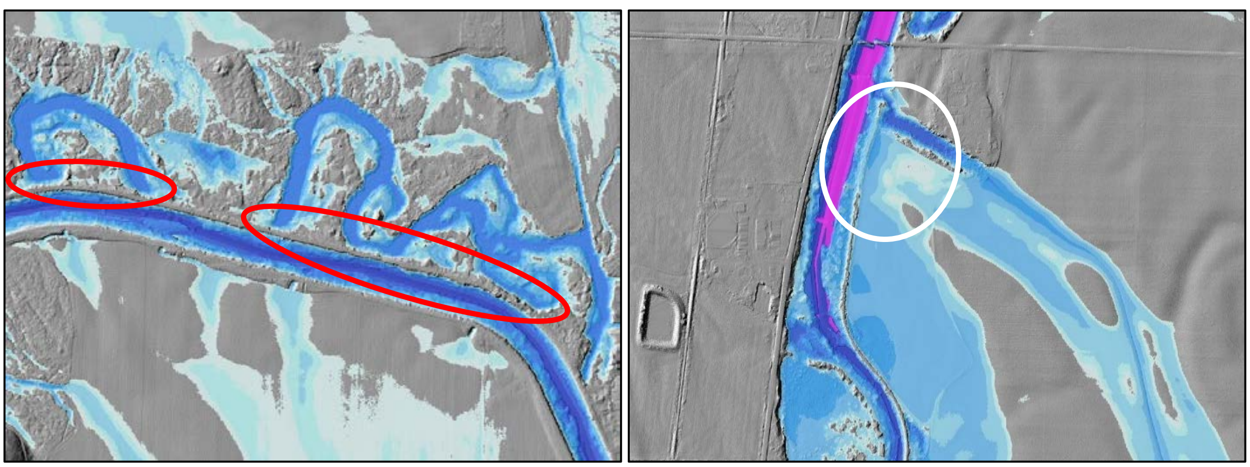

Figure 4-2. The example on the left includes inundated oxbows that are separated from the Long Tom River by a bank levee that is highlighted in the red circles. The example on the right shows a channel that is connected via surface water (highlighted in white circle) to the Long Tom River.

The purpose of completing this type of "bathtub" analysis is to identify areas that could potentially be connected to the river via surface connection by modifying or removing existing obstructions. Improving connectivity between the Long Tom River and the adjacent floodplain is expected to provide increased water storage, decrease localized flooding and bank erosion, and provide improved habitat conditions for native fish and wildlife.

Five reach maps depicting the predicted floodplain inundation were created for the 24-mile study area and are included in Appendix A. Figure 4-3 shows an example inundation map panel. The reach maps are anticipated to be used by the Long Tom Watershed Council and other local stakeholders to identify and prioritize potential floodplain reconnection projects and as outreach materials to engage landowners along the lower Long Tom River.

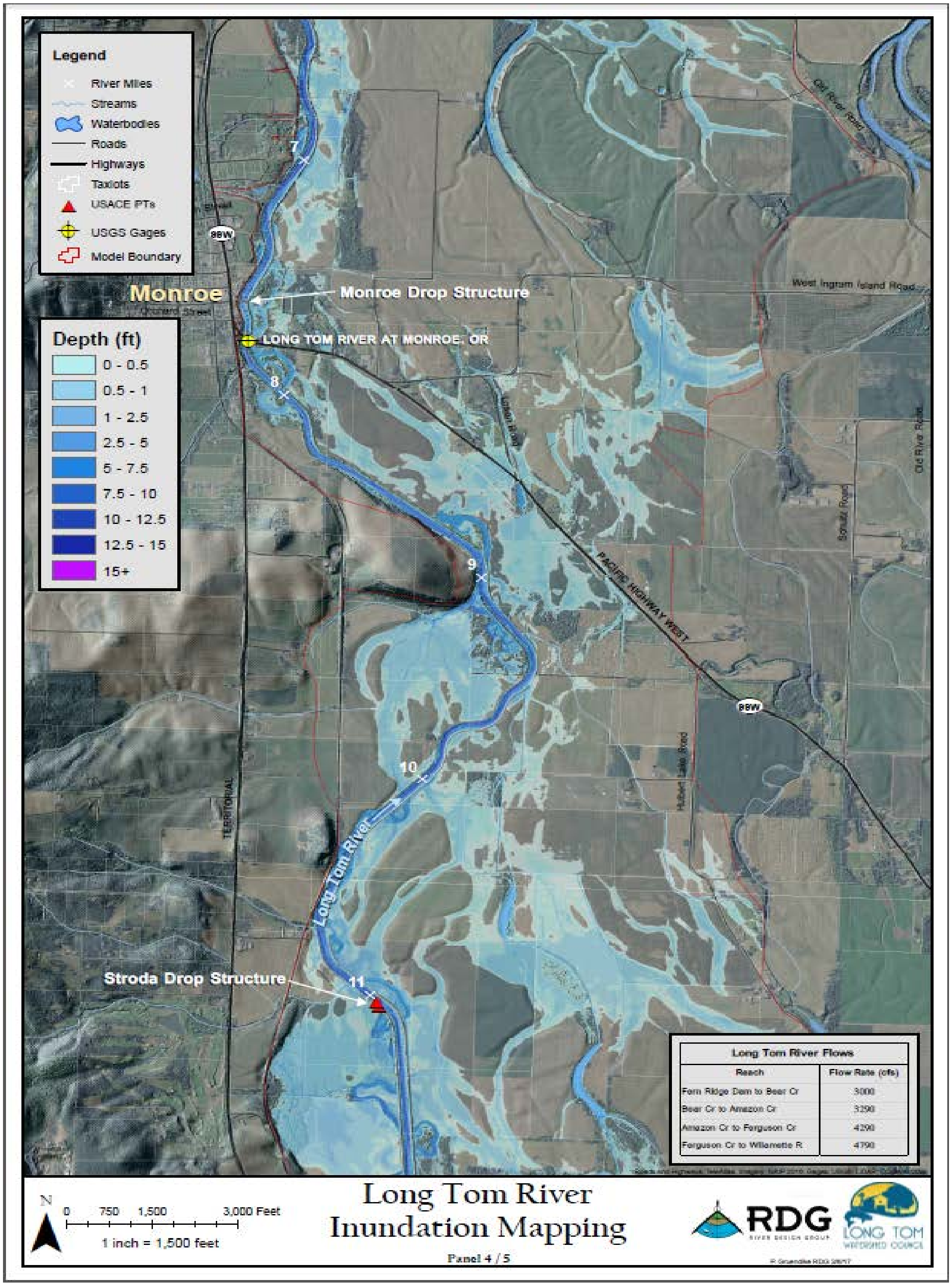

Figure 4-3. Example inundation map used to identify and prioritize potential floodplain reconnection projects along the lower Long Tom River.

In summary, RDG coordinated with LTWC to complete a floodplain inundation analysis for the Long Tom River from Fern Ridge Dam downstream to the confluence with the Willamette River. RDG modified an existing one-dimensional HEC-RAS model and incorporated additional hydrologic and topographic data to update the hydraulic model. The water surface profile generated from HEC-RAS for the 4,790 cfs flow was joined to the modified cross-section geometry and then converted to a TIN using ArcGIS tools. The bankfull water surface TIN was then converted to raster data as an ESRI grid and then overlaid with the combined topographic – bathymetric surface model. ArcGIS tools were used to calculate the difference between the water surface grid and the underlying elevation surface model to create the inundation depth grid. Five inundation map panels were produced for evaluating potential river-floodplain habitat enhancement opportunities and for landowner outreach.

5 References

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