Final Camas Creek Oregon Geomorphic Assessment

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Prepared for:
Confederated Tribes of the Umatilla Indian Reservation
46411 Timine Way
Pendleton, Oregon 97801
541-276-3447

Natural Systems Design

1900 N. Northlake Way, Suite 211
Seattle, WA 98103

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1. EXECUTIVE SUMMARY

The Confederated Tribes of the Umatilla Indian Reservation contracted Natural Systems Design to characterize geomorphic, hydrologic, and hydraulic processes and historic disturbances governing current conditions in the Camas Creek watershed above Ukiah, Oregon. The assessment utilized a process based approach to identify natural and anthropogenic mechanisms of habitat development and degradation. The assessment area was divided into Primary and Secondary Areas of Interest (PAOI and SAOI, respectively) based on geomorphic characteristics, disturbance mechanisms, and potential restorative actions. The PAOI includes mainstem Camas Creek below the confluence with Cable Creek, including the town of Ukiah and the large alluvial fan spanning from river mile (RM) 14.75 to the downstream extent of the study area (RM 11). The SAOI includes the Camas Creek watershed above the Cable Creek confluence, including the Cable Creek subwatershed. Historic and current conditions were assessed during a September 2015 field visit and a desktop study of available literature, geospatial data, and 1- and 2-D hydraulic and sediment transport modeling.

The historic condition of Camas Creek was an anabranched channel with a healthy, forested riparian corridor that maintained wood supply to the creek, provided shade, and increased bank stability. Beaver augmented instream wood in the channel and floodplains, increasing water and sediment storage and reducing celerity of flow peaks, while buffering summer water temperatures. Instream wood provided deep pools intercepting cool groundwater, while providing cover for rearing juvenile salmonids. Side channels and off-channel wetlands once found along the creek provided ample rearing opportunities as well as refugia during high flow events.

Natural disturbances were common in the watershed historically, and played a role in the creation and maintenance of habitat. Wildfires, beaver, floods, and landslides all would have altered the creek in varying ways. Intact physical and biological processes allowed for a dynamic equilibrium, whereby natural disturbances or rapid alterations to the system would be gradually diffused along the creek, and slowly recovered back to something close to the pre-disturbance condition. These natural disturbances are distinct from anthropogenic, or human-induced disturbances in that the human changes to the creek made in response to the disturbance (i.e. levee creation) do not allow the creek to recover back to the pre-disturbance condition. In addition, the response of the creek to disturbances along the creek has had negative consequences downstream. The current condition of Camas creek is one that is attempting to recover from historic anthropogenic disturbances where the opportunity exists, and remaining in a degraded state where there is no opportunity.

Historic anthropogenic disturbances included homesteading, beaver trapping, grazing, logging, channelization, levees, roads (and associated culverts & bridges), and diversions. These disturbances have altered the natural geomorphic processes (i.e. channel migration, a multi-thread channel form, and floodplain connectivity), resulting in degraded instream and floodplain conditions. The location and degree to which these disturbances are altering processes varies across the watershed. In general, the upper watershed and tributaries have been most impacted from logging, beaver removal, and road building. The lower watershed and mainstem Camas Creek through Ukiah, Oregon have been most impacted from grazing, channelization, levees, road construction, and diversions.

In the upper watershed and tributaries to Camas Creek, historic logging and fire suppression replaced the historic ponderosa pine forest with more shade tolerant and less fire resistant species. This change in forest composition combined with high fuel loads resulted in a more fire prone forest community, exacerbating the devastation following the Tower Fire of 1996. This stand-replacing fire destabilized steep slopes within the burned area, contributing excess sediment from Cable Creek. This sediment was largely retained within the creek, and is actively diffusing downstream but at a slow rate so as to not dramatically alter the channel downstream in Ukiah. In adjacent Hidaway Creek, road construction into the watershed in the 1960's initiated a pulse of sediment downstream that entered Camas Creek and continued downstream to Ukiah. Over time the rate of sediment delivery to Camas Creek has diminished.

The removal of beaver throughout the watershed has altered groundwater-surface water exchange, and has resulted in a loss of backwatered areas that would have supported vast wetland complexes. In the upper watershed these impacts have resulted in water flowing at a faster rate during spring runoff and during storm events which results in increased peak flows and reduced water storage. This reduction in groundwater recharge has likely reduced summer low flow and resulted in greater duration and area of channel dewatering in the Ukiah area. In the lower watershed, loss of beaver has virtually eliminated the wetland complexes once found along Camas Creek and across the Ukiah alluvial fan.

In mainstem Camas Creek and the lower watershed including through Ukiah, natural processes are absent due to channelization, levees, and road construction. Channelization and levee construction occurred at a large scale in response to the flood of record in 1965, resulting in a straight, single thread channel through Ukiah to the Camas Street bridge. This dramatic change in channel planform initiated an immediate channel response, with meanders developing within the new levees following their construction. This process lead to the rapid erosion of the levees from the migrating creek, delivering high sediment loads to the creek downstream from the eroded levees and floodplain. As the levees continued to erode over time, the sediment delivered downstream deposited in the creek as it flows through Ukiah. An expansion of the creek through town (widening of the levees) has resulted in a loss of transport capacity and deposition of sediment in the creek. In addition to this accumulated sediment, the Camas Street bridge creates a backwater during large floods that induces additional aggradation up to 350 ft upstream of the bridge. The accumulation of sediment due to the levees and bridge has essentially buried the channel through town as it dewaters regularly in the summer months. Upstream of Ukiah, where the levees have eroded, the channel has regained its anabranch planform, and habitat elements such as large wood, pools, and even beaver are starting to reappear.

Major findings:

- Historic anthropogenic disturbances have altered geomorphic and hydrologic processes within Camas Creek and its tributaries in a way that has degraded habitat conditions.
- Historic anthropogenic disturbances have altered the movement of water through the watershed in ways that have contributed to degraded habitat conditions.
- Flood control measures taken after the 1965 flood of record, including construction of levees and channel straightening, have degraded habitat conditions and resulted in a river in dis-equilibrium.
- Channel adjustments (levee erosion) due to straightening have resulted in high sediment loads entering the creek. This excess sediment has deposited in the channel through Ukiah due to the levees being further apart and the channel being wider, resulting in increased flood risk to Ukiah.
- Camas St Bridge creates a localized effect that are a minor contributor to flooding in Ukiah, the confinement of the channel upstream and orientation of the levees through town is the primary contributor to flood risk to Ukiah.

2. PROJECT BACKGROUND

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) have contracted Natural Systems Design (NSD) to assess watershed- and site-scale geomorphic and habitat conditions in order to develop an action plan for restoration of critical areas within Camas Creek, a tributary to the North Fork John Day River (NFJD) in Oregon. Camas Creek (Camas) and its tributaries support Endangered Species Act (ESA)-listed Mid-Columbia summer steelhead and bull trout, spring Chinook salmon, Pacific lamprey, and redband trout along with endemic cool water fishes (ODFW 2014). The CTUIR recognizes the importance of access to First Foods in preserving tribal culture, also in protecting and restoring the natural processes that enable sustainable harvest of these food resources in perpetuity (Jones et al. 2008). The Camas watershed's natural ability to provide these cultural resources has been greatly impacted by land use and development of the floodplain, channelization and flood control structures, water withdrawals, timber harvest, grazing, and fire suppression. Streams within the watershed have been listed as having impaired water quality due to habitat modifications, increased sediment loading and temperature, and reduced dissolved oxygen concentrations (DEQ 2012). Restoring Camas Creek and its tributaries and distributary channels through increased floodplain connectivity and habitat complexity will improve the five Touchstones of the CTUIR River Vision, which include hydrology, geomorphology, native riparian vegetation, native aquatic biota, and the connections between these factors (Jones et al. 2008).

This assessment is the first step in identifying restoration opportunities within the framework of stakeholder concerns related to existing infrastructure and property (flood risk), channel forming processes, hydrology, and water quality and habitat degradation. NSD's assessment is aimed at characterizing historic conditions, anthropogenic disturbances, and their link to the current conditions within the watershed. Findings from this assessment and the forthcoming Restoration Opportunities will guide community members and resource managers in developing a strategic approach to holistically improving conditions in the Camas Creek watershed.

2.1 Study Area

The Camas Creek watershed drains 408 square miles of northeastern Oregon, spanning a vertical relief of 4,070 ft from its headwaters in the Blue Mountains (6,770 ft) to its confluence with the NFJD River at river mile (RM) 57 (2,700 ft) (Map 1). The Camas watershed is approximately 50 miles south of Pendleton and 50 miles west of La Grande, and is largely within Umatilla County, with headwaters extending into Union and Morrow Counties. Nearly 52 percent (214 square miles) of the Camas watershed is within the Umatilla and Wallowa-Whitman National Forests, which are managed for multiple uses, including timber harvest, grazing, wildlife habitat, and recreation (USFS 2015). Approximately 69 percent of the watershed is forested, with remaining areas predominantly arid shrub and grasslands and some agriculture.

The study area for this assessment includes the Camas watershed above RM 11, approximately 1 mile downstream of Ukiah, Oregon. The drainage area included in the watershed-scale geomorphic assessment covers 205 square miles of Umatilla County, ranging in elevation from 3,290 ft at RM 11 to 6,770 ft in the Blue Mountains. Major tributaries to Camas Creek within the study area include Pine, Cable, Hidaway, Lane, Bear Wallow, Rancheria, Mud (a tributary to Hidaway), and Frazier Creeks. A Primary Area of Interest (AOI) focusing on the mainstem Camas Creek from the confluence with Cable Creek at RM 17.8, downstream to RM 11, is also assessed in greater detail and is the focus of the hydraulic and sediment transport modeling.

3. HYDROLOGIC ANALYSIS

3.1 Watershed Hydrology

The Camas watershed has a predominantly continental climate, with moderate temperature fluctuations and precipitation in the form of winter snow and late fall/early spring rainfall. The Blue Mountains comprising the upper portions of the watershed are partially influenced by a maritime climate, with snowfall beginning in October and peaking in December through February. Snowmelt occurs predominantly before June, though north facing slopes and higher elevations in the basin may retain snow into June and July (Zakrajsek 2012). Average temperatures in the watershed have an annual range between 10 – 90 degrees Fahrenheit, with mean annual precipitation of more than 30 inches in the vicinity of Tower Mountain to less than 17 inches near the town of Ukiah. Mean normal climate data compiled for Ukiah is presented in Figure 1 (WRCC 2015a). Mean temperature in Ukiah ranges from 15 – 85 degrees Fahrenheit throughout the year, with average precipitation of 16.8 inches per year. 60 percent of total precipitation occurs in the winter and spring months.

Streamflow characteristics in Camas display a seasonal regime that begin the water year (WY) with low flows in October and rise in November then remain high through April and May. Streamflows then recede over summer, to an annual minimum in August and early September. USGS maintained a streamflow measurement station on Camas Creek near Ukiah from WY 1914-1917, 1920-1923, and 1932 – 1991 (#14042500). The gage has since been operated by Oregon Department of Water Resources (ODWR) for WY 1992-1997, 2001, and 2009 – present (#14042500). The gage site near Ukiah is located at approximately RM 18.8, and does not include contributing flow from Cable Creek. Daily streamflow statistics, showing the probability of flows exceeding a given magnitude at the gage site are plotted for a water year in Figure 2.

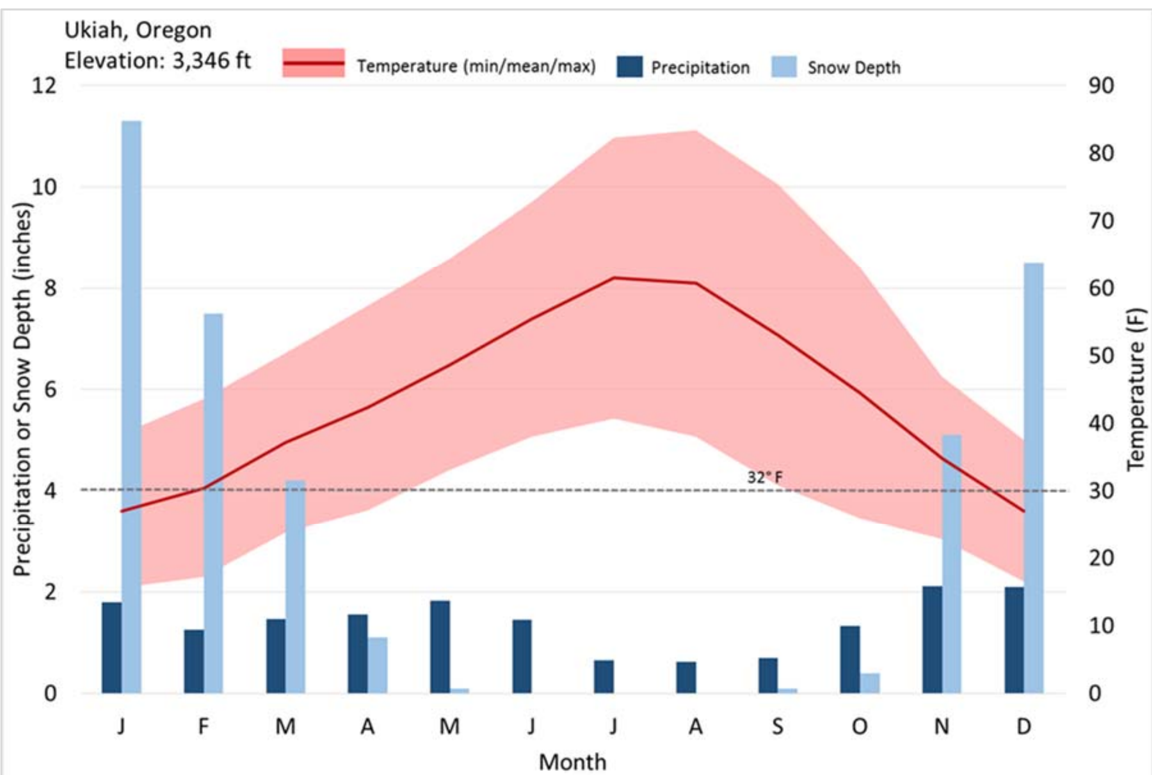

Figure 1. Monthly average precipitation and temperature for Ukiah, Oregon (data from WRCC 2015a).

The period between December and March has the greatest variability, ranging between about 5 and 750 cfs, as winter flows are driven by episodic pulses due to storm events. Streamflow in April and May is dominated by snowmelt runoff, with flows ranging between about 80 and 900 cfs and median values generally exceeding median winter streamflows (Figure 2). Average streamflow peaks in April, with summer baseflows receding as snowmelt declines. Summer flows typically range from 2 to 15 cfs.

A flow duration curve for the gage record was derived according to the methods detailed in Searcy (1959). Flow duration exceedance probability statistics for all mean daily flow values from the record are presented in Figure 3. This curve represents the percentage of days on the gage record for which a given flow has been equaled or exceeded, and provides insight into estimates of how often discharge can be expected to reach or exceed a specified flow. It also provides insight into the expected duration of a given flow range. This is important to understanding both the duration and range of low and high flows occurring in Camas Creek, which has implications for minimum flow requirements for fish and water use as well as flows needed for sediment transport.

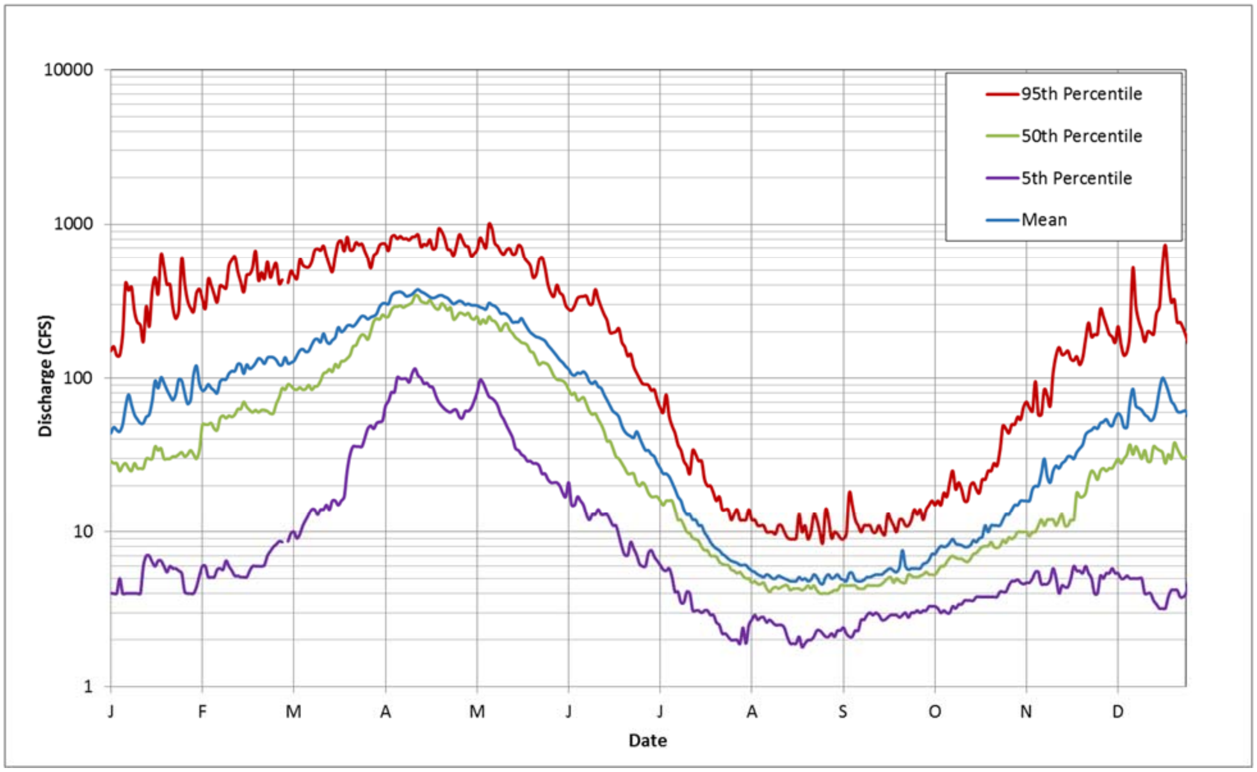

Figure 2. Daily streamflow statistics for USGS/ODWR Gage #14042500 on Camas Creek near Ukiah, OR.

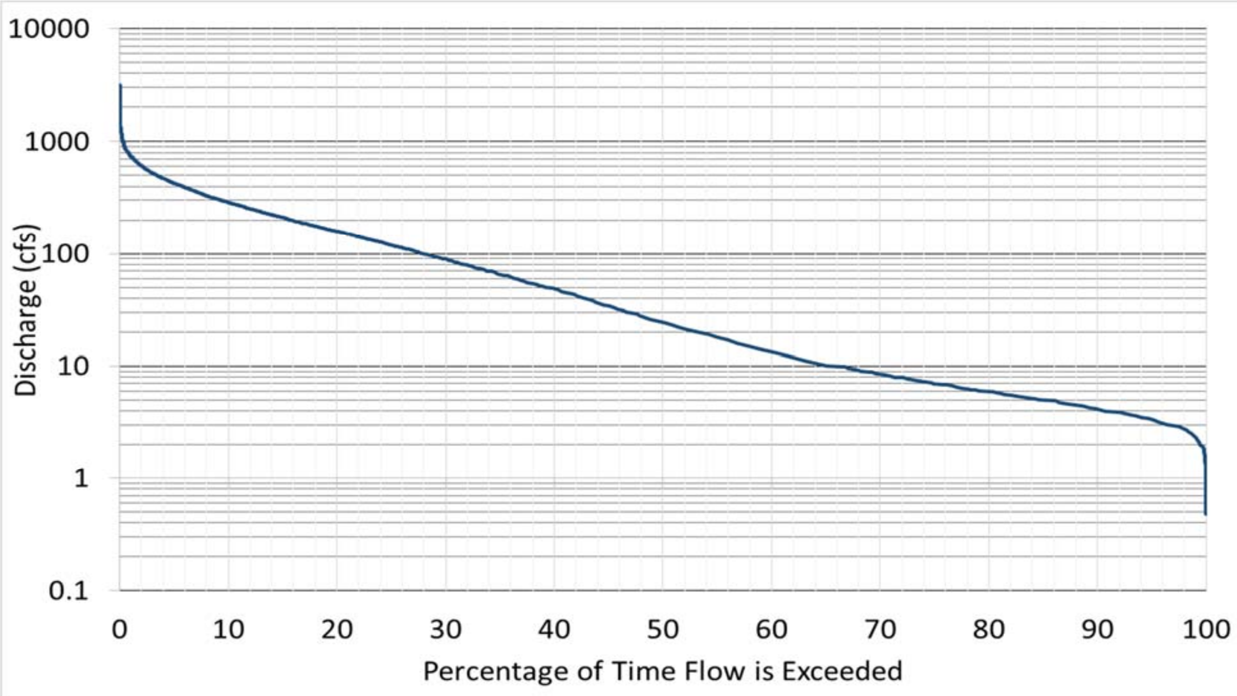

Figure 3. Flow duration exceedance probability curve for mean daily discharge at USGS/ODWR Gage #14042500 on Camas Creek near Ukiah, OR.

Shallow soils and bedrock combined with steep topographic relief and limited vegetative cover result in a flashy hydrologic regime when rainfall occurs, concentrating flows into stream channels. Shallow soils and bedrock near the surface prevents the vertical movement of water to groundwater aquifers or soil storage areas. Steep topography combined with this lithology results in a largely lateral movement of water. In the absence of vegetative cover to intercept and utilize rainfall, storm water is directed to stream channels. This process has likely been exacerbated by historic timber harvest and fires throughout the watershed, stream channelization and floodplain infringement, and a reduction in wetland area due to beaver removal, flood control efforts, and water extraction. Hyporheic exchange and lateral groundwater movement can buffer summer flows in the lower gradient meadows of the valley bottom in lower Camas between June and late September, however portions of the stream channel near Ukiah can run dry in the late summer, depending on snowpack and summer precipitation (Figure 4). Groundwater flows of significantly lower temperature than surface waters enter Camas Creek near Pine Creek below Ukiah (Zakrajsek 2012). The groundwater table in Lower Camas

Figure 4. Downstream extent of wetted channel just upstream of Ukiah in September 2015.

Creek has likely been lowered as a result of channel incision and a loss of floodplain connectivity and wetlands.

3.2 Peak Flow Analysis

NSD conducted an analysis of peak flows for Camas at RM 11 to determine appropriate streamflow values for use in the hydraulic analysis. Flood events that are expected to be equaled or exceeded once on average during any 1.01-, 2-, 10-, and 100-year period (recurrence interval) have a special significance for flood planning purposes and potential river restoration projects. These events are commonly referred to as the 1-, 2-, 10-, and 100-year floods. Recurrence intervals represent a long-term, average period between floods of a specific magnitude. However, it is important to note that autocorrelation of multiple large floods within shorter periods of the hydrologic record suggests that low-frequency, or rare floods, could occur at shorter intervals or even within the same year, rather than on a predictable cycle as might be suggested by average values. Of particular importance to channel forming processes in Camas are the 2- and 100-year flows. The top ten peak flows on record are presented in Table 1 below, with the complete peak flow record included in Figure 5.

Table 1. Top Ten Peak Flows for Camas Creek near Ukiah (USGS 14042500).

RANK	DATE	PEAK FLOW VALUE (CFS)*
1	1/30/1965	3840
2	1/1/1997	2870
3	3/18/1932	2600
4	5/19/1991	2570
5	5/8/1956	2510
6	2/8/1996	2420
7	3/13/1972	2380
8	12/12/1946	2350
9	1/16/2011	2310
10	2/20/1982	2230

*Basin area at gage location is 121 square miles. Total drainage at RM 11 is approximately 205 square miles.

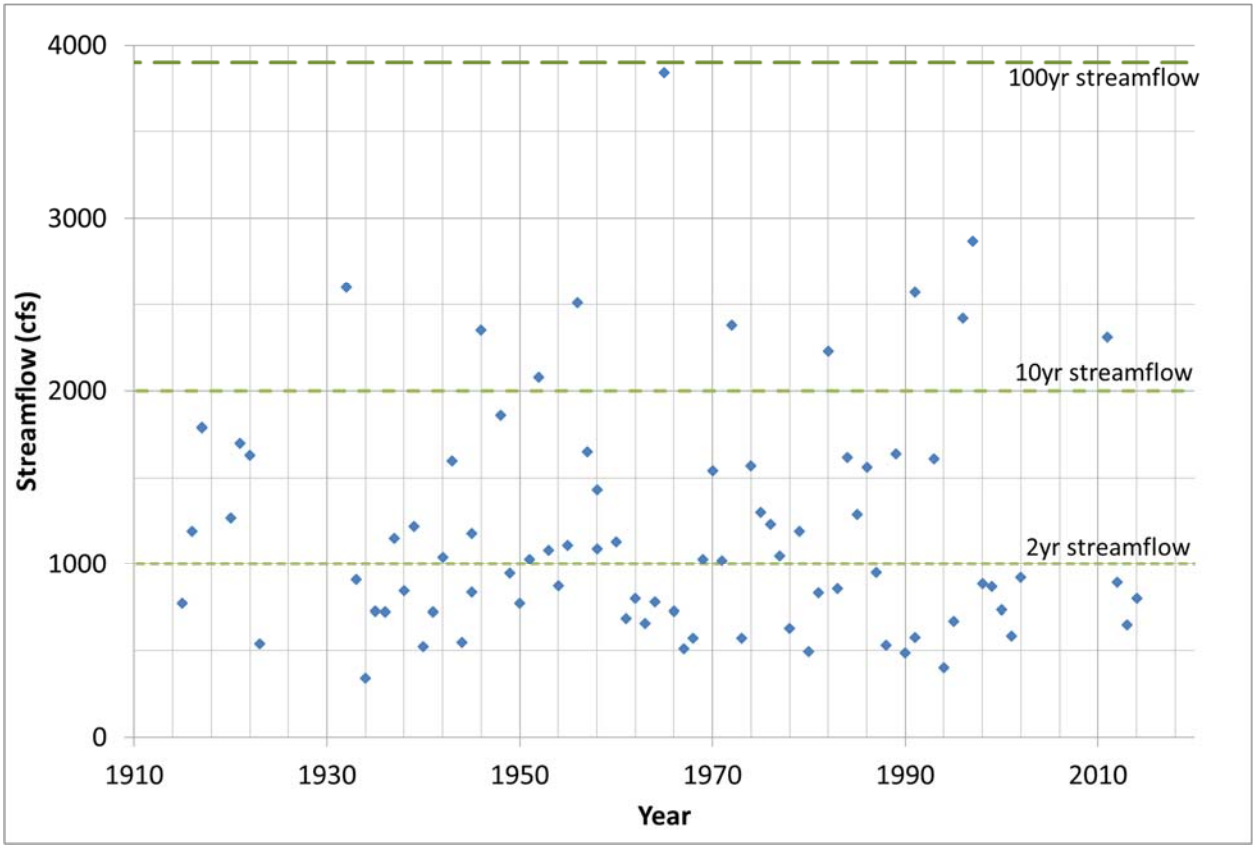

Figure 5. Historic peak flow record for Camas Creek near Ukiah, OR (USGS 14042500).

Review of historic precipitation data for Ukiah suggests that the hydrologic regime of the upper watershed above the flow gage is distinct from that of the primary area of interest within the alluvial fan. None of the top peak flow events correspond with periods of high rainfall or snowpack at Ukiah. Because no other precipitation data is available within the watershed above Ukiah, determining the primary drivers (eg. heavy rainfall, rain-on-snow, etc.) of these peak flows is difficult, however it is likely they are linked to heavy rain or rain on snow events. Peak flows may occur during the winter or spring months, dependent on elevation gradient in rainfall and the influence of marine or continental climate (Ecovista 2003). Peak flows in the upper watershed or spring months are often associated with spring snowmelt or occasional rain on snow events, whereas winter flooding is driven by rain on snow or heavy rain falling on frozen soils with low infiltration rates. The flood of record in January of 1965 corresponds with a statewide record period of rainfall for Oregon that spanned from December 1964 – January 1965. Several locations in central and eastern Oregon recorded more than two thirds of total annual rainfall in less than five days (WRCC 2015b).

Peak discharge estimates for the active gage record were evaluated utilizing a Log Pearson Type III and following USGS Bulletin #17B procedures (USGS 1981). Following recommendations by Cooper (2006) the peak flow values for the gage site were scaled to the drainage area corresponding with RM 11 at the lower end of the project area below Ukiah (205 square miles). Peak flow values were scaled by the same method to obtain the discharge for the contributing area above the Camas Street Bridge (170 square miles), for use in the hydraulic analyses. Data for the USGS period of record (1914 – 1991) were originally utilized to determine peak flow estimates for use in the hydraulic analysis. Following completion of the hydraulic analysis, additional data were obtained from the ODWR, which operated the Camas gage for WY 1992-1997, 2001, and 2009 – present (#14042500). Additional flow records were then added to the peak flow analysis to assess any significant changes to NSD's peak flow estimates. Lower recurrence interval flows were unchanged by the inclusion of the additional flow records, with higher flows (eg. 100-yr) changed by as much as 5.5 percent. The resulting peak flow estimates are presented in Table 2 below.

Table 2. Peak Flow Estimates for Camas Creek.

RECURRENCE INTERVAL (YEARS)	USGS GAGE 14042500[1] (CFS)	USGS/ODWR COMBINED GAGE RECORD 14042500[2] (CFS)	RM 11 – USGS RECORDS ONLY[3] (CFS)	RM 11 – USGS/ODWR COMBINED RECORD[4] (CFS)	CAMAS BRIDGE – USGS RECORDS ONLY[5] (CFS)	CAMAS BRIDGE- USGS/ODWR COMBINED RECORD[6] (CFS)
1.01	400	400	600	600	500	500
2	1000	1000	1700	1700	1400	1400
5	1600	1600	2500	2500	2200	2100
10	2000	2000	3200	3200	2700	2800
25	2600	2700	4200	4300	3500	3600
50	3100	3200	4900	5100	4200	4400
100	3600	3900	5800	6100	4900	5200

1 Estimated peak flows for Camas Creek based on the gage record for USGS 14042500 near RM 18.8 (1914-1991).
2 Estimated peak flows for Camas Creek based on the combined USGS and ODWR gage records for #14042500 near RM 18.8 (1914-2014).
3 Estimated peak flows for Camas Creek near RM 11 based on scaling methods from Cooper (2006) for the USGS period of record (1914-1991). Drainage area includes Pine Creek.
4 Estimated peak flows for Camas Creek near RM 11 based on scaling methods from Cooper (2006) for the USGS/ODWR combined period of record (1914-2014). Drainage area includes Pine Creek.
5 Estimated peak flows for Camas Creek at the Camas Street Bridge based on scaling methods from Cooper (2006) using only the USGS period of record (1914-1991). These values were utilized in the Hydraulic Analysis prior to receipt of additional gage records for 1992-2014.
6 Estimated peak flows for Camas Creek at the Camas Street Bridge based on scaling methods from Cooper (2006) using only the USGS/ODWR combined period of record (1914-2014).

3.3 Climate Change Impacts on Streamflow

Temperature observations from Northeast Oregon weather stations show a warming trend over the historical period with increases in average annual temperature between 1.1° F and 2.5° F during the period 1895-2014. Future climate projections for atmospheric conditions with increased greenhouse gas concentrations show additional warming at an even greater rate over the 21st century (Mote and Salathé 2010). Model scenarios for the Pacific Northwest region indicate increases in average annual temperature between 3.3° F and 9.7° F by 2099 (compared to the period 1970-1999).The ensemble average of climate simulations of the A1B emissions scenario (moderate increases in emissions) project a 6.1° F increase in temperature (Mote and Salathé 2010). Warming temperatures will drive changes in the timing of streamflow that have important implications for aquatic habitats and water resource management (Elsner et al. 2010).

Seasonal runoff patterns in the Camas Creek watershed are representative of a transitional flow regime with mixed rainfall and snowmelt contributions. The range of average daily minimum and maximum temperatures at Ukiah is between 16.4° F and 39.8° F during the core winter months from December to February. Future increases in temperature will result in a concurrent increase in freezing level elevations and a greater proportion of winter precipitation falling as rain as opposed to snow. Water year (WY) 2015 presented an interesting example of potential future conditions due to anomalously warm temperatures that closely resembled model projections for the late 21st century. Winter temperatures in WY 2015 were approximately 5° F above average and precipitation totals (PPT, cumulative total of rain & melted snow) were at or above normal throughout the winter period. Precipitation and snowpack data from the U.S. Department of Agriculture SNOTEL site (Lucky Strike; approximately 1.5 miles north of the Camas Creek watershed) comparing WY 2015 to average values over the historical record show a strong reduction in the amount of water contained within the snowpack, measured as snow water equivalent (SWE), due to the anomalously warm temperatures in 2015 (Figure 6).

Future changes in the seasonal pattern of runoff from the contributing watershed have been simulated by model projections of future climate scenarios by the UW Climate Impacts Group as part of a regional dataset for the Columbia River Basin (Hamlet et al. 2013). Variable Infiltration Capacity (VIC) model projections for the A1B emissions scenario show a 16% decline in maximum SWE values for the Camas Creek watershed upstream of the project area by the 2040s. Modeled streamflow metrics based on daily simulations of the VIC model project little to no change in annual flow totals; however, streamflow variability is projected to increase with an approximately 13% decline in mean summer baseflows and 20% increase in peak flows by the 2040s (Table 3).

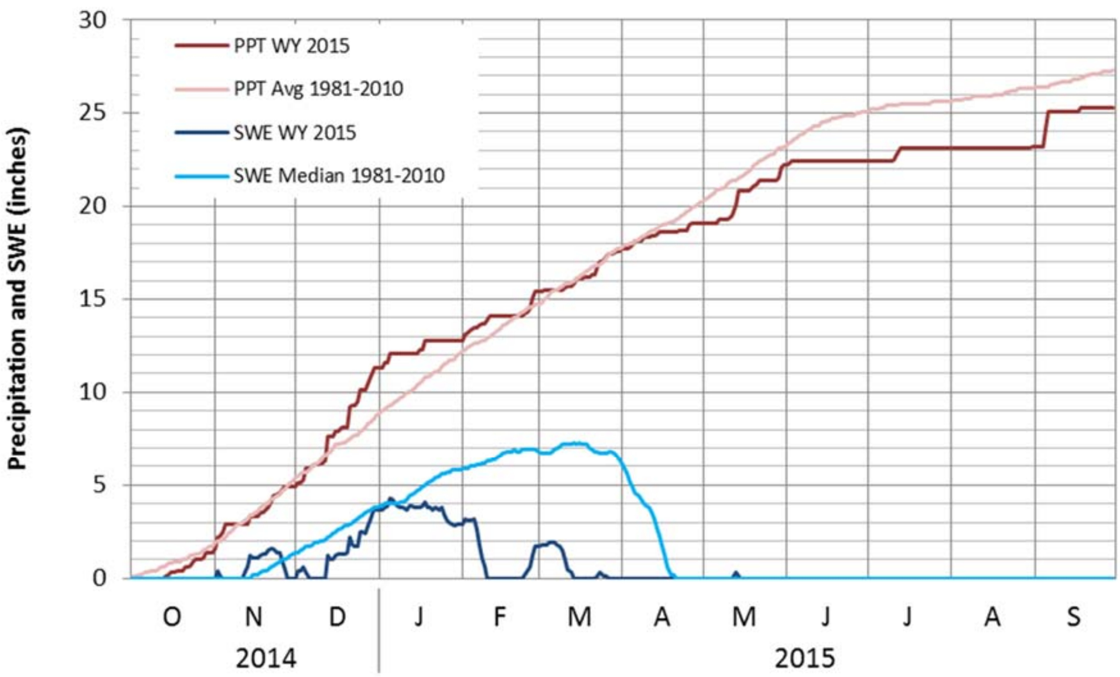

Figure 6. SNOTEL data (Lucky Strike) comparing cumulative precipitation totals (PPT) and snow water equivalent (SWE) from WY 2015 with average values for the historical record.

Table 3. Modeled streamflow metrics as a percentage change from historical averages based on VIC model simulations (A1B emissions scenario). Source: Western U.S. Stream Flow Metrics database (USDA 2015)

	SIMULATED CHANGE (A1B SCENARIO)	
	2040s	2080s
Mean Annual Flow	0%	+3%
Mean Summer (June-Sept)	-13%	-18%
Mean August Flow	-13%	-18%
Peak Flow (T = 1.5 Years)	+20%	+31%

4. HYDRAULIC ANALYSIS

4.1 2-D Hydraulic Model

The primary objective of NSD's hydraulic analysis was to evaluate flow patterns, hydraulic parameters, and inundation extents to characterize current riverine conditions within the Primary AOI (the Cable Creek confluence downstream to RM 11). The hydraulic analysis was conducted for the 2- and 100-year peak flow discharges described in the preceding section of this report (USGS gage record only, 1914-1991, see Table 2). All model runs were performed in steady state (discharge does not vary with time) with a non-deformable bed (no adjustments for scour, sediment transport or deposition). Hydraulic models were created representative of existing conditions using Hydronia's RiverFlow-2D Plus GPU and Aquaveo's Surface-water Modeling System (SMS) v11.2 computer software. RiverFlow-2D is a two-dimensional finite volume computer model that provides depth-averaged hydraulic parameters at nodes within a triangular model mesh domain by solving the shallow water equations resulting from integration of the Navier-Stokes equation. The Navier Stokes equation is derived from applying Newton's Second Law (Force = mass*acceleration) to fluid motion, and is generally expressed as:

$$\overbrace{\rho\left(\underbrace{\frac{\partial v}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{v \cdot \nabla v}_{\text{Convective acceleration}}\right)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu\nabla^2}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{f}_{\text{Other Body forces}}$$

Where ρ = fluid density

μ = dynamic viscosities

p = pressure

∇ = del operator (abbreviation for derivative (gradient) of 3D vector field)

f = term representing body forces acting on the fluid (per unit volume)

SMS is a GIS-based program that creates the triangular model mesh, model input files, and displays model results. The following sections provide more in-depth information on specific components of our hydraulic analysis, data development, and results. Actual model results and figures are provided in Appendix A.

4.1.1 Model Topography

All hydraulic models utilized the LiDAR data collected by Quantum Spatial March 28, 2015 to represent channel and floodplain topography. The horizontal and vertical datum of all data utilized and referenced in the report is NAD 1983 Oregon Statewide Lambert feet and NAVD88 feet, respectively. Due to the limited light penetrating abilities of near infrared (NIR) LiDAR scanners, channel topography utilizing only NIR LiDAR is representative of the water surface at the time of LiDAR acquisition, not the channel bottom. Review of the 2015 LiDAR data indicates that the channel bathymetry is not well represented but the majority of out of water areas (gravel bars, floodplain, etc.) are representative of current conditions. Because no active gage data was available for Camas Creek at the time of the hydraulic analysis, flow at the time of LiDAR acquisition was estimated from the average discharge for March 28 (241 cfs) for the 67 year period of gage records. This flow was then scaled for the contributing basin area at the project site, and was determined to be approximately 340 cfs. The flow estimate was validated by comparison of discharge at an active gage on the MFJD and historic flow records at the Camas gage. Historic daily flows at the Camas gage are approximately 49 percent of the MFJD. Mean flow in the MFJD on the day of LiDAR acquisition was 493 cfs. Multiplying this discharge by 49 percent and scaling by basin area at the project site, the flow estimate obtained from this approach is also 340 cfs. Comparison to recent gage data obtained from ODWR for Camas at #14042500 indicates that flow at the time of LiDAR acquisition was approximately 320 cfs at the alluvial fan.

To account for the relative difference between the water surface and channel bed during LiDAR acquisition, the estimated discharge present in the channel (340 cfs) was subtracted from the modeled peak flows. Although this provides a close approximation of the wetted extent and water surface elevation (WSE), flow depths are likely underestimated in the model results. The existing conditions model simulations utilized a point cloud derived directly from the ground and water surface points delivered in the raw LiDAR data. If model runs of flows lower than 340 cfs are requested in future phases of this project, we would recommend channel survey data be acquired at key locations to increase the accuracy of model results.

4.1.2 Mesh

A mesh or wireframe is a key component to any 2D hydraulic model. The model derives one depth-averaged flow velocity (direction and magnitude) at each node of the 2D (x-y) mesh. To predict vertical variations in flow within the water column would require a 3D model. The mesh is composed of nodes and elements that are coded with elevation and roughness values needed to run the computational routine. RiverFlow-2D utilizes a flexible tri-angular mesh to solve for volume conservation and momentum in the x and y directions at each node (representing depth average). The model mesh begins approximately 320 ft downstream of the Cable Creek Road bridge crossing near RM 17.8 and extends downstream 7.1 miles to RM 11.7 below the confluence with Pine Creek. For this project the model mesh utilized 497,080 triangular elements and 249,920 nodes. The governing equations are applied at each node in an iterative routine until converging on a solution that achieves conservation of mass and energy to within an acceptable error.

To create the model mesh, a map consisting of arcs and regions delineating the channel, floodplain features, and material types was developed using Aquaveo's SMS software. Arcs were drawn along significant topographic features (top of bank, levees, bars, side channels, roadways) and changes in roughness (ground cover type, logjams, cleared areas). Arcs function as breaklines during the mesh creation process to ensure the model mesh is an accurate representation of the channel/floodplain topography and to create regions within the map to which different roughness values can be assigned. The spacing of nodes along an arc also functions to affect the density or refinement of the model mesh. The level of refinement of a model mesh is an important consideration during 2D modeling, as a finer (more dense) mesh creates a more accurate representation of the channel and floodplain topography and reduces model instability issues, but increases model computation time. For this project, the spacing of nodes along each arc was adjusted to increase node density in areas of interest to between 10 and 15 ft (main channel, side channels, etc.) and reduced in other regions to between 20- to 40-ft (outer edge of floodplain, upland areas, etc.). In this way, the model mesh was optimized to provide detailed information in areas of interest while also balanced with reduced computational times to increase the number of model iterations.

4.1.3 Roughness

Hydraulic analyses require an assessment of the resistance (drag force) the ground surface and other physical features exert against the movement of water. This drag force is commonly referred to as roughness. The most accepted method to assess roughness uses the Manning's n resistance factor (Chow, 1959). Common factors that affect roughness values include: channel sediment size, gradation, and shape; channel shape, channel meandering, bank and floodplain vegetation, obstructions to flow, flow depth, and flow rate. Manning's n values for this project were assigned to different roughness types using a hillshade image derived from the 2015 LiDAR and 2014 aerial imagery from the USDA National Agriculture Imagery Program (NAIP) and in accordance with standard hydraulic reference manuals and then adjusted based on field observations (Chow, 1959; Barnes, 1967; Hicks and Mason, 1998). 2D hydraulic models explicitly calculate momentum losses caused by channel shape, meandering, and floodplain topography not normally accounted for in 1D hydraulic models. As such, Manning's n values in 2D models can generally be lower (up to 30%) than those normally used for 1D hydraulic models (Hydronia, 2012). A Manning's multiplier of 0.8 was thus applied to the n values within SMS to reduce the modeled roughness by 20 percent. Model roughness values are shown in Table 4 below.

Table 4. Model Roughness Values.

ROUGHNESS TYPE	MANNING'S N VALUE	MODELED N VALUE*
Channel – Main	0.033	0.027
Channel – Side	0.035	0.029
Gravel bar	0.039	0.032
Vegetated gravel bar	0.06	0.049
Standing water	0.026	0.021
Pier	0.26	0.21
Forest	0.1	0.084
Grassland	0.05	0.04
Infrastructure	0.068	0.056
Pavement	0.013	0.011
Gravel road	0.031	0.025

*Manning's N value reduced by 30 percent using a Manning's multiplier of 0.7.

4.1.4 Boundary Conditions

All hydraulic models require the user to input a known boundary condition at the upstream and downstream extents to begin the computational routine. The upstream boundary condition for all model runs includes flow from Camas Creek set to the corresponding peak flow rate described in the hydrology section of this report for the 2-yr recurrence interval flow. The peak flow was then adjusted to remove the approximate discharge present during LiDAR data acquisition (March 28, 2015 estimated discharge of 340 cfs, see Model Topography section for additional information). The downstream boundary condition for all model runs was set to a free outflow, which enables the model to calculate velocities and WSE. Model boundary condition values are shown in Table 5.

Table 5. Model Boundary Conditions.

RECURRENCE INTERVAL	CAMAS CREEK DISCHARGE (CFS)	MODELED DISCHARGE* (CFS)	DOWNSTREAM BOUNDARY CONDITION
2 year	1400	1060	Free Outflow
100 year	4900	4560	Free Outflow

*Discharge adjusted by subtracting approximate flow of 340 cfs during LiDAR acquisition. Peak discharges estimated using USGS period of record only (1914-1991, see Table 2).

4.1.5 Existing Conditions Hydraulic Results

Results from the existing conditions model simulations are attached to this report as Appendix A. Completed model runs were initially reviewed in SMS to verify accuracy of results and then exported to a GIS compatible data file. GIS files include data for each node and hydraulic parameter within the model mesh (bed elevation, water surface, flow depth, velocity, shear stress, etc.) to facilitate development of raster grids representing the model results. Key observations from the existing conditions model results are described below.

Hydraulic model results illustrate the confinement of Camas Creek by SR 244 (Ukiah-Hilgard Highway) and the intact levee structures spanning the channel through much of the alluvial fan for both the 2- and 100-year flows. During the 2-year flow, Camas is confined to a single thread, high velocity channel from RM 17.8 (Cable Creek) to 17.3, 16.7 to 16.2, 14.9 to 14.35, and 13 to 12.75. Mainstem depths and velocities range from 0.4 – 3.9 ft and 2.6 – 11.9 ft/sec for the 2-year flow, and from 0.7 – 8.2 ft and 2.5 – 17.1 ft/sec for the 100-year flow. Basal shear stress along the thalweg ranges from 0.1 – 1.7 lbs/ft^2 for the 2-year flow and from 0.1 – 2.9 lbs/ft^2 during the 100-year flow. Floodplain and side channel flow depths and velocities vary considerably throughout the model domain, but are generally more shallow and slower than mainstem flows. Flow statistics for the channel thalweg are presented in Table 6.

Table 6. Thalweg Flow Statistics.

RECURRENCE INTERVAL	DEPTH (FT)			VELOCITY (FT/S)			SHEAR (LBS/FT^2)		
	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX
2 year	0.4	2.1	3.9	2.6	7.5	11.9	0.1	0.7	1.7
100 year	0.7	4.1	8.2	2.5	10.7	17.1	0.1	1.2	2.9

An anabranched (flow within several channels) or multi-thread channel forms in locations where the channel is not confined by levees or the SR 244 road prism. These locations also correspond with reduced mainstem velocities and flow depths (Figure 7). In anabranched reaches or areas with side channel connectivity, mainstem velocities are reduced by as much as 40 percent relative to single thread reaches. When discharge remains constant, the continuity equation (Q = VA) requires that velocity decrease when wetted channel cross-sectional area increases. Conversely, velocity increases when wetted channel cross-sectional area decreases. This pattern is observed in Camas where the active channel width fluctuates from anabranched reaches or locations with intact floodplain (eg. RM 16, 14.2, 12.4) to confined segments where cross sectional area is reduced (eg.RM 14.6, 12.9).

During the 2-year flood, a total of 153 acres are inundated. Approximately 46 percent of the inundated area is within the main channel and adjacent gravel bars. Much of the additional flooding occurs above the fan where SR 244 runs along the valley wall, between RM 14.35 and 13.6 where the levees have eroded, and in the intact floodplain area downstream of the Camas Street bridge. At the 2-year flow, Camas is almost entirely disconnected from the left bank floodplain and alluvial fan from RM 17.8 to below the Camas bridge, where the left bank levee has been breached and flood flows inundate the lower portion of Pine Creek.

For the 100-year flood, a total of 400 acres are inundated, with the active channel corridor comprising 17 percent of total flooded area. Most of the stream corridor between the southern valley wall and SR 244 is inundated from the upstream model boundary (Cable Creek, RM 17.8) to the head of the alluvial fan at RM 14.8. SR 244 confines flooding to the southern side of the highway between RM 16.65 and 16.2, reducing floodplain width by 85 percent. Inundation of the left bank initiates at the alluvial fan channels near RM 14.6, where the levee along the left bank appears to have been breached. 100-year flows run along the southern side of the levee, then continue across the fan to the southwest, inundating the artificial impoundment/pond adjacent to RM 13.6 and eventually flowing into lower Pine Creek. Much of the floodwater flowing over the alluvial fan is shallow, with depths below 0.5 ft and velocities ranging from 0.1 – 5 ft/sec. The levees spanning the right bank in the vicinity of the former mill site (RM 14.9 – 14.4) are effective at retaining 100-year flows, disconnecting the channel from approximately 20 acres of low-lying floodplain to the north of the levee and south of SR 244. With the exception of backwater from downstream near RM 14.3, much of the floodplain in this area remains unwetted, despite being at a lower elevation than the low flow channel surface (Appendix C).

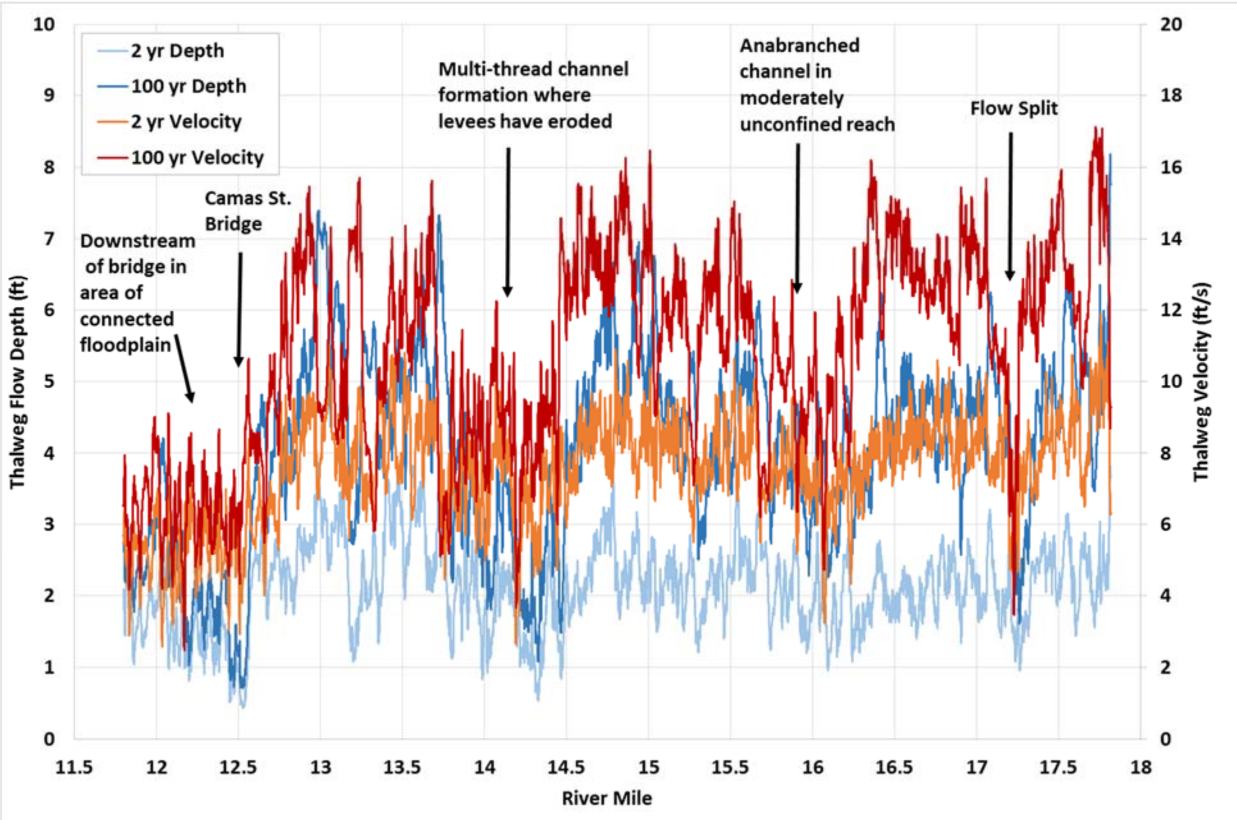

Figure 7. Thalweg depth and velocity profiles for the 2- and 100-year hydraulic model outputs. Areas of reduced flow depth and velocity generally correspond with a wider, intact floodplain and multiple channel threads.

4.1.6 Existing Conditions in Ukiah and at the Camas Street Bridge

The entirety of the 2-year flood peak and much of the 100-year flood flow is concentrated into a narrow channel in the vicinity of Ukiah, resulting in a deep, fast channel with increased water surface elevations (WSE). During the 100-year flow, flooding of Ukiah is initiated at RM 12.8, where the active channel width is reduced from 320 ft at RM 13 to less than 100 ft, constricting flow. This constriction results in a localized backwater effect extending for approximately 500 ft upstream, reducing velocities between RM 12.9 and RM 13 and raising the WSE. This increase in WSE initiates flooding of the right floodplain, conveying flow into Ukiah south of State Street. Mill, Pine, Alba, and Camas Street are flooded, with depths and velocities up to 2.5 ft and 3 ft/sec, respectively. Within the confined channel segment downstream of RM 12.9, velocities are increased by up to 65 percent due to a reduction in channel area.

Backwater at the Camas Street bridge locally increases WSE, flooding the right bank for the 2-year flow and both the left and right banks at the 100-year flow. 2-year floodwater along the right bank pools along the private property to the east of Camas Street, flooding Alba Street and a private road running parallel to the right bank of Camas Creek. During the 100-year flow, portions of Camas Street are flooded with flow up to 0.5 ft in depth. Flows overtopping the left bank are conveyed along the Soap Hill Road prism to the south, overtopping the road where it lowers to grade approximately 900 ft the south of the bridge.

The backwater at the bridge also reduces flow velocities by more than 40 percent relative to the confined reach upstream. Reduced velocities in the vicinity of the bridge are also likely to govern shifts in sediment transport capacity, whereby the mobile particle size is effectively reduced, resulting in the deposition of coarse material. The relationship between particle size and the velocity needed to maintain a particle in motion is illustrated in Figure 8.

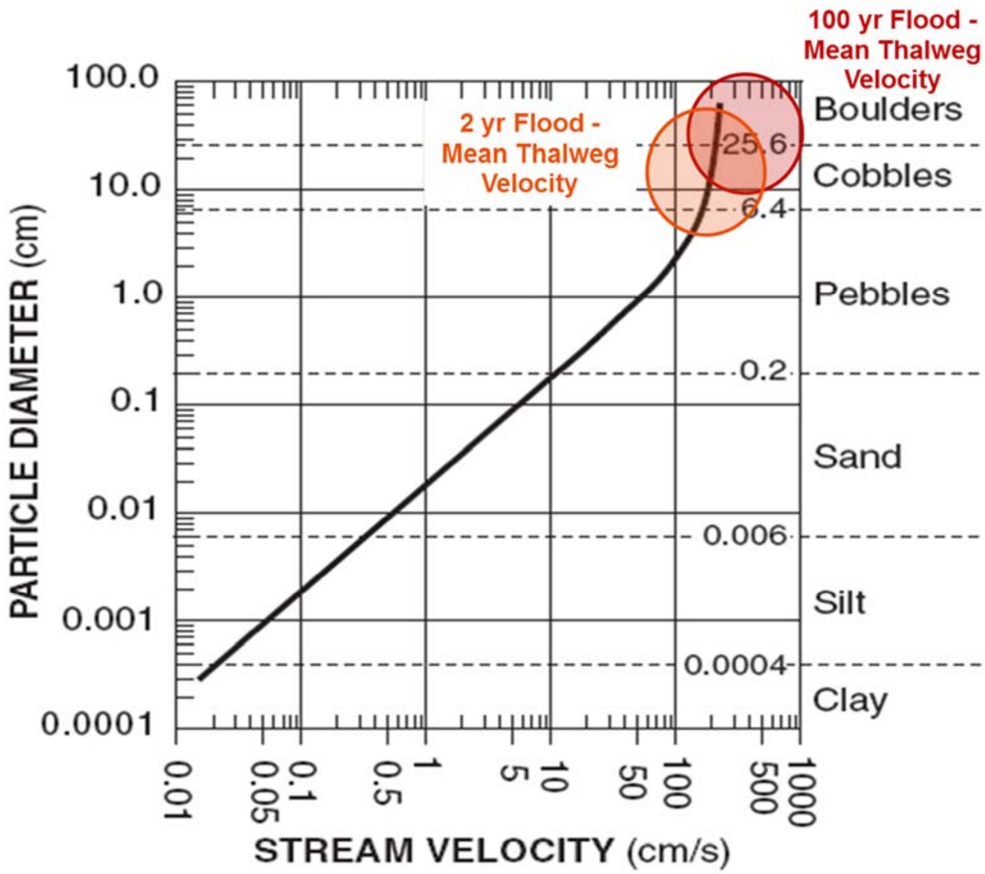

Figure 8. Relationship between stream velocity and mobile particle diameter. Modified from UNSY (2011).

The flow velocity and shear necessary to mobilize a particle depends on the distribution of grain sizes and the embeddedness of material, however based on a general lack of gravels and fine material throughout the project reach, velocities in the Primary AOI are sufficient to mobilize material smaller than medium to large cobble, with flood flows capable of moving larger material. The minimum stable particle size for Camas Creek is mapped in Appendix A, and was determined following the Shield's equation:

$$D = \frac{\tau}{(\rho_s - \rho_f)} g\, \tau c$$

In which D = stable particle size – D50; τ = shear stress; ρ_s = density of the particles (165.4 lbs/ft^3); ρ_f = density of water (62.4 lbs/ft^3); g = force of gravity (32.2 ft/s^2); and τ_c = Shield's constant (0.045).

Sediment transport and equilibrium can also be evaluated in terms of Lane's principle, which states:

$$Q_s d \propto Q_w S$$

Where Q_s = sediment discharge; d = particle diameter; Q_w = water discharge; and S = slope. Human modifications to this equilibrium, such as changes in slope or discharge, result in adjustments to sediment transport or particle size as the channel attempts to regain equilibrium.

The slope or gradient of Camas Creek has been increased by a shortening of the channel length in areas of channelization by levees and straightening, thereby increasing sediment transport in these locations. Where the channel slope decreases (eg. anabranched reaches or areas of backwater), the channel attempts to reach equilibrium through a reduction in sediment discharge, aggrading the channel. The Camas Creek channel has a natural tendency to meander or form anabranches in reaches where the active channel width is not constrained by levees. This process reduces channel slope, which suggests that Camas Creek, in an equilibrium state, tends toward a meandering or anabranched planform given its natural sediment supply and flow regime. In areas where this equilibrium has been disrupted, such as channelized segments, the creek channel is attempting to reduce its slope through aggradation. When constrained by hydraulics, this process is only able to occur where flow velocity and sediment transport diminishes, such as the backwater area upstream of the Camas Street bridge or at RM 12.65 where the levees widen relative to the confined segments upstream, resulting in formation of large gravel/cobble bars within the active channel.

4.1.7 Flood Risk

To examine flood risk potential within Ukiah, 100-year model outputs were compared to levee elevations along Camas from RM 13.25 – 12.45. The results of this assessment are presented in Appendix A (page 50). Freeboard represents the vertical difference between the 100-year water surface elevation (WSE) and the peak levee elevation adjacent to the channel surface. Locations where freeboard is lower (shades of red and orange) indicate areas along the levees where flood potential or the risk of flood peaks overtopping the levee are highest. Conversely, areas where there is greater freeboard are indicated by shades of green, and are less likely to be overtopped during the 100-year flood peak. Note that the hydraulic model output assumes a static or immobile bed, which also means the levees remain intact during the model simulation. It is likely, however, that high flows might damage portions of the levee, undermining or eroding the levee prism, thereby increasing flood risk. 100-year model results indicate that the left and right bank levees between RM 12.7 and 12.5 (Camas Street bridge) would be overtopped during the 100-year event. The left bank levee would also be overtopped immediately downstream of the bridge crossing. These levee areas coincide with the southern portions of Albee, Main, and Camas Streets along the right bank and the western portion of Mossie Road along the left bank. Overbank flow is also initiated along the left bank near RM 13.2, where the active channel width is constricted by up to 75 percent relative to the area upstream, locally raising the WSE. Other levee areas within the area examined retain a freeboard ranging from 0.25 – 4.5 ft during the 100-year flow event.

Flood risk was also assessed by simulating an unsteady discharge, increasing flows over the course of 12 hours from 1,000 cfs to 9,800 cfs (twice the 100-year flow) to determine the discharge at which banks, levees, and roadways are overtopped. The results of this assessment are presented in Appendix A (pages 51 – 55), with flood risks outlined below:

- SR 244 is overtopped near RM 17.5 at a discharge of approximately 9,800 cfs, inundating the north side of the roadway.
- SR 244 is overtopped at RM 16.3 where the channel is constricted between the roadway and the southern valley wall at a flow of 7,340 cfs. The roadway is also overtopped further upstream near RM 16.5 when discharge reaches 9,340 cfs.
- At the upsteam end of the alluvial fan, activation of the left bank floodplain initiates at RM 14.6 when discharge reaches 1,500 cfs. The floodplain channels are fully engaged at 2,000 cfs, flowing to the southwest into the ponds on the alluvial fan.
- The left and right banks at RM 14.8 are overtopped at a discharge of 5,400 cfs, engaging the floodplain channel along the southeastern portion of the alluvial fan and the low-lying floodplain area to the north of the right bank levee (south of SR 244).
- The left bank levee at RM 13.25 is overtopped at a discharge of 4,900 cfs, flooding portions of the alluvial fan.
- The left and right bank levees at RM 12.9 are overtopped at a discharge of 6,000 cfs. Overbank flow is directed to the south and west along the alluvial fan, with portions of flow reconnecting with the mainstem of Camas downstream.
- The right bank at RM 12.8 is overtopped at 4,300 cfs, inundating portions of Ukiah. The left bank in this location has a higher levee, and is overtopped at a discharge of 7,000 cfs.
- The left and right banks immediately upstream of the Camas Street bridge are overtopped at a discharge of 1,500 – 2,000 cfs, inundating portions of Ukiah. At higher discharges, floodwater overtops Camas Street to the north of Camas Creek.
- At higher flood stages, the upper alluvial fan becomes activated, diverting flood flows away from the present mainstem channel of Camas, thus reducing the overall flood magnitude at Ukiah. The floodplain channels along the alluvial fan are not well connected at flows below the 100-year discharge (4,900 cfs) due to channel incision driven by levee confinement. Lowering or breaching of the levees at the head of the alluvial fan would alleviate flood risk in Ukiah, directing portions of total flow across the fan and into Lower Pine Creek.

5. GEOMORPHIC ASSESSMENT

5.1 Watershed Characteristics

The Camas Creek watershed drains a total of 408 square miles within Umatilla, Morrow, and Union Counties in Northeastern Oregon. Approximately 52 percent of the watershed is managed by the USFS within the Wallowa-Whitman and Umatilla National Forests (WWNF and UNF, respectively, Map 1). The drainage area contributing to the downstream project boundary at RM 11 encompasses 205 square miles, spanning a vertical relief of 3,480 ft from 3,290 ft at RM 11 to 6,770 ft in the Blue Mountains. Approximately 35 square miles (17 %) of this area contributes flow to Pine Creek, which enters Camas from the east approximately 0.5 miles downstream of Ukiah. Camas flows generally west from its headwaters (RM 37) through a confined to moderately confined alluvial valley with a mean width of 400 ft until RM 15, at which point it flows southwest across a broad alluvial fan and through the town of Ukiah. The alluvial fan is approximately 2.5 miles in length, with a mean width of 4,500 ft. Below Ukiah, Camas turns to the west for 1 mile and then south through a moderately confined basalt canyon to its confluence with the NFJD near RM 57. Of the study area, approximately 75 percent (151 square miles) is within the WWNF and UNF, which includes Camas above RM 22, South and North Forks Cable Creek, and upper Hidaway Creek (Map 1). Much of the lower study area (Primary AOI) including lower Cable, Hidaway, and Pine Creeks and large portions of the Camas alluvial fan are in private ownership.

5.2 Geomorphic Setting

5.2.1 Geology

The Camas study area is underlain by basement rocks comprised of Triassic to Devonian period (~210 – 360 mya) Elkhorn Ridge Argillite of the Baker terrane, Carney Butte gabbronorite (~150 mya), porphyritic rhyolite and caldera-fill tuff of the Tower Mountain volcanic field (~24 mya), and volcanics of the Limber Jim Creek formation (~28 mya) (Ferns et al. 2001). In the lower elevation portions of the Blue Mountains, these basement formations are overlain by more modern (< 20 mya) Tertiary-formed volcanic deposits of the Grande Ronde and Picture Gorge basalts. The Grande Ronde basalt flows were the most significant of all Columbia River Basalt Groups, with lava inundating and subduing previously formed topography, resulting in a vast plateau 100 – 1000 ft thick that covered much of the Blue Mountain range, with the exception of the tallest peaks (Walker 1973, Orr and Orr 1996). Tectonic activity during the middle and late miocene era (~16.5 – 5 mya) resulted in several fault lines oriented to the northwest, shaping the Cable and Hidaway valleys.

Tectonic folding is believed to have formed the low-lying depression of the present day Camas valley, oriented predominantly to the northeast (Walker 1973, Clarke et al. 1997). Confined by basalt bedrock on either side, Camas flows through a confined to moderately confined valley until RM 15, where the valley widens, forming a broad alluvial fan. Fanglomerate and terrace deposits of sedimentary rock around Ukiah were overlain with Quaternary alluvium, and alluvium and landslide deposits infilled the tectonically formed depressions and fluvial valleys, shaping the modern deposits observed throughout the low-lying portions of the study area (Ferns et al. 2001, DOGAMI 2009). In areas of the upper watershed not overlain by basalt flows or Quaternary deposits, Tower Mountain volcanic rocks and intrusives of the Baker terrane comprise the surficial geology (Map 2). Exposed tuff and tuffaceous sedimentary rock in the upper Cable and Hidaway Creek subbasins is characterized by relatively soft, porous rock formed by compaction of volcanic ash and dust.

5.2.2 Soils

Soil formation in the Camas basin is largely the result of volcanic activity, with volcanic ash and pumice deposition comprising a significant amount of the soil content (Zdanowicz et al. 1999, Zakrajsek 2012). The most prominent deposition event occurred with the eruption of Mount Mazama at Crater Lake approximately 6,600 years ago, depositing ash over the entire watershed. Mechanical weathering and redistribution of this material and parent bedrock have shaped the soils present today. Camas soils overlie old loamy soils buried at depths of 1 – 5 ft (Ecovista 2003). Organic matter is generally concentrated within the upper soil horizons, declining with depth. Lower elevation soils are dry throughout the summer, with higher elevation soils having a greater capacity for water retention, enabling the growth of robust plant communities in the Cable and Hidaway Creek subbasins (Ecovista 2003). These soils are also less prone to erosion than the dry, loess deposits found throughout the low relief portions of the lower watershed. Highly erodible soils occur along steep portions of tributary valleys and in the upper watershed where water retention capacity and soil development are limited by steep topography. In these areas, mechanical weathering of tuff and tuffaceous sedimentary rock are the primary drivers of soil formation.

Soil texture varies with elevation, water retention, and vegetation throughout the watershed. Soils in the alluvial fan area are predominantly gravelly loam, with silt loam in the low lying hillslopes surrounding Ukiah and lower Pine and Cable Creeks (Map 3). At higher elevations, increased moisture content and denser forest form a more organic soil texture with slightly decomposed plant material. Cobbly silt loam forms in upland areas of tributary valleys. Much of the watershed within the UNF and WWNF does not have complete soil texture mapping (Map 3). Ashy silt loam and cobbly ashy silt loam are present on the lower relief plateaus of upper Camas and Dry Camas Creek.

5.2.3 Ecoregions

The entire study area is within the Blue Mountain ecoregion, which is characterized by a low to mid-elevation complex of mountain ranges that are more broad and open than the neighboring Cascades and Northern Rockies (Thorson et al. 2003). Sub-regions within the Blue Mountains ecoregion vary considerably with shifts in elevation and surface geology, which shape distinct microclimates and corresponding landcover within the Camas watershed (Map 4). Upper Camas Creek lies within a maritime influenced zone which intercepts marine weather moving east through the Columbia River Gorge (Thorson et al. 2003). This zone also contains loess and ash soils over basalt that retain sufficient moisture to support forest cover at lower elevations than elsewhere in the Blue Mountain ecoregion. Ponderosa pine and Douglas fir forests in this zone contain a dense and diverse shrub understory, which can delay forest regeneration following logging (Thorson et al. 2003). Within the Camas study area, this zone also contains extensive whitebark pine stands at higher elevations (Map 5, USGS 2012).

Upper Cable and Hidaway Creeks in the southeastern study area and Upper Lane and Bear Wallow Creeks in the northernmost portion of the study area are characterized by a mesic forest zone that comprises the higher elevations of the watershed. This zone is also influenced by marine precipitation patterns, but contains ashy soils that retain moisture through the dry season, supporting a productive spruce-fir forest and stands of whitebark pine (Thorson et al. 2003). Lower Hidaway and Cable Creeks, Pine Creek, and the alluvial fan near Ukiah are all within the cold basins ecoregion, which is characterized by high, wet meadows with silt-clay soils and (typically) high water tables when streams have not been channelized (Thorson et al. 2003). Areas within the cold basins ecoregion with unconstrained streams are typically too moist to be suitable for crops, other than hay, and are heavily grazed by cattle and elk.

Current landcover within the study area is predominantly evergreen forest in the upper watershed (60%) and arid shrub steppe and scrub in the lower elevations and the alluvial fan near Ukiah (37 %, Map 6). Other land cover types within the study area include rural development, small to medium-scale agriculture/pasture, herbaceous cover, and wetlands (Fry et al. 2011).

5.3 Pre-European Disturbance Conditions

5.3.1 Upland and Riparian Vegetation

"There are open glades surrounded by beautiful groves. The prairie is about ten miles wide by twenty miles in length, and is interspersed with groves of pine, fir and tamarack. One branch of the John Day River… runs right through the valley and in places spreads out in a vast marsh… where the settlers of the lower valley get their hay, and the Indians get their camas." -William M. Hilleary 1865, in Harer 1986.

The geomorphic setting and ecology of the Camas study area suggest that large portions of the watershed were once covered with mixed coniferous forest at mid to upper elevations, with wet meadows and moisture tolerant riparian plant and tree species and grasslands in the lower, flatter valleys and terraces. Surveyor's notes from early General Land Office (GLO) mapping of the Camas study area depict the tributary valleys and large swaths of land in the lower basin as being forested with pine, fir, and tamarack (larch) species (GLO 1880). GLO mapping depicts valley slopes in the watershed with broken lands, interspersed with stands of coniferous forest and healthy grasses and marshy meadows. Upland slopes surrounding the Camas valley are described as rolling prairies. Noteworthy in these early survey maps is the presence of several homesteads throughout the Ukiah area, alluvial fan, and surrounding hillslopes, indicating settlement and probably land use impacts associated with timber harvest and grazing had occurred prior to 1880.

Gannett (1902) describes the early 20th century forest as "a large, irregular isolated body of timber covering the Blue and Wallowa Mountains… These forests are open and light as compared with those in the western part of the State." Photos taken by Gannett in Figure 9 depict a forest with large diameter timber at relatively sparse stem density and younger trees in between. Undergrowth is dominated by grasses.

Figure 9. Photo of a Tamarack/Yellow Pine (PIPO) grove in the Blue Mountains. Gannett, circa 1900.

The timber species mentioned in early survey maps include pine, fir, and tamarack. Western larch (*Larix occidentalis*), the only native tamarack in Oregon, is generally associated with the more moist and cool north and east facing slopes within hot, dry ecoregions such as the Blue Mountains. Larch also thrive in open areas where burning has occurred, and they themselves are a fire tolerant species due to their thick bark. It is possible that references to tamarack refer to lodgepole pine, which is also known as tamarack pine in some areas. Grand fir (*Abies grandis*) is also native to northeastern Oregon, and prefers cool, moist sites but is less fire tolerant than larch or ponderosa pine. Ponderosa pine (*Pinus ponderosa*) is a fire tolerant species generally growing in dry, well-drained mountainous regions. Ponderosa pines (PIPO) are shade intolerant, and generally thrive in areas with frequent (5 – 10 yrs), low intensity fires that remove competing shade tolerant species. These species all grow to large height and diameter, resulting in thin to moderate stand densities with understory species governed by moisture and fire regime. Several large (24 – 36 inch DBH) PIPO were observed in the Camas alluvial fan area, suggesting their presence in the lower study area for at least the last 130 – 150 years. Multiple PIPO stumps aged at 140-150 years were also observed throughout the Camas alluvial fan. Large PIPO observed during the field visit generally corresponded with the low-lying relic channel swaths that run northeast to southwest across the alluvial fan.

Historically, stream valleys throughout the Camas basin supported healthy riparian plant communities, with ample large wood supply available for recruitment to the channel. Several areas of intact riparian forest in the upper watershed are probably indicative of what the Camas valley bottom was like prior to widespread timber harvest and channel modifications. These riparian corridors are characterized by willow, alder, aspen, and hawthorne, all of which thrive in the moist valleys and floodplains of the basin.

Beavers were prevalent in the Camas watershed historically (Langston 1995), which also suggests their food sources consisting of abundant deciduous riparian trees were present. At slightly higher, less frequently inundated elevations in the floodplain, large conifer species are present. Field observations of large diameter (>36 inch DBH) trees and stumps throughout the alluvial fan suggest that the forest in the Camas study area was once comprised of larger timber. The cold basins zone within the Blue Mountains ecoregion of lower Camas and the alluvial fan area is characterized by wet meadows with intermittent stands of aspen, spruce, and fir (Thorson et al. 2003). Few of these features are present in the Ukiah area today.

5.3.2 Geomorphic Conditions

Within the 1880 GLO mapping of the lower study area, Camas Creek terminates at a 'slightly marshy' meadow in the alluvial fan near Ukiah. The reference to 'marshy' is also suggestive of an area with ample fine sediment and a high water table. The deposition of fine sediment is indicative of low sediment transport capacity, suggesting the channel slope and cross sectional area was significantly less than the present day channel. These references are indicative of a historic Camas Creek in which channel length and floodplain connectivity were greater, stream velocities were lower, and mean substrate size was smaller relative to the current channel condition. Review of the 2015 LiDAR data and historic aerial imagery clearly shows the presence of multiple channels spanning the valley bottom upstream of RM 15 and across the alluvial fan. Camas is also attempting to re-establish an anabranched planform in areas where the channel is unconfined or where levees have been breached.

Intact riparian vegetation comprised of a mix of deciduous and coniferous trees likely influenced channel forming processes through the creation of stable hard points in the floodplain, maintaining a multiple thread channel network with smaller, shallower channels. Riparian forest also would have maintained bank stability through added root cohesion, preventing the channel from over-widening during peak flow events. When bank erosion did occur, trees of sufficient size to influence channel hydraulics were recruited to the channel. With rootwad and canopy intact, this large wood would form stable obstructions within the channel, or move downstream to accumulate in debris jams. Stable wood pieces or jams would deflect flow away from eroding banks while inducing backwater upstream, thereby slowing velocities and trapping fine sediment. In other areas, log jams allowed for the accumulation of sediment in their lee, resulting in the formation of forested islands in the long-term. As one or several channels on the alluvial fan aggraded, flows would migrate or avulse to channels of higher grade, re-setting the channel or re-occupying a previous channel alignment within the alluvial fan.

Beavers certainly contributed to this process by expediting the recruitment of wood to the channel. Beaver dams also induce a backwater upstream, increasing floodplain engagement and reducing flow velocities. Beaver activity in low relief riparian areas of the mid- and upper-watershed also would have reduced the celerity of flow peaks during high flow events by retaining water, releasing it gradually from backwater pools and via groundwater exchange with wetlands. This same process likely buffered in-channel flows during the low flow period of the summer and early fall (Parker 1986). A forested watershed retained snowpack later in the spring and summer, further augmenting low flows and regulating stream thermal regimes. Healthy forests in the riparian corridor and uplands also would have reduced the celerity of peak flow discharge, regulating runoff through the processes of interception and evapotranspiration and slowing overland flow.

5.3.3 In-Stream Habitat

Both the Umatilla and Cayuse Tribes were known to hunt, fish, and collect roots and berries in the Camas study area (Ogle et al. 2010 and references therein). Fish was the most abundant and dependable food supply in the Camas basin for the Umatilla Tribe, who overwintered along the mainstem of Camas and the John Day and spent summers hunting, fishing, and harvesting native roots and berries throughout the basin (Boula et al. 1995, Ogle et al. 2010). Known fishing locations include a site near RM 15 on Camas, and another site in lower Pine Creek to the south and east of Ukiah (Ogle et al. 2010). Healthy riparian forests provided cover and shade to streams in the Camas study area, and formed complex habitat features upon recruitment to the channel. Large wood in the channel reduced flow velocities, creating slow moving backwater areas upstream, with scour pools adjacent to wood pieces and logjams. Deep, cold pools with complex cover provided refugia for juvenile fish, with spawning sized gravels deposited in the lee of obstructions or in slow moving backwater areas. A higher water table increased hyporheic exchange with the floodplain, buffering thermal regimes and flows throughout the summer. Increased floodplain connectivity also created off channel habitat for fish during high flow periods, with side channel habitat available for spawning and rearing. Wetlands and forested riparian corridors also created habitat and substrate for insects and aquatic invertebrates, increasing basal food sources for fish.

5.4 Historic Disturbances

Disturbance regimes play an important role in shaping aquatic ecosystems through their influence on spatial and temporal heterogeneity of sediment and large wood delivery, hydrologic regime, land cover, and biota. Ecosystem response to disturbances varies with geomorphic setting, which ultimately governs the type and magnitude of a disturbance (Montgomery 1999). Thus, changes to geomorphic factors or to the setting in which a disturbance occurs will also influence the impact a disturbance has on the ecosystem. Disturbances within the Camas Creek study area can be broadly divided into natural and anthropogenic types, however it is important to note that human alterations to the natural setting have also altered the natural disturbance regime.

5.4.1 Natural Disturbance Regime

The primary natural disturbance within the Camas Creek study area is wildfire. The entire Camas Creek watershed is subject to naturally occurring wildfires. These disturbances were recorded throughout early settlement of the area (Boula et al. 1995), and frequent fires occur throughout the watershed today (Map 7). Historically, the upland forests likely burned frequently (every 5-10 years) with low intensity fires that regulated the growth of understory species and reduced overall fuel loading in the watershed (UNF 2002, USGS 2012). Historically, these fires were naturally occurring and ignited by summer lightning strikes (Boula et al. 1995), however, it is also likely that native peoples intentionally burned areas of the Camas watershed to clear forest and increase grassland area to improve forage for horses and as a form of thinning for huckleberry (CTUIR pers comm., Williams 2001, Powell 1997, Boula et al. 1995 and references therein). High intensity fires resulting in replacement of forest stands occurred less frequently (35 – 200 years) in mid-elevations of the watershed outside of riparian corridors (Map 7). Low to moderate intensity fires would occur in the riparian areas and lowlands of the Camas basin, and were generally infrequent (35-200 years).

The largest recorded fire in recent history was the Tower Fire of August 1996, which burned a total area of more than 80 square miles, nearly half of which occurred within the Camas watershed (Powell 1997, UNF 2015). The Tower Fire was a high severity crown fire, which scorched and killed much of the dry and mesic forests in the upper Cable and Hidaway Creek watersheds. Since the Tower Fire, thousands of snags have been delivered to the valley bottoms of these systems, and standing snags are visible in aerial imagery (Figure 10).

Fires in the PIPO forests and meadows of the Camas watershed were also intentionally ignited by native tribes for multiple purposes, which included maintaining a mosaic of ecotones on the landscape, encouraging growth of prairie grasses, and reducing shrubs and tree cover for hunting (Williams 2001, Powell 1997, Boula et al. 1995 and references therein). Fire suppression throughout the watershed and particularly within the UNF and WWNF over the past century has dramatically reduced the frequency of low and moderate severity fires (Boula et al. 1995). This practice has increased fuel loading and altered the stem density and dominant species (more shade tolerant trees) within coniferous forests of the Camas basin, thereby increasing fire severity while reducing the abundance of fire tolerant species such as PIPO and western larch. Forest stem density in areas recovering from logging or wildfires (DBH < 6 inches) is up to 100 times higher than in patches of mature forest (12 – 30+ inch DBH). Without thinning of high stem density areas, it is likely there will be another catastrophic fire similar in magnitude and extent to the Tower Fire in the next twenty years. This altered disturbance regime would result in a cycle of forests being reset every 30-40 years, not allowing stands to reach maturity.

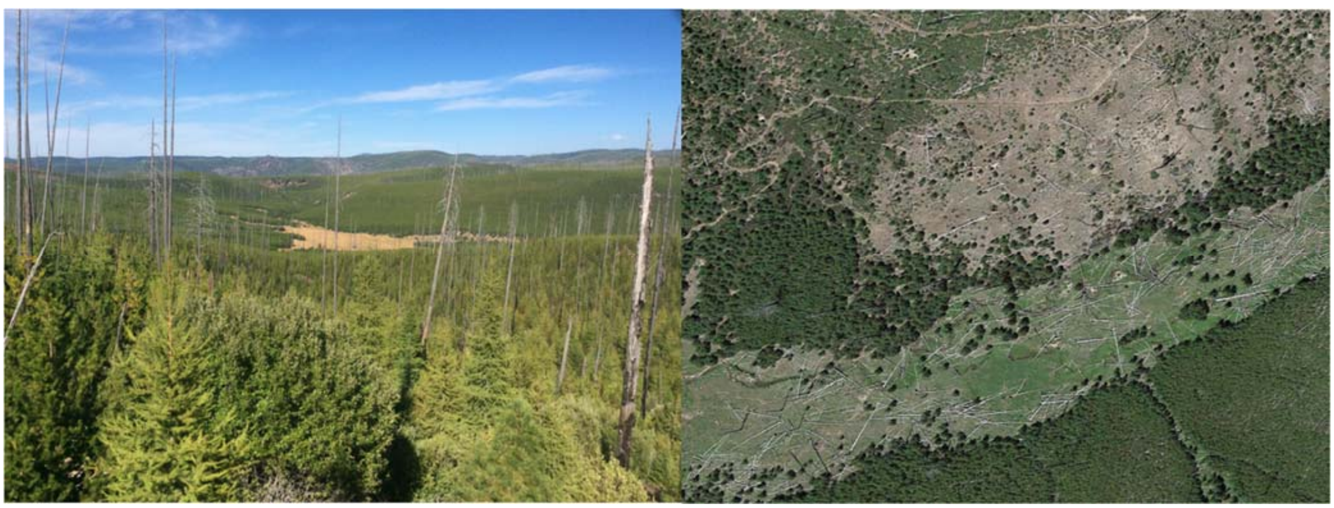

Figure 10. Standing snags in young, regenerating forest with stem density of approximately 8,000 - 13,000 stems/acre (left) and large wood delivered to valley bottom (right).

Following wildfires, debris flows and landslides can occur due to reductions in vegetative cover, root cohesion, and interception of precipitation by the canopy. In North Fork Cable Creek, comparison of pre- and post-fire aerial photographs suggests that debris flows and large volumes of sediment delivery occurred following the Tower Fire, however this sediment does not appear to have mobilized downstream through Cable Creek (Figure 11), as would be evidenced by an overwidened channel with excess sediment and debris. Cable Creek downstream of the burn area retains a meandering, anabranched planform with mostly intact riparian canopy. Sediment retention was certainly influenced by the large volume of wood that entered Cable Creek following the burn event. Landslides occur less frequently in the watershed following heavy precipitation events or in areas where road building has altered slope, cover, and hydrology. Mapped landslides in the study area are mainly concentrated in North Fork Cable Creek, upper Hidaway Creek, and in upper Camas Creek above RM 30 (Map 8).

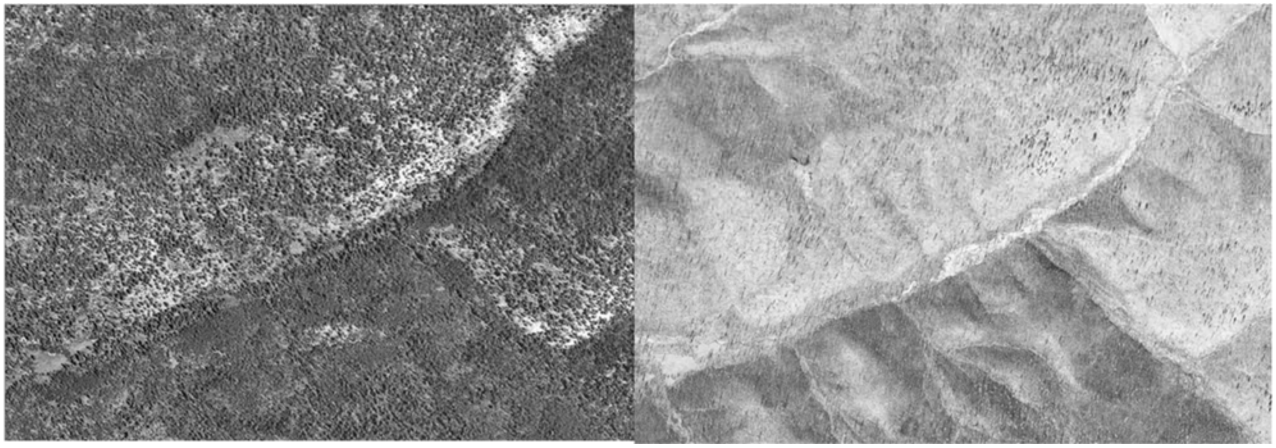

Figure 11. 1995 (pre-fire) and 2000 (post-fire) conditions in North Fork Cable Creek.

Historically, beavers were a widespread natural disturbance mechanism within the study area (Langston 1995, Zakrajsek 2012). Through the removal of riparian trees and the formation of backwater ponds and wetlands, beavers greatly alter the geomorphology and hydrology of riparian corridors. Beaver impoundments trap sediment and organics, reduce flow velocity, increase floodplain engagement, and regulate runoff and thermal regimes (Naiman et al. 1988). Beaver impacts to ecosystems include the creation of habitat for fish, amphibians, aquatic birds, and insects, but also the modification of canopy habitat for other species. Beaver foraging activity changes the heterogeneity, ecological succession, species composition, and age structure of riparian plant communities (Rosell et al. 2005).

Aside from the elements of risk to property and infrastructure, the impact of flooding as a natural disturbance varies with flood magnitude, frequency, and duration. Flood frequency and magnitude in the Camas study area are more thoroughly discussed in the hydrologic analysis of this report. There is not sufficient evidence on the Camas gage record to suggest that peak flow magnitude or frequency has increased over the period of record (Ecovista 2003). However it is likely that the celerity of peak flows and the velocities associated with peak flow events have been increased as a result of land use practices and flood control efforts in the lower study area. The impacts of peak flow events include the delivery, transport, and deposition of sediment and large wood, formation or reconfiguration of channel morphological features, and the wetting and drying of inundated areas.

5.4.2 Anthropogenic Disturbances

Homesteading and Grazing

Much of the Camas watershed has been altered from its historic condition as a result of anthropogenic disturbances. Euro-American presence in the study area is first known to have occurred in the early 19th century when fur trappers and early explorers were beginning to travel through the Blue Mountains (Ogle et al. 2010). Settlement of the area around Ukiah by Euro-American immigrants began in the mid-19th century, followed shortly after by the Treaty of 1855 that formed the Umatilla Indian Reservation. The Homestead Act of 1862 encouraged the settlement of lands by immigrants traveling west on the Oregon Trail, which crossed the Blue Mountains in several established corridors to the north of the Camas watershed (Ogle et al. 2010). Early settlers harvested timber in the lower watershed to construct homes and the town of Ukiah, with many homesteaders also clearing land for agriculture and for grazing sheep and cattle (Popek 1995). Tribal peoples of the Umatilla continued to hunt and fish for subsistence, with some crop cultivation (Boula et al. 1995, Popek 1995).

Figure 12. Hydraulic sluicing in the UNF. Photo from John Guthrie, circa 1930.

Early settlers to the Camas Prairie are reported to have homesteaded large parcels of land in the latter half of the 19th century, some claiming plots as big as 800 acres (Harer 1986). One settler homesteaded 320 acres in the lower valley, on which was an estimated 1.5 million board feet of timber (Harer 1986). Both early settlers grazed cattle. By 1880, a newspaper article wrote that 25-30 families were overwintering in the Camas Prairie (Harer 1986).

'Severe range deterioration' and riparian degradation is reported as early as 1906, and is associated with large, nomadic herds of sheep and cattle in the watershed (Popek 1995). Trapping of beaver for pelts virtually eradicated the species from the Camas basin, likely contributing to the historic loss of wetlands and moist meadow habitat in the watershed (Boula et al. 1995, Ogle et al. 2010). In the early 20th century, sheep herds began to decline, with sharp increases in the number of cattle herds. Riparian shrubs and trees were actively removed for grazing, with stream bank stability further impacted by cattle directly accessing stream channels. Currently, both livestock and wild ungulate grazing contribute to considerable damage to riparian vegetation (CTUIR pers. comm.).

Historic losses of wolves and other predators have likely increased the density and residence time of wild game such as deer and elk, increasing pressure on emergent riparian vegetation following natural disturbance events (Zakrajsek 2012, Beschta & Ripple 2012, Ripple et al. 2015). Both livestock and wild ungulate use in the Dry Camas, Rancheria, and Salsbury drainages has resulted in considerable damage to riparian vegetation and has led to exclosure fencing, off-channel watering, and rest-rotation management in efforts to reduce impacts (Ecovision 2003).

Gold mining occurred throughout the Blue Mountains in the late 19th and early 20th century (Boula et al. 1995, Ogle et al. 2010). It is unclear whether or not placer mining or hydraulic sluicing of river corridors occurred in the Camas study area, however its use within the UNF is documented (Figure 12).

Timber Harvest

Reports as early as 1902 suggest that significant timber harvest had already occurred in the Blue Mountains of Umatilla County (Gannett 1902). A sawmill east of Ukiah was established sometime between 1907 and 1920, with most of the milled timber harvested from private lands (Popek 1995). Skidding logs with horses and later with tractors was used to transport timber to nearby roads or railways (Powell 2008). Skidding typically increased soil erosion, and was often done across stream corridors, impacting riparian vegetation and bank stability. A railroad constructed by the Mt. Emily Logging Company in the early 20th century enabled easy transport of selectively harvested large PIPO along Camas and Rancheria Creeks (Figure 13, Popek 1995). Large volumes of timber were transported to nearby La Grande for milling (Powell 2008). The 1937 Camas Creek timber sale to the Milton Box Company allowed the removal of more than 220 million

Figure 13. Large diameter PIPO was selectively harvested throughout the Camas watershed in the early 20th century. Photo from John Guthrie, 1927.

board feet of timber in most of Upper Camas and Hidaway Creeks, North Fork Cable Creek, Lane Creek, Bear Wallow Creek, Pine Creek, Bowman Creek, and Rancheria Creek (Powell 2008). Timber appraisal calculations suggest that the total timber sale allowed an 'over-cut' of 71 million board feet for a five year period (Powell 2008). In 1941 the Brown and Hoxie Mill opened shop in Ukiah, and is reported to have processed up to 1 million board feet per month at its peak (Harer 1986). The mill closed after 10 years in operation, probably due to increased harvest throughout the basin by the Milton Box Company and Harris Pine Mills centered in La Grande, both of which had much greater capacity than Brown and Hoxie (Jorgensen 1948).

90 percent of old growth PIPO mapped in 1937 has been lost as a result of selective timber harvest during the 20th century (Boula et al. 1995). Existing old growth in the basin is more fragmented than under historic conditions, with only three large (> 300 acres) intact stands of old growth trees left. Riparian hardwoods and shrubs and stands of aspen have also declined dramatically since the 1930s, partly due to harvest, road construction, and clearing of riparian areas for grazing (Boula et al. 1995). The total area of moist meadow habitat has also been reduced since human settlement of the watershed, though the total area lost is difficult to quantify due to a lack of historic mapping (Boula et al. 1995). Areas currently undergoing reforestation by the Forest Service following timber harvest or wildfire have a stem density that is roughly 100 times higher than the old growth PIPO forest of the historic watershed (Figures 10 and 14). These densely planted stands not only increase fuel loading, but they promote the succession of shade-tolerant species that were not prominent in the open PIPO forest that once spanned much of the Blue Mountain ecoregion.

Channel Modifications and Floodplain Infringement

Channel and floodplain modifications likely began with early settlement in the 19th century, though no written records confirm this. Early agricultural diversions and large scale irrigation projects are documented by 1918, with plans for three dams, a canal, and a tunnel comprising the Teel Irrigation Project in the Camas basin (Harer 1986, Popek 1995). The project began with trenching a nearly 4 mile long canal to divert flows from three proposed dams in Cable, Hidaway, and Camas Creeks to a tunnel through Battle Mountain, eventually connecting with Butter Creek to the west. A giant steam shovel and a boiler powering jackjammers for the tunnel boring reportedly used large amounts of timber, harvested by young workers from nearby forests (Harer 1986). The project was never completed, however, due to poor planning and the tunnel caving-in during its construction.

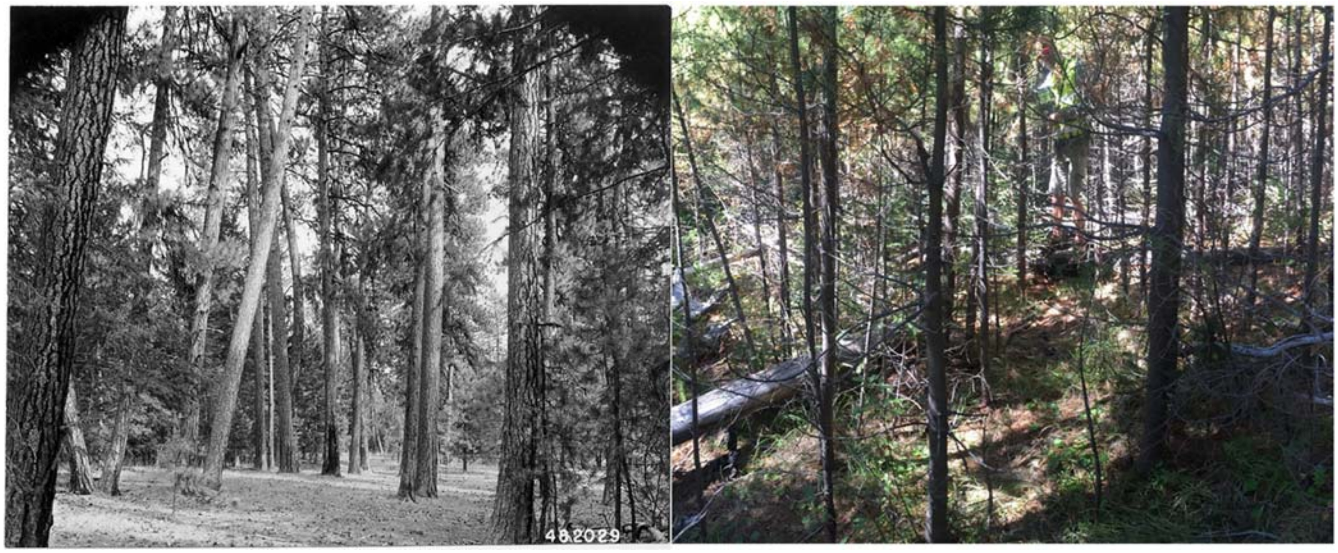

Figure 14. Mature stand of PIPO with stem density of ~20 trees/acre (left, Frank Flack 1956) and a young, very dense forest with conifer forest comprised largely of lodgepole pine and shade tolerant species (right).

Channel modifications to Upper Camas Creek associated with construction of the Mt Emily Timber railroad occurred in the early 20th century. The railroad ran parallel to Camas from its confluence with Rancheria Creek to several miles east of Ukiah (Popek 1995). The railroad grade has been destroyed by the construction of modern logging roads in many places, but is still apparent in aerial imagery along portions of the valley wall in Camas Creek. It appears that the grade followed the valley toe throughout much of its course in the lower valley. Channelization of Upper Camas Creek associated with expansion of SR 244 from Starkey to Ukiah occurred in the 1950s (Popek 1995). Prior to the construction of SR 244 in the lower study area, a county road running parallel to Camas Creek ran east from Highway 395 along the valley toe, along what was likely the old railroad grade. Due to its location along the edge of the alluvial fan and floodplain upstream, this road alignment did not impede with the natural course of Camas or confine the floodplain. With the 1954 completion of SR 244, the floodplain was bifurcated in many places, including the alluvial fan from RM 13.6 – 14.7; in the unconfined valley bottom from RM 16.2 – 16.7, RM 17.4 – 17.7, RM 17.9 – 18.3, RM 18.5 – 18.9, RM 20.4 – 20.5, and RM 21.5 - 21.8; and in the upper watershed at 29.3. Cumulatively, the SR 244 road alignment acts as a levee, and results in more than 85 acres of disconnected floodplain and potential off-channel habitat areas. The road also occupies the low-lying portion of the Camas valley throughout much of the upper watershed, though it is unclear if grading of the stream corridor occurred. Regardless, the current road alignment constricts Camas to a straightened, confined channel for much of its course where it flows adjacent to SR 244.

SR 244 and several forest roads also cross Camas in at least 10 locations in the study area, locally confining the active channel and floodplain at each bridge crossing or culvert. Many other road crossings along tributary channels in the watershed likely confine these channels. Constrictions along the mainstem channel of Camas are noted in Table 7 below.

Table 7. Bridges and Culverts along Camas Creek.

ROAD NAME	RIVER MILE	NOTES
Camas Street	12.5	Bridge, 170 ft span
Unnamed Road	13.6	Bridge, 60 ft span, removed or destroyed in 1964 - 1965
Cable Creek Road	17.8	Bridge, 40 ft span
Unnamed Road	19.55	Bridge, 60 ft span, removed or destroyed between 1995 - 2000
NF 054	26.8	Bridge, 50 ft span
NF 390/Lehman Springs Rd	29	Bridge, 40 ft span
NF 5226	30.2	Bridge, 30 ft span
SR 244	32.4	Culvert
NFSr 210	32.5	Culvert
SR 244	32.7	Culvert
NFSr 780	34.2	Bridge, 20 ft span

The Camas Street bridge confines Camas to a width of 170 ft, which is less than one third of the active channel width in the unconfined reach just downstream (500 – 700 ft). The elevated Cable Creek Road prism and bridge crossing constrict the channel to a width of just 40 ft, relative to its floodplain width of 300 ft just upstream (historically 400 ft, before SR 244 construction). A bridge crossing formerly at RM 19.55 was destroyed or removed between 1995 and 2000, however the elevated road and abutment to the north of the former bridge location still confine the channel to a width of 60 ft. Floodplain width immediately upstream of the crossing is 360 ft. NF Road 054 crosses Camas at RM 26.8, reducing floodplain width from 330 to 50 ft. Floodplain width and active channel widths further upstream are difficult to discern based on aerial imagery and the USGS digital elevation model, however it is likely that these crossings also locally constrict the floodplain, increasing velocities, scour, and channel incision through the spans while creating backwater upstream, altering sediment transport capacity. The extent to which the culverts in the upper watershed confine the floodplain and active channel width is unknown, however it is likely that culverts are undersized. Further field examination is needed to verify this.

Road development for logging and recreation has likely increased delivery of fine sediments to tributaries in the Camas watershed. Roads also tend to concentrate flows into roadside ditches due to reduced infiltration rates by compacting and sometimes surfacing, increasing flashy runoff and inputs to tributary channels. Roads located within 150-feet of creek channels are considered to provide the highest risk to riparian function and high road densities are likely impacting the hydrologic regime and fine sediment delivery to tributaries in the study area (Ecovista 2003).

Forest road densities were mapped for the Camas watershed and are presented in Map 9. Many areas in the upper watershed tributaries have road densities greater than 4 miles per square mile, and high road densities generally correspond with areas of steep slope (Map 8). Areas with road densities greater than 4 miles per square mile are identified as limiting factors, exhibiting in-stream effects on Bowman, Hidaway, and Lane Creeks (Zakrajsek 2012). According to the Camas Creek Assessment (Ecovision 2003), the subwatersheds that are most likely to be impacted from roads are the upper Camas (Bowman Creek), lower Hidaway, and the Cable Creek subwatersheds.

The most heavily impacted portion of the study area with regard to channel modifications and floodplain infringement is within Ukiah, the alluvial fan, and upstream to RM 18.7. Beginning at the upstream end, there is a levee along the right bank at RM 18.7 adjacent to several privately owned structures. This levee reduces the floodplain width to 80 ft. The buildings along the right bank were built sometime prior to 1964. Further downstream at the Cable Creek confluence, levees constructed between 1946 and 1956 span the right bank for more than 1,300 ft in the vicinity of the ODOT maintenance area. A 400 ft long levee spans the right bank between Camas and SR 244 at RM 16.9, straightening the channel to a single thread where an anabranched reach existed prior to 1956. A series of rock barbs along SR 244 at mile post (MP) 5 or RM 16.6 and another series of three barbs along right bank at RM 13.4 reduce high flow velocities approaching the highway. The SR 244 alignment in this location reduces the historic floodplain width by 80 percent, resulting in a straightened channel for nearly half a mile where a sinuous, anabranched channel existed prior to 1956. An elevated road stemming from SR 244 to the south at RM 14.9 reduces floodplain width by approximately 50 percent, acting like a large barb on the right floodplain.

Levees along the right bank spanning from RM 15.1 – 14.7 and along the left bank from RM 14.8 – 14.6 were constructed sometime before 1939, straightening Camas within a channel corridor less than 50 ft in width. Channel straightening and levee construction in the upper fan near RM 14.5 appear to have occurred to some extent prior to 1956, with additional levees and channel straightening at RM 13.6. Levees spanning much of Camas Creek from approximately RM 14.8 to 12 were then constructed following the 1965 flood event (Popek 1995). Channel straightening associated with the Brown and Hoxie Mill along the left bank at RM 12.6 occurred before the mill opened in 1941, with levees, a diversion, and a pond near the mill visible by 1946. Also visible in 1946 imagery are portions of straightened channel between RM 12.4 and 12.1 downstream of the Camas Street bridge, where a channel anabranch appears to have been blocked by a levee. Boulder riprap lines the left bank below the bridge, with several rock barbs further downstream.

Diversion of flow to pond structures on the alluvial fan near RM 13.6 is visible as early as 1939. By 1946 there is a low dam on Camas just upstream of RM 13.6 and an additional pond further to the south. By 1961 the ponds in this location nearly tripled in surface area, diverting flow from the mainstem of Camas and a secondary channel spanning the fan from RM 14.6 to lower Pine Creek. Following channelization and levee construction along the inlet to this secondary channel, it appears that the series of ponds was fed by a diversion at RM 13.7, where another low dam was constructed following the 1965 flood event.

5.5 Geomorphic History & Process Characterization

Assessing historic changes to channel planform provides context on how Camas responds to human channel or land use modifications and significant hydrologic events. The Primary AOI from Cable Creek to RM 11 below Pine Creek was divided into six geomorphic reaches to discuss changes within each of the broader planforms or land use constraints present today. These geomorphic reaches are illustrated in Map 10, with observed changes and conditions detailed in the sections below.

5.5.1 Historic Aerial Photograph and Channel Analysis

Aerial photographs were compiled for the period of record, which spans from 1939 to 2014. Data was retrieved from CTUIR, USDA National Agriculture Imagery Program (NAIP), the ArcGIS Image Service for the state of Oregon, and USGS Earth Explorer. The entire suite of historic aerial photographs used in this assessment is included as Appendix B. Channel changes and significant geomorphic features were documented within each geomorphic reach and are described below.

Reach 1 – Cable Creek to Alluvial Fan

Overview:

- Construction of SR244 in the 1950's has reduced floodplain capacity, reduced channel sinuosity, and altered the historical anabranching form to a single thread channel.

Reach 1 spans from the Cable Creek confluence (RM 17.8) to RM 14.75 at the upstream end of the alluvial fan. The reach is characterized by a moderately confined alluvial valley with a width ranging from 200 – 600 ft. The 1939 aerial imagery only extends to RM 16.6, however the channel occupies the entire valley bottom downstream to RM 15.2, with anabranched channels and intermittent stands of intact forest. Ground disturbance at the mill site along the right bank at RM 15 is already underway, with the channel confined from RM 15.1 downstream to the fan. By 1946 additional forest has been removed in the valley bottom from RM 16.1 to 16.6, but the anabranched planform is still visible from RM 16.7 to 15.7, where a natural constriction forces the channel into a single thread.

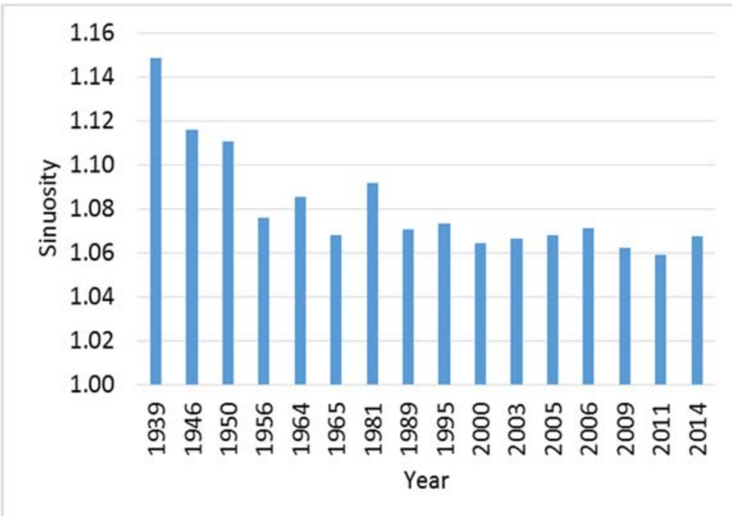

Figure 15. Historic changes in channel sinuosity in Reach 1. Construction of SR 244 occurred between 1950 and 1956.

The construction of SR 244 through the floodplain is nearly complete in the 1956 aerial imagery, confining the channel to a single thread from RM 16.7 to 16.2, and reducing the floodplain width by as much as 80 percent. The active channel in reaches where the channel is unconfined appears to have widened between 1950 and 1956, likely in response to increased scour or channel incision in the confined segments. Mainstem channel sinuosity (channel length: valley length) is reduced by 6 percent following construction of SR 244, with no significant change in mainstem channel length since the construction of the road (Figure 15). Prior to the 1965 flood of record, the 1964 photos show a meandering channel with anabranched reaches in unconfined segments (eg. RM16.1 – 15.7, RM16.8 – 16.6). Ground disturbance and possibly a levee along the right bank near the Cable Creek confluence appears to have confined the channel to a width of 120 ft, reducing overall channel length in this segment.

Unconfined channel segments appear to have aggraded and widened following the 1965 flood event. In the aerial records following the flood, the channel appears to adjust to additional sediment load by increasing sinuosity slightly. By 2000 the channel has resumed a meandering, anabranched planform in unconfined segments, with a straight, single thread in confined segments adjacent to the highway and mill site. Shrubs and riparian trees begin to appear on gravel bars within the floodplain. Exposed gravel bars in the 2011 aerial image suggests that some amount of aggradation occurred during the May 2011 flood event. Portions of these bars have begun to revegetate by 2014.

Reach 2 – Upper Alluvial Fan Confined by Levees

Overview:

- Levee construction has resulted in a single-thread and incised channel.

Reach 2 includes the upper alluvial fan from RM 14.75 to 14.4, and is currently spanned by levees on both the left and right banks. Modification of the left and right banks between RM 14.7 and 14.8 appears as early as 1939. This portion of the channel is already straight at the beginning of the photo record, though channel scars along the upper portion of the alluvial fan are visible on both the left and right floodplain. An intermittent channel spanning the alluvial fan to the southwest is present at RM 14.6 and several distributary channels appear to be active along the northern portion of the fan.

Comparison of two aerial photographs from 1950 illustrates the seasonal and hydrologic fluctuation in channel engagement in the upper alluvial fan area (spanning Reaches 2 and 3). One photo from June 29, 1950 when mean discharge was approximately 120 cfs has nearly 16 miles of wetted channel spanning the alluvial fan (Map 11). The June 1950 image shows a clear flow split occurring at RM 14.6, with one anabranch channel approximately 40 ft in width crossing the alluvial fan to the southwest until joining Pine Creek, and another channel approximately 65 ft in width flowing west, spreading into a multi-threaded channel network for one mile before returning to a single thread at RM 13.6. Later in the summer, a September 11, 1950 photo shows dramatically less wetted channel at a discharge of 5 cfs (Map 11). However, even at low flow there are still anabranched reaches in the upper fan between RM 14.5 and 13.6 (Map 11). By 1956, SR 244 has reduced the active floodplain area by 48 acres, acting as a levee across the fan from RM 14.7 – 13.6. Prior to 1964, a portion of the right floodplain appears to have been excavated, with material likely used in the construction of a levee spanning from RM 14.6 – 14.5.

The 1965 flood event appears to have created a large channel along the south side of SR 244 immediately downstream of this levee, with visible disturbance and aggradation along the roadway. Levees span the entire length of Reach 2 in the 1965 photo, confining the channel to a width of 60 ft. The levees have confined Reach 2 to a narrow, single threaded channel since their construction, with a partial breach at RM 14.6 occurring sometime between 2005-2006. The channel is still not engaged at the 2-year flow, with only shallow flow crossing the fan during the 100-year event (Figure 16). The inlet to the historic channel anabranch at RM 14.6 is now perched 4.5 ft above the channel water surface.

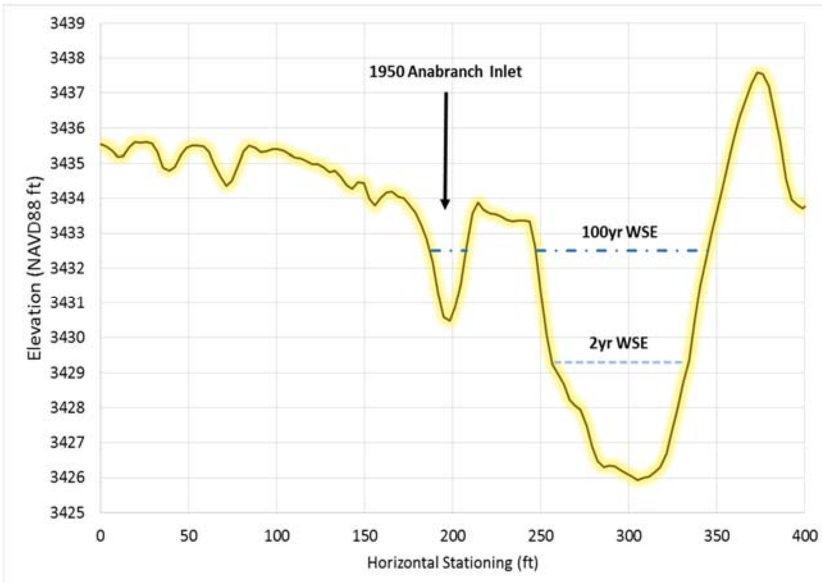

Figure 16. Cross section at inlet to historic (1950) anabranch channel near RM 13.6.

Reach 3 – Upper Alluvial Fan Anabranch

Overview:

- Construction of SR 244 and levees changed the historical anabranching channel type to a single-thread channel with a reduced sinuosity.
- As erosion of the levees has progressed, the channel has widened its migration corridor and has re-established multi-thread and side channel features.

Reach 3 spans from RM 14.4 to 13.95 on the upper alluvial fan where the channel has regained some of its historic anabranching planform. Prior to confinement by the 1965 levees, this reach had a sinuous, meandering or anabranched planform (eg. 1939-1950). The alignment of SR 244 in 1956 cut off over 4,500 ft of intermittent channel length in the right floodplain, however the anabranches to the left or south

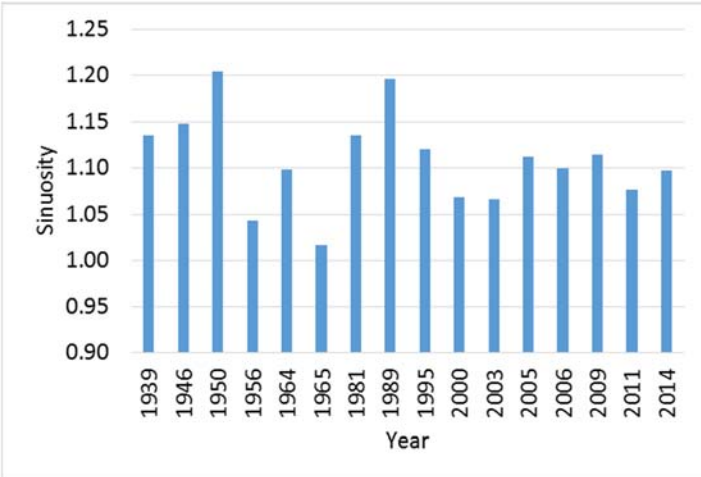

Figure 17. Historic changes in channel sinuosity in Reach 3. Levees created a straight, single thread channel in 1965.

remained active until the levees were built. Construction of the levees occurred sometime between the January 1965 flood event and the aerial photo from July 6, 1965. By July, the channel within Reach 3 had already begun to start redeveloping a meander, with gravel deposits clearly visible, alternating between the left and right portions of the confined channel. Figure 17 illustrates the short duration of the levee confinement, however total channel length is still below historic levels. The 1981 aerial photo shows Camas meandering across an active channel 200 ft in width, more than triple the constructed channel width imposed by the levees.

Camas regained an anabranched planform between 1981 and 1989. Erosion of the levees continues through 1995 and the recent photo record, with the active channel 450 ft wide in some places. The wetted channel alignment in this reach is fairly dynamic, responding to the deposition of material delivered from the confined reach upstream. A lack of stable wood has prevented the development of forest within the active channel area, allowing the channel to migrate across this inset floodplain as sediment accumulates and redirects flow. Several intermittent side channels engaged at higher flows have been present since the channel reoccupied a wider active channel corridor, however these features are also unstable, migrating periodically and preventing the development of high quality habitat with complex cover.

Reach 4 – Middle Fan Limited Access Area

Overview:

- Construction of SR 244 and levees changed the historical anabranching channel type to a single-thread channel with a reduced sinuosity and some channel incision.
- The channel has re-established a narrower channel corridor with periodic channel avulsion and limited anabranching.

Reach 4 spans from RM 13.95 to 13.05, and includes the middle portion of the alluvial fan that is under private ownership with limited access. Reach 4 had a low gradient, anabranched and meandering planform with intermittent side channels until being partially confined by levees prior to 1956. Levee alignments in both the 1956 and 1965 photos indicate areas where several meander bends and secondary anabranch channels were cutoff, straightening the channel and increasing slope. The active channel width was reduced from 330 ft to 60 ft at RM 13.5, isolating a 700 ft long meander channel on the left floodplain. Further downstream at RM 13.3, a vegetated island surrounding by two channels was also leveed into a straightened channel. The 1965 modifications in this reach reduced wetted channel length by 1500 ft. The channel has since begun to redevelop an anabranched planform. Mean active channel width nearly doubled in the period from 1965 to 1989, with the formation of anabranches at RM 13.7, 13.5, 13.4, and 13.3. The lower portion of the reach from RM 13.2 to 13.05 remains confined by levees and SR 244 to a single thread channel 60 ft in width. Between 1989 and 1995, nearly the entire reach (except RM 13.7 – 13.6) regains a meandering or anabranched planform within the channel corridor, which varies in width from 90 ft near RM 13.2 to 275 ft at RM 13.9. The meander radius of curvature is greatest at the upstream end of Reach 4, and seems to propagate downstream over time as the channel redistributes sediment eroded from levees in point bars.

Between 1995 and 2000, the channel avulses across a meander bend at RM 13.5, occupying a straightened channel alignment from RM 13.6 to 13.35. A partial avulsion at RM 13.3 initiates between 2000 and 2003, with an anabranched planform developing by 2005. By 2011 the main channel occupies a straightened alignment from RM 13.6 to 13.2, groundwater expression or backwater in the former anabranch channel at RM 13.3. The straightened channel appears to be incising, leaving the anabranches and floodplain perched, with only partial engagement during the 2-year flood (Appendix A). Recent aerial imagery indicates that some sediment is aggrading on points bars in the lower portion of Reach 4 at RM 13.2 and 13.1, however the channel remains confined by high ground to the left and the SR 244 alignment to the right, preventing these meanders from expanding.

Reach 5 – Lower Fan Confined by Levees

Overview:

- Levee construction on both sides of the channel has resulted in the confinement of the channel, a change from an anabranching to single-thread planform, and a disconnection from the historical floodplain.

Reach 5 spans the alluvial fan through the town of Ukiah from RM 13.05 to 12.45 just downstream of the Camas Street bridge. The 1939 aerial image shows this reach in an anabranched planform, with a primary channel meandering southeast of Ukiah and several secondary channels (likely intermittent) on either bank. Nearly 3500 ft of anabranch channels and side channels spanned the alluvial fan within Reach 5 in 1939, spanning an active channel width of 500 ft in some places. These multithreaded channel segments had wetted channel widths of 30 ft, with a mainstem width of 50 to 80 ft. The early photo record is suggestive of a highly connected floodplain with frequent engagement of secondary channels. There is, however, virtually no intact riparian forest or vegetation.

By 1946, Ukiah had begun to expand into the right bank floodplain, with homes occupying one of historic anabranch channels. The Brown and Hoxie Mill is also encroaching the left bank, with clear channel modifications including straightening and levees adjacent to the mill site. Areas of exposed bank within the mainstem of Camas suggest that the channel had begun to incise, and many of the anabranch channels are no longer visible.

By 1950, Camas is predominantly a single thread, meandering channel, with a straightened reach from RM 12.7 to the bridge near the mill. The 1956 photo shows the alignment of SR 244 and a levee along the left bank confining the channel to a straightened reach between RM 13.05 and 12.9, with a width of only 50 ft. The mill had closed by this point, and the channel appears to have regained some of its width upstream of the bridge during the 1956 flood event, which was approximately a 25 year flood. There are several snags deposited upstream of the Camas Street bridge and scattered along the gravel bars between RM 12.5 and 12.8. The active channel widened to 300 ft at RM 12.75 between 1950 and 1956, reoccupying its 1939 alignment and portions of a constructed channel entering a pond near the mill.

By 1964, levees extend from RM 13.05 to 12.7 on the right bank and from RM 12.9 to 12.7 on the left bank, confining the channel. The area immediately upstream of the bridge appears to be reforming a meandering planform, and many of the gravel deposits are revegetating. Following the 1965 flood, the entire reach downstream of RM 12.9 flows within a widened active channel corridor ranging from 80 ft at the bridge to 300 ft at RM 12.7. Several flow paths are forced into a single thread through the bridge span, and significant sediment aggradation appears to have occurred during the flood.

Levees are reconstructed prior to 1981, confining Camas to an active channel of 60 to 160 ft in width. Gravel bars at RM 12.6 and 12.7 create small anabranch reaches, but the channel is predominantly straight elsewhere, with very little intact vegetation. The channel appears to incise between 1981 and 1995, and the anabranch channels begin to revegetate. The 2000 air photo clearly shows the right half of the channel near the bridge aggrading, with vegetation colonizing sediment deposits. The exposed gravel riffle at RM 12.55 in the photo record from 2003 to 2014 appears to expand downstream, aggrading near the bridge. The remainder of Reach 5 upstream of RM 12.8 remains straight throughout the recent record.

Reach 6 – Lower Fan Anabranch

Overview:

- Below Camas Street Bridge the channel regains it's anabranching planform and exhibits a relatively stable form.

Reach 6 spans the anabranched channel area below the Camas Street bridge from RM 12.45 to RM 11. In 1939, human encroachment of the floodplain in this reach is apparent, with little intact riparian vegetation and few trees below Pine Creek. Upstream of Pine Creek the channel is anabranched, with stands of intact forest and low lying floodplain. Below the confluence with Pine Creek, the wetted channel widens from a mean width of 30 ft to a mean width of 50 ft. There are off-channel alcoves in nearly every meander bend, likely fed by hyporheic flow and groundwater inputs, with some backwater from the main channel. Several anabranch or secondary channel flowpaths are visible but appear unconnected with the main channel. These channels appear wet in some areas, suggesting groundwater connectivity, even in early August when the 1939 aerial was taken. By 1946 the channel appears to have been artificially straightened between RM 12.3 and 12.1 and further upstream below the bridge. The remainder of the reach retains a sinuous alignment.

The main channel appears to have aggraded slightly in response to the 1956 flood, also widening in some areas by as much as 100 ft, with material deposited along point bars. However the channel planform is still anabranched and meandering following the flood. The lack of braided channel segments in the reach following this large flood suggests that the anabranched channel was able to store or transport sediment efficiently, not overwidening as observed further upstream. The 1965 flood also results in some sediment aggradation, but the main channel remains stable, as do many of the anabranch channels. The observed aggradation in the reach is also driven by the confinement of the channel upstream, which increased downstream sediment conveyance to Reach 6 where it can be stored. Both the left and right anabranches at RM 12.2 widen to 90 – 150 ft by 1989, then begin to revegetate in the period from 1995 to 2000. The left channel at RM 12.2, which conveys the most flow, widens in response to the 2006 and 2009 floods. Some sediment deposition is also observed downstream. The main channel alignment and the anabranched channels have remained relatively stable in the recent photo record.

5.6 Current Geomorphic Conditions

5.6.1 Terrain Analysis

As part of the geomorphic assessment for the study area, a terrain analysis was performed to evaluate the elevations of floodplains, side channels, levees, and relic channels relative to the current main stem channel (Appendix C). The methods used for this analysis were adapted from Jones (2006), and utilized the 2015 LiDAR bare earth terrain surface. The resultant relative elevation map (REM) depicts elevations of floodplain and instream features relative to the water surface elevation of the channel at the time when the 2015 LiDAR was collected. The results were field verified during the September 2015 site surveys by comparing the bank heights with that predicted from the terrain analysis, and were found to be accurate to within 1-ft. The REM is useful in identifying side channels, potential avulsion (new channel) pathways, presence of terraces, flow obstructions, and relic channel scars. Avulsion is the rapid abandonment of a river channel and the formation of a new river channel. Avulsions occur as a new channel forms creating a straighter path through the landscape, typically during large floods in areas where the new channel slope is greater than that of the old channel.

Active side channels (both perennial and intermittent) are shown as shades of blue, with darker blues more frequently inundated (lower relative elevation). Similarly, floodplains that are inundated more frequently are shades of blue, with darker blues indicating more frequent inundation. Floodplains that are shades of green are inundated less frequently, with lighter greens to yellow only inundated during high flow events. The distribution of these features typically indicates areas where side channels are present and floodplains are relatively low (good floodplain connection), compared to areas where there are no side channels and floodplains are relatively high (disconnected floodplain). Many of the low-lying areas within the Camas REM are obstructed or disconnected by levees and elevated roads. The REM for Camas illustrates the presence of many relic channel features on the alluvial fan, but also the potential for reconnection of floodplain storage areas, off-channel habitat, and secondary channels for flood relief.

A series of cross sections and historic channel alignments spanning the alluvial fan are shown in Appendix D. Mean channel length and sinuosity of the relic channels is greater than the existing alignment of Camas Creek. No significant difference in channel slope was measured, with the exception of Pine Creek, which was included for reference due to its sinuous, low-relief channel network, which likely resembles Camas prior to widespread settlement and human impacts on the fan. The valley-scale cross sections illustrate channel incision in the areas confined by levees, which are, on average, 6-8 ft below the relic channels on the floodplain. The cross sections also show how dikes or levees and the SR 244 road prism confine the active channel, leaving low-lying floodplain and off-channel habitat disconnected from the channel. Cross section (XS) 3 shows how the current channel is actually perched above low-lying floodplain areas where the channel has eroded the levees, increased sinuosity, and deposited sediment. A similar pattern is observed downstream of the Camas Street bridge at XS-8, where the channel has resumed an anabranched planform, except where levees and the road alignment constrict channel migration. The longitudinal profile extracted from the LiDAR shows a relatively consistent slope from Pine Creek to Cable Creek, with the exception of the segment near the Camas Street bridge, where slope is reduced immediately upstream and downstream. Closer examination of the mainstem Camas profile shows a slight reduction in slope in two areas where the levees have eroded, allowing the channel to meander and form a braided or anabranched channel planform.

Examination of the REM (Appendix C) suggests that Camas has not aggraded or incised from the Cable Creek confluence down to approximately RM 15. One exception to this may be between RM 16.5 and 16.3 where the SR 244 alignment constricts the channel, however there is no connected floodplain for reference. Relative elevations to the north of SR 244 in this segment show that the floodplain would be connected with the road removed, suggesting the channel has not significantly incised. Trends of channel incision are most prevalent in the confined segment from RM 15 to 14.35. At RM 14.35 where the channel transitions to an anabranched planform, some aggradation is apparent. Camas has incised from RM 14 to 12.6, mostly in the segments confined by levees. Just upstream of the Camas Street bridge in Ukiah (RM 12.6) there are channel areas at lower relative elevations than the wetted channel, indicating areas of aggradation. These low areas persist downstream to RM 12.1, suggesting an aggraded reach. Downstream of RM 12.1 to the lower end of the LiDAR coverage there is no evidence of incision or aggradation.

To estimate the volume of sediment mobilized by the breaching of historic levees in the alluvial fan, former and current levee locations were digitized from aerial photographs and the LiDAR DEM. Former levee areas were then multiplied by a mean levee height of 6 ft to obtain a volume of material eroded. The mean levee height was determined relative to the neighboring floodplain and channel bed in locations where the 1965 levees remain intact, and is considered to be a conservative estimate. Eroded volumes were then summed to obtain an estimated sediment load of roughly 98,000 cubic yards. This material has presumably been mobilized downstream or redistributed within the active channel areas adjacent to the levee blowouts.

Figure 18. Cattle grazing along the right bank of Camas.

Current Geomorphic Reach Characterization

Current geomorphic conditions were assessed for the same sub-reaches within the Primary AOI described in historic geomorphic characterization using a combination of the 2015 LiDAR, 2014 aerial imagery, and the September 2015 field assessment. Geomorphic reach characteristics are summarized in Table 8, with each reach described below.

Table 8. Current Geomorphic Reach Characteristics.

REACH METRIC	1	2	3	4	5	6
River Mile	14.75 – 17.8	14.4 – 14.75	13.95 – 14.4	13.05 – 13.95	12.45 – 13.05	11 – 12.45
Dominant Planform	Meandering/ Anabranched	Straight Single Thread	Anabranched	Anabranched/ Single Thread	Straight Single Thread	Anabranched
Active Width (ft)	40 – 180	40 – 60	130 - 240	60 – 180	60 – 130	80 – 240
Floodplain Width (ft)	80 – 400	40 - 60	340 - 600	100 – 500	60 – 190	600 -1400
Sinuosity	1.1	1	1.1	1.1	1	1.3
Main Channel Length (mi)	3	0.4	0.4	1	0.6	1.7
Secondary/ Side Channel Length (mi)	0.5	0	0.4	0.4	0	1.2
Riparian Conditions	Fair[1]	Very Poor	Poor	Poor	Very Poor	Fair
Wood Loading[3]	Undesirable	Undesirable	Undesirable[2]	Undesirable	Undesirable	Undesirable

REACH METRIC	1	2	3	4	5	6
Wood (pieces/mi)	8.0	0.0	10.1[2]	1.0	0.0	2.9
Pools/ mi[3]	Undesirable	Undesirable	Undesirable	Undesirable	Undesirable	Undesirable
Pools/ mi	3.7	0	8.8	Unknown[4]	1.6	16.5

1 Riparian conditions considered 'Fair' along left bank, but 'Poor' along right bank adjacent to SR 244. "Fair" conditions describe multi-canopy riparian community with regeneration, but with sparse coverage due to ungulate grazing. "Poor" conditions describe single-canopy riparian conditions with limited regeneration. "Very poor" conditions describe sparse single-canopy conditions with little to no regeneration.
2 Wood loading is skewed by short reach length; only 4 pieces of wood were observed in Reach 3, none were engaged with the wetted channel.
3 Benchmarks based on Habitat Ratings in Ecovista (2003) Appendix 1.
4 No pool data due to limited property access

Reach 1 – Cable Creek to Alluvial Fan

Overview:

- SR 244 confines large portions of Reach 1 to a single thread channel, lacking habitat features such as pools and large wood.
- Areas with intact floodplain exhibit an anabranched channel morphology.
- Riparian vegetation along most of the right bank has been impacted by ungulate browsing and grazing.

Current geomorphic conditions within Reach 1 vary considerably with changes in the active channel and floodplain width. At the upper end of the reach, the channel is confined to a single thread channel for approximately a half mile due to the placement of the ODOT maintenance site, a levee along the right bank, and SR 244. There are no large wood pieces or pools from RM 17.8 – 17.3, however riparian conditions are somewhat intact along the left bank, with continuous forest cover. The right bank has a few remnant patches of mature trees, but much of the bank is bordered by levees and the highway. At RM 17.25, the active channel widens to 280 ft, with several pieces of large wood, a small logjam, and a side channel spanning the right bank for 300 ft. Riparian cover along the right bank here is fair, with a small patch of mature trees, however the left bank is largely unvegetated until RM 17.1, where the valley wall steepens and coniferous forest is intact. Cattle grazing directly up to the channel was observed during the field visit, with obvious impacts to riparian vegetation and bank stability (Figure 18).

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The channel segment from RM 17.1 to 16.6 is moderately confined by the valley wall to the south, and SR 244 to the north. The channel is confined to a straightened plane bed reach from RM 16.5 to 16.2, cutoff from a large floodplain area and former anabranch channel by SR 244. At RM 16.15 the active channel corridor widens to a maximum width of 400 ft. This segment of Reach 1 contains several pieces of large wood, multiple pools, and an anabranched planform. Few of the pools have complex cover or shade, and some are only engaged during higher flows (Figure 19). A large wood assemblage near RM 16.1 has led to the formation of a gravel bar in its lee, creating a flow split within the right anabranch channel with several pools. Most of the wood within the reach is perched on gravel bars or low-lying floodplain and is not engaged at regular and low flows, limiting its influence on habitat. Riparian cover is non-existent along the right bank, with intact forest along the steep left bank to the south. The right anabranch conveys the majority of flow, and has virtually no complex cover or shade.

Figure 19. Large wood forced pool with stagnant water in Reach 1. Pool is only accessible during higher flows and lacks cover.

Further downstream, the channel corridor narrows slightly, reducing overall channel complexity and floodplain connectivity. A high flow channel at RM 15.6 may provide some off-channel habitat during spring freshets or winter storms, but has no large wood or cover. Riparian canopy from RM 15.7 to 14.75 is poor along the right bank, and fair along the left bank where the channel abuts the forested southern valley wall. The lower portion of Reach 1 has very little channel or habitat complexity, with the exception of a backwater alcove near RM 15.4 along the left bank, where an ephemeral tributary enters Camas from the south. There is limited riparian cover and no large wood in this alcove. There are several pools between RM 15.7 and 14.75, none of which have complex cover. Floodplain width ranges from 120 ft near RM 15.5 to 300 ft near RM 15.2, with planform dominated by a single thread plane bed channel.

Reach 2 – Upper Alluvial Fan Confined by Levees

Overview:

- Reach 2 is confined to a single thread plane bed channel by levees on both banks and lacks pools and large wood.

Reach 2 is currently confined between levees on both banks for the entire channel length, resulting in a straight plane bed channel with no habitat complexity, pools, or large wood (Figure 20). The channel and floodplain width are constrained to 40 – 60 ft from RM 14.75 to 14.4. Riparian cover on both banks is very poor, with few trees and virtually zero cover or shade. There is relatively low lying floodplain on either bank beyond the levees, with some areas below the wetted channel surface (Appendix C). A high flow channel where some levee erosion appears to have occurred at RM 14.6 is engaged during the 100 year flow event, however the flow spanning the alluvial fan within this channel is predominantly shallow (< 0.5 ft) and thus provides little to no habitat or refugia during high flow events.

Reach 3 – Upper Alluvial Fan Anabranch

Overview:

- Reach 3 has re-established an anabranched planform in areas where the 1965 levees have eroded, but lacks sufficient large wood or riparian cover for quality habitat.
- Reach 3 includes the upstream extent of summer dewatering within mainstem Camas Creek.

Figure 20. Reach 2 is confined to a bankfull width of 40 ft by levees on either side, resulting in a straight, plane bed channel with no cover.

Reach 3 currently has an anabranched channel planform where the 1965 levees have been eroded. This process has allowed the channel to re-engage some of the low-lying floodplain to the north along SR 244 and to the south on the alluvial fan. Floodplain width in Reach 3 ranges from 340 to 600 ft, with an active channel width of 130 – 240 ft. Total channel length is nearly doubled by the amount of secondary or anabranch channels within the reach. These channels are not all perennial, however they likely provide flood storage and slow water off-channel habitat during winter and spring flows. Substrate within the secondary channels contained smaller gravels when compared to the main channel, which is consistent with bed mobility estimates from the 2D hydraulic model results. Several of the channels were wetted during the field visit, with pool habitats formed by both alluvial processes and wood recruited by beavers (Figure 21).

The main channel within the lower portion of Reach 3 below RM 14.2 was dry during the September 2015 field visit, with flows spread out in multiple channels upstream. The ground water table in this reach is below the floodplain soil depth, which comprises a layer of fine sandy silt 2 ft deep over cobble and coarse gravel material. Portions of the 1965 levees remain intact, with a mean height of 6 ft above the channel bed. Riparian cover is considered poor due to a general lack of forest throughout the active channel corridor. Wood loading in the reach is artificially high due to the short reach length. Only 4 pieces of large wood were counted, with very few pieces actually engaged with the channel. Pool frequency in Reach 3 is fair, however few pools have complex cover or shade.

No field observations were obtained within Reach 4 due to limited access constraints. Existing geomorphic conditions within Reach 4 were characterized using remotely sensed LiDAR and aerial data. Reach 4 currently has a variable planform, with the active channel and floodplain intermittently confined by intact levees and SR 244. Active width ranges from 60 – 180 ft, with the widest channel segment between RM 13.8 and 13.6 where the levees have eroded. Floodplain width is also greatest at the upstream end of the reach, where the channel has room to engage the low right floodplain adjacent to SR 244. A small, intermittent channel flowing parallel to SR 244 enters the reach from the right bank at RM 13.8, also providing some off-channel habitat with limited riparian cover during higher flows. High flow channels span the point bars from RM 13.8 to 13.6, with limited riparian cover due to their proximity to remnant levee segments. The meandering planform between RM 13.9 and 13.6 likely has some pools, but the locations of meander apices generally coincide with high eroding banks with no intact riparian forest, limiting the recruitment of wood and reducing the overall quality of pool habitat.

Between RM 13.6 and 13.4 the channel is confined to a narrow, straight, plane bed channel with a mean width of 60 ft. There is some perched floodplain along the left bank at RM 13.5, but this is not engaged during the 2-year flow. Between RM 13.4 and 13.2 there are relic channel anabranches with some groundwater expression visible in the 2014 aerial image. These channels have begun to revegetate and may provide quality off-channel habitat during higher flows. There is no large wood and no visible evidence of pool formation within this channel segment. The lower portion of Reach 4 is confined by SR 244 along the right bank and by remnant levees along the left. The channel widens slightly at RM 13.1 where the left bank has eroded. Sediment deposition in this location is apparent from aerial photos, creating a short riffle segment with shallow flow. Very little riparian forest is present within Reach 4, with the largest continuous patches along SR 244 near RM 13.2. Several mature trees border a relic channel perched on the floodplain near RM 13.6.

Figure 21. Beaver dam and large wood within Reach 3.

Reach 5 – Lower Fan Confined by Levees

Overview:

- Levees confine much of Reach 5 to a single thread channel with few pools or large wood.
- Areas where the levees widen are subject to ongoing sediment deposition due to reduced transport capacity.

Reach 5 is currently characterized by a straight, plane bed channel confined by levees on either side. Channel width ranges from 60 to 130 ft, with floodplain width ranging from 60 – 190 ft. Floodplain width is greatest at the upper end of the reach near RM 13.05 where the left bank levee is set back from the channel and portions of the left channel corridor are engaged at high flows. A gravel bar spanning from RM 12.6 to 12.75 creates a small side channel alignment parallel to the mainstem channel and the left bank levee, which is engaged at the 2-year flow. The gravel bar has begun to revegetate with young willow and shrubs. A similar channel is beginning to form along the right bank between RM 12.8 and 12.7 and was observed during the field visit, but is not as prominent in the LiDAR data (Appendix C). Neither channel has any large wood, with riparian cover consisting of young deciduous trees and shrubs, high banks nor channel substrate comprised of coarse cobble material. Only 1 pool was observed during the field visit, and contained no wood or cover. There are currently no large wood pieces within Reach 5. Overall riparian condition is poor due to a lack of mature trees and very little shade or cover. Several locations along the right bank within the reach seem to be eroding between RM 12.7 and 12.55. Low-lying floodplain on either bank upstream of the bridge is currently disconnected by the placement of the levees. The entirety of the Reach 5 channel was dewatered during the field visit.

Field measurements below the Camas Street bridge suggest that the channel has aggraded by as much as 5 ft at the bridge since its construction (Figure 22). Figure 22 shows the 1983 as-built drawing, with the 2015 bed elevations superimposed on the original bed cross section. Aggradation within the right (northern most) channel is less severe, with increased bed elevations of 2 – 2.5 ft. Just upstream of the bridge, a large gravel/cobble bar is obstructing the right half of the channel, forcing the majority of flow through the left (south) bridge span. Part of this sedimentation also forms a riffle immediately upstream of the bridge.

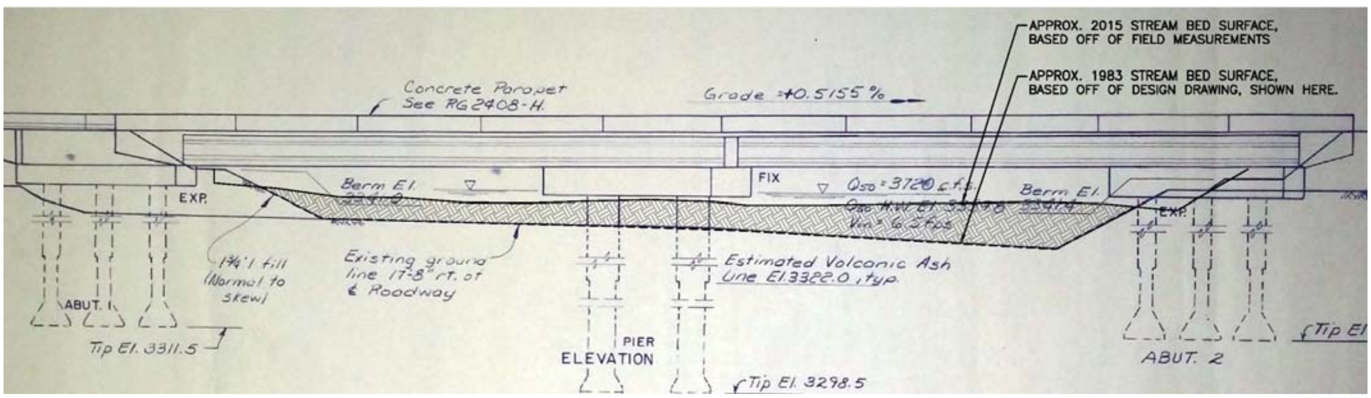

Figure 22. 1983 as-built drawing of Camas Street bridge with measured 2015 bed elevations superimposed on cross section. View is looking upstream.

Reach 6 – Lower Fan Anabranch

Overview:

- Reach 6 has an anabranched channel with areas of well connected floodplain and the greatest pool frequency within the PAOI, but lacks large wood and riparian cover.

Reach 6 below the bridge is characterized by an anabranched channel network that spans the low-lying floodplain near the confluence with Pine Creek. This sub-reach has the highest amount of intact floodplain, channel length, and pools within the primary area of interest examined. Current conditions in Reach 6 are the closest analog to what historic conditions were probably like throughout the Camas alluvial fan prior to human channel modifications, deforestation, and grazing impacts. With the exception of a remnant levee between RM 12.2 and 12.1 along the left bank, the reach is relatively unconfined, with lots of low-lying floodplain areas accessible to fish and water during high flows. Groundwater levels in the reach appear to be closer to the surface relative to the upstream reaches, which is likely a result of high floodplain and secondary channel connectivity, inflow from Pine Creek, and finer substrate. This groundwater expression was evident in numerous pools within the active floodplain, several of which had no surface connection to the main or secondary channel network in early September 2015.

Active channel width ranges from 80 to 240 ft, with the widest channel segments in areas where sediment appears to be aggrading (eg. RM 12, RM 11.5). Floodplain width ranges from 600 to 1400 ft. Several secondary channels stem from the right bank near RM 12.3, flowing southwest across the fan and rejoining the main channel between RM 12 and 11.8. These channels are typically narrower than the mainstem, ranging from 20 – 40 ft in width. Approximately 1.2 miles of secondary channel within Reach 6 results in nearly double the total channel length, providing lots of water and sediment storage and high quality habitat. Additional anabranches occur at RM 11.65 and 11.4, where the channel splits into multiple flow paths, meandering throughout a wide floodplain.

Figure 23. Bank erosion and possible channel incision within Reach 6 near RM 12.35.

Pool frequency in this sub-reach is substantially greater than in all other reaches observed (Table 8). Wood loading is limited to a few scattered pieces of large wood, few of which are engaged with the low flow channel. Riparian conditions are rated as fair due to a general shortage of intact mature forest. There are several remnant stands of mature PIPO on the floodplain, but few channel segments with mature trees along the bank. Much of Reach 6 is in the process of revegetation, with active tree planting occurring along the floodplain from RM 11.9 to 11.

Several areas of bank erosion with cobble lenses perched 3-4 ft above the channel bed suggest that Camas has also incised within some channel segments within Reach 6 (Figure 23). The left bank in the meander bend at RM 12 also shows some signs of bank erosion, however the cut bank is much lower than that observed upstream below the bridge.

6. SEDIMENT TRANSPORT

6.1 Rapid Sediment Budget

A rapid evaluation of sediment budgets was conducted to characterize sediment production, storage, and controls on transport within the Camas Creek watershed. A sediment budget is an accounting of the sources and deposition of sediment as it travels from its point of origin to its exit from the watershed. Locations and relative magnitude of erosion and deposition were identified along Camas Creek and its major tributaries to characterize the spatial distribution of sediment production and storage. Channel reaches in equilibrium conditions (no long-term change in sediment storage or production) and controls on sediment transport (bridges, culverts, natural channel constrictions, etc.) were identified as well to better understand the character of sediment transport throughout the watershed.

6.1.1 Methods

The methods used were adapted from Reid and Dunne (1996), relying primarily on the available historic air photos (Appendix B), topographic data, and field observations. Sediment production from hillslopes and channels was characterized by process (landslides, debris flows, sheet wash erosion), grain size of sediment mobilized, and the relative rate of production. Sediment production from hillsides include mass failures that are either actively contributing sediment directly to the channel, or locations where sediment has historically entered the channel. The most current air photo (Appendix B) was used to identify locations of recent mass wasting delivering sediment to the channel. Historically mapped landslide deposits (Ferns et al. 2001) and colluvium (Busskohl 2006) were assessed to evaluate historic sediment contribution from these sources. Sediment production from within stream channels was identified at recent bank erosion locations observed in the field and from historic air photos (Appendix B).

Locations of temporary sediment storage in the channel and floodplain were identified and characterized for Camas Creek and its major tributaries. These locations, indicating sediment storage, included exposed gravel bars in the channel, alluvial fans at the toe of slopes, exposed overbank sedimentation, and braided channel reaches. The locations of sediment production and storage were evaluated spatially to characterize sediment transport through the watershed.

6.1.2 Results

The geology of the Camas watershed is a primary control on the production of sediment, as the nature of the rock types present controls the rate of physical and chemical breakdown into sizes typically thought of as sediment. The higher the rate of rock weathering, the greater the rate of sediment production. Much of the Camas watershed is composed of Grande Ronde Basalt, with the south-central portion of the watershed a mix of variable extrusive rock types named the Tower Mountain Volcanics (Map 2). The Tower Mountain Volcanics have a higher rate of weathering than the adjacent Grande Ronde Basalts. This higher weathering rate results in greater sediment production and hillslope instability. Hillslopes within the Tower Mountain Volcanics are generally 30% steeper and more prone to failure (landslides) than those of the Grande Ronde Basalts (Maps 2 and 8). Based on this understanding of the primary driving control on hillslope sediment production, the focus of identifying chronic sediment sources was on the upper watersheds of Cable and Hidaway Creeks, where the Tower Mountain Volcanics are exposed.

Sediment Production

Sediment production was first evaluated for historic conditions, using the mapped landslides (Ferns et al. 2001, Busskohl 2006) (Map 8). A total of 27 landslides were identified by Ferns et al. (2001) within the Camas

Creek watershed. Within the Tower Mountain Volcanics a total of 25 landslides were mapped, totaling 2,890-ac, with an additional 2 landslide totaling 299-ac mapped in the Grande Rond Basalt (Maps 2 and 8). In addition to the mapped landslides, 7 colluvium deposits were mapped by Busskohl (2006) (Map 8). These deposits occur within the Baker Terrane, Grande Ronde Basalt, and Tower Mountain Volcanics (Maps 2 and 8). The locations where these landslide deposits are mapped typically represent larger scale failures that are apparent on the landscape, and have occurred in recent geologic time (Quaternary period). These locations were compared to the historic air photos where available, and only one of these mapped sites is currently contributing sediment to the channel (on Hidaway Creek approximately 3-mi upstream of Line Creek confluence). The remaining locations have stabilized and are not significant contributors to sediment load in the creek. The sediment introduced to the channels from these historic failures has likely been evacuated from the watershed, given the time since their occurrence and the condition of the channel in the historic record. Reaches of Camas Creek that have not been significantly altered in the historic record do not exhibit a braided planform, nor are there significant exposed gravel bars indicating high sediment load. This lack of indications of high sediment load in Camas Creek suggests most of the material introduced to the channel from the mapped landslides was moved through the system prior to the early to mid-20th century.

Current sediment production was evaluated using the most current air photo, identifying locations of active slope failure delivering sediment directly to the creek. A total of 7 sites were identified, all within the upper watershed of Cable and Hidaway Creeks (Map 12). Each of the active failures are characterized as rapid shallow translational sides that exhibit periodic mass failure, with chronic rill erosion contributing sediment directly to the channel. Of the 7 locations identified, only the 2 sites in upper Hidaway were present prior to the 1996 Tower Fire. The remaining 5 sites are in the upper Cable Creek watershed that experienced significant tree mortality during the Tower Fire. The loss of forest cover on these already steep slopes was sufficient to initiate slope failure and continued delivery of sediment to the channel.

The condition of Camas, Hidaway, and Cable Creeks were assessed relative to overall channel stability (channel form changes, significant bank erosion) over time to interpret the transport of sediment derived from hillsides through the system. Key locations for this assessment were the confluences of Hidaway and Cable Creeks with Camas Creek, as they would exhibit a response to a change in sediment loading originating from the tributaries. If sediment loads increased in one of the tributary creeks, gravel bar formation and expansion of existing gravel bars at and immediately downstream of the confluence would be anticipated. At the Cable Creek confluence, the channels remain relatively stable through the historic air photo record until 1964, when significant disturbance likely associated with the rock quarry to the north of the creek appears to have delivered sediment to Camas Creek downstream of the confluence (Appendix B). The following year this area was straightened and leveed. Following 1965 there has been relatively little change in the arrangement and size of gravel bars at the confluence with Cable Creek, indicating there has not been a significant change in sediment load entering Camas Creek from Cable Creek during this time.

The confluence with Hidaway and Camas Creeks has been more dynamic over time than the Cable Creek confluence. The earliest available air photo is from 1947, where there are no large exposed gravel bars at or immediately downstream of the Hidaway confluence (Figure 24). Camas and Hidaway Creeks remain relatively unchanged until 1965, where significant changes are apparent. The new SR 244 highway bisects much of the Camas Creek floodplain at the confluence with Hidaway, and there are a number of new roads along lower Hidaway Creek (Figure 24). In addition to these anthropogenic changes, there is a large new gravel bar immediately downstream of the Hidaway confluence. This new gravel bar is approximately 2.4-ac in area, with an estimated volume of 10-20,000 cubic yards (CY) (based on an estimated thickness of 3-5 ft). The flood of record occurred in 1965, prior to the air photo taken in 1965. Thus, the transport of sediment depositing the large gravel bar likely occurred during this event, however the production of sediment is likely attributed to the new roads and extensive logging in the Hidaway Creek watershed (Figure 24). The channel and gravel bar remain relatively unchanged until 1995, when the channel migrates 130-ft to the southeast (river left), through the large gravel bar. Between 1995 and 2001 Camas Creek moves 130-ft back to the northwest (river right) where it was located between 1965 to 1989. Woody vegetation is starting to establish on the highest part (downstream end) of the gravel bar, indicating that the channel is gradually cutting down and that there is no longer excess sediment entering Camas Creek from Hidaway. A number of peak flows since 1965 (Table 1) have occurred that did not result in expansion of the large gravel bar deposited in 1965, indicating sediment production in the Hidaway watershed has decreased/stabilized over time. The more dynamic confluence with Hidaway Creek indicates that sediment loads from Hidaway Creek have historically been high, however the recent relative stability suggests sediment loads have decreased over time.

Sediment production from the channels related to bank erosion was not observed to be a major contributor to sediment loading to Camas Creek or any major tributaries. Levees constructed in lower Camas Creek in response to the 1965 flood have been eroded over time, contributing sediment to the channel. The erosion of these levees initiated in the 1980's and has expanded to cover an area of the channel between RM 13.2 and 14.6. The cumulative volume of sediment introduced to the channel from these eroded levees was estimated to be 98,000-CY. Much of the sediment used to create the levees was likely dredged from the creek, thus this volume of sediment would have been transported downstream if not used to build the levees.

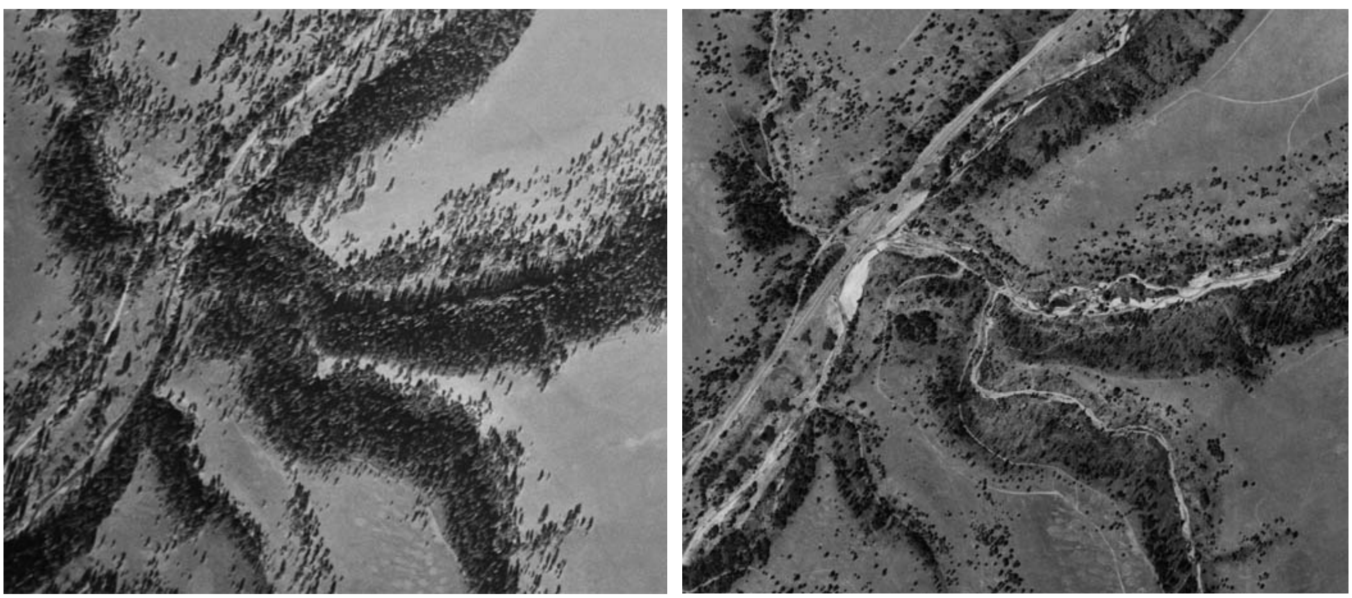

Figure 24. Confluence of Hidaway and Camas Creeks in 1947 (left) and 1965 (right).

Sediment Storage

Locations of sediment storage were identified along Camas Creek and its major tributaries, with sites identified where the channel has adjusted to a more braided planform, and where new gravel bars have formed or grew in size over time. A total of 12 locations exhibiting significant sediment storage were identified using the historic air photo record (Map 12) (Appendix B). Four of these locations are in the upper Cable Creek watershed, and occurred within 1.5-mi downstream of active sediment production sites (Map 12). At the lower end of Hidaway Creek near the confluence with Camas Creek, 3 additional sediment storage sites were identified, 2 in lower Hidaway Creek and 1 in Camas Creek immediately downstream of the confluence (Map 12). The remaining 5 sites are all in Camas Creek, with 2 locations between Cable Creek confluence and the head of the alluvial fan (Reach 1), 1 location immediately downstream of the eroded leveed near RM 14.5 (Reach 3), and 2 sites in Ukiah (Reach 5) (Map 10).

In addition to these site specific locations, historic beaver populations in both Cable and Hidaway Creeks would have provided additional sediment storage behind dams constructed on these tributary channels. The potential storage of these beaver dams is a function of the channel width and slope, as well as the spacing of beaver dams and their height. The relationship takes the form of:

$$V \cong \frac{\frac{h}{2} lw}{2}$$

where *V* is the potential volume of sediment stored, *h* is the height of the beaver dam, *l* is he spacing of beaver dams, and *w* is the channel width. This equation assumes that storage is maximized for the given channel slope, with backwatering from one beaver dam extending upstream to the toe of the next beaver dam. This assumption is unlikely to occur along an entire channel course, thus a range of estimates is provided based on 50% and 10% of the volume predicted from the equation above.

Cable Creek

The 4 sediment storage locations identified in the upper Cable Creek watershed are sections of the channel that have experienced dramatic changes in channel planform, from a single thread to wide braided channel. All of these locations first appear in the 2000 air photo, and are coincident with the appearance of the upstream sediment production sites doing the same time period, following the 1996 Tower Fire (Map 12). Comparing the 1995 and 2000 air photos, the channel width increases 10-fold (20-ft to 200-ft) over a very short timespan (Figure 25). This rapid expansion of the channel and extensive gravel bar development indicates a large influx of sediment to the channel from upstream as it adjusts to a planform that can more efficiently transport sediment.

Evaluation of the sections of the channel that experienced significant aggradation of sediment following the Tower Fire shows that the initial pulse of sediment to the channel has been evacuated slowly over time. The channel downstream of these aggraded areas have new gravel bar development, indicating that the sediment stored in the channel is moving downstream, but at a rate that still maintains a meandering planform. The abundant tree fall in the channel and valley bottom has likely helped to attenuate sediment pulses migrating downstream during flood events, by slowing flow velocities and creating accommodation space for the incoming sediment. The condition of Cable Creek between 2 - 4-RM downstream of these 4 sediment storage sites was that of a meandering channel in equilibrium with the incoming sediment load, and well connected to its floodplain. At the confluence with Camas Creek, Cable Creek has not experienced rapid bar growth or other signs of an increase in incoming sediment load. These indicators of channel equilibrium all corroborate that sediment is slowly metered out over time from the 4 storage locations identified, and that phenomenon is attributed to the abundance of downed trees in the creek and valley bottom.

The potential for sediment storage in Cable Creek from beaver dams that were once common is between 35,000 – 7,000 CY. The historic removal of beaver would have resulted in the release of this sediment over time downstream. Because beaver dams create backwater areas upstream, it is likely that sediment accumulated in these areas would have been very fine grained, and would flush downstream easily and not contribute to aggradation of the channel. This sediment could potentially have been stored on downstream floodplains if transported during a high flow event.

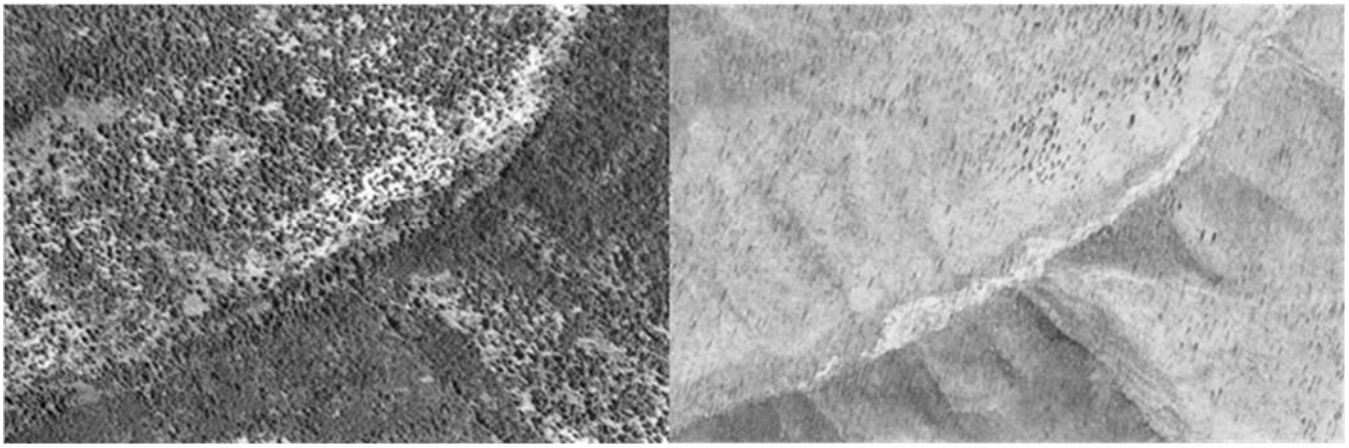

Figure 25. Widening of Upper Cable Creek from 1995 (left) to 2000 (right) following the Tower Fire.

Hidaway Creek

There are 2 additional sediment storage locations in the lower reach of Hidaway Creek, approximately 0.35 and 0.95 RM upstream of the confluence with Camas Creek (Map 12). This segment of Hidaway Creek remained relatively stable until the 1965 air photo, when nearly the entire length of the channel experienced a 2-5 fold increase in channel width (from 30 to 150-ft). This dramatic channel response is attributed to the flood of record that occurred in 1965, and significant road development up Hidaway Creek that destabilized channel banks and contributed to elevated sediment loads. From 1965 to the present, most of the channel has narrowed over time as vegetation encroaches on the channel. It is unclear if the sediments accumulated circa 1965 have been evacuated from the channel, or if the channel has incised through the aggraded sediments. Access to these sites was not attained during the field surveys to verify if the aggraded sediment remains, however a review of the channel character from air photos indicates that sediment is still being stored at the 2 locations identified (Map 12). These locations appear to occur immediately upstream of natural constrictions in the Hidaway valley, thus a natural backwater occurs at these locations during larger floods where sediment is deposited.

The potential for sediment storage in Hidaway Creek from beaver dams that were once common is between 80,000 – 16,000 CY. The historic removal of beaver would have resulted in the release of this sediment over time downstream. Because beaver dams create backwater areas upstream, it is likely that sediment accumulated in these areas would have been very fine grained, and would flush downstream easily and not contribute to aggradation of the channel. This sediment could potentially have been stored on downstream floodplains if transported during a high flow event.

Upper Camas Creek

Along Camas Creek, a total of 4 sediment storage locations were identified (Map 12). The furthest upstream site is between RM 15.1 and 16.2, starting immediately downstream of where SR 244 bisects the valley bottom. During construction of SR 244 Camas Creek was relocated to the south side of the valley, and up to 75% of the valley bottom was cutoff from the creek by the road. This considerable constriction of the channel has resulted in increased sediment transport capacity through this confined reach of the channel. As the channel exits this confined section of the channel, the transport capacity rapidly decreases, resulting in the deposition of sediment in the channel. Prior to the construction of SR 244, Camas Creek between RM 15.1 and 16.2 did not exhibit the large, unvegetated gravel bars that have formed over time and currently remain. The channel has started to incise through these accumulated sediments, indicating that the incoming sediment supply has diminished over time.

Downstream of Eroded Levees

Downstream on Camas Creek between RM 13.2 and 14.7, the channel was straightened and levees constructed on either side of the channel in 1965, likely a response to the flood of record earlier the same year (Appendix B). Almost immediately, the straightened and leveed channel began to re-meander, eroding the levees as meanders expanded (Figure 16). Erosion of the levees initiated at the downstream end and propagated upstream over time. It is likely that the material used to construct the levees was taken from the adjacent floodplain, magnifying the quantity of sediment available for transport should the banks erode into the levee. This increase in the available sediment, coupled with the creek trying to re-meander (through bank erosion) where straightened, resulted in large pulses of sediment entering the channel immediately downstream of the eroded levee. The quantity of available sediment exceeded the transport capacity of the channel, resulting in the deposition of gravel bars and conversion to an braided planform. Over time the channel has periodically expanded, following larger flood events that initiate additional levee erosion upstream. It was estimated that up to 98,000 cubic yards of sediment from the eroded levees has been introduced to the channel since 1965. In addition to the sediment volume of the levees, additional sediment was introduced to the channel as it re-meandered through the newly available floodplain. This sediment is shown to have migrated downstream, as bars begin to build downstream in the channel by 1989, all the way to the Pine Creek confluence (Appendix B). The potential capacity to store sediment in this section of the channel has likely been met, as we see gravel bars have developed downstream to the extent possible given the confinement from levees allowing meandering to occur.

Ukiah

Dating back to the earliest available air photo from 1939, there was a bridge over Camas Creek near RM 12.45 where Camas Rd crosses the creek (Appendix B). The creek upstream of this bridge is a multi-thread channel with expansive gravel bars, indicating that this bridge was a hydraulic control that induced backwatering during high flows. Deposition of sediment in the channel due to this constriction at the bridge is evident by the size and number of gravel bars in the creek upstream, which gradually diminish upstream (Appendix B). No levees are apparent on the channel banks, however Camas St appears to be raised and act as a levee, further contributing to backwatering and aggradation of sediment upstream.

The Brown and Hoxie Mill was constructed on the left bank near RM 12.6 in 1941. Coincident with the mill and visible on the 1946 air photo, was channel straightening, diversions, and levees along the creek, as well as new housing on the right bank of the creek through Ukiah (Appendix B). There are long linear features in the 1956 creek between RM 12.5 - 12.6 that appear to indicate removal of accumulated gravels just upstream of the Camas Rd Bridge (Appendix B). The creek gradually incises into the aggraded sediments in the channel between 1946 and 1964, as vegetation is shown to colonize the exposed gravel bars over time. Following the 1965 flood of record, continuous levees were constructed on either side of the creek through Ukiah, significantly narrowing and straightening the channel. The channel was narrowed from nearly 300-ft wide prior to 1965, to 90-ft upstream of RM 12.8 and 120 - 200-ft wide downstream of RM 12.8 to the Camas Rd Bridge (Appendix B). By 1981, large exposed gravel bars are present in the creek through Ukiah, with the largest in the segment of the channel between the Camas Rd Bridge and RM 12.8. The increase in width between the levees through this reach created space for sediment to accumulate into large unvegetated bars. The source of this sediment is inferred to come from the erosion of the levees upstream between RM 13.2 - 14.4, including the sediment comprising the levees as well as floodplain sediments recruited into the channel as it re-meandered following the erosion of the levee. The erosion of the levees had already occurred by 1981, and large gravel bars appear in the channel during this same time-period.

Camas Street Bridge

In 1983 a new bridge span was constructed on Camas Street over Camas Creek. This new bridge span crosses Camas Creek approximately 340-ft upstream of the old bridge location. The new bridge crosses the creek oblique to flow, and is located where the levees are further apart (120-ft) relative to the pre-1983 bridge location (90-ft), resulting in less confinement with the new bridge. The gravel bar just upstream of the old bridge, and on the right bank, remained in the same location after the new bridge was built upstream (Appendix B). This gravel bar is unvegetated prior to 1983, remains unvegetated through 1989, and starts to show vegetation colonizing the bar by 1995. Following 1995, the gravel bar continues to colonize with vegetation, and vegetation matures over time. The establishment of vegetation on these gravel bars suggests that no significant deposition has occurred during this time-period (1995 to present), as aggrading sediments would bury vegetation, leaving an unvegetated bar surface.

When comparing the change in bed elevation under the new bridge (Figure 22) it was found that the gravel bar on the right (north) side of the channel that constricts most of the flow through the bridge, has aggraded 2 – 2.5-ft since 1983. Given the character of vegetation colonization of this bar, it is our interpretation that most of this aggradation occurred shortly after the bridge was installed. For this amount of sediment to accumulate at this location, the bar would have aggraded at an average rate of around 0.2-inches/year. However, it is likely that aggradation occurred during high flow events versus gradually over time.

A total of 4 floods approximately at the 5-yr return interval, and 1 25-yr flood occurred in the 12 years after the new bridge was constructed. These flood events would have been sufficient to mobilize sediment, and initiate channel adjustments (aggradation, erosion) reflecting any changes in hydraulics due to the new bridge. Based on our comparison of channel surveys, and review of historic air photos, we believe that most of the aggradation predicted to have occurred at the bridge, happened very shortly after installation, and that for the last 20 years the rate of aggradation has slowed as the channel has adjusted to the hydraulics in and around the new bridge.

The bridge and sediment that deposited shortly after installation of the bridge, continue to reduce the conveyance of flood waters. However, the hydraulic effects of the bridge are localized, extending approximately 350 ft upstream during the 100-yr flood, and less (extending a shorter distance upstream) during more frequent and lesser floods. As opposed to the localized effects of the bridge, the levee confinement on either side of the channel upstream of the bridge has a much larger effect on the conveyance of floodwaters passing through Ukiah. The widening of the levees through Ukiah has created space for sediment to deposit over time, building a large gravel bar within the levees. This accumulated sediment dramatically reduces the conveyance of floodwaters as they pass through Ukiah, and is the primary driver contributing to flood risk to Ukiah.

6.2 Channel Substrate Characterization

Channel substrate was characterized at 12 surface locations and 10 subsurface locations using Wolman (1954) pebble counts during the September 2015 field visit. Surface grain size is representative of the armor layer comprising the channel bed surface, with subsurface particles more representative of mobile bed load transported through a reach during higher flows. Channel bed armoring occurs when finer grains are winnowed from the surface of the channel bed, occurring during flows that can mobilize finer particles but not the larger cobble and gravel on the channel bed. Over time this process leads to a coarsening of the channel bed (average grain size), with only larger particles present. Below this armor layer the channel bed still contains all of the finer particles that are more characteristic of the sediment load moving through the channel. For this lower portion of the channel bed to be entrained, the upper armor layer must first be mobilized. Once the threshold needed to mobilize the armor layer has been met, the bed will mobilize and mix the armor and sub-layers. Following a bed-mobilizing event, the channel bed will no longer be armored until it is again winnowed of its fines until the next large flood. Grain size distributions for both the upper armor and lower channel layers are summarized in Table 9 below, with full distributions for each sample location presented in Appendix E.

Table 9. Summary of Grain Sizes.

LOCATION	SURFACE D50 (MM)	SURFACE D90 (MM)	SUBSURFACE D50 (MM)	SUBSURFACE D90 (MM)
Upper Hidaway Creek	59	139		
Camas RM 15.2	41	90	16	80
Camas RM 14.6	90	197		
Camas RM 14.35	55	112	21	55
Camas RM 14.3 Left High Flow Channel	37	84	15	64
Camas RM 14.3	54	133	30	63
Camas RM 12.75	52	111	13	67
Camas RM 12.51	54	108	14	63
Camas RM 12.5	50	89	21	61
Camas RM 12.45	65	125		
Camas RM 12.2	53	100	15	61
Camas RM 12	41	78	14	35
Camas RM 11.95			29	56

Based on visual observation (not included in Table 9), grain size within Camas Creek immediately downstream of the Cable Creek confluence is slightly higher than upstream of Cable Creek, suggesting either coarse sediment input or hydraulic factors such as the constriction by the Cable Creek Road bridge and the levees immediately downstream. Relative to the field observations near the Cable Creek confluence, smaller particles are deposited in the widened reach at RM 15.2, with median grain size increasing significantly within the confined levee segment at RM 14.6. The median grain size immediately downstream of the levee constriction is reduced, indicating reduced sediment transport capacity in the anabranched reach. Grain sizes within the left high flow channel in this segment are smaller relative to the mainstem, storing finer gravels and cobbles transported from upstream. The sediment deposits immediately upstream of the Camas Street bridge and at the bridge are consistent with grain size distributions in the wider, anabranched reaches, suggesting that the bridge is causing a hydraulic backwater that reduces sediment transport capacity within the confined channel segment. Just downstream, where flow velocity is high through the bridge span, median grain size is slightly higher, then diminishes downstream as flows spread out, allowing sediment to fall out of transport. These results are consistent with the minimum stable particle sizes predicted by the 2-year model output. This result suggests that channel forming processes are occurring at the 2-year flow event.

6.3 1-D Sediment Transport Model

The primary objective of NSD's 1-dimensional (1-D) hydraulic analysis was to estimate sediment transport in the study area to determine where erosion and deposition of sediment is occurring at higher flow stages. A 1-D sediment transport model was developed using the U.S. Army Corps of Engineers Hydrologic Engineering

Center's River Analysis System (HEC-RAS), version 4.1.0. The following sections provide more detail on specific components of our 1-D hydraulic analysis, data development, and results.

6.3.1 Methods

A total of 247 cross sections were developed using elevation data from the 2015 LiDAR DEM. Cross section locations represent computational points within the model where the water surface and other hydraulic parameters are determined. The river schematic and cross section layout is shown in Map 13. Camas Creek was modeled as a single reach through the project area, with cross-sections spanning the active channel corridor based on the extent of inundation from the 2-D hydraulic model output. Boundary resistance was estimated by Manning's roughness coefficient (n) with values in the main channel set to 0.033 and overbank areas set to 0.05 according to the methods described in the 2-D hydraulic model section. A combination of field observations, LiDAR data, and aerial imagery was used to establish the locations and extents of ineffective flow areas, levees, and roughness boundaries used in the model. HEC-RAS iteratively solves for a 1-dimensional (1D) energy equation to attain an energy balance between successive cross-sections along the study reach.

The energy equation is:

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Where Z_1, Z_2 = elevation of the main channel inverts; V_1, V_2 = average velocities (total discharge/total flow area); α_1, α_2 = velocity weighting coefficients; g = gravitational acceleration; h_e = energy head loss.

The energy head loss (h_e) between cross-sections is the sum of friction losses and contraction and expansion loss. The equation for energy head loss is written as:

$$h_e = LS_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

where L = discharge weighted reach length; S_f = representative friction slope; and C = expansion or contraction coefficient.

The friction slope between successive cross-sections is derived from a form of Manning's equation written as:

$$Q = \frac{1.49}{n} A R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

Where Q = discharge; A = flow area; R = hydraulic radius (area/wetted perimeter); S_f = friction slope (energy gradient); an n = Manning's roughness coefficient.

6.3.2 Boundary Conditions

Similar to the 2-D hydraulic model, HEC-RAS requires the user to input known boundary conditions to begin the computational routine. 1-D model runs were computed using a quasi-unsteady hydrograph representing the 25-year flow event reaching a peak discharge of 3500 cfs. Hydrograph data for a March 1921 peak flow event on Camas with a maximum discharge of 1520 cfs was scaled to the 25-year flow of 3500 cfs. Rising and falling limbs were scaled using the mean slope of the gage hydrograph. The gage record and scaled hydrograph data used in the model simulation are presented in Figure 26. The flow varies from 420 cfs at the start of the simulation up to a peak discharge of 3500 cfs and back down to 420 cfs. This variable flow defines the upstream boundary condition. The downstream boundary condition was assigned to a normal depth based on mean channel gradient at the downstream model boundary of 0.42%.

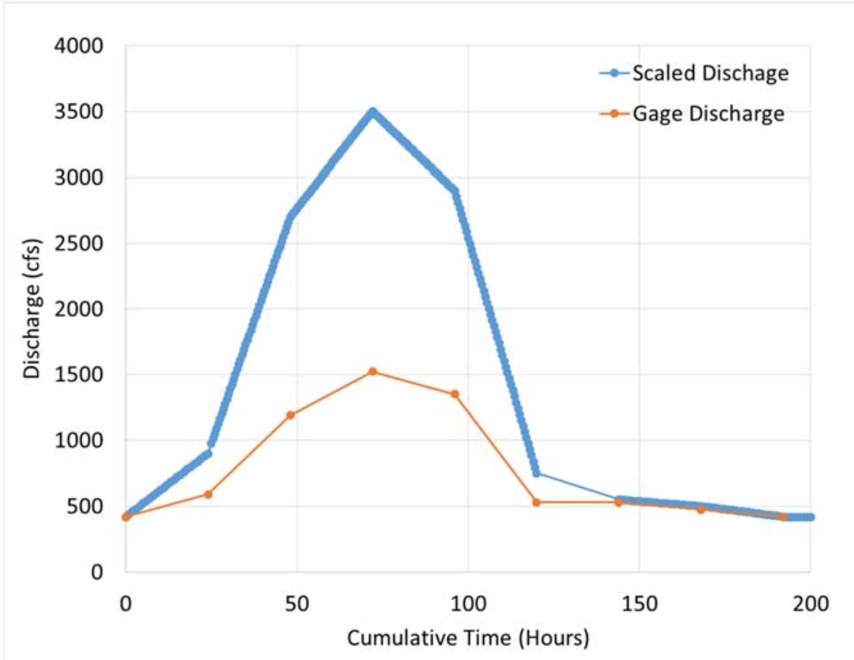

Figure 26. Model hydrograph scaled from daily mean discharge to 25-year peak flow (3,500cfs).

6.3.3 Sediment Data

Parameters defining the sediment transport model were entered into the sediment data editor in HEC-RAS. The Meyer-Peter Muller (MPM) transport function (Meyer-Peter and Müller 1948), using recent corrections by Wong (2003) and Wong and Parker (2006), was selected as the most appropriate option based on the characteristics of the study area (USACE 2010). The portion of the cross section between the channel banks defines the extent of mobile boundary on the section, with immobile boundaries at the toe of levee structures and SR 244. Sediment gradations were attributed to each cross section in the model using pebble count data collected along the creek during field surveys (Appendix E). The sediment transport model requires an upstream boundary condition to define the incoming sediment load. Due to a lack of data sufficient to create a sediment rating curve, the equilibrium load option was used for the upstream boundary condition. The equilibrium load option determines the transport capacity of the flow for each time increment during the flow simulation, and uses that load as the sediment inflow to the model. Using the equilibrium load option is the most conservative approach, as it assumes the system is transport limited and there is sufficient sediment available upstream for transport over the range of flow conditions.

6.3.4 1-D Sediment Transport Model Results

The results of the 1-D sediment transport model demonstrates the influence of man-made infrastructure on the downstream transport of sediment through the Primary AOI. Figure 27 is a plot of the cumulative mass leaving each cross section in the model, with the upstream end of the model domain (confluence with Cable Creek) to the right side. The cumulative mass out (tons) represents the total sum of mass leaving each cross section through the entire 25-YR flow simulation. Locations along the creek where the cumulative mass out is decreasing in the downstream direction represents deposition, with the slope of the line indicating the relative rate of deposition (greater slope = higher deposition rate). Similarly, locations where the cumulative mass out is increasing is representative of erosion, with the slope of the line indicating the relative rate of erosion.

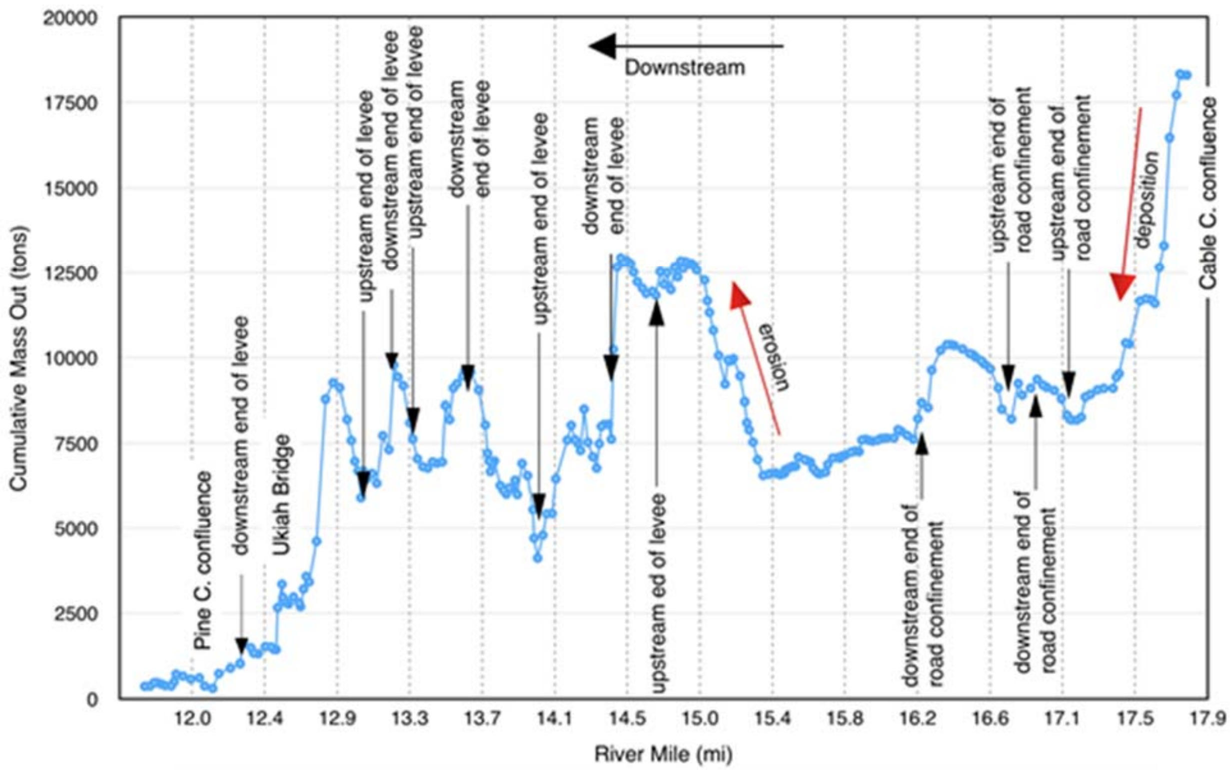

Figure 27. Model results of cumulative mass out (tons) for the duration of the 15-year peak flow (3500cfs) along the modeled reach.

At the upstream end of the model at the Cable Creek confluence (near RM 17.8) there is a significant sediment load entering the model due to the equilibrium load boundary condition. This high sediment load quickly deposits in the immediate downstream cross sections, down to RM 17.3. This modeled deposition (and associated aggradation in the channel) is a relic of the modeling software and equilibrium load boundary condition, and is not representative of expected sediment transport in this reach of the channel. Downstream of RM 17.3 the model results are representative of the anticipated sediment transport character of the channel. Near RM 17.1 approximately 1/3rd of the floodplain to the north of the channel is disconnected from the creek by SR 244 (Appendix C), and continues downstream to near RM 16.9. The response of the channel is to erode (increasing cumulative mass out) through this confined section of the channel, transitioning to deposition (decreasing cumulative mass out) immediately downstream of the confinement (Figure 27).

The floodplain is again disconnected downstream between RM 16.7 and 16.2 (Appendix C), with a similar response of increasing erosion through the confined section of channel, however the transition to deposition occurs within the confined segment of channel (Figure 27). We interpret this result with deposition occurring within the confined section of channel resulting from the longer length of confinement (0.5-mi) relative to the confined segment upstream (0.2-mi). The rapid expansion of the flow at the downstream end of the confined section of channel propagates upstream into the confined segment of creek, decreasing the transport capacity within the confined reach. This loss of transport capacity, coupled with the increased load from the erosion occurring immediately upstream, results in deposition occurring at the downstream end of the confinement.

The channel is slowly losing/depositing sediment downstream of RM 16.2, where the channel is anabranched and exposed gravel bars are prevalent (Appendix B). The size of exposed gravel bars diminishes near RM 15.2, near where the model predicts an abrupt transition from deposition to erosion (Figure 27). There is no change in channel slope (Appendix D) at RM 15.2 that would explain this transition to erosion, however the REM and field observations indicate that the creek begins to be incised near this location (Appendix C).

The creek continues to erode at a high rate until it reaches the head of the alluvial fan reach of the channel (near RM 14.8), at which point the channel transitions to deposition (Figure 27) until it reaches the upstream end of the levees near RM 14.7. Erosion increases within the leveed reach and continues until near the downstream end of the levee, where there is rapid deposition (Figure 27). Similar to the channel between RM 16.7 and 16.2 where SR 244 confines the channel, there is a dramatic increase in exposed gravel bars and anabranch channels immediately downstream of the levees where the model predicts deposition (Appendix B). The pattern (anabranch channels with exposed gravel bars) persists downstream to RM 14, at the upstream end of the next levee, at which point transport capacity and erosion increases (Figure 27). A similar channel response of deposition at the downstream end of the levee (near RM 13.6), followed by increased erosion through the next downstream levee (between RM 13.3 and 13.2).

The leveed reach of the channel through Ukiah starts near RM 13, with increasing erosion downstream to RM 12.8 (Figure 27). At RM 12.8 the channel width between the levees increases from 75-ft to 140-ft, and the model predicts a transition from erosion to rapid deposition (Figure 27). This high rate of deposition continues downstream to near RM 12.7, where a large exposed gravel bar has deposited within the levees (Appendix B). Sediment transport remains uniform (no change in mass out) for the 0.1-mi upstream of the Camas Street Bridge, where the channel width between the levees decreases to 110-ft (Figure 27). Due to a lack of topographic data underneath the bridge, and the interpolation of elevations from the up and downstream sides through the bridge, it is likely that the accumulation of sediment on the northern (right bank) side of the channel through the bridge is under-represented in the analysis. If this deposit were to be included, we would anticipate more predicted deposition upstream of the bridge due to the backwater from this deposit. The model predicts rapid deposition downstream of the Ukiah Bridge where the channel exists the leveed reach and gravel bars become visible (Appendix B). The lower reach of the creek downstream of RM 12.4 (Camas Street bridge) has a main channel with exposed gravel bars on the inside of meander bends, with multiple anabranch channels through the floodplain that convey a small faction of the low-flow (Appendix B). The model predicts a stable channel (cumulative mass out is not changing) and is likely representative of a pre-disturbance channel condition (Figure 27).

7. FISH PRESENCE AND HABITAT LIMITING FACTORS

7.1 Fish Presence and Use

The John Day River supports some of the last remaining wild populations of summer steelhead (*Oncorhynchus mykiss*) and spring Chinook salmon (*Oncorhynchus tschawytscha*) in the Columbia River Basin with no hatchery supplementation. Despite significant recovery efforts, these populations remain depressed compared to historic levels. Currently, Camas Creek supports several fish populations that are found in the John Day River basin which are also targeted for recovery efforts; these include (USFWS 2002, NPCC 2005, NMFS 2009, ODFW 2013, 2014, Bare et al. 2015:

- Middle Columbia Summer Steelhead (*Oncorhynchus mykiss*)
    - Includes spawning and rearing habitat.
- Spring Chinook Salmon (*Oncorhynchus tshawytscha*)
    - Includes spawning and rearing habitat.
- Bull Trout (*Salvelinus confluentus*)

Populations of spring Chinook and summer steelhead depend on distinct habitat features at each life stage, from egg to maturity. Within the John Day basin, features such as habitat diversity, water quality, stream flow levels, and adequate spawning gravel are crucial for salmonid survival and reproduction. Out of basin influences, such as hydroelectric dams, ocean conditions, and human harvest, also have a impact on steelhead and Chinook returns (BLM 2012).

Map 14 shows fish distributions based on data provided by ODFW (2014). Camas Creek supports a small percentage of spring chinook in the John Day Subbasin, and typically use Camas Creek opportunistically for spawning when temperature and flow conditions permit (Ecovista 2003). Summer steelhead use in Camas Creek has fluctuated over time with adult spawning occurring in March through May, and juvenile outmigration occurring with the following spring runoff flows (February through June) (Ecovista 2003). A more detailed discussion of both species and their presence in the North Fork John Day and Camas Creek watersheds is provided below.

7.1.1 Summer Steelhead

John Day Basin steelhead are classified as "A-run" summer steelhead, as distinguished by a length at return of less than 78 cm and returning over Bonneville Dam primarily from July to September. In 2004 the ODFW, with financial support from the Bonneville Power Administration (BPA), started conducting standardized Environmental Monitoring and Assessment Program (EMAP) steelhead spawning ground surveys and juvenile salmonid surveys throughout the John Day River watershed (ODFW 2004). Many of these surveys were within the Camas Creek sub-basin. ODFW has also conducted PIT tagging and smolt trapping efforts for *O. mykiss* on the John Day River, but these data are unspecific to Camas Creek.

Spawning ground surveys indicated that summer steelhead construct redds from March through June in the John Day River watershed, including Camas Creek. ODFW has consistently observed that steelhead construct redds slightly later in the North Fork than in other sub-basins of the John Day River (ODFW 2013). Between 2004 and 2012, 22 sites within the Camas Creek sub-basin were selected for spawning ground surveys. One of these sites was surveyed annually, seven were selected to be surveyed on a four-year rotating cycle, and 14 were selected for only a single survey. Each site was 2.0-2.3 km in length and was surveyed one to four times during the spawning season. Over the nine surveys seasons, steelhead redds were documented at 11 (50%) of the 22 sites (ODFW 2013).

Between 2004 and 2007, 13 sites within the Camas Creek sub-basin were selected for juvenile salmonid surveys. From July to October each year, snorkeling or electrofishing methods were used to sample fish from each pool in the same reaches used for steelhead spawning ground surveys. *O. mykiss* were documented at 11 (84.6%) of the 13 sites. Comparatively, Chinook salmon were documented at only 2 (15.4%) of the 13 sites. ODFW also conducted mark-recapture surveys for juvenile *O. mykiss* across the John Day River watershed in 2011 and 2012. Four sample sites were located in the Camas Creek watershed. In both years the North Fork (which includes Camas Creek) had the second highest average densities of *O. mykiss* of all the John Day sub-basins, with 1.6 fish/m in 2011 and 1.4 fish/m in 2012 (ODFW 2013).

ODFW data suggest that Camas Creek and its tributaries provide significant spawning and rearing habitat for and are heavily used by summer steelhead.

7.1.2 Spring Chinook

Middle Columbia spring Chinook are not ESA listed, but are a key anadromous species in the John Day River system. Spring Chinook smolt at age 1 and spend 1 to 3 years in the ocean before they return to freshwater, passing Bonneville Dam from mid-April to early July. In the North Fork John Day River spring Chinook primarily spawn above the mouth of Camas Creek, including Camas Creek, Desolation Creek, Granite Creek, and other tributaries (ODFW 2013).

ODFW conducted exploratory Chinook spawning ground surveys on Camas Creek from 2000 to 2006. Surveys were conducted at varying locations along the mainstem and one tributary (Cable Creek) between August and October each year. In the year 2000, 30 km of stream were surveyed and only 3 Chinook redds were identified. From 2001 to 2006, an average of 2.68 km were surveyed each year and no redds were identified in any of the surveys (ODFW 2006).

Between 2004 and 2007, 13 sites within the Camas Creek sub-basin were selected for juvenile salmonid surveys. From July to October each year, snorkeling or electrofishing methods were used to sample fish from each pool in the same reaches used for steelhead spawning ground surveys. Juvenile Chinook were observed at 2 (15.4%) of the 13 sites. ODFW also conducted mark-recapture surveys for juvenile salmonids across the John Day River watershed in 2011 and 2012, but there were not enough juvenile Chinook present in Camas Creek and its tributaries to estimate abundance or density (ODFW 2013).

ODFW has also conducted PIT tagging and smolt trapping efforts for spring Chinook on the John Day River, but these data are not specific to Camas Creek.

ODFW surveys have shown that spring Chinook use the Camas Creek sub-basin for spawning and rearing. However, it is currently a minor spawning and rearing area, and O. mykiss appear to use Camas Creek and its tributaries much more than spring Chinook. This may be due to a general lack of spawning habitat, which could be improved with restoration of geomorphic processes with the PAOI and SAOI.

7.1.3 Data Gap

A key data gap for this study is the documentation of fish use by life history stage within the Primary AOI. During the September 2015 field assessment juvenile fish, presumed to be steelhead, were observed throughout the Primary AOI. In many locations these juveniles were stranded in a dewatered section of stream in shallow pools and without cover. A comprehensive survey of fish use throughout the yearly water cycle would help inform and direct future restoration actions.

7.2 Limiting Habitat Factors

As part of the overall assessment NSD conducted a reconnaissance to document habitat elements and riparian conditions within the primary area of interest from August 31 – September 3rd. This reconnaissance documented riparian conditions, instream habitat elements (pools, large wood), side channels, and areas of summer/low flow fish stranding. The field reconnaissance data was combined with analysis of the 2014 aerials in Table 8. Map 10 also shows the habitat assessment data.

The Warm Springs John Day River Restoration Strategy for the NFJD identifies altered sediment routing, degraded water quality, degraded riparian, degraded floodplain, and degraded channel conditions as primary limiting factors in Upper Camas Creek (both PAOI and SAOI)(CTWSRO 2014). Additionally, fish passage and altered hydrology are identified as limiting factors, but to a lesser degree than other impaired processes in Upper Camas (CTWSRO 2014). As observed in the field, fish use between Pine Creek to just below Cable Creek may be non-existent in the PAOI in some years due to low or subsurface flow between RM 14 and 12.3 (Map 10) and high water temperatures (Ecovista 2003). Additional factors that likely impact both adult and juvenile life history stages include summer fish stranding through the town of Ukiah, and limited floodplain connectivity and ability for fish access to off-channel habitats for rearing and over wintering throughout the PAOI. Reach 6 (immediately below Ukiah) is the one exception to this, which currently contains some intact floodplain and numerous pools, but lacks overall riparian cover and habitat complexity. The poor riparian quality in the PAOI is primarily attributed to historical land clearing and long-term and persistent grazing and browsing impacts. The lack of a robust riparian community has resulted in reduced channel shading and higher stream temperatures, a lack of large wood recruitment and a similar reduction in pool formation (Ecovista 2003).

Based on ODFW and the field data, the pool frequency and large wood loading are both below "desirable" conditions (Ecovista 2003). Pool frequency ranged from 0 pools/mi. to 1.6 pools/mi in reaches through or above Ukiah in the primary area of interest, which is well below the ODFW criteria for a "desirable" condition (~15 pools/mi). Large wood loading ranged from 0 key pieces/mi. to 10.1 pieces/mi., which is below the ODFW criteria for a "desirable" condition (> 20 pieces/mi) (Ecovista 2003).

The lack of pools, large wood, the predominant riffle habitat, lack of summer flow, and poor riparian quality identified during the field survey in 2015 all correlate to the primary limiting factors for steelhead and Chinook salmon within Camas Creek as documented in the Camas Creek Watershed Assessment (Ecovista 2003). The Watershed Assessment documented the following limiting factors and their primary causal mechanisms:

- Habitat simplification (lack of pools and large wood),
    - Riparian timber harvest and roads.
- High stream temperatures,
    - Riparian timber harvest and roads, lack of canopy cover.
- Flow variation,
    - Subwatershed timber harvest, riparian roads and high road density, cutbank and ditch erosion, soil compaction, soil and water detention and storage capacity, and bedrock storage capacity.
- Sediment.
    - Subwatershed timber harvest, riparian roads and high road density, surface erosion, slumps and slides, subsoil erosion, cutbank and ditch erosion.

The Watershed Assessment also ranked the subwatersheds which contribute the greatest to limiting steelhead and Chinook salmon production or survival based on the four primary limiting factors. These subwatersheds from highest to lowest are:

- Lower Owens Creek
- Bowman Creek
- Snipe Creek
- Cable Creek
- Camas/Wilkins Creek
- Upper Owens Creek
- Hidaway Creek
- Lane Creek
- Lower Camas Creek.

This list provides a good framework for the implementation of future restoration actions as described in the Action Plan.

8. LIMITATIONS

We have prepared this report for the Confederated Tribe of the Umatilla Indian Reservation, their authorized agents and regulatory agencies responsible for the Camas Creek geomorphic assessment and action plan project. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices for geomorphology in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

We appreciate this opportunity to be of service to the CTUIR for this project and look forward to continuing to work with you. Please call if you have any questions regarding this report, or if you need additional information.

Sincerely,

Natural Systems Design, Inc.

John Soden, MS, PWS
Senior Biologist

Mike Ericsson, MS, PG
Project Geomorphologist

Tim Abbe, PhD, PEG, PHG
Principal Geomorphologist

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Maps

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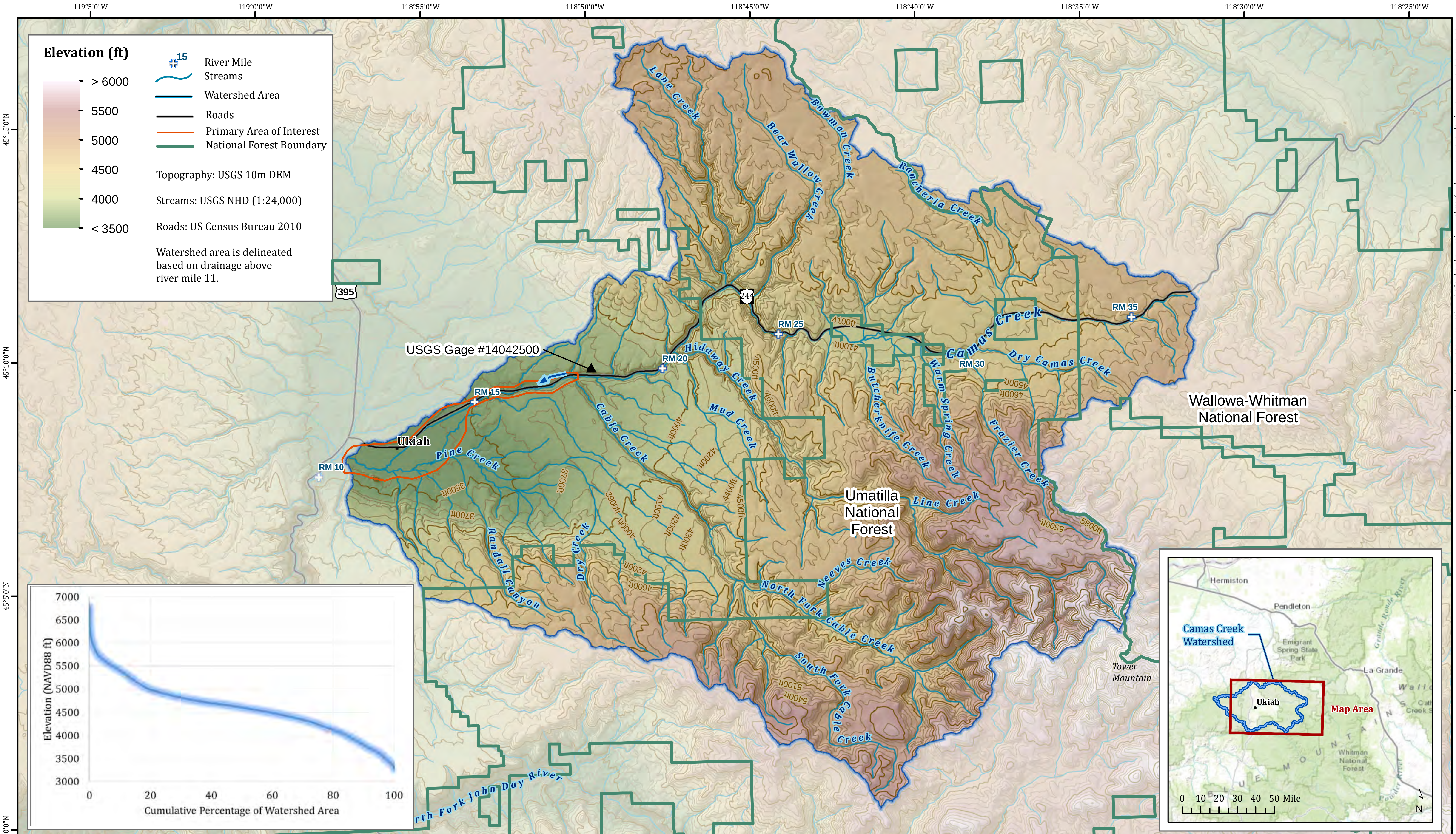
P.O. Box 15609, Seattle, WA 98105 T: (206) 834-0175



Camas Creek Geomorphic Assessment & Action Plan

Map 1 - Shaded Relief Map

Topographic data source: USGS 10 meter DEM

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 100 ft

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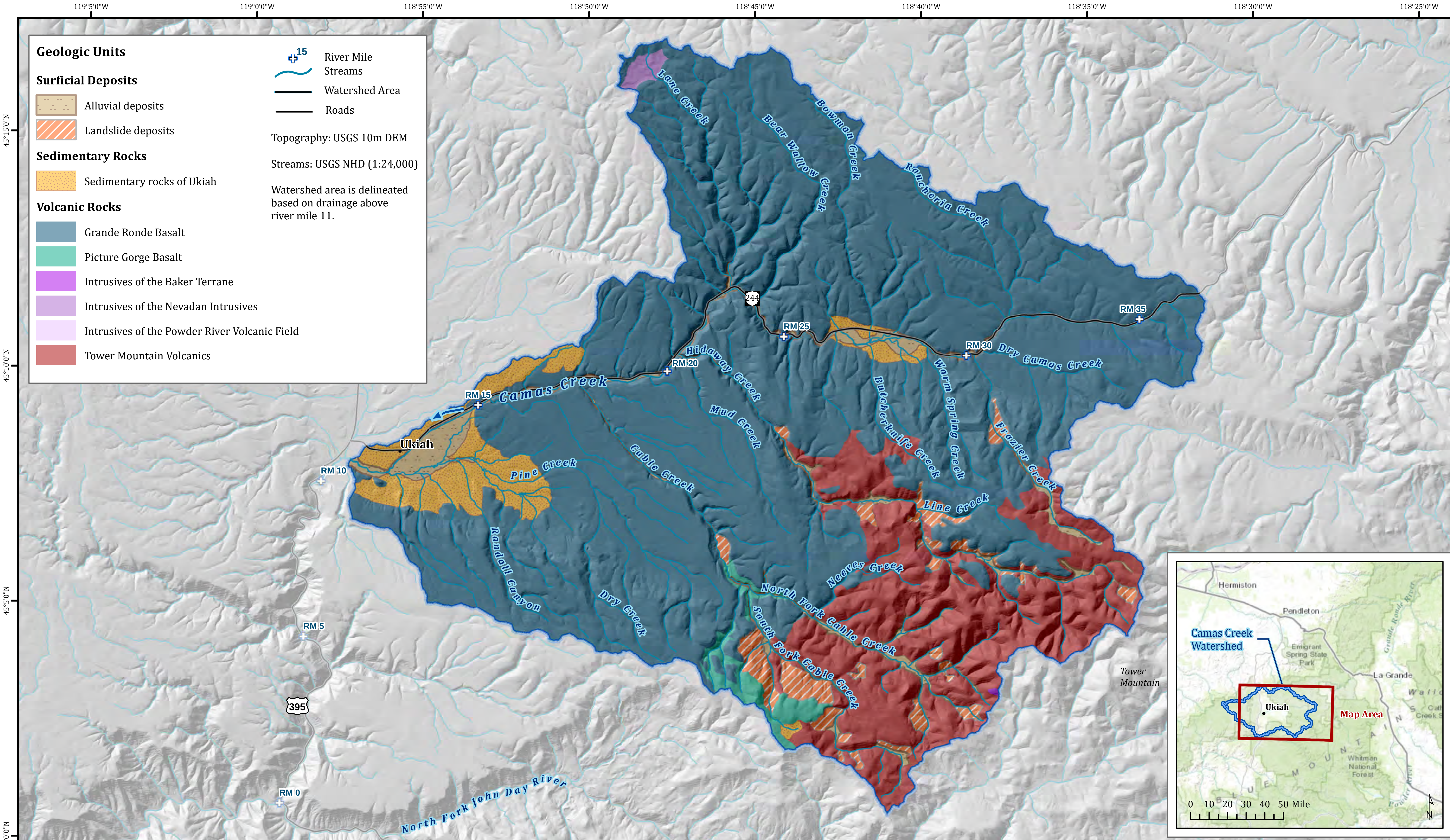

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Camas Creek Geomorphic Assessment & Action Plan

Map 2 - Geologic Units

Surficial geology compiled by the Oregon Department of Geology and Mineral Industries (DOGAMI 2009).

N

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

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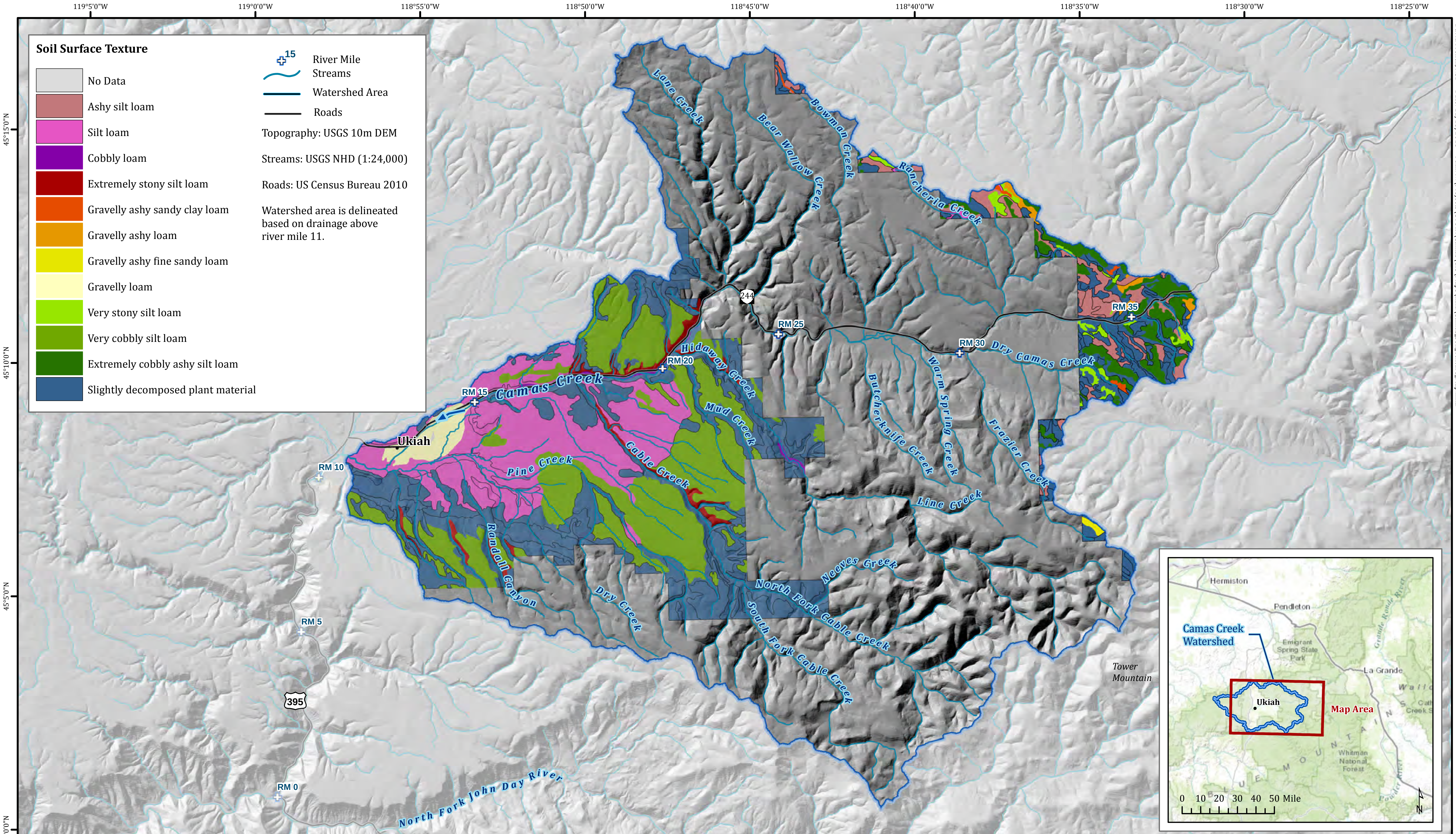


Camas Creek Geomorphic Assessment & Action Plan

Map 3 - Soil Surface Texture Map

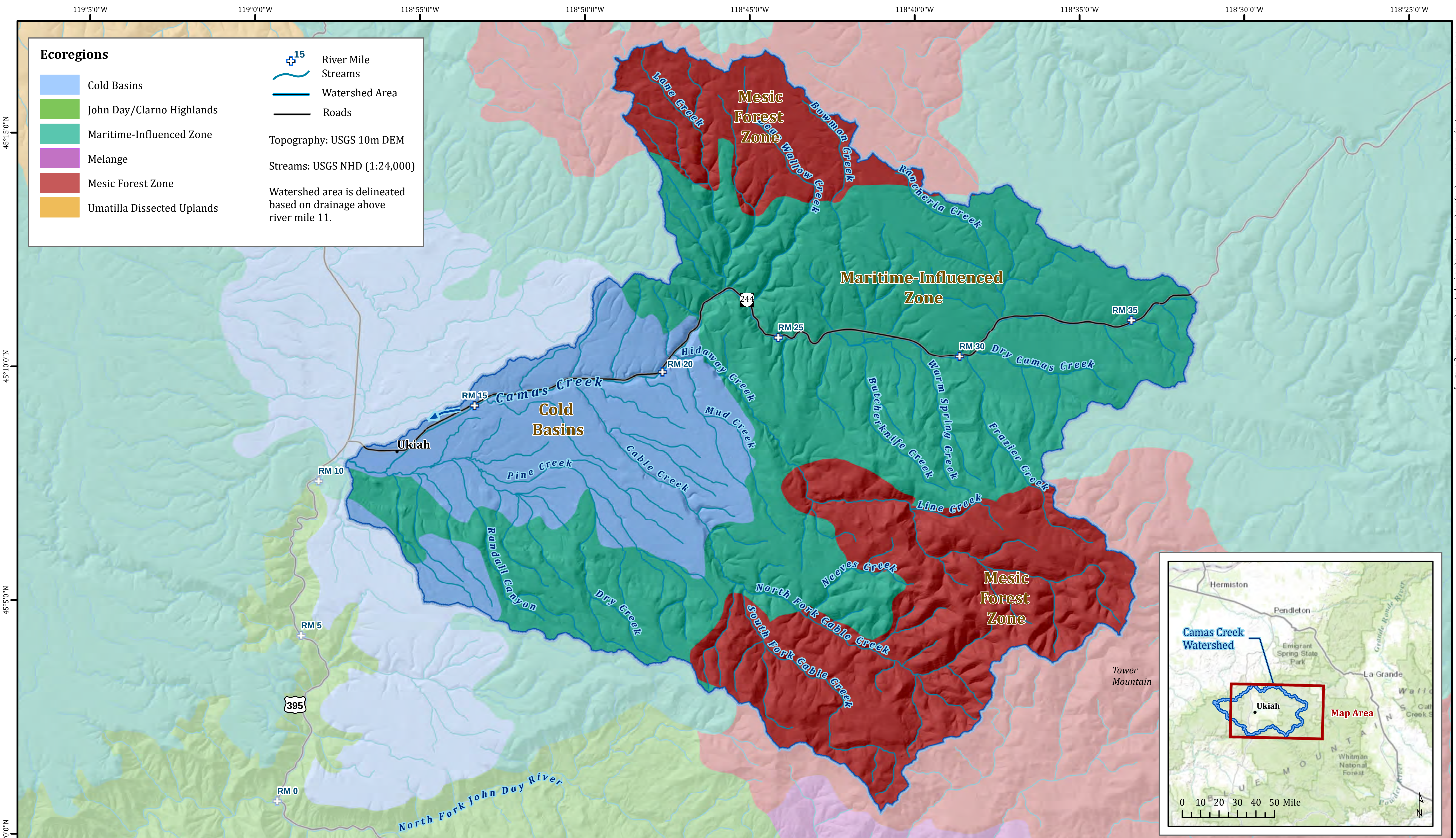
Soil data from SSURGO datasets for Umatilla and Union Counties (NRCS). Mapped soil units for Umatilla National Forest are not yet available.Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. "Loam," for example, is soil that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If the content of particles coarser than sand is 15 percent or more, an appropriate modifier is added, for example, "gravelly."

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 100 ft

Natural Systems Design



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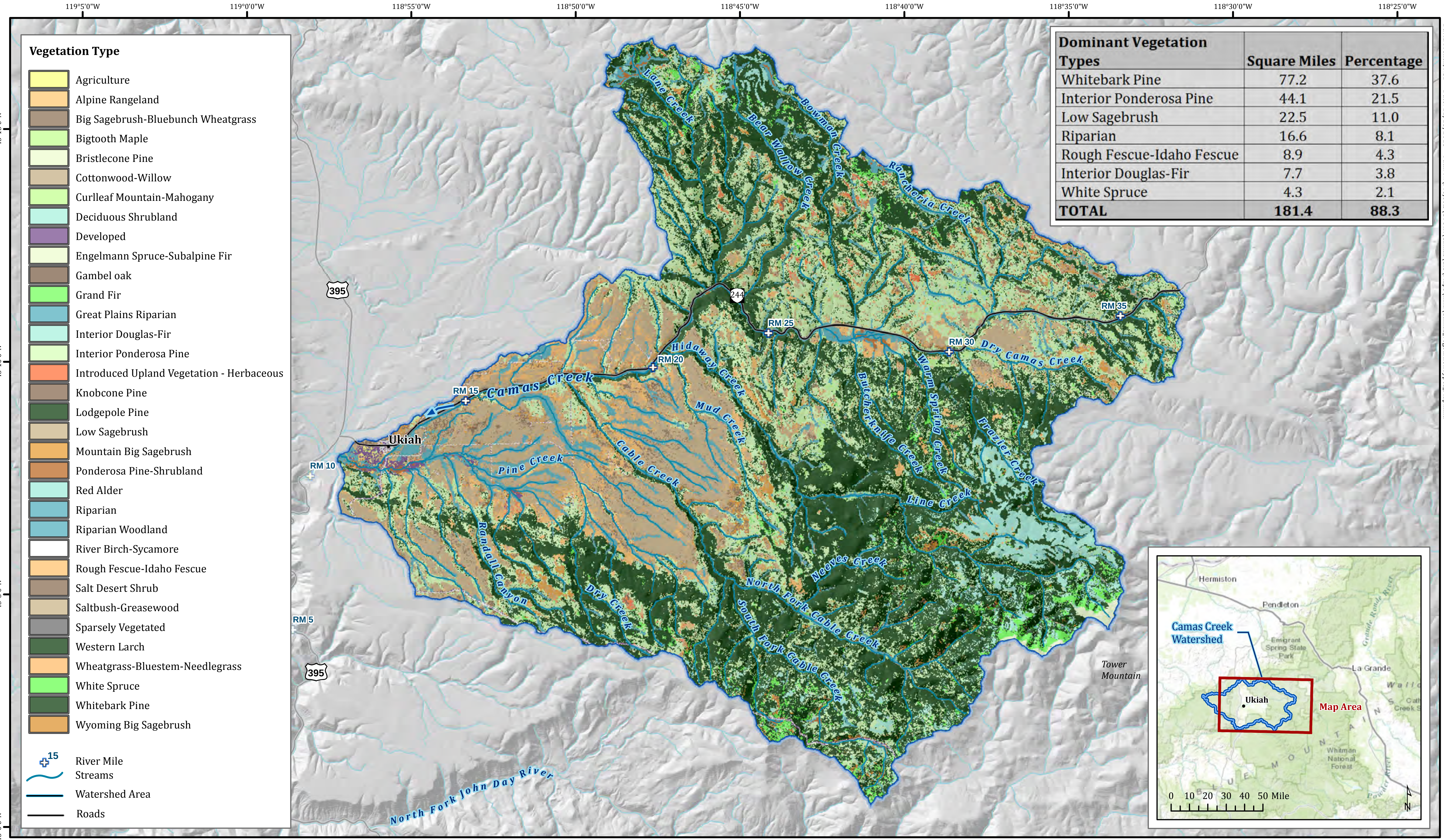
Camas Creek Geomorphic Assessment & Action Plan

Map 4 - Camas Watershed Ecoregions

Level 4 Ecoregions compiled by the U.S. Environmental Protection Agency (2012).

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Dominant Vegetation Types	Square Miles	Percentage
Whitebark Pine	77.2	37.6
Interior Ponderosa Pine	44.1	21.5
Low Sagebrush	22.5	11.0
Riparian	16.6	8.1
Rough Fescue-Idaho Fescue	8.9	4.3
Interior Douglas-Fir	7.7	3.8
White Spruce	4.3	2.1
TOTAL	**181.4**	**88.3**

Camas Creek Geomorphic Assessment & Action Plan

Map 5 - Watershed Vegetation Types

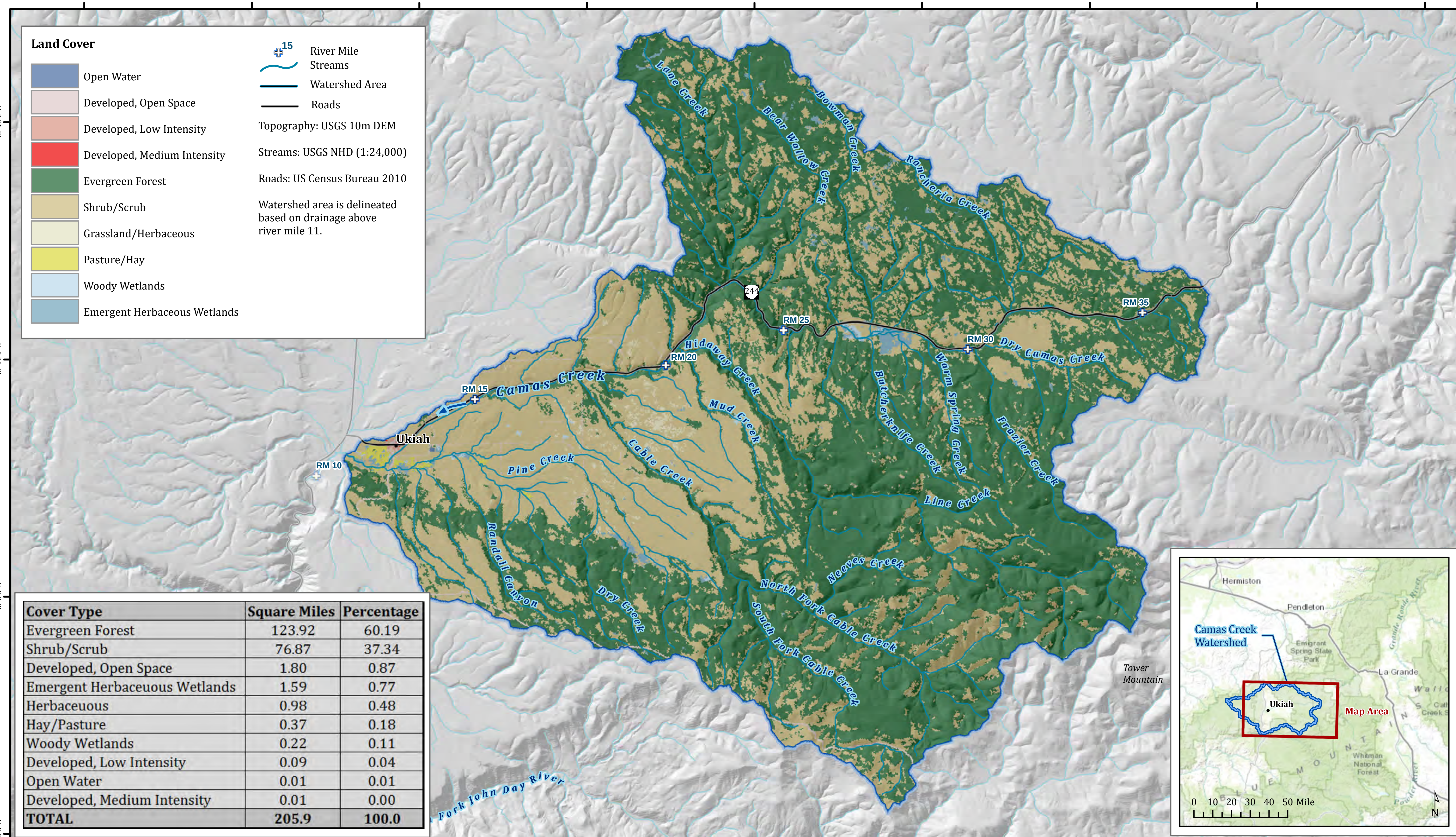
Vegetation types are mapped by USGS as part of the Landfire database (2012) using predictive landscape models based on extensive field reference data, satellite imagery, biophysical gradient layers, and classification and regression trees.
Data sources: USGS 10m DEM , USGS NHD (1:24,000), US Census Bureau 2010 Roads.
Watershed area is delineated based on drainage aboveriver mile 11.

N

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Cover Type	Square Miles	Percentage
Evergreen Forest	123.92	60.19
Shrub/Scrub	76.87	37.34
Developed, Open Space	1.80	0.87
Emergent Herbaceuous Wetlands	1.59	0.77
Herbaceuous	0.98	0.48
Hay/Pasture	0.37	0.18
Woody Wetlands	0.22	0.11
Developed, Low Intensity	0.09	0.04
Open Water	0.01	0.01
Developed, Medium Intensity	0.01	0.00
TOTAL	**205.9**	**100.0**

Camas Creek Geomorphic Assessment & Action Plan

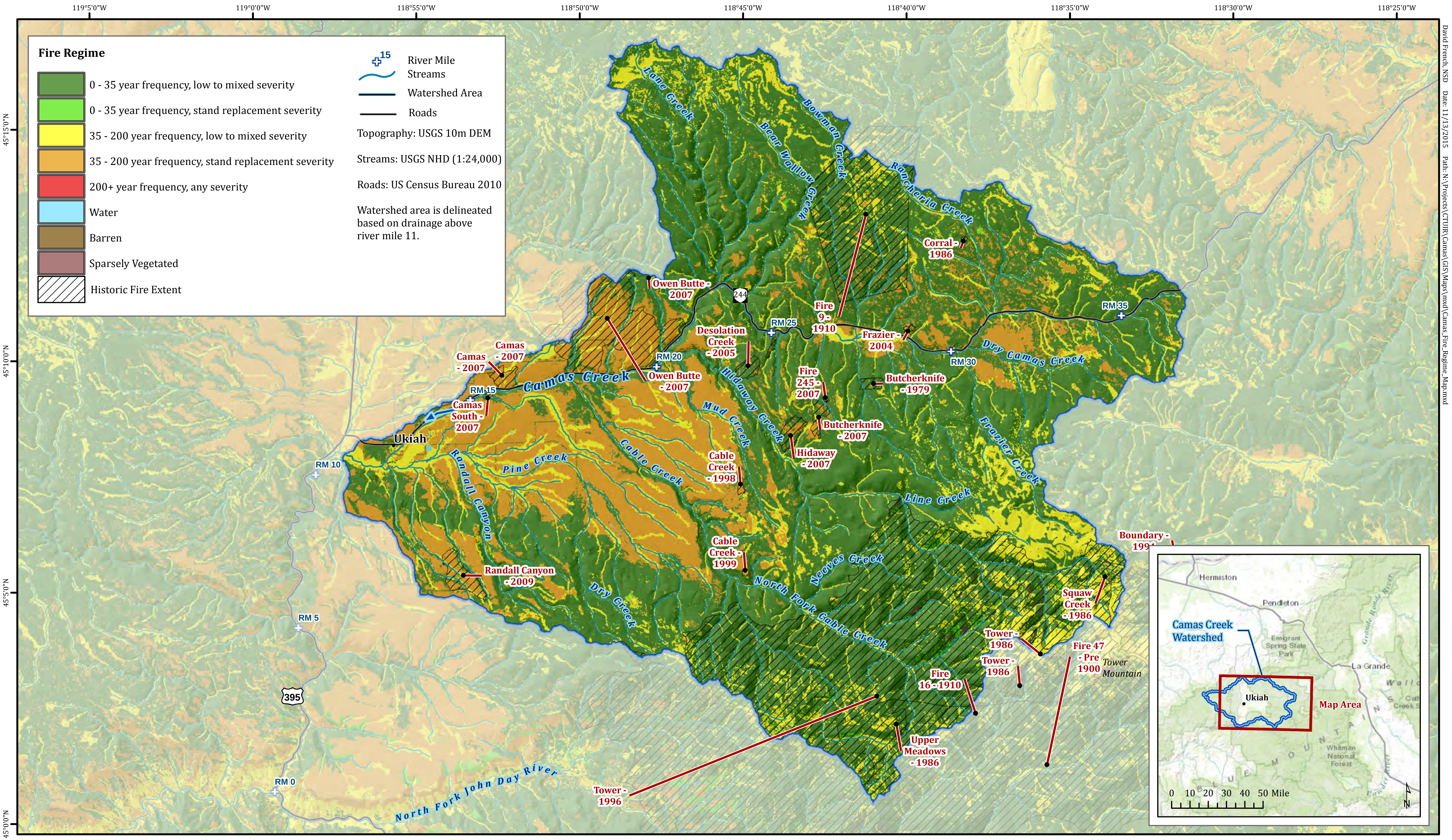
Map 6 - National Land Cover Database - 2006

National Land Cover Database (NLCD) is a land cover classification scheme applied to the conterminous U.S. at a spatial resolution of 30 meters and is based on interpretation of Landsat satellite data (Fry et al. 2011).

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

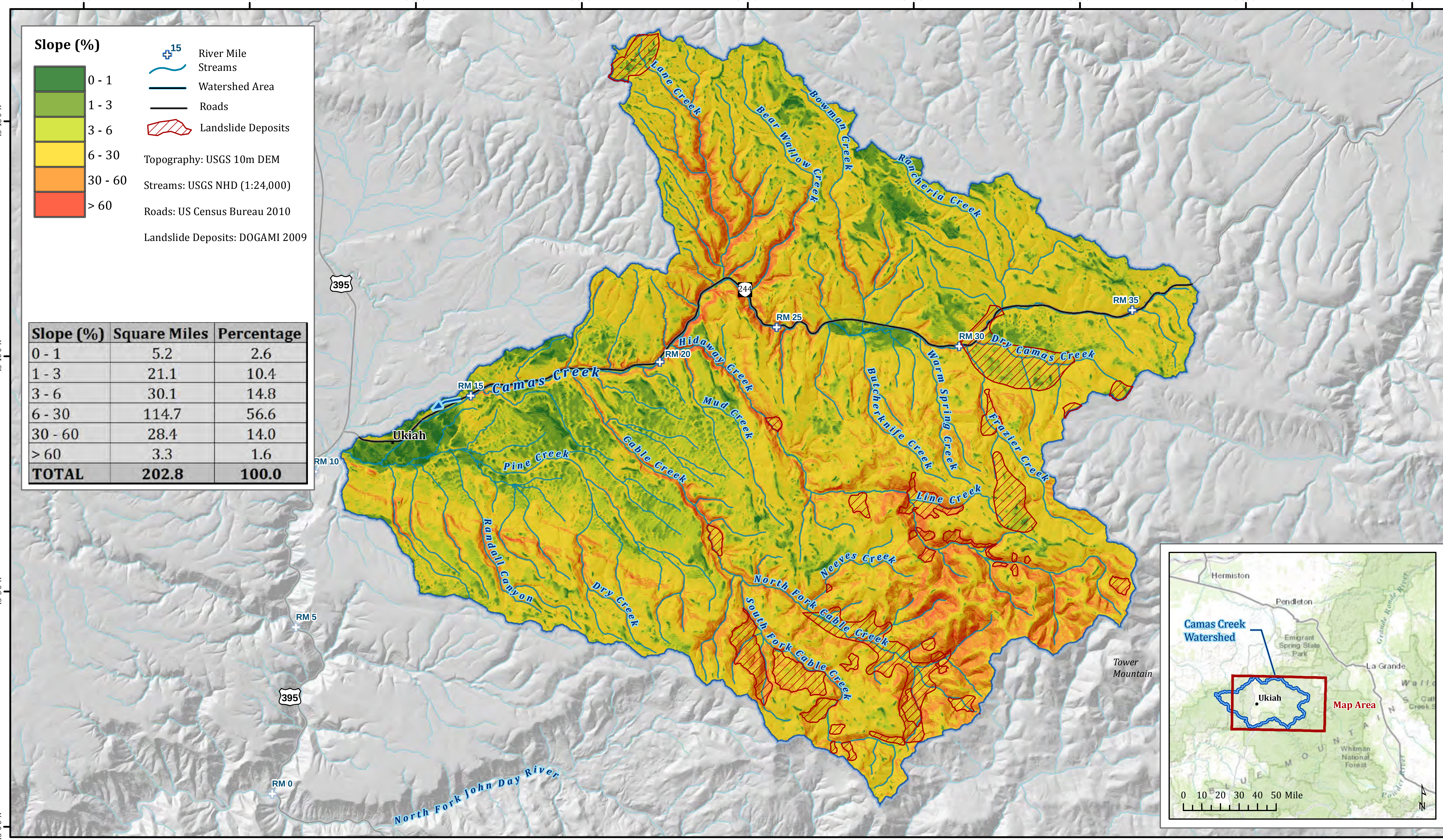
Map 7 - Fire Regimes and Historic Burns

Fire regime data extracted from USGS Landfire 2012 dataset. Historic fire extents from Umatilla National Forest 2015.

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Slope (%)	Square Miles	Percentage
0 - 1	5.2	2.6
1 - 3	21.1	10.4
3 - 6	30.1	14.8
6 - 30	114.7	56.6
30 - 60	28.4	14.0
> 60	3.3	1.6
TOTAL	**202.8**	**100.0**

Camas Creek Geomorphic Assessment & Action Plan

Map 8 - Watershed Slope and Landslide Mapping

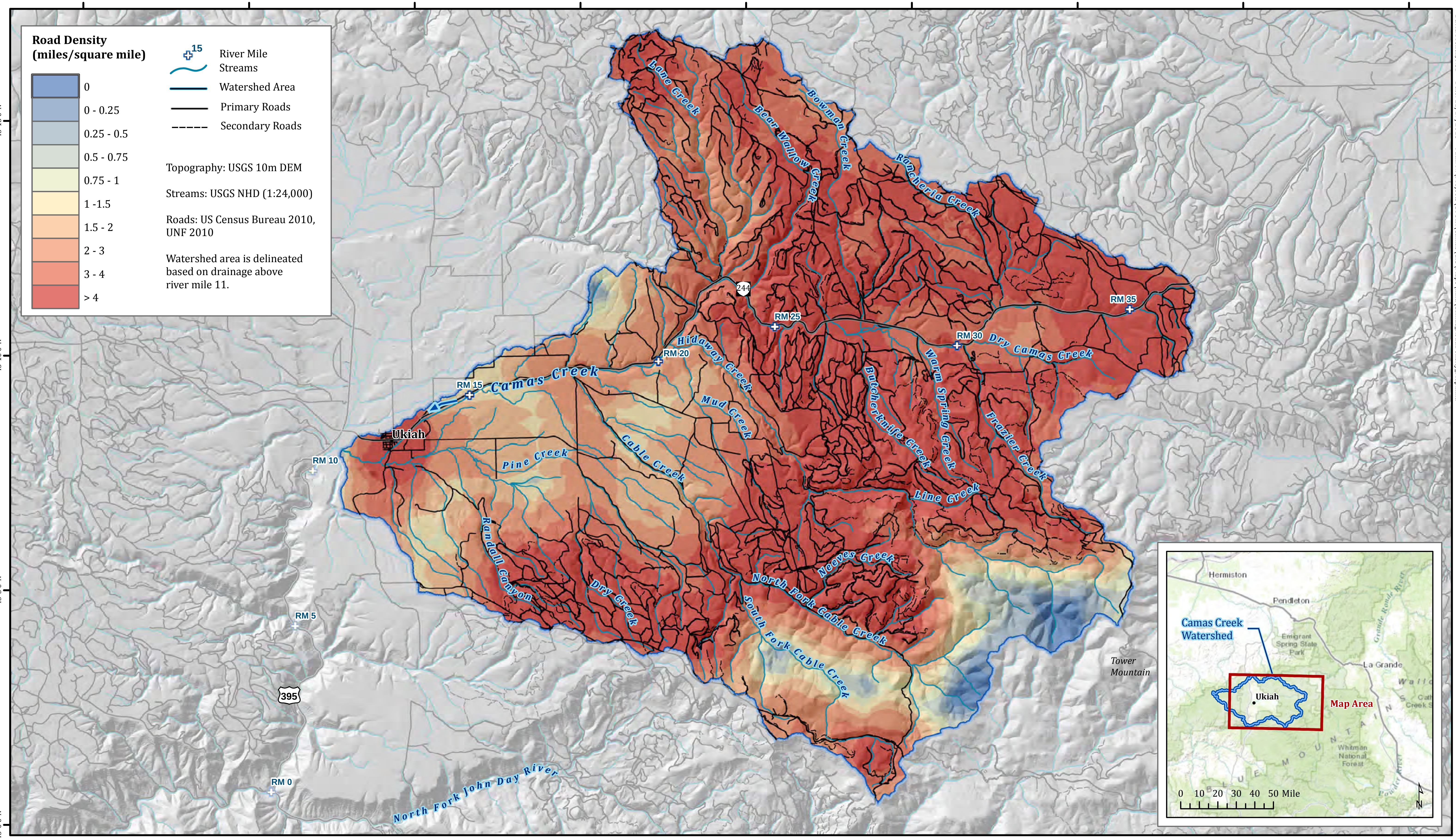
Topographic data source: USGS 10 meter DEM

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 100 ft

Natural Systems Design



David French, NSD Date: 11/17/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Camas_RoadDensity_Map.mxd

Camas Creek Geomorphic Assessment & Action Plan

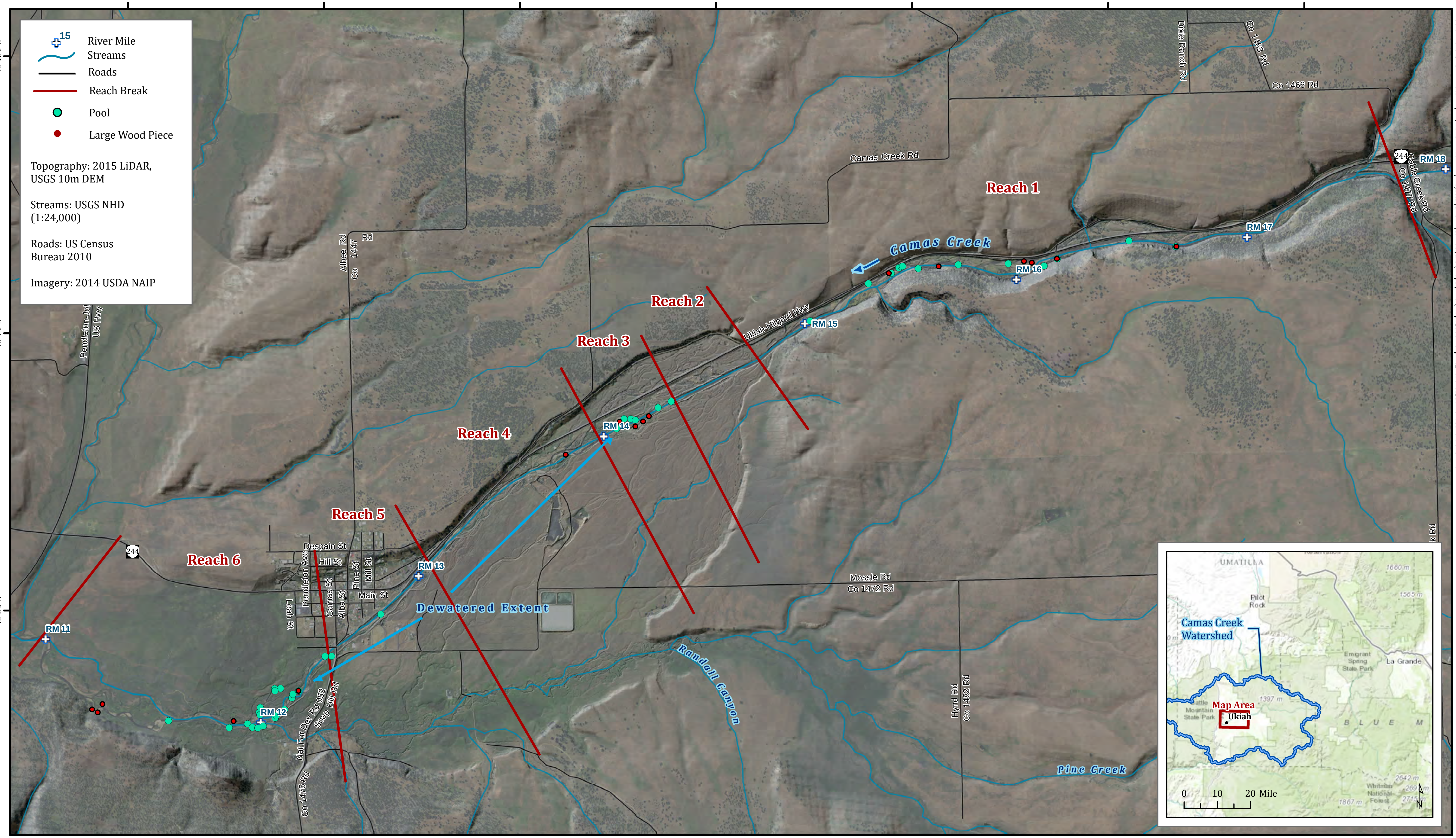
Map 9 - Road Density in the Camas Watershed

Road density is derived as the number of linear miles of motor vehicle roadway per square mile of drainage area.

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Map 10 - Geomorphic Reaches and Current Conditions

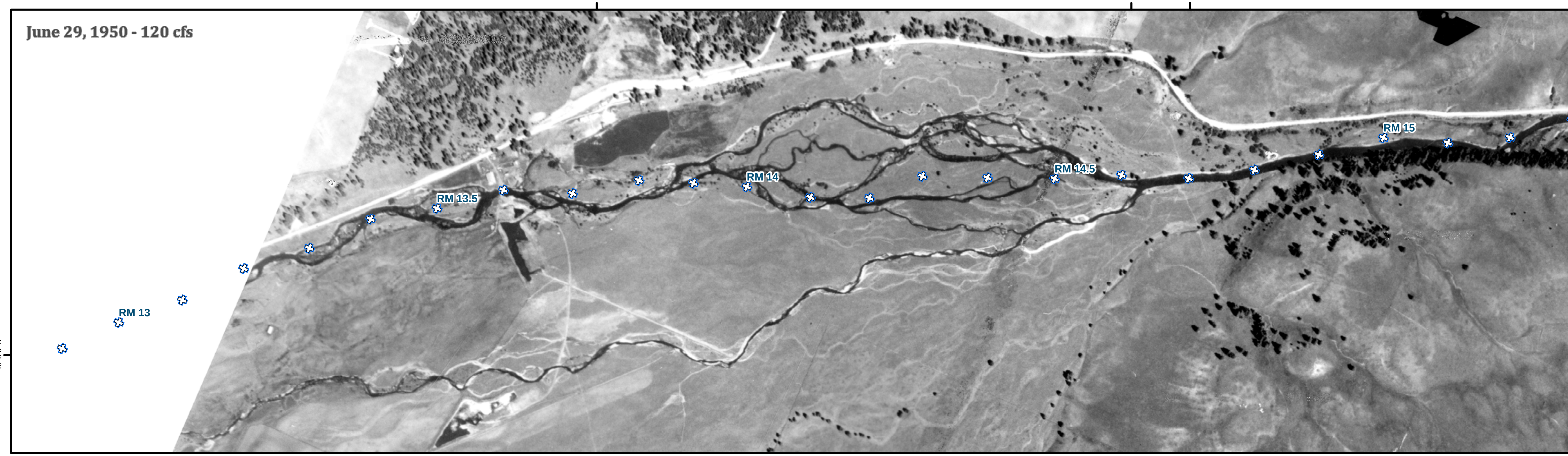
Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.

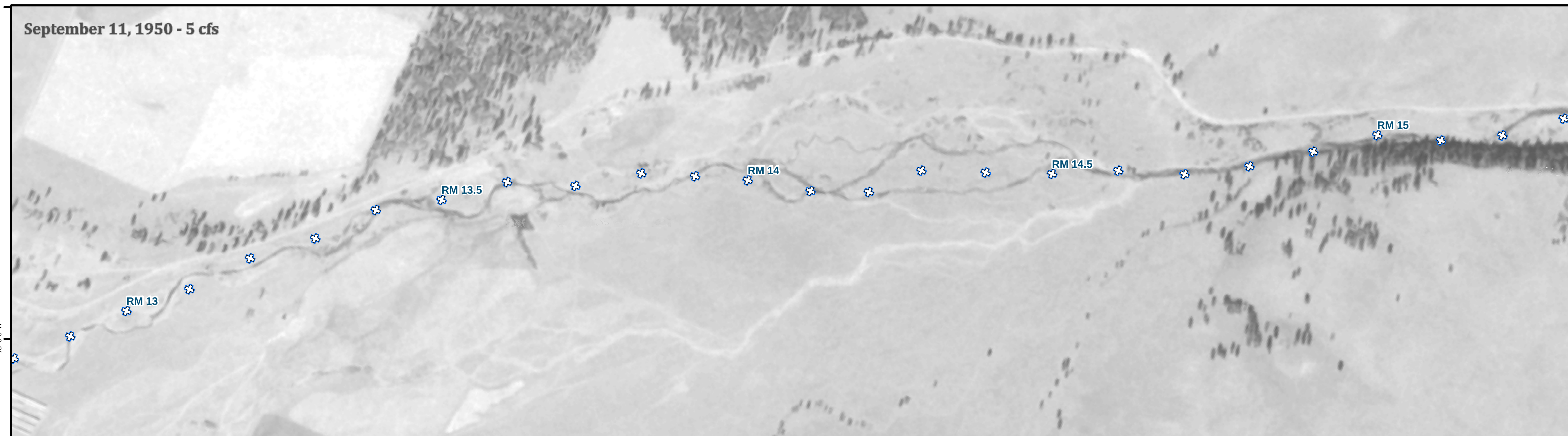
N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design





David French, NSD Date: 11/17/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Map10_1950s_Aerial_Photos_2Pane.mxd

Camas Creek Geomorphic Assessment & Action Plan

Map 11 - June and September 1950 Aerial Photos

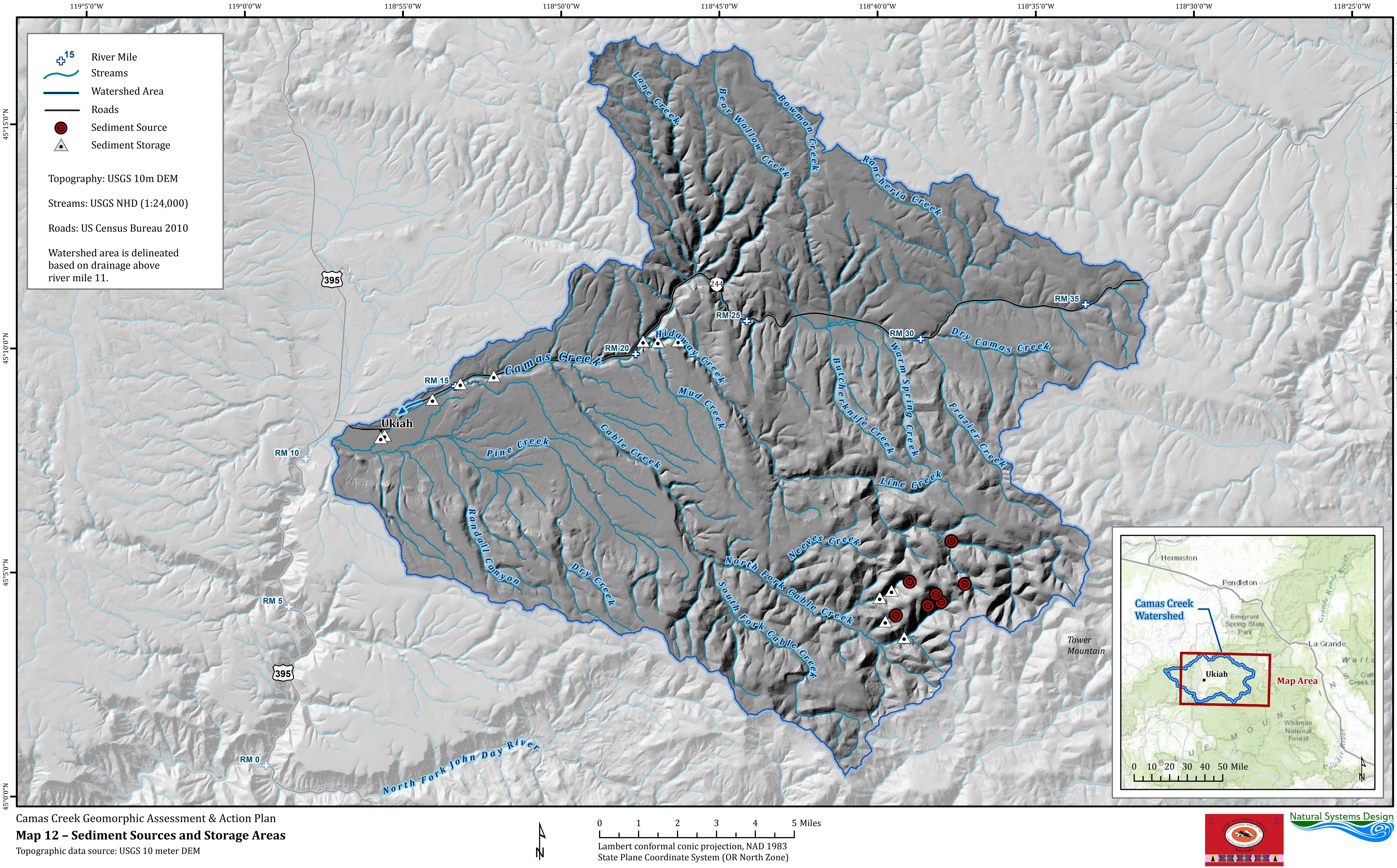
Data courtesy of USGS Earth Explorer and CTUIR

0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

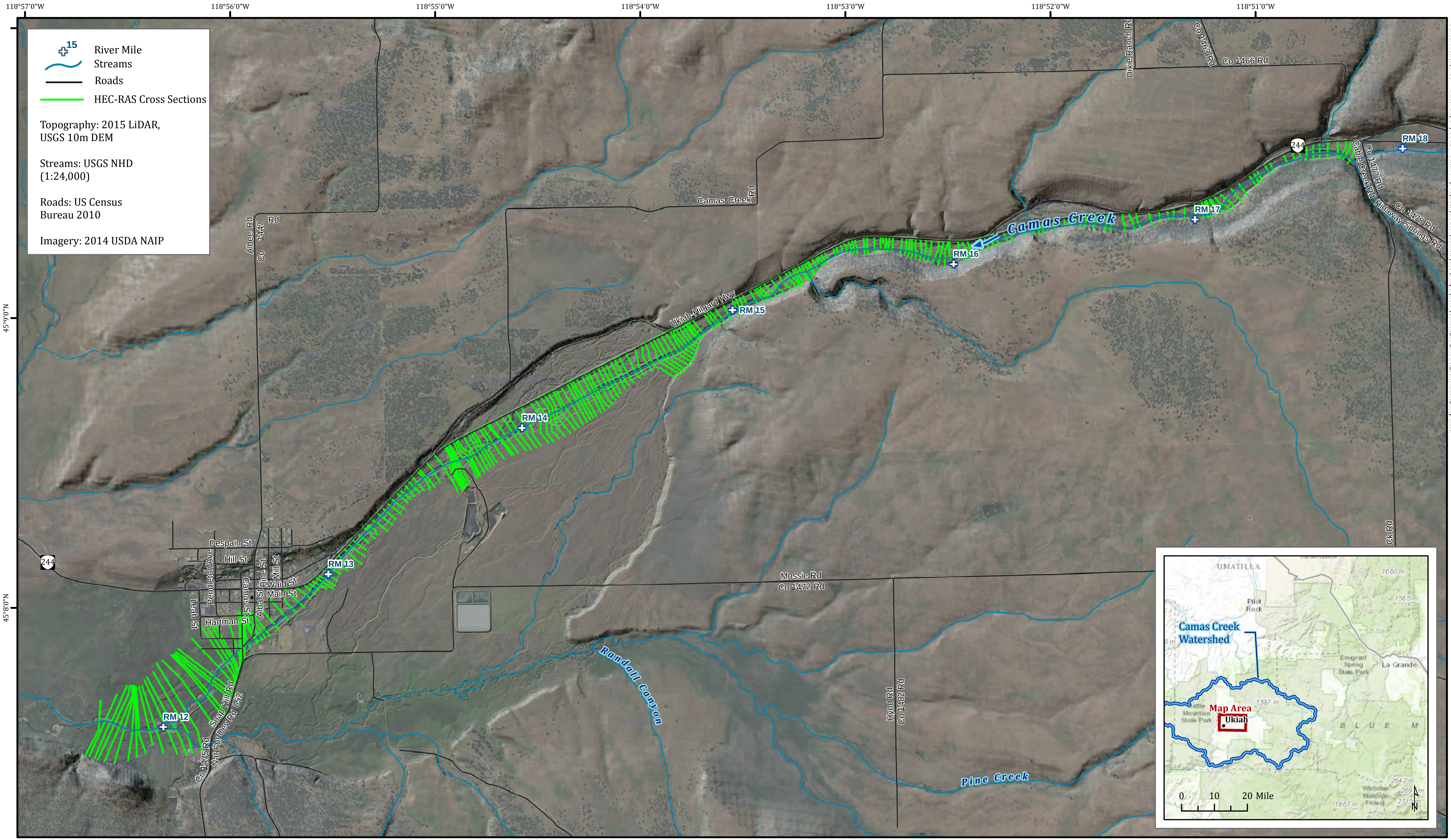
Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Map 12 – Sediment Sources and Storage Areas

Topographic data source: USGS 10 meter DEM



Camas Creek Geomorphic Assessment & Action Plan

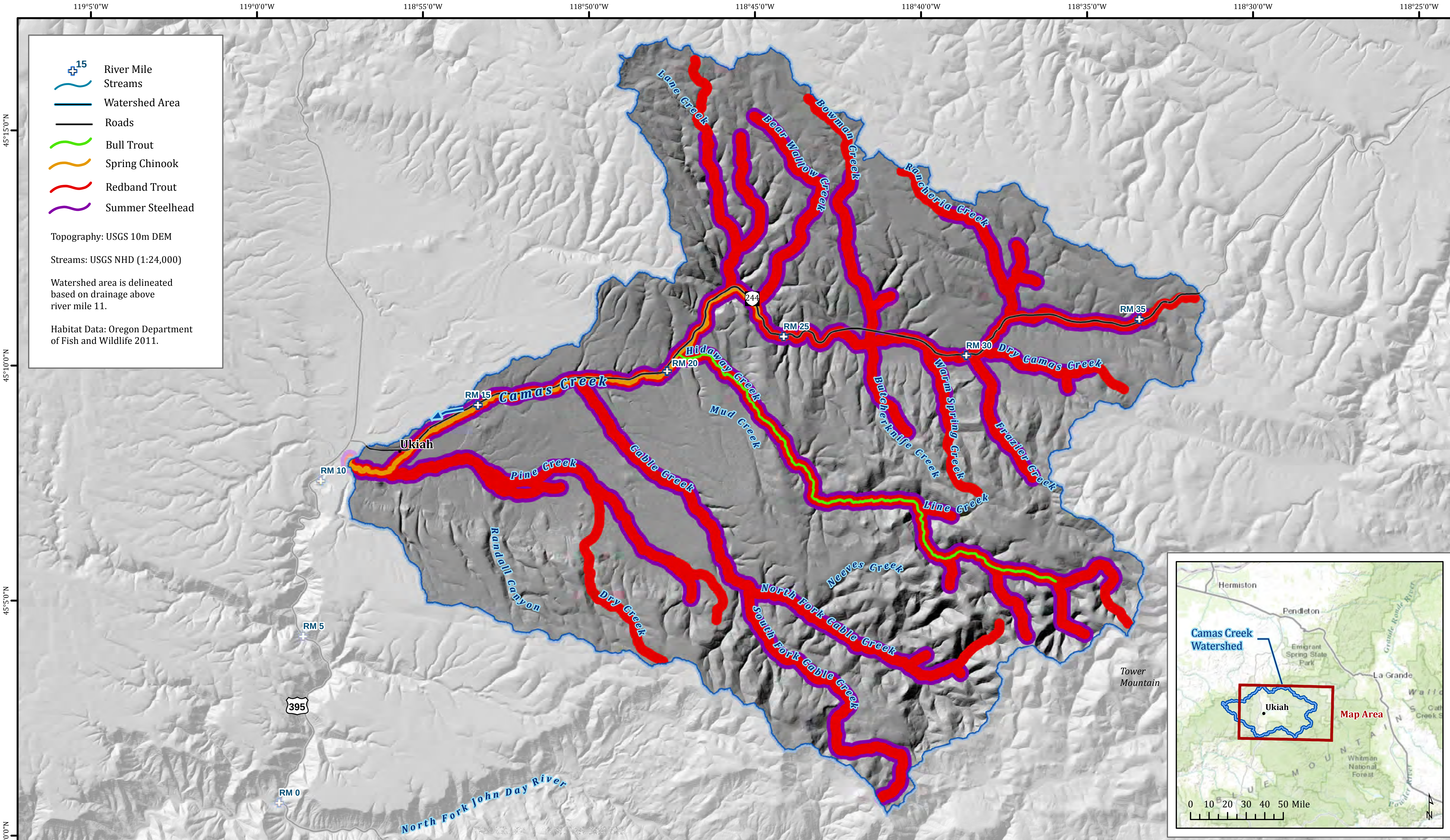
Map 13 - 1D Model Schematic Map

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Map 14 - Fish Habitat Distributions

Fish habitat distributions represent both current and historic fish usage based on habitat criteria adopted by ODFW in 2014.

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

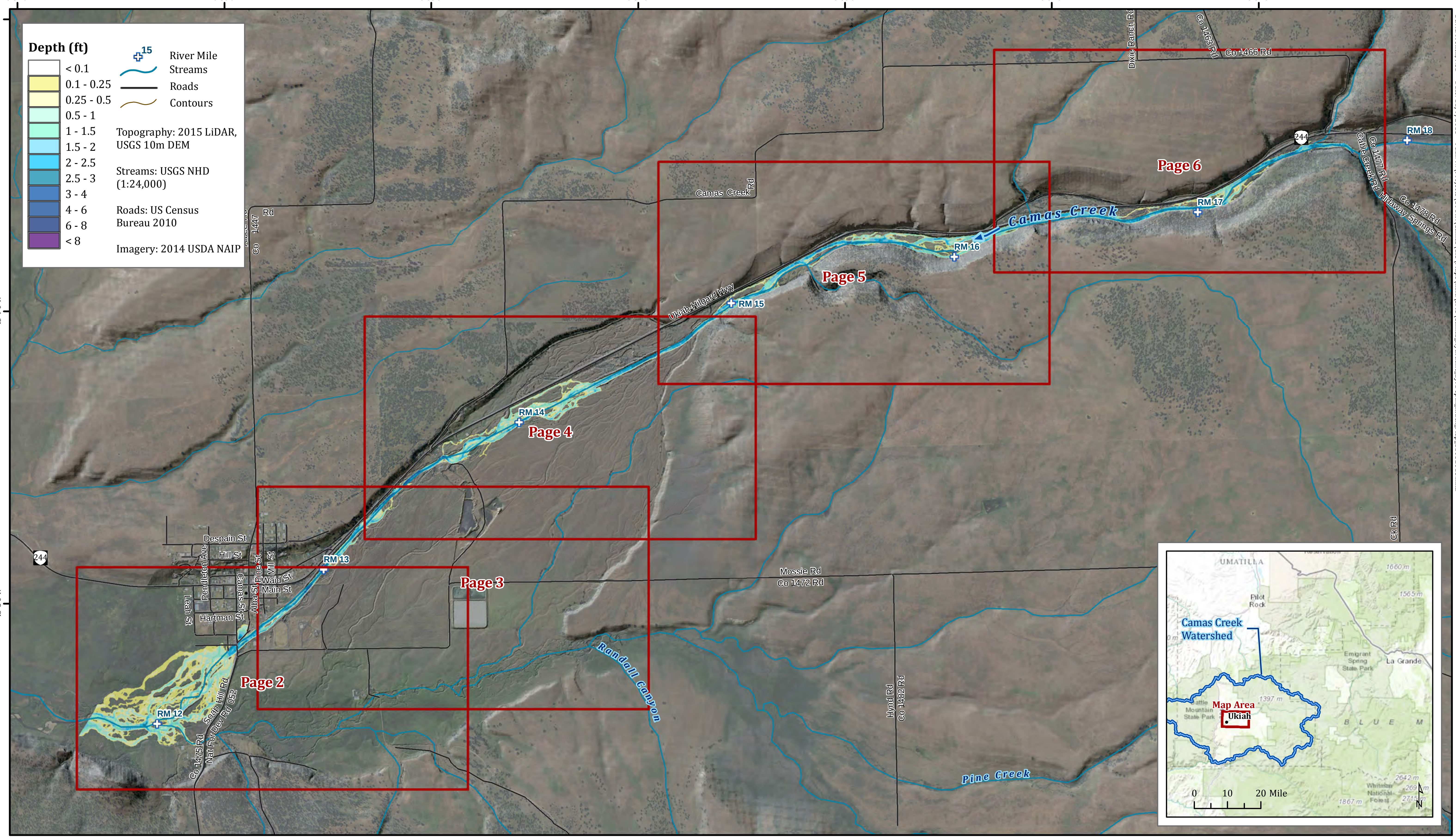
Natural Systems Design

APPENDIX A

2D Hydraulic Model Results

Natural Systems Design

P.O. Box 15609, Seattle, WA 98105 T: (206) 834-0175



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Depth Map Book - Page 1 of 6

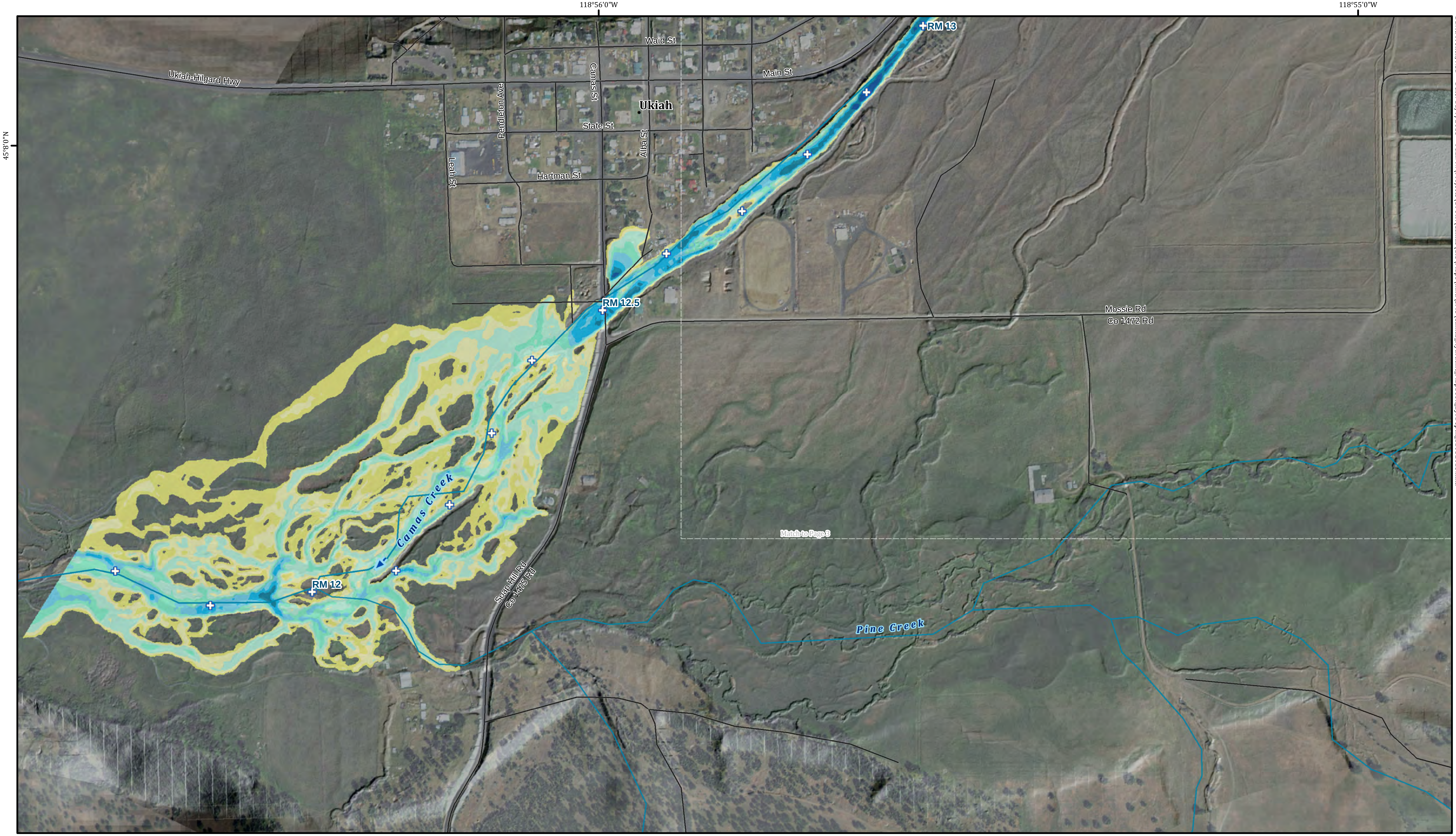
Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design

David French, NSD Date: 11/9/2015



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Depth - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

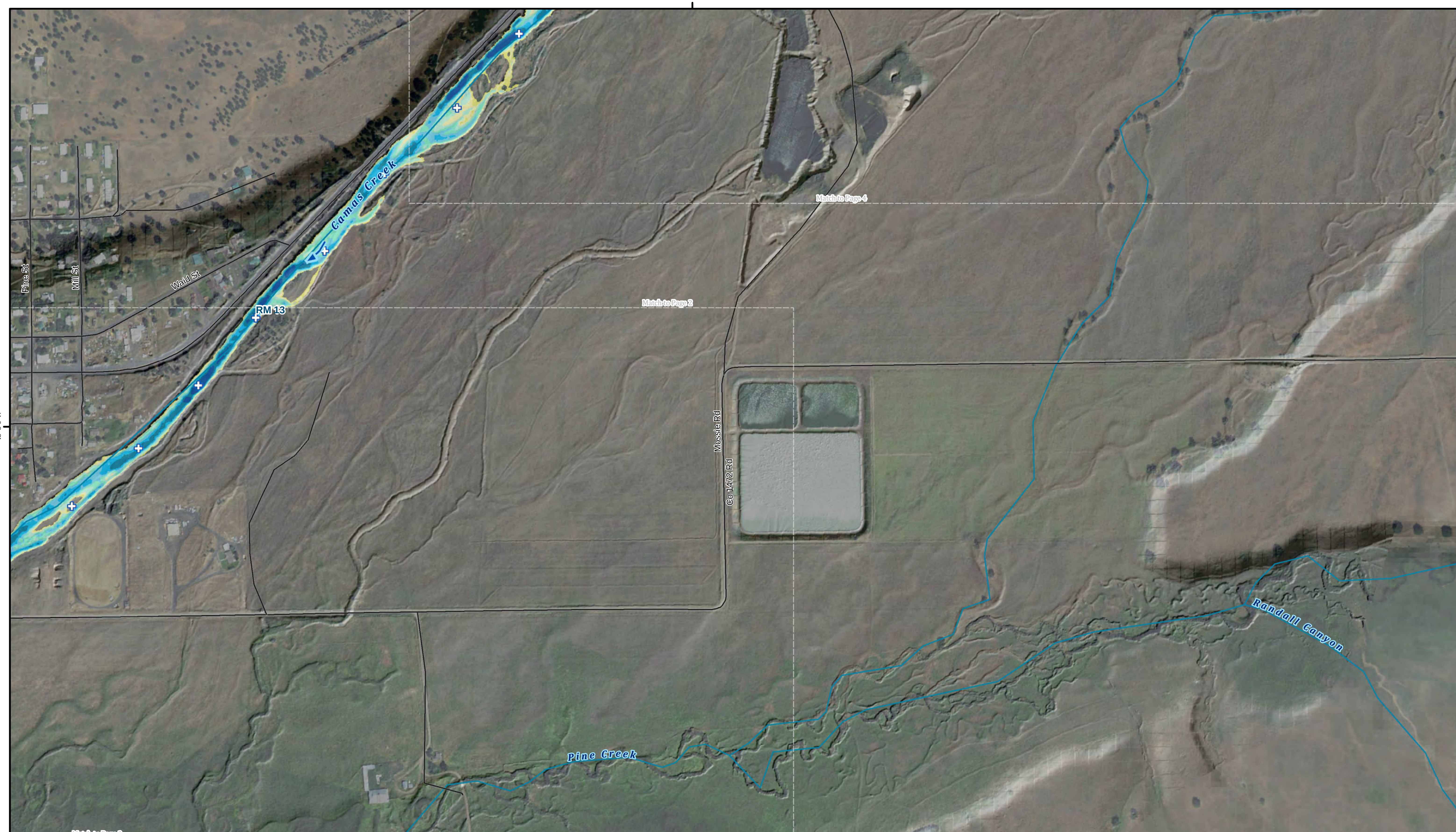
Depth (ft)

< 0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, 3 - 4, 4 - 6, 6 - 8, > 8

15 River Mile
Streams
Roads

Natural Systems Design

118°55'0"W
118°54'0"W
45°8'0"N



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Depth - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

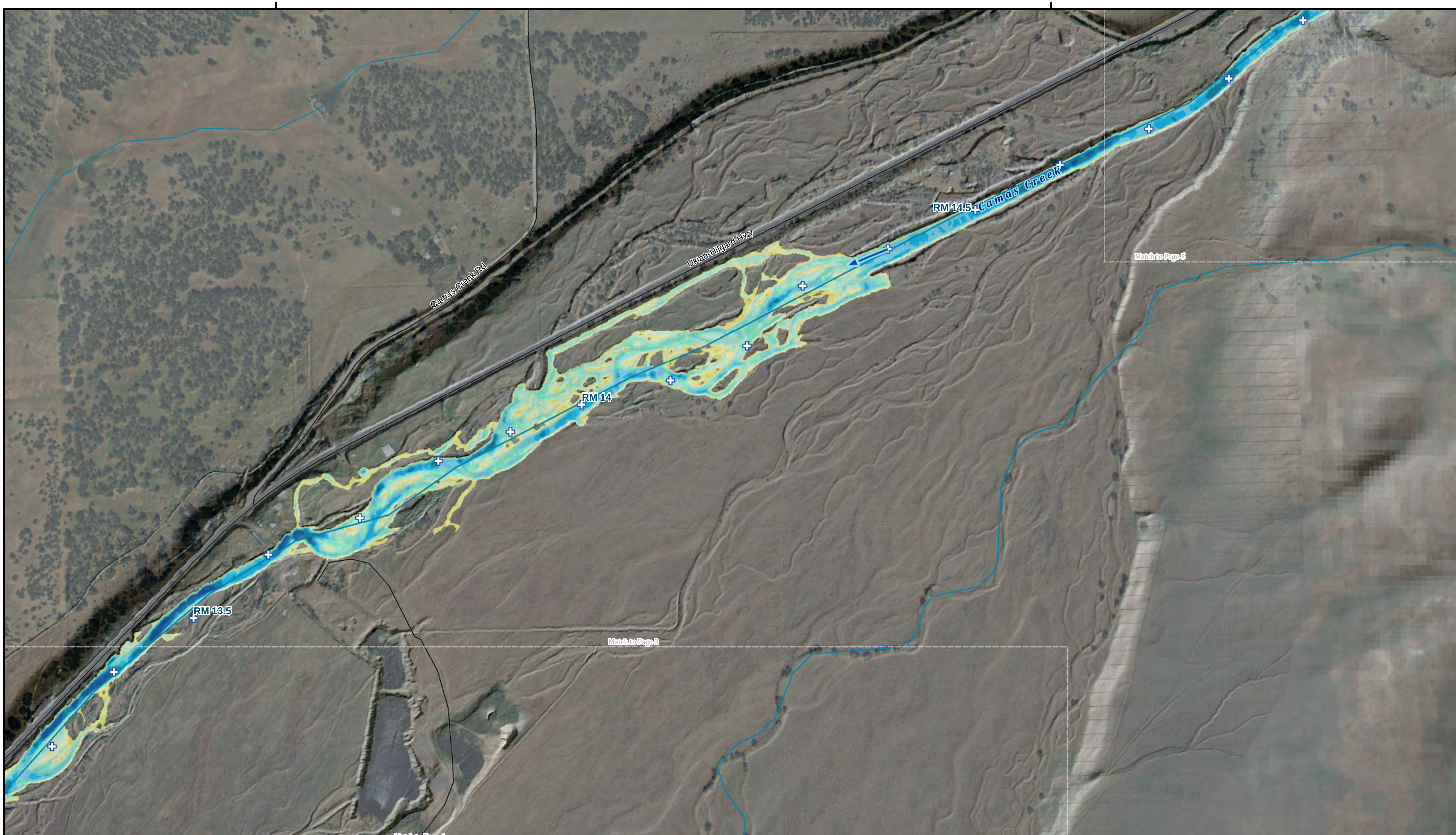
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, 3 - 4, 4 - 6, 6 - 8, > 8

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Depth - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
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Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, 3 - 4, 4 - 6, 6 - 8, > 8

15 River Mile
Streams
Roads

Natural Systems Design

David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_2yrDepth_11052015.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Depth - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
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Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

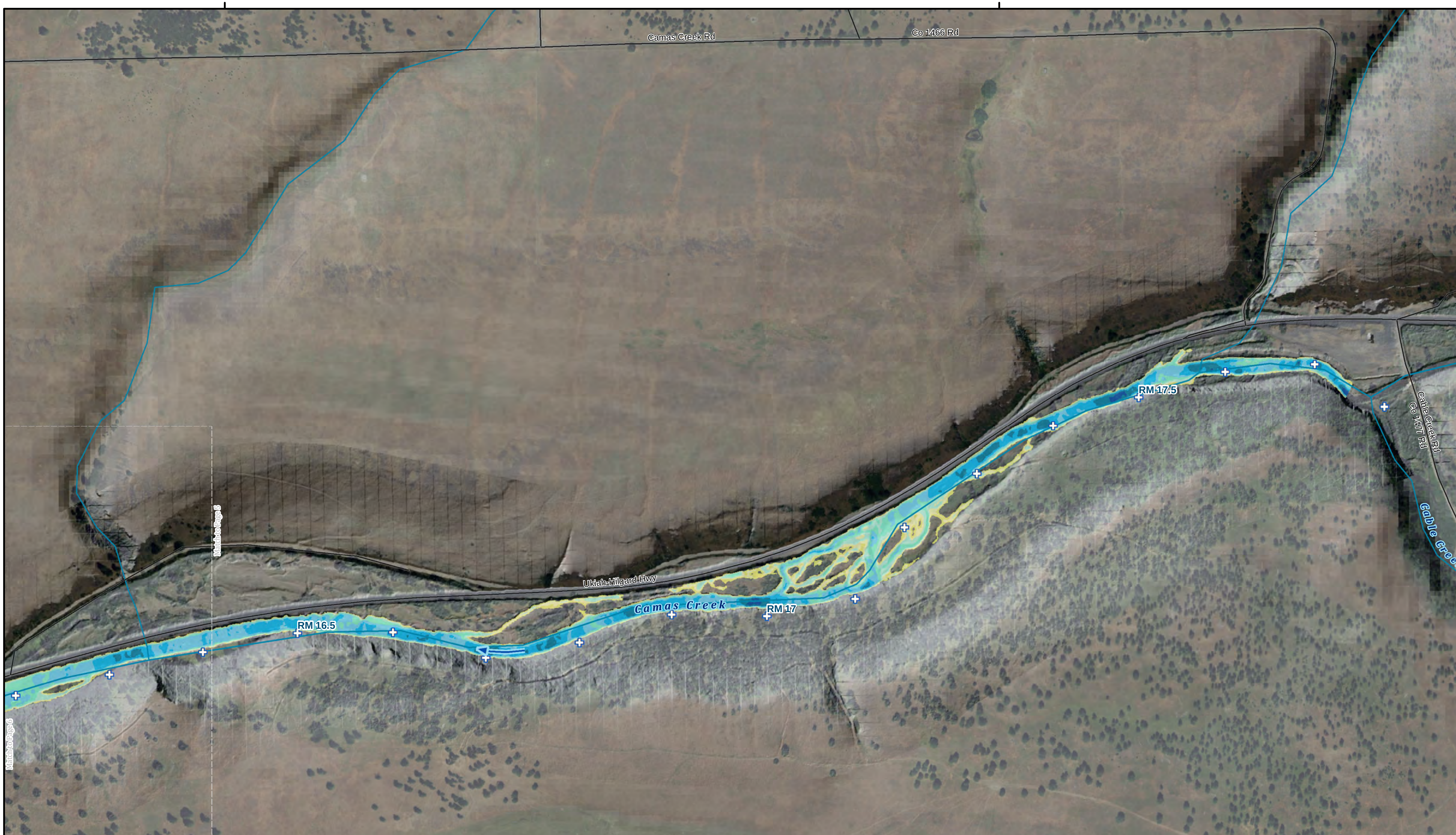
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, 3 - 4, 4 - 6, 6 - 8, > 8

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Depth - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
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Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

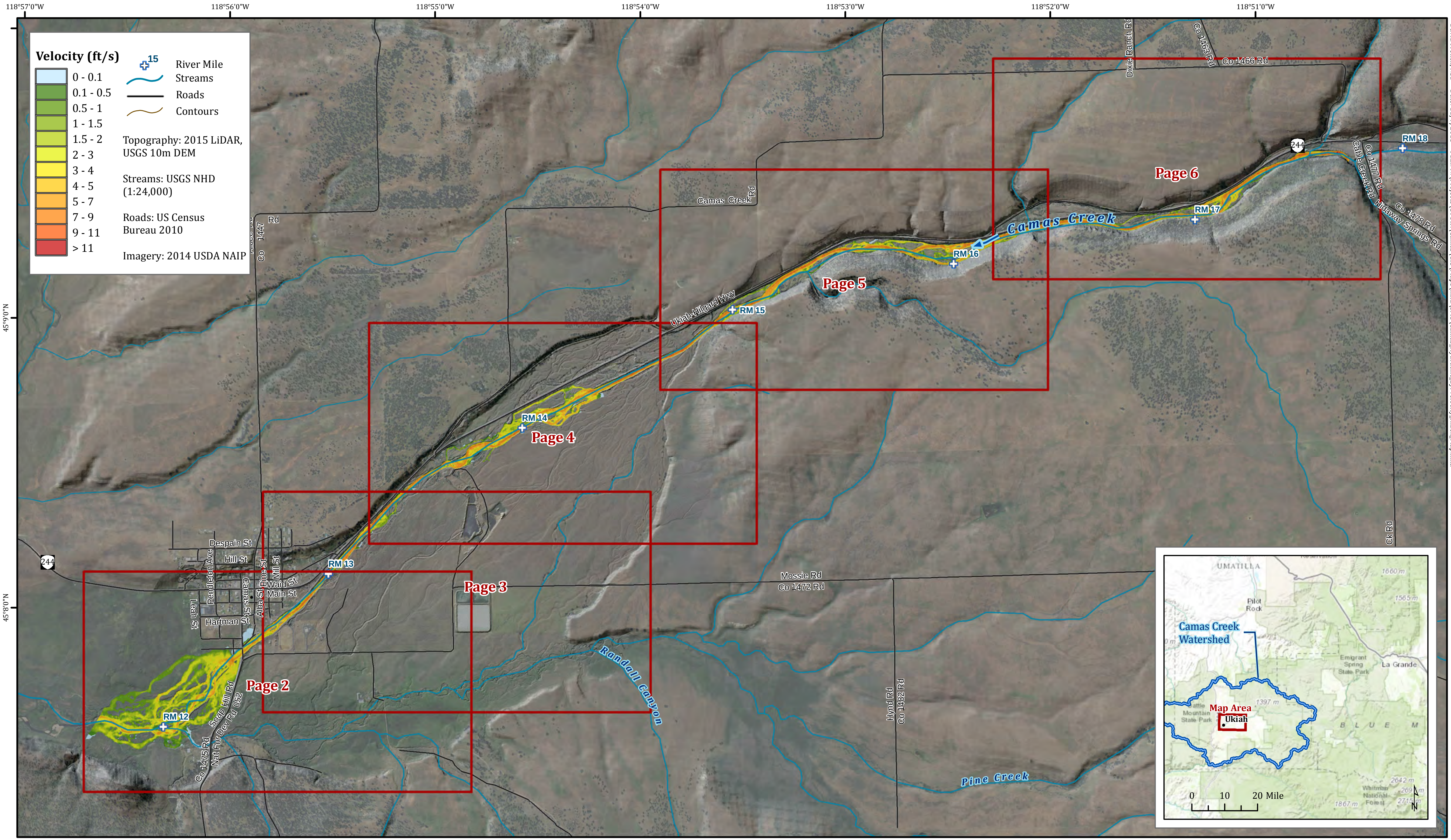
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 3, 3 - 4, 4 - 6, 6 - 8, > 8

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Velocity Map Book - Page 1 of 6

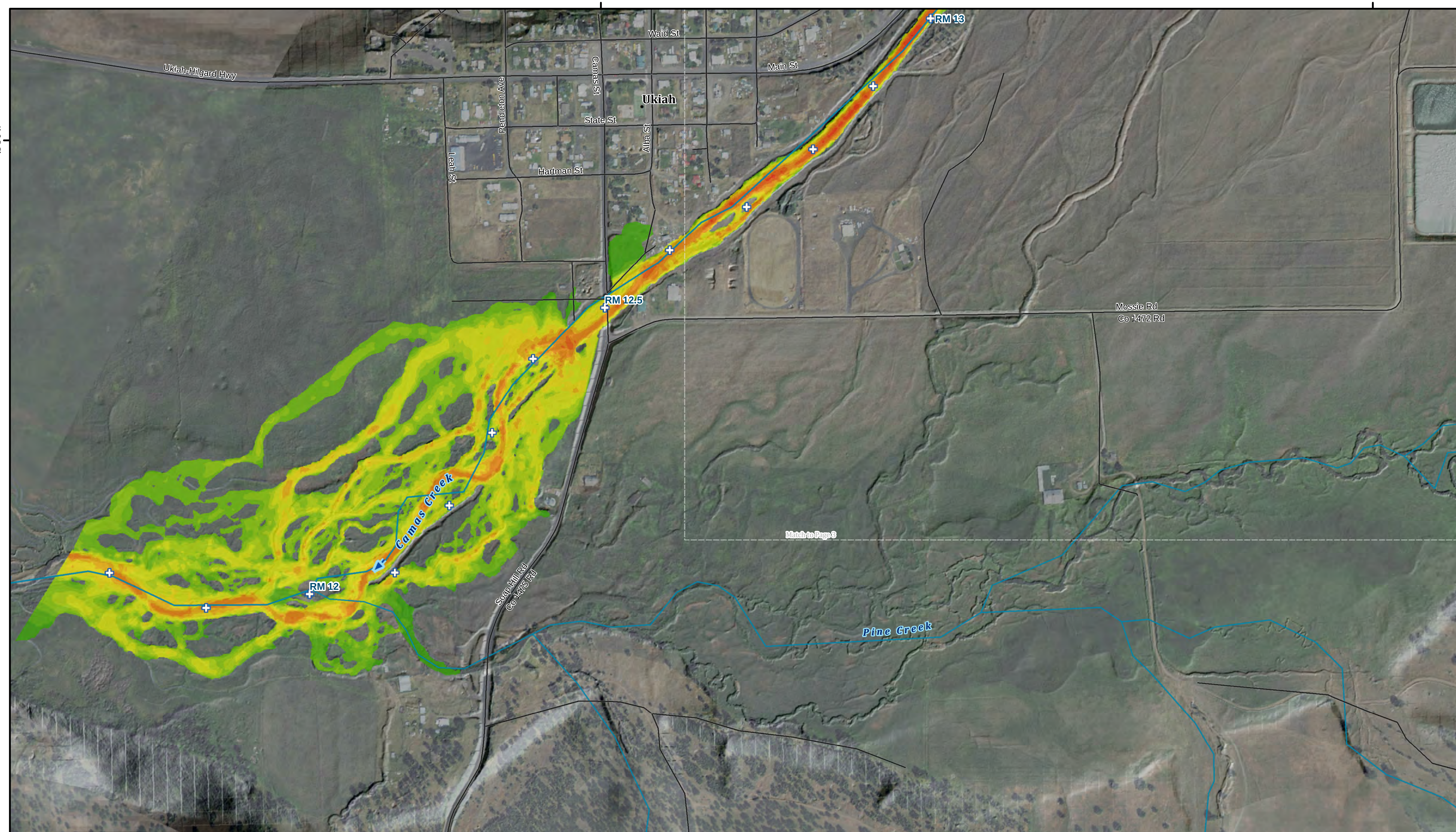
Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Velocity - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

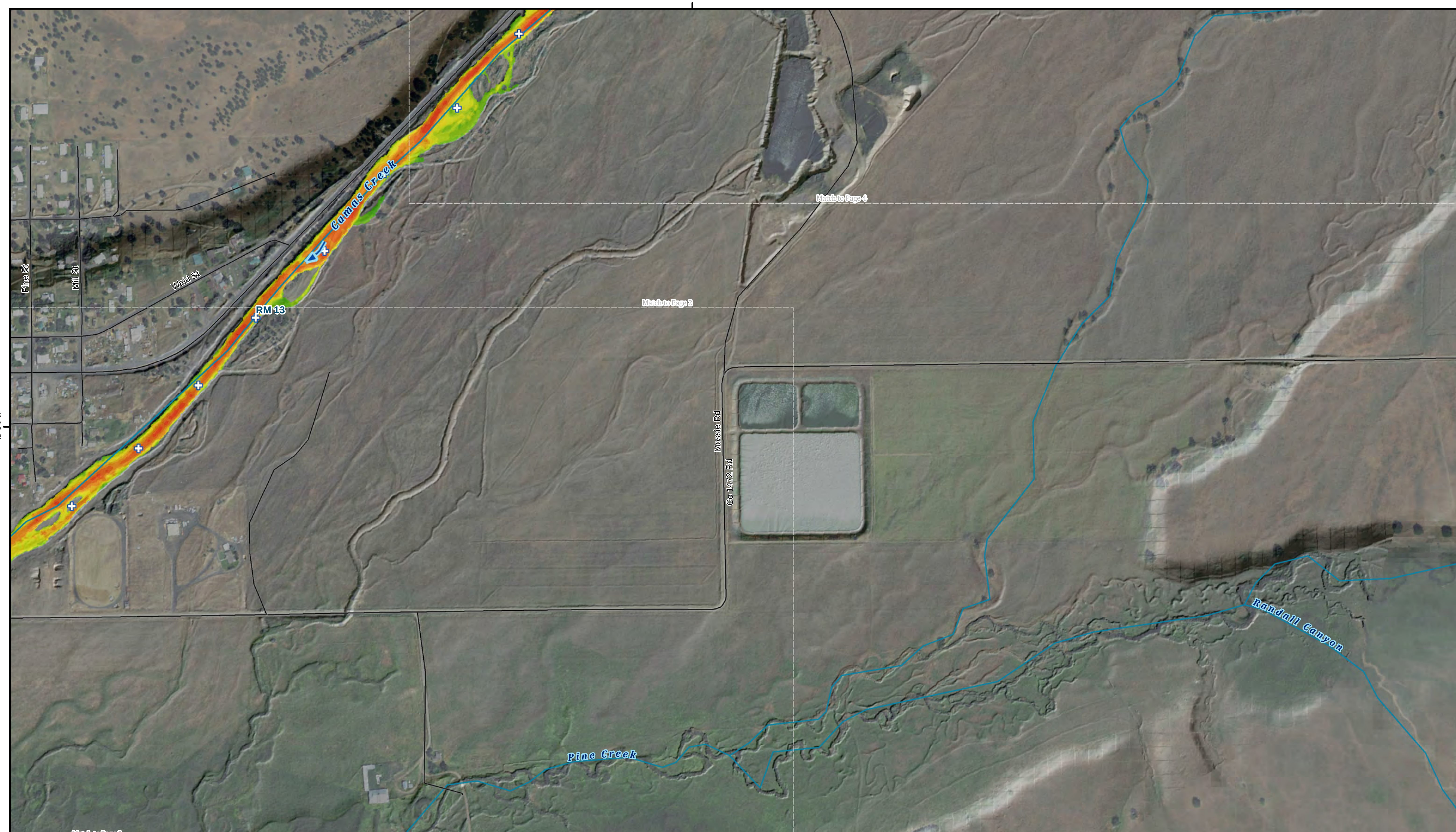
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 7, 7 - 9, 9 - 11, > 11

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Velocity - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
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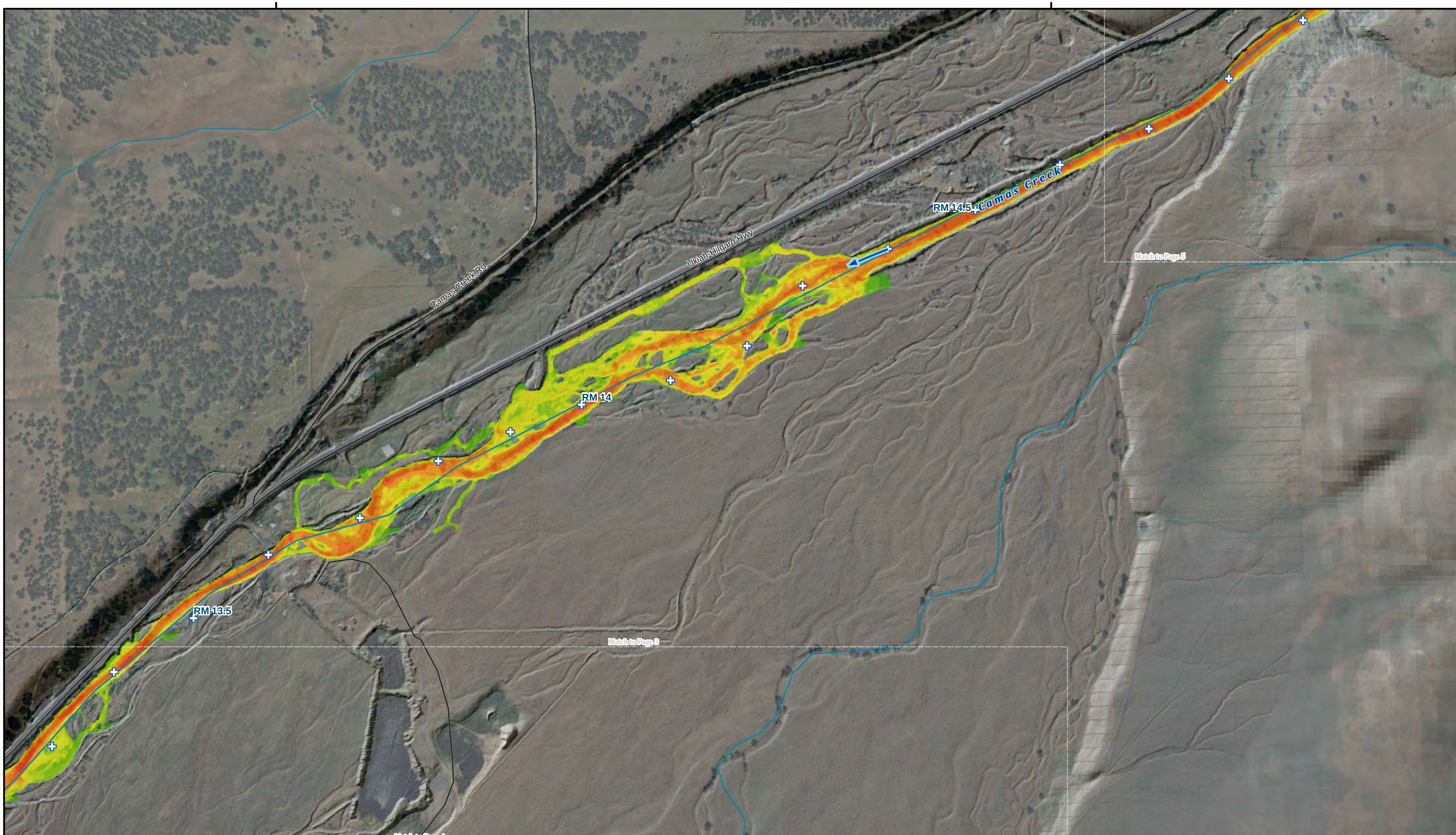
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Velocity - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

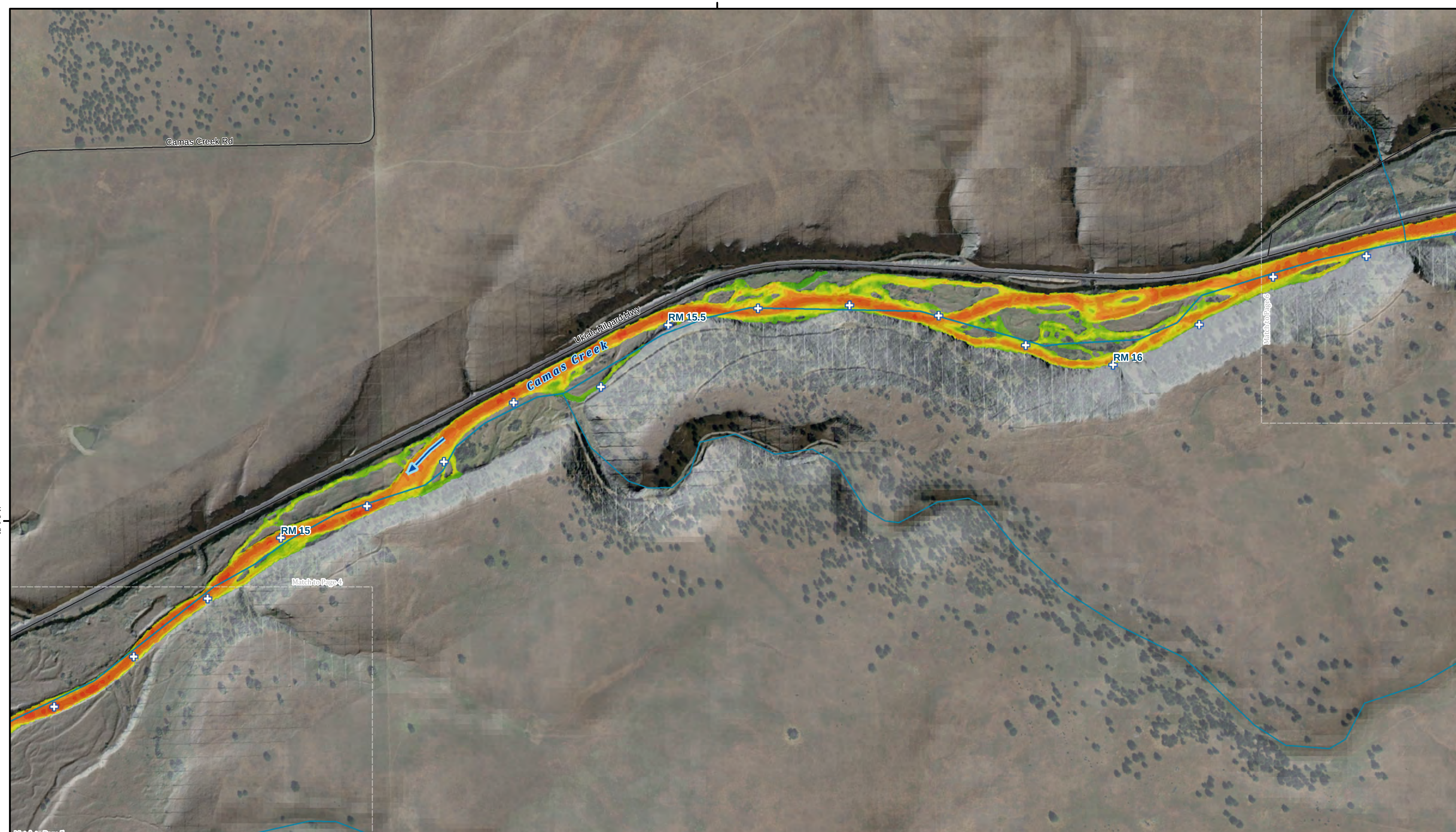
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 7, 7 - 9, 9 - 11, > 11

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Velocity - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

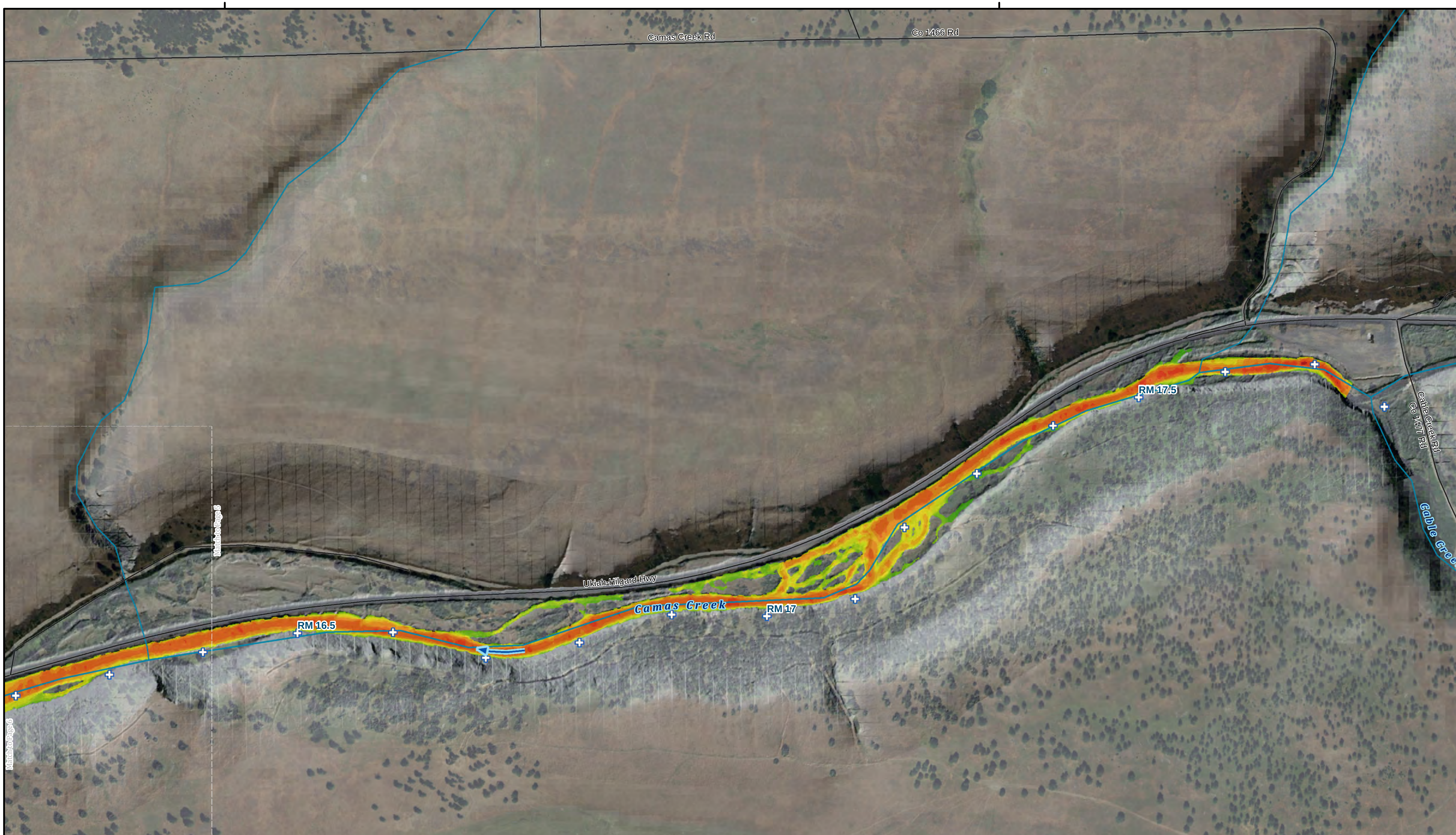
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 7, 7 - 9, 9 - 11, > 11

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Velocity - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

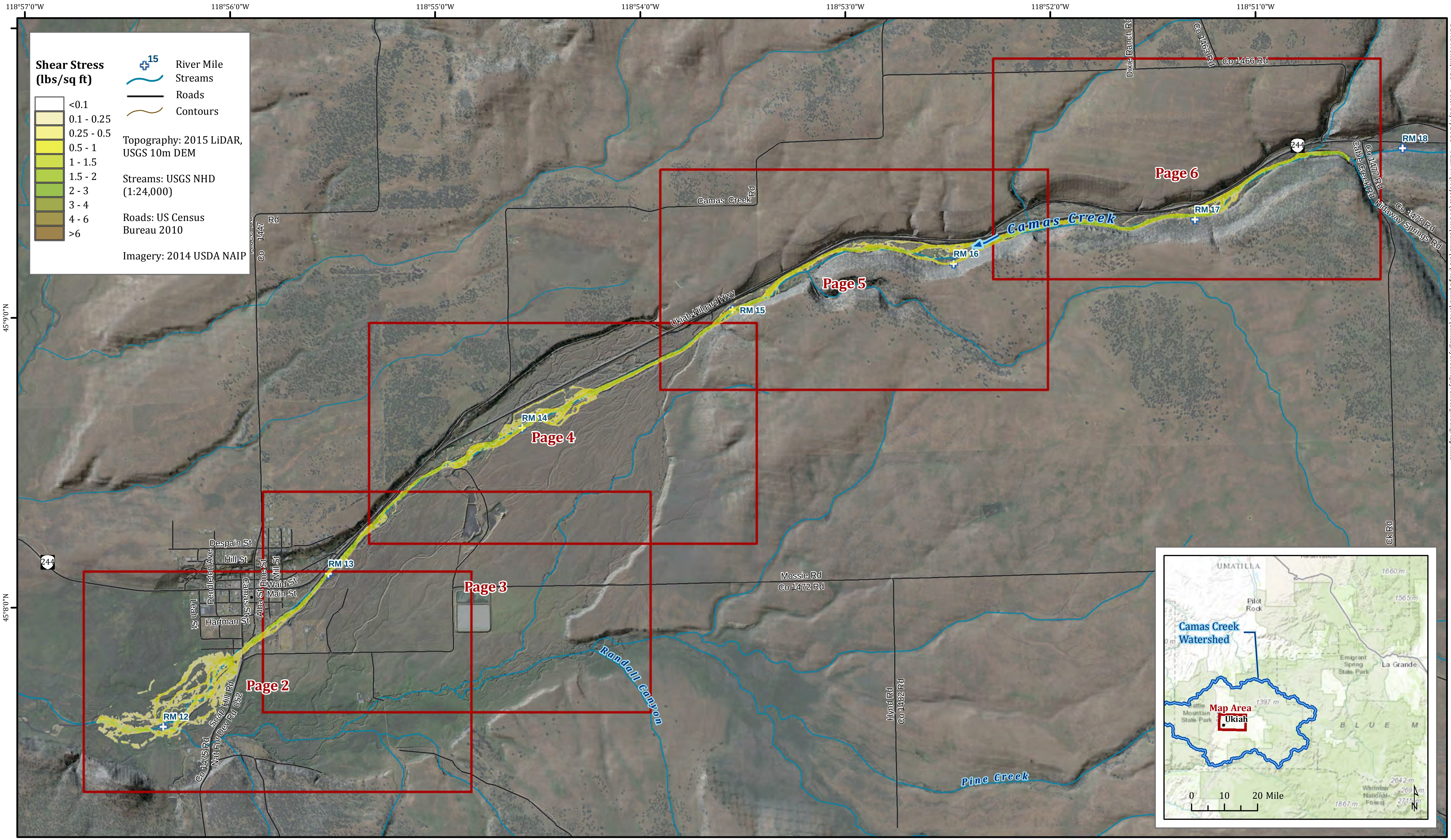
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 7, 7 - 9, 9 - 11, > 11

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Basal Shear Stress Map Book - Page 1 of 6

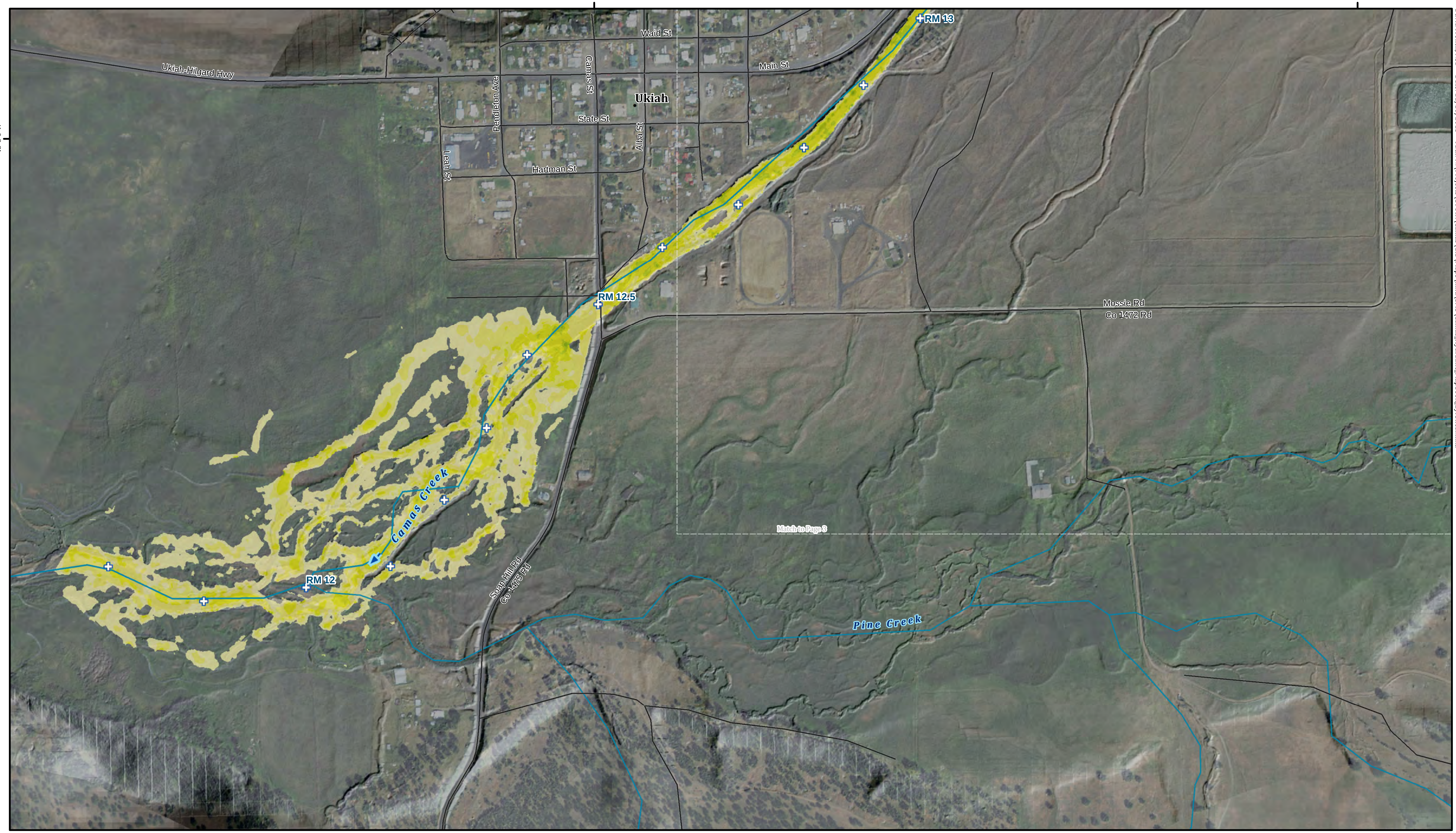
Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Basal Shear Stress - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

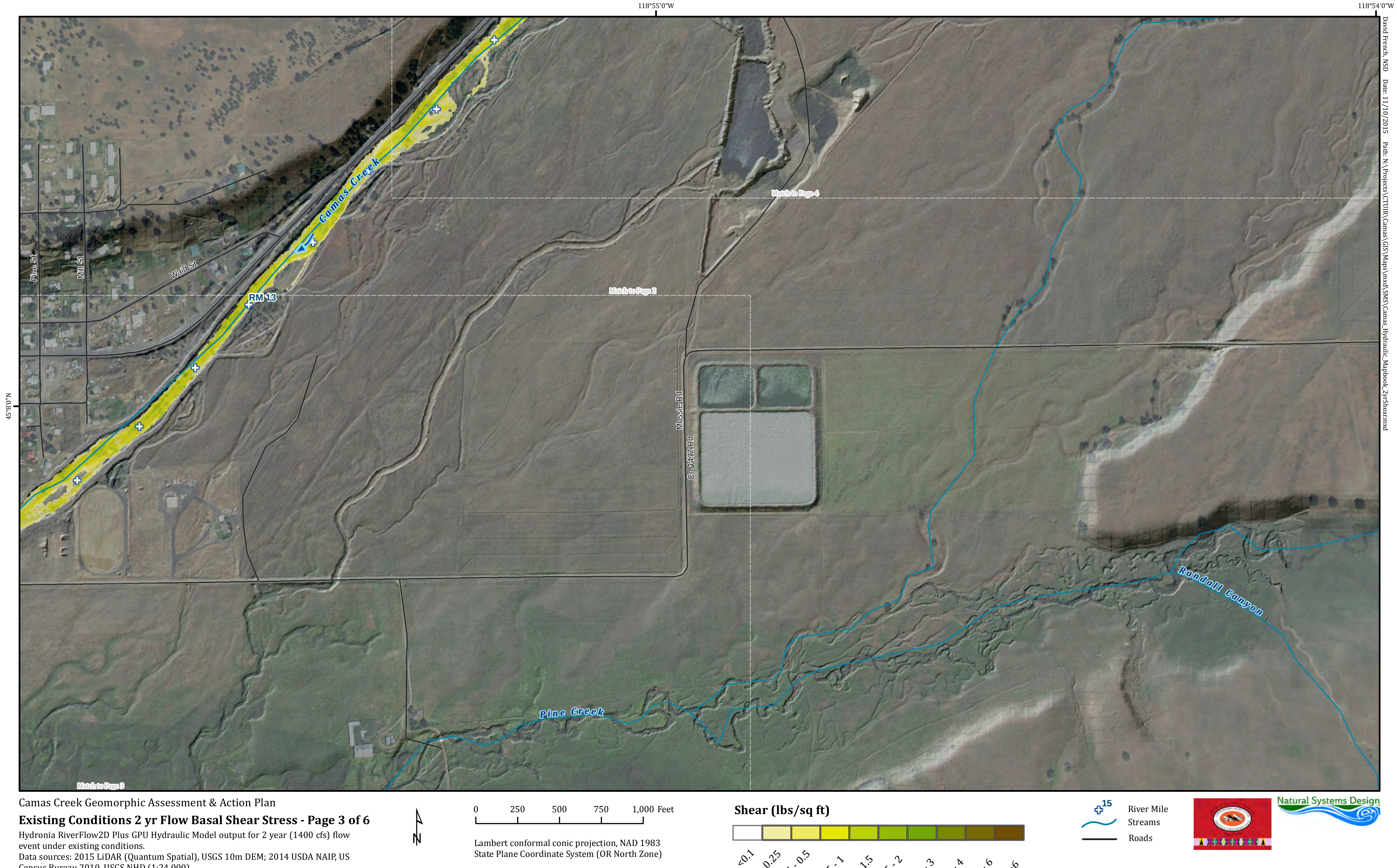
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1 | 0.1 - 0.25 | 0.25 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | 2 - 3 | 3 - 4 | 4 - 6 | >6

15 River Mile
Streams
Roads

Natural Systems Design

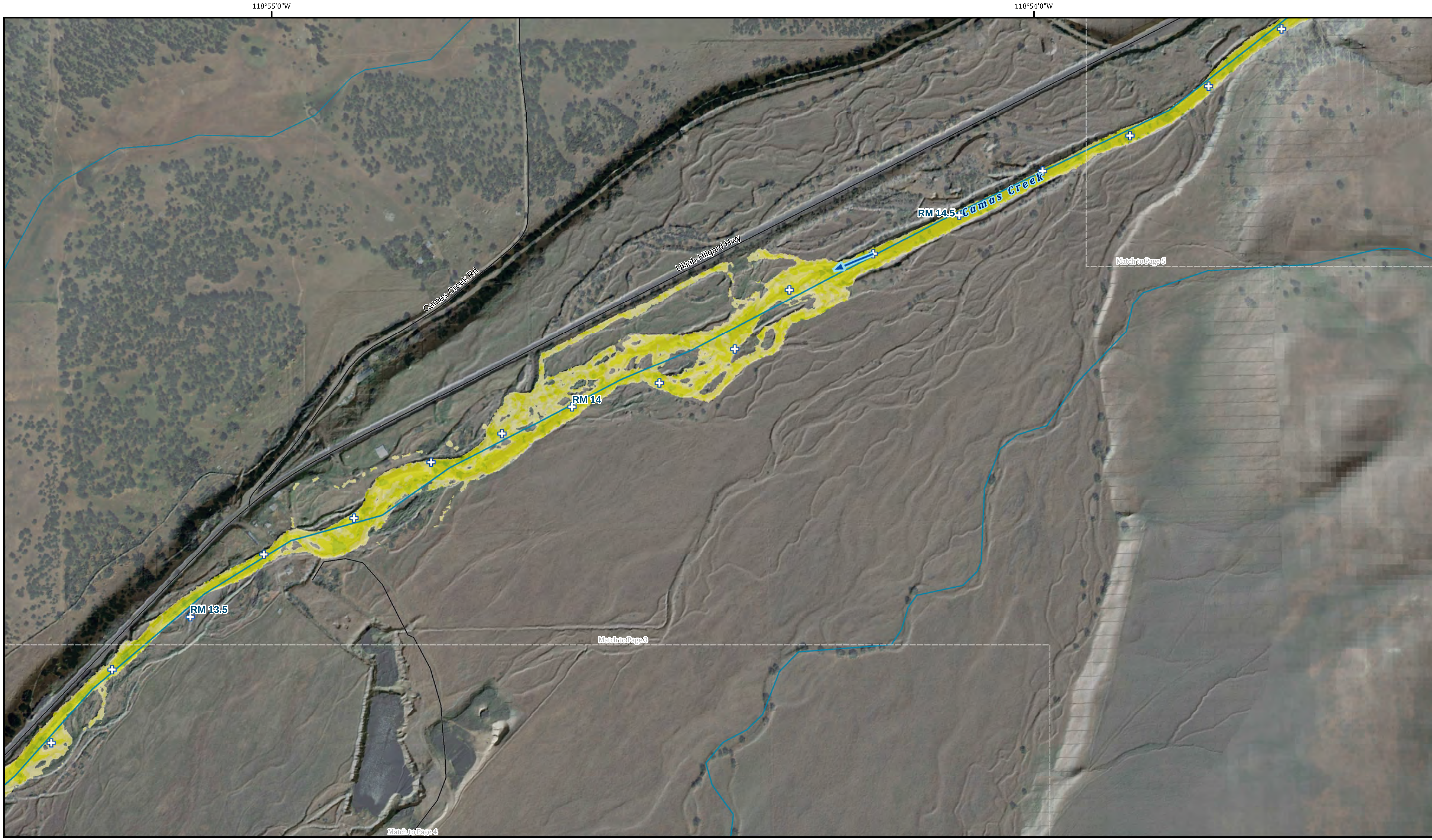


Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Basal Shear Stress - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Basal Shear Stress - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 6, >6

15 River Mile
Streams
Roads

Natural Systems Design

David French, NSD Date: 11/10/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_2yrShear.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Basal Shear Stress - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

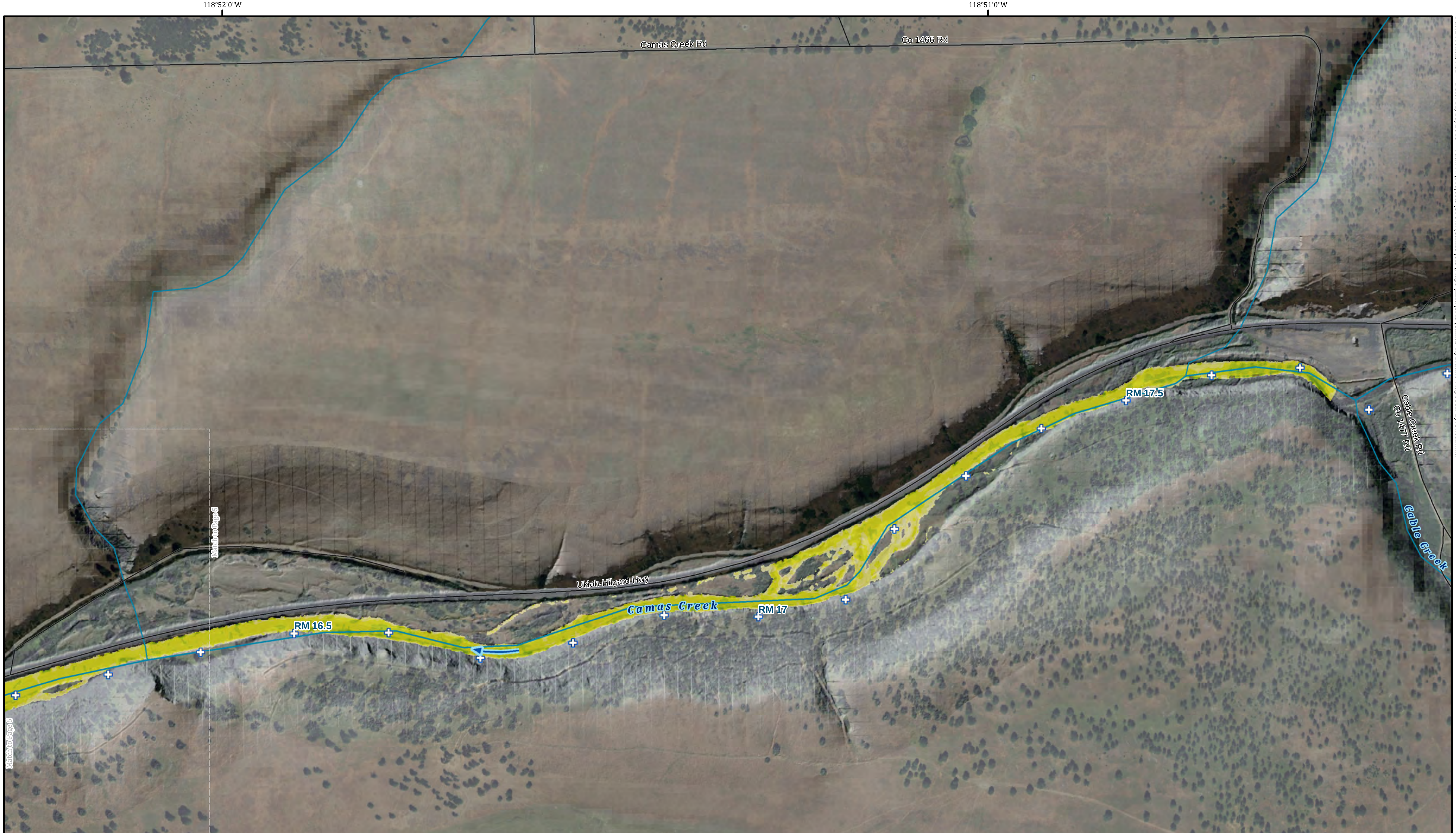
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 6, >6

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Basal Shear Stress - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

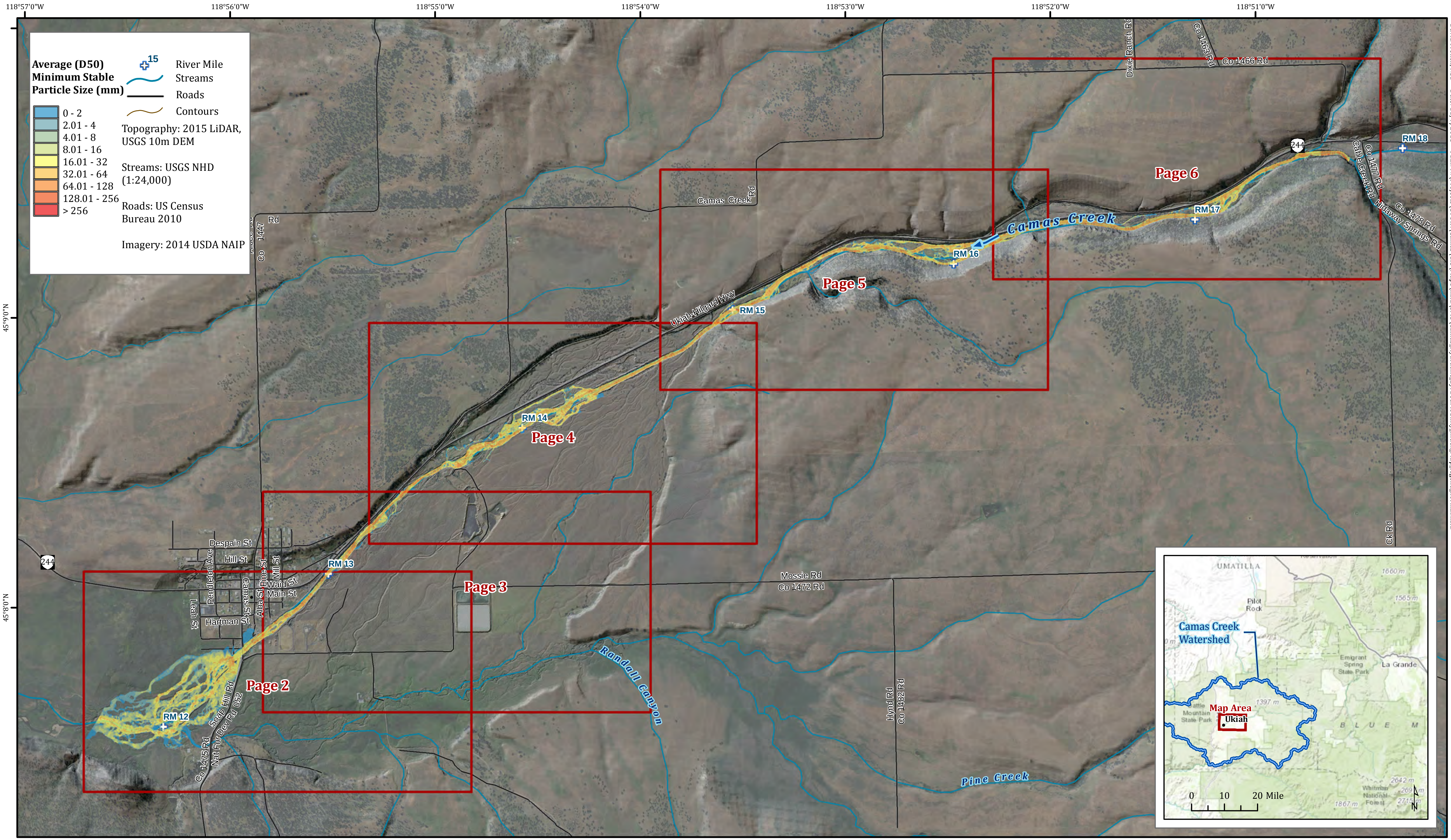
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 6, >6

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Bed Mobility Map Book - Page 1 of 6

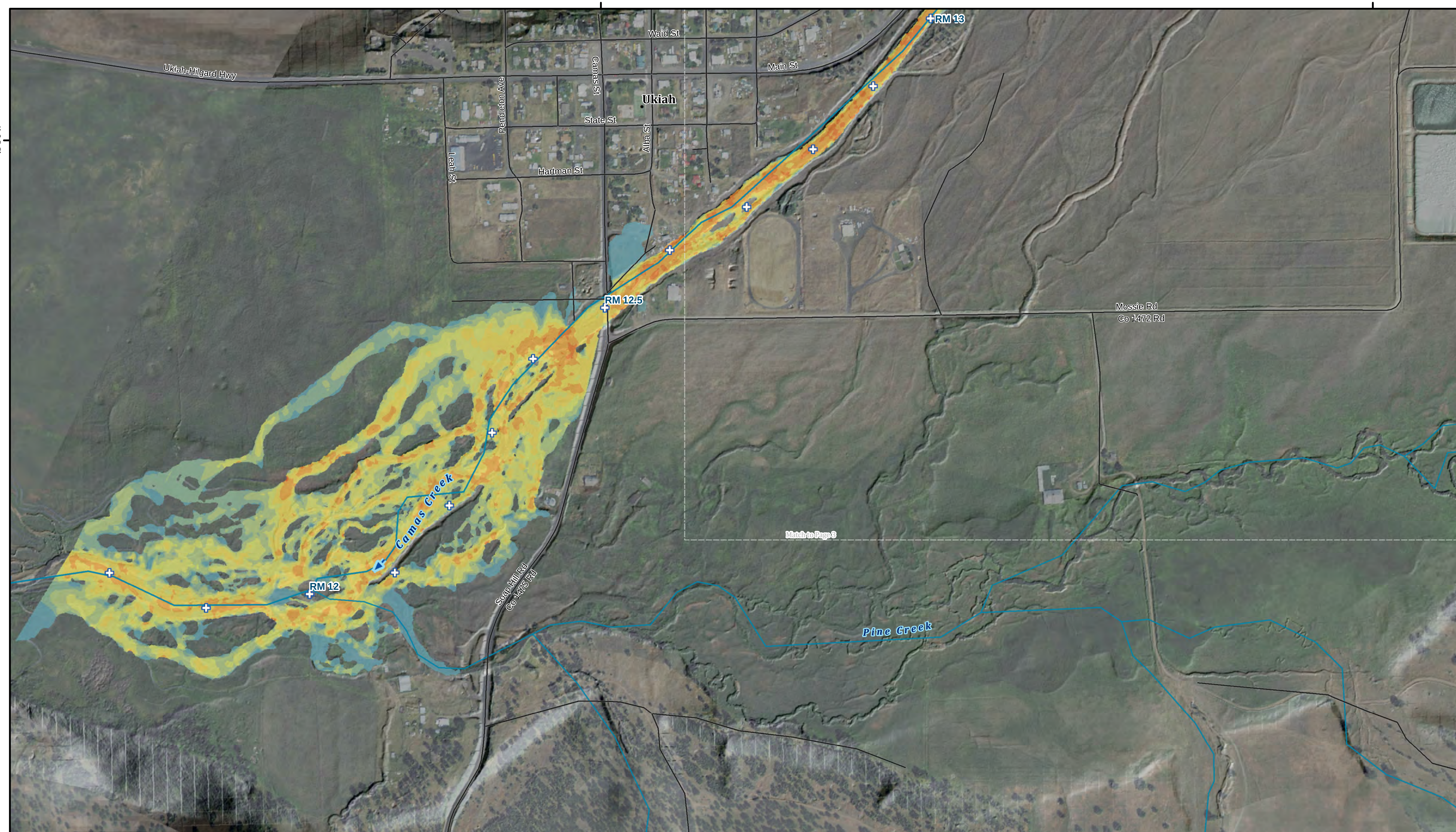
Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Bed Mobility - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

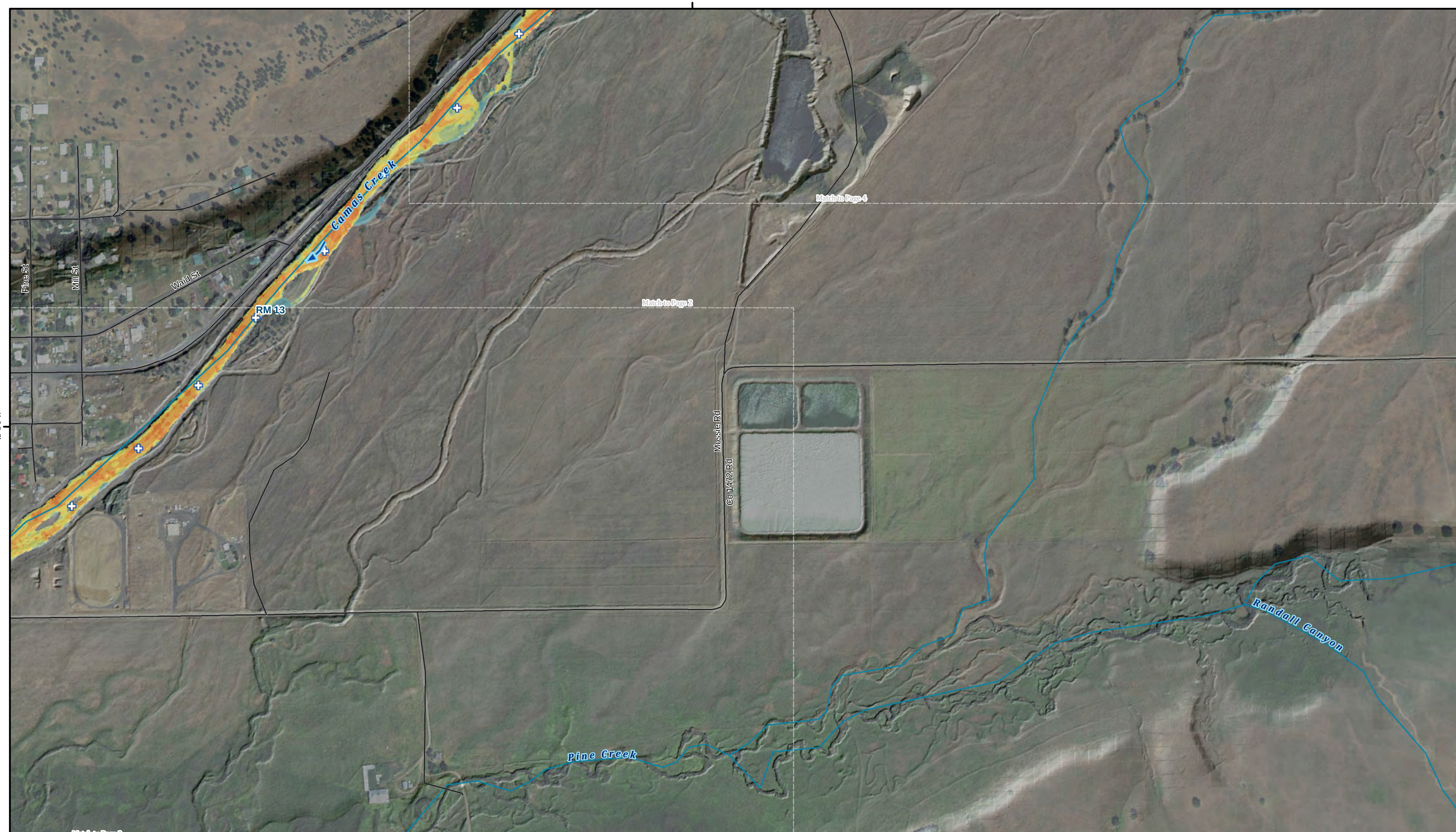
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Bed Mobility - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

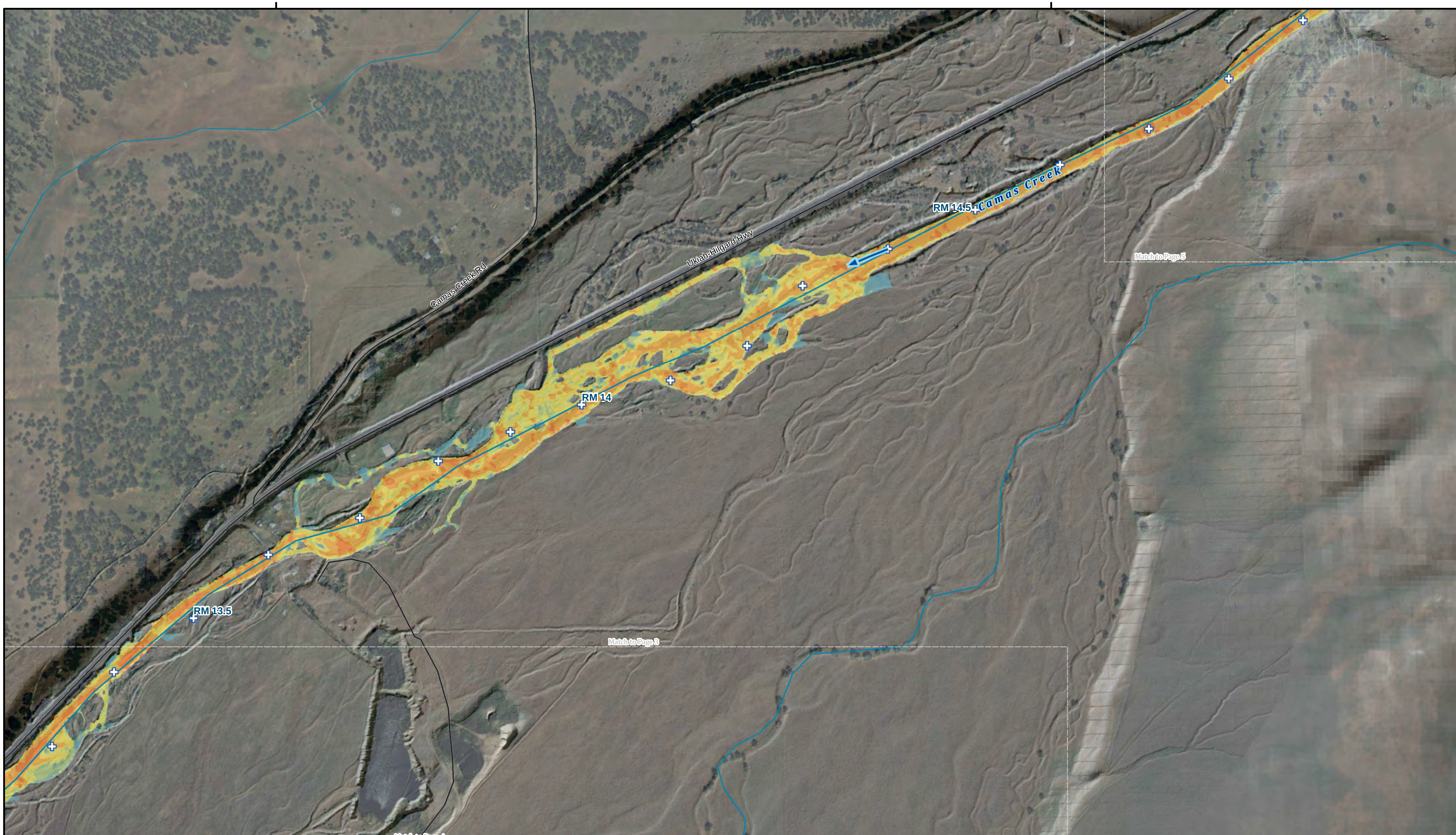
Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design

118°55'0"W 118°54'0"W



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Bed Mobility - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Bed Mobility - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

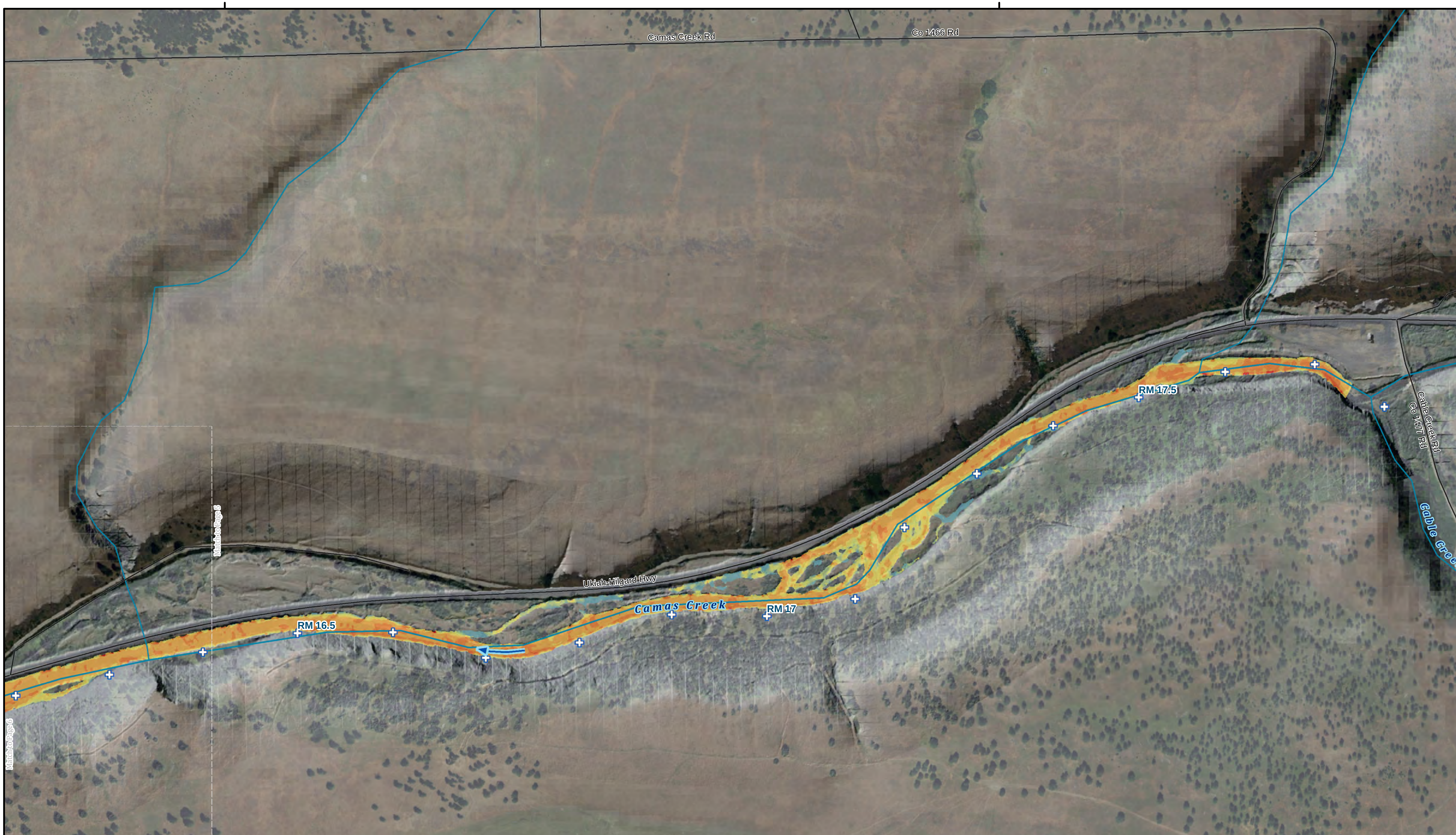
Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design

118°52'0"W
118°51'0"W



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 2 yr Flow Bed Mobility - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 2 year (1400 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

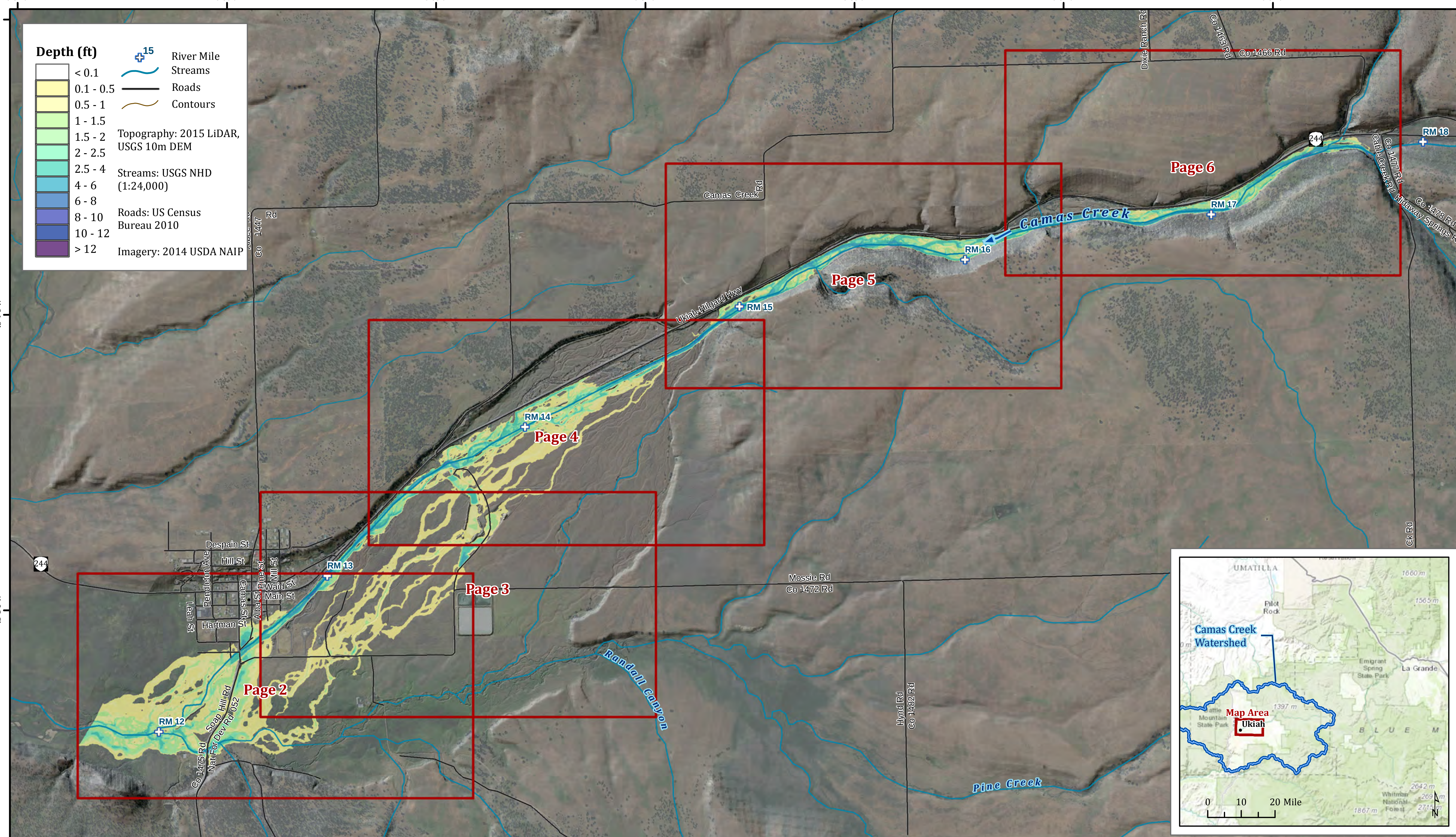
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Depth Map Book - Page 1 of 6

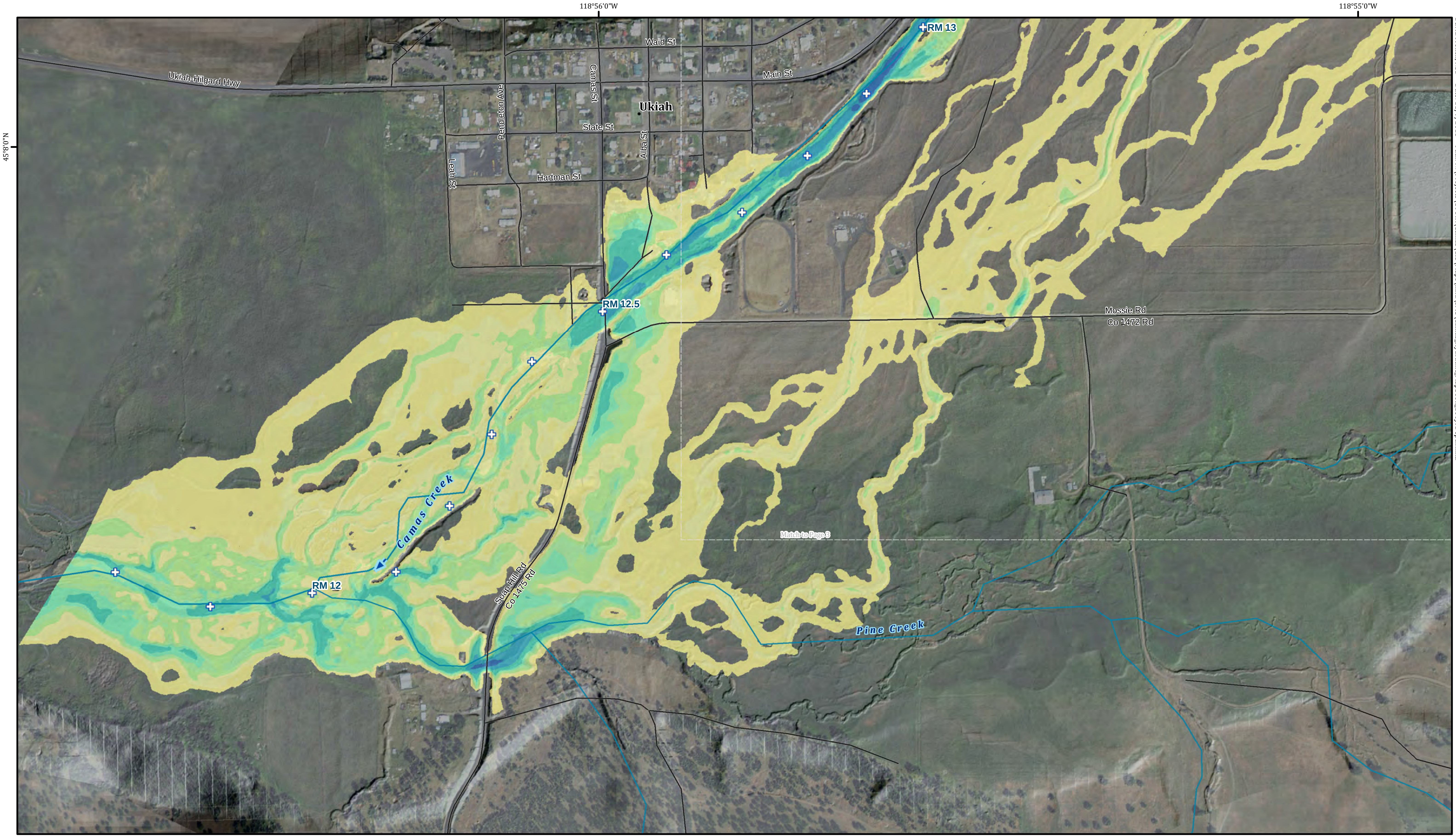
Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Depth - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Depth (ft)

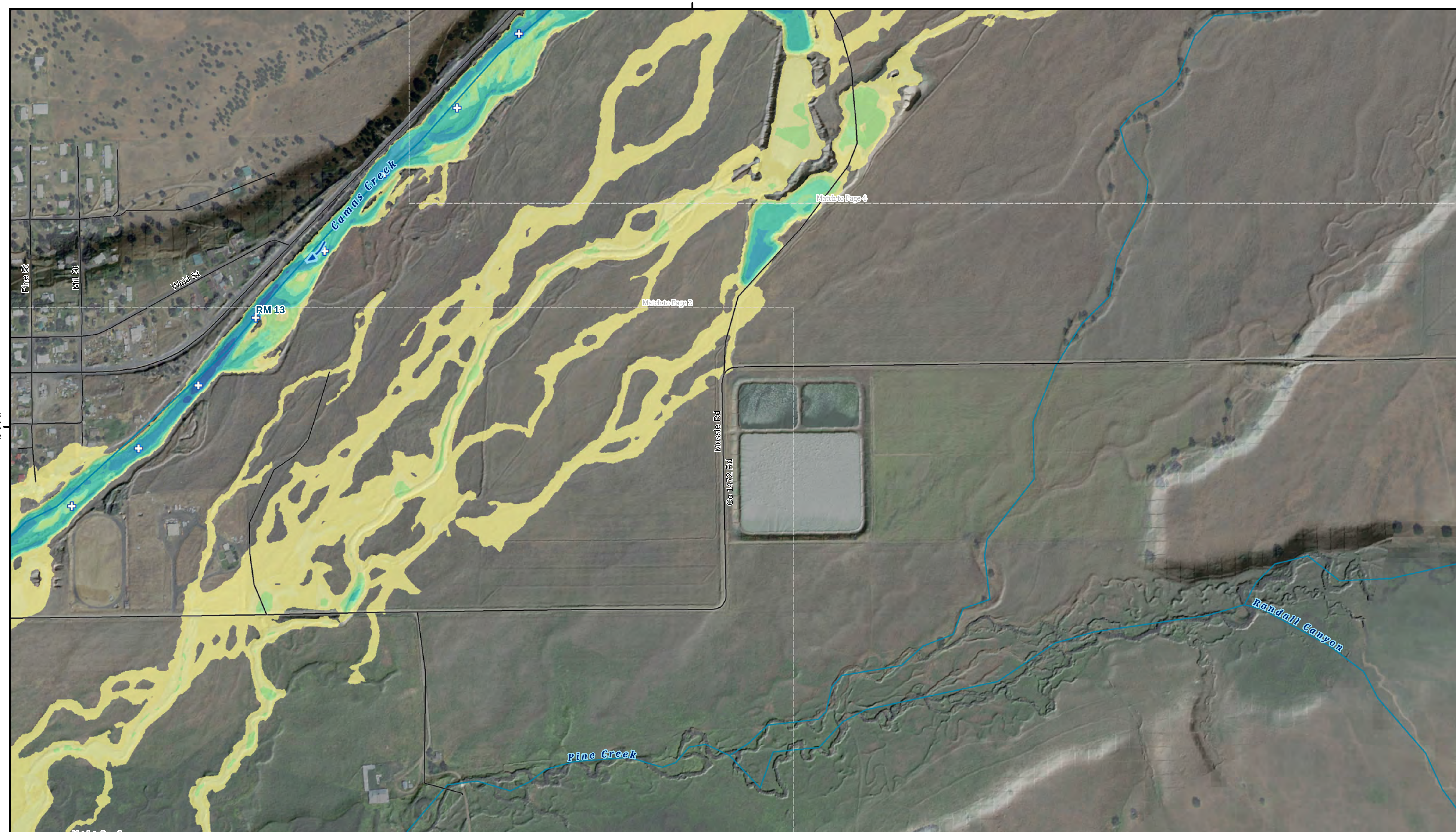
< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, >12

15 River Mile
Streams
Roads

Natural Systems Design

118°55'0"W

118°54'0"W



45°8'0"N

David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrDepth.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Depth - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

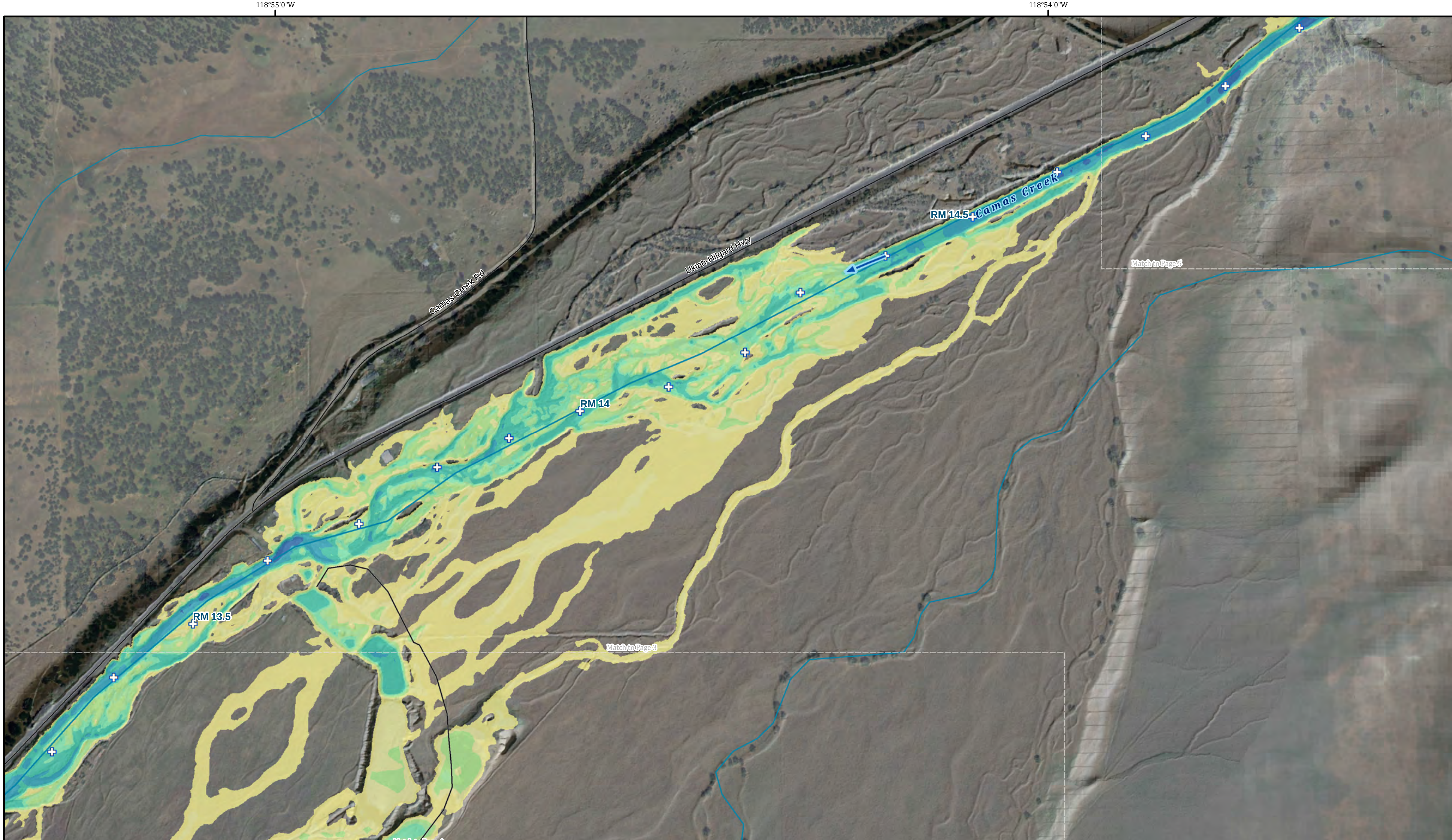
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, >12

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Depth - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

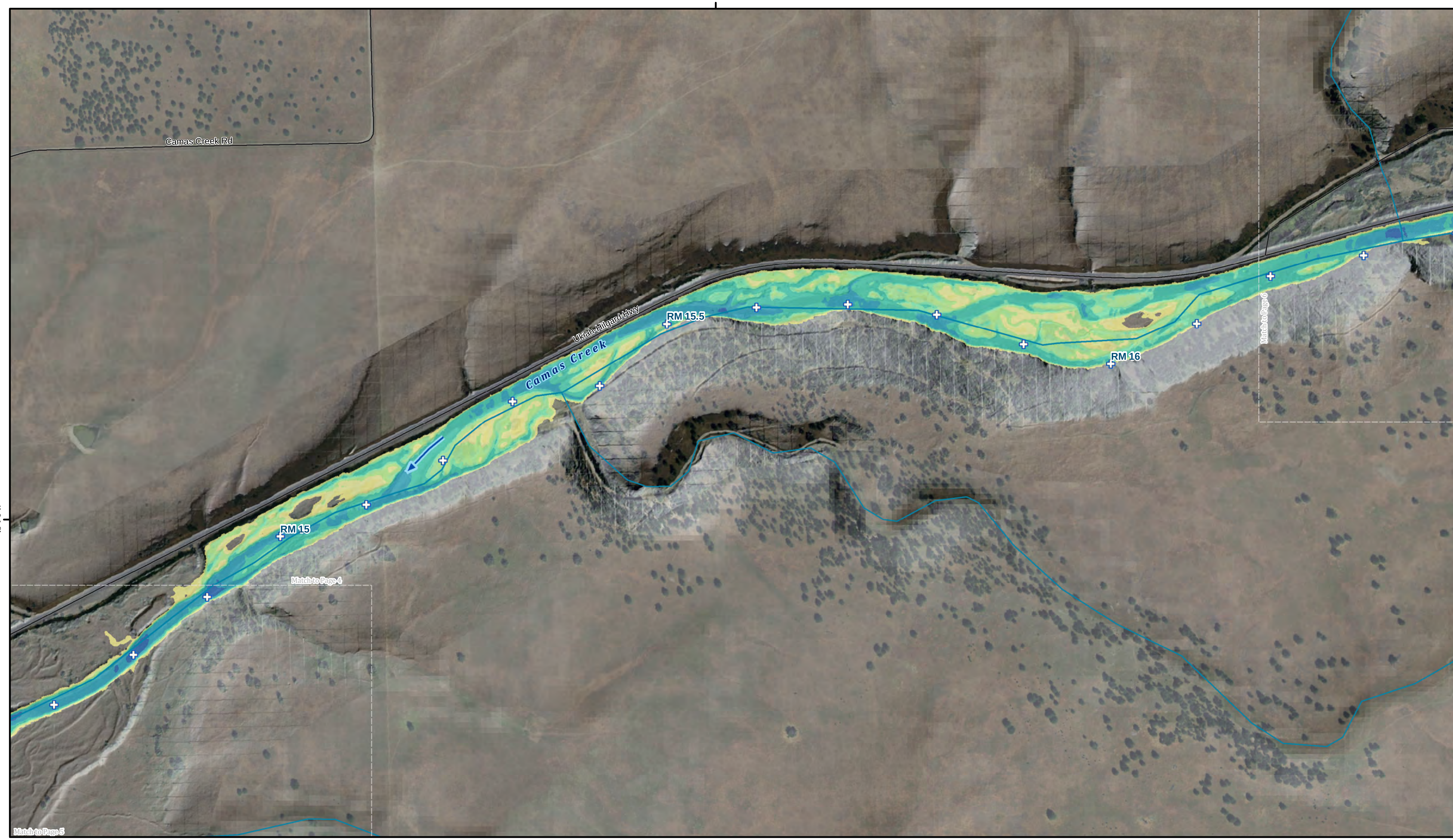
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, >12

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Depth - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

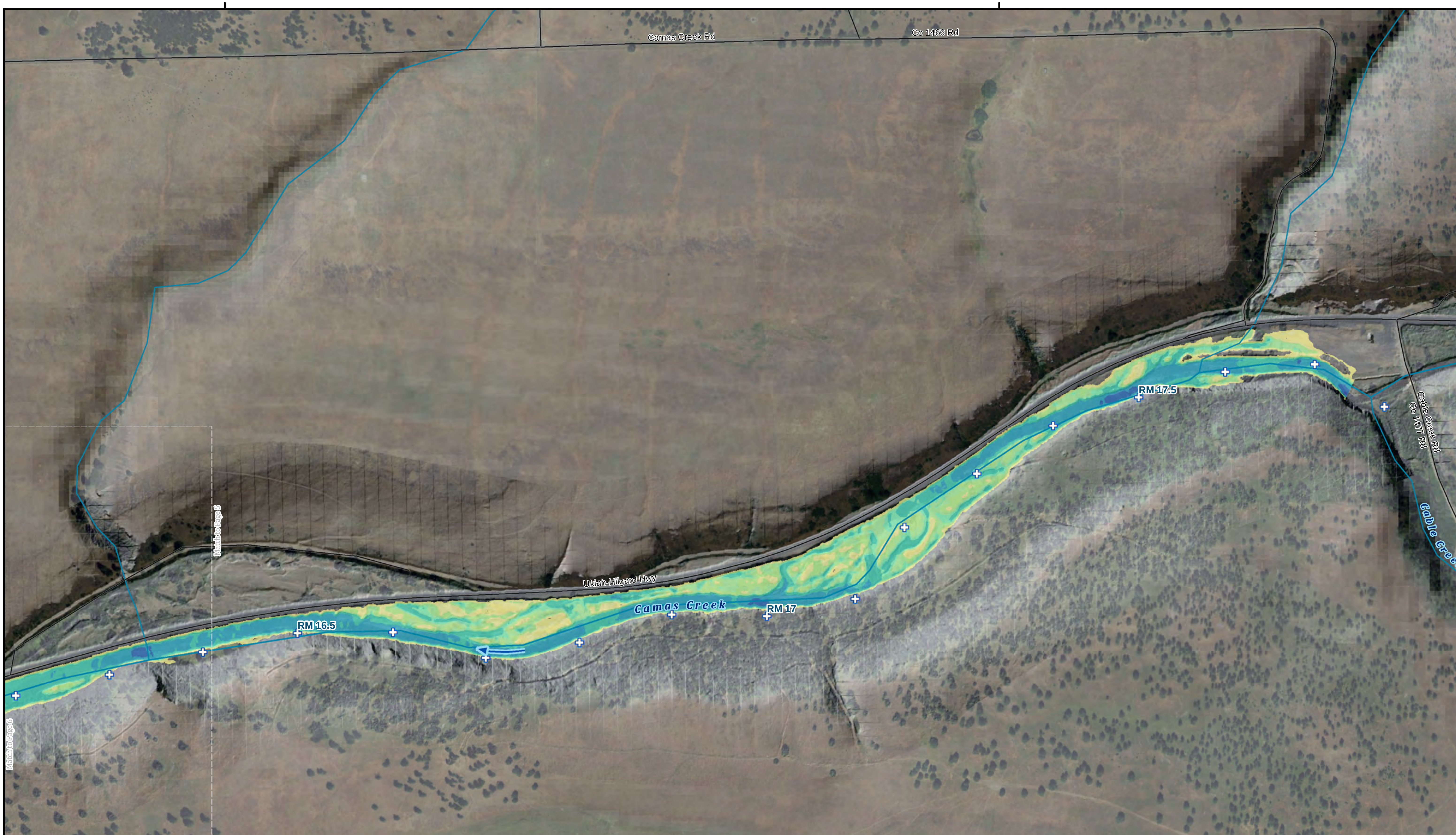
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, >12

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Depth - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

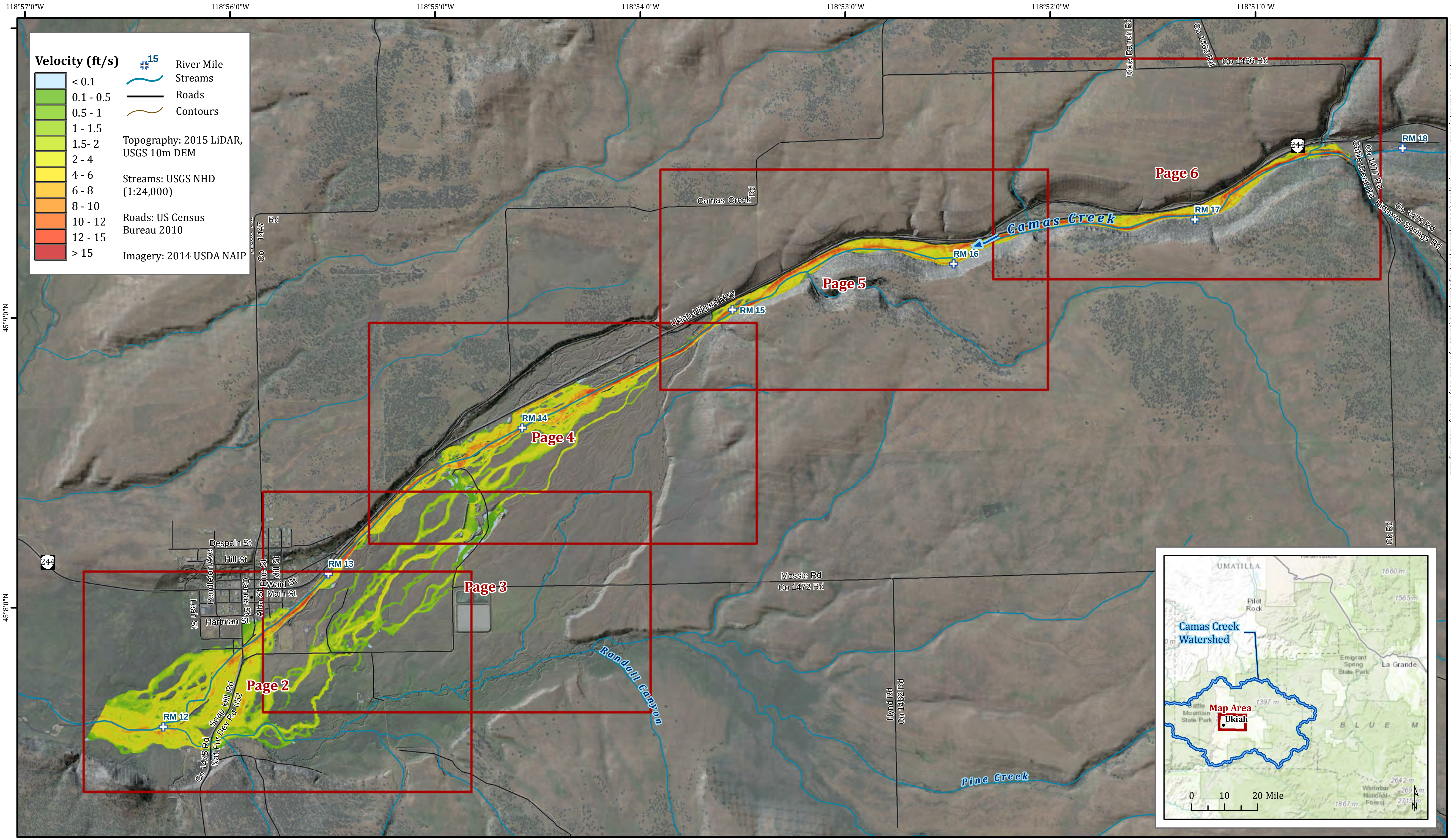
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Depth (ft)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 2.5, 2.5 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, >12

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Velocity Map Book - Page 1 of 6

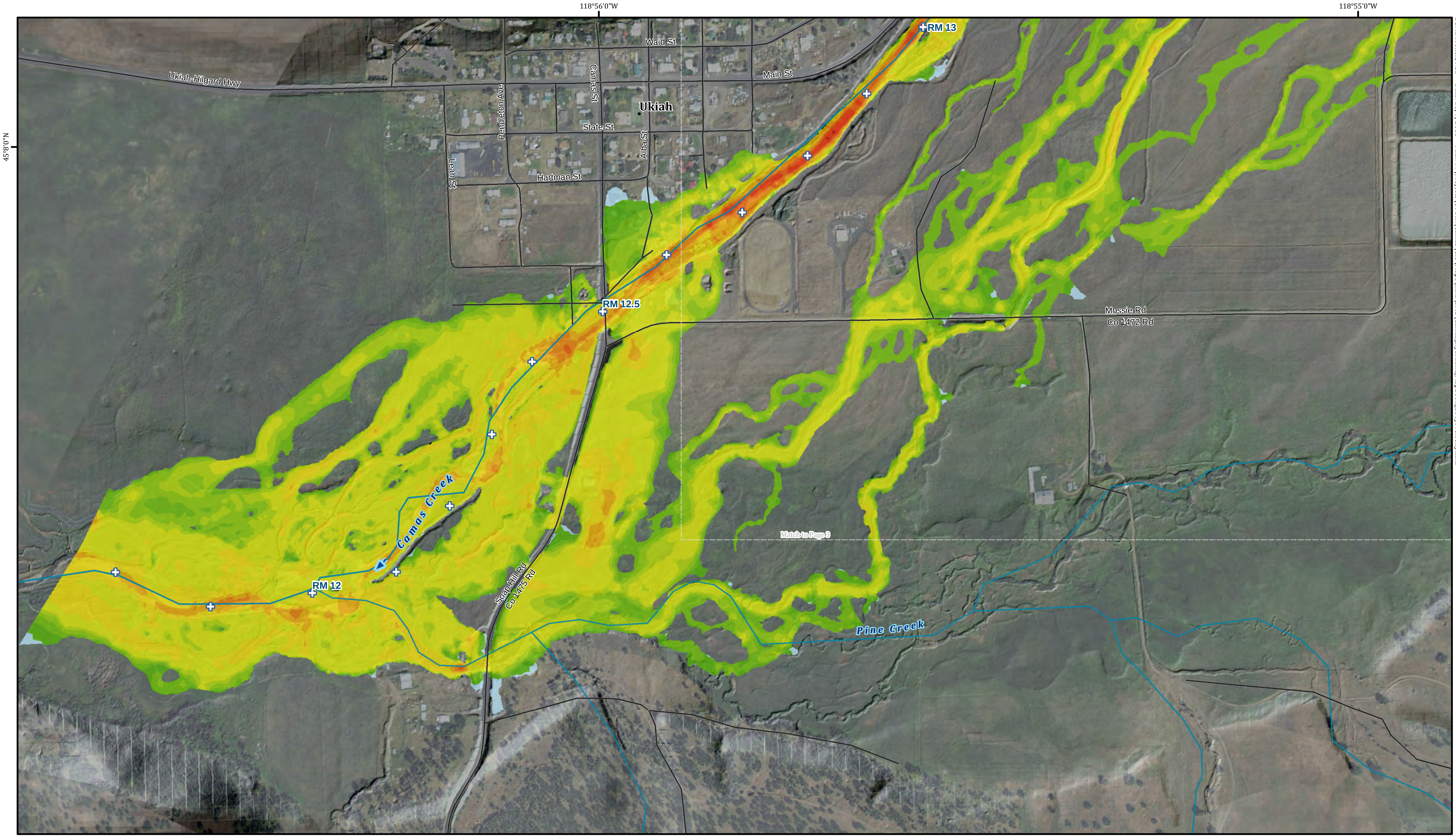
Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Velocity - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

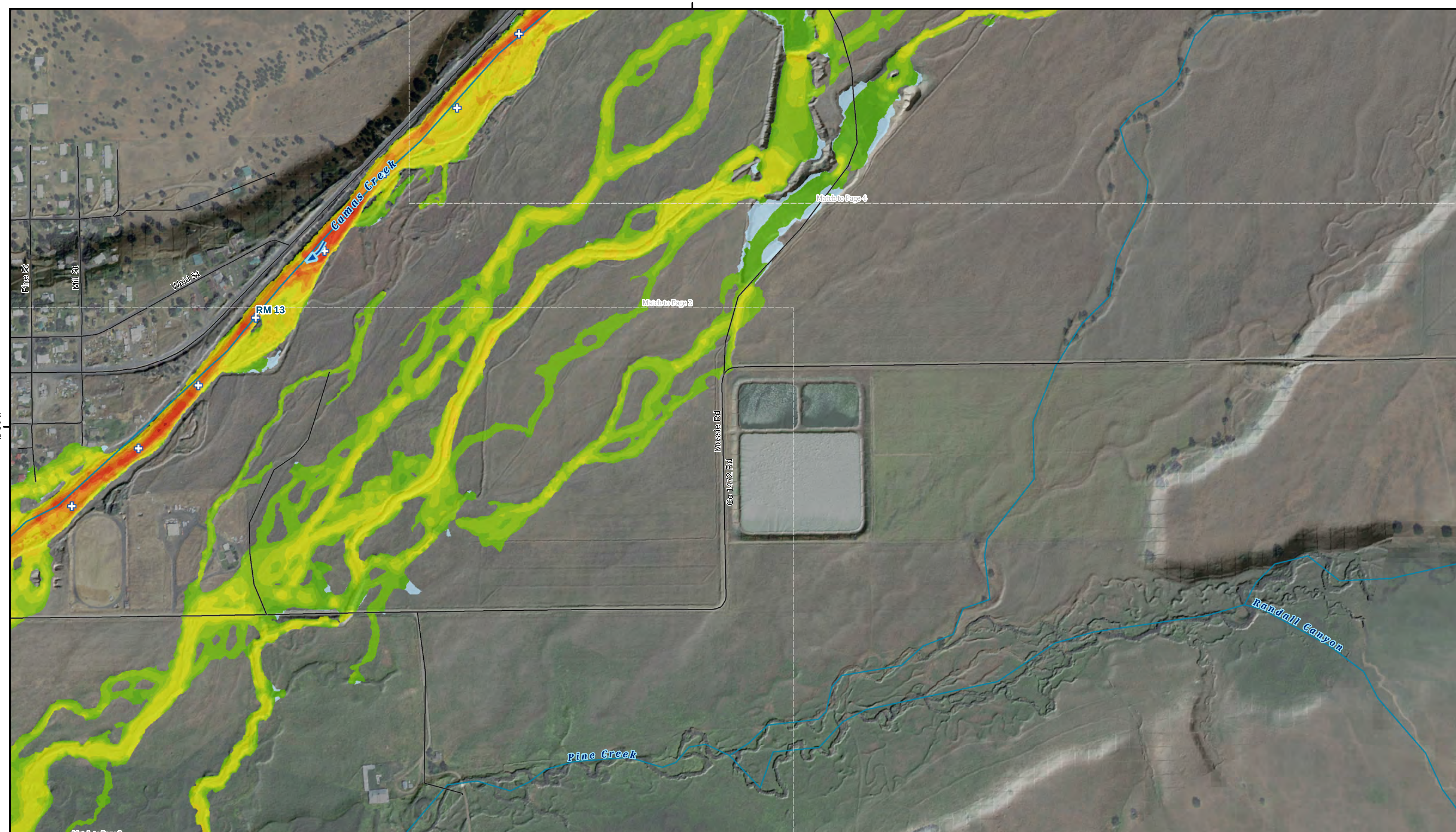
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, 12 - 15, > 15

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Velocity - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

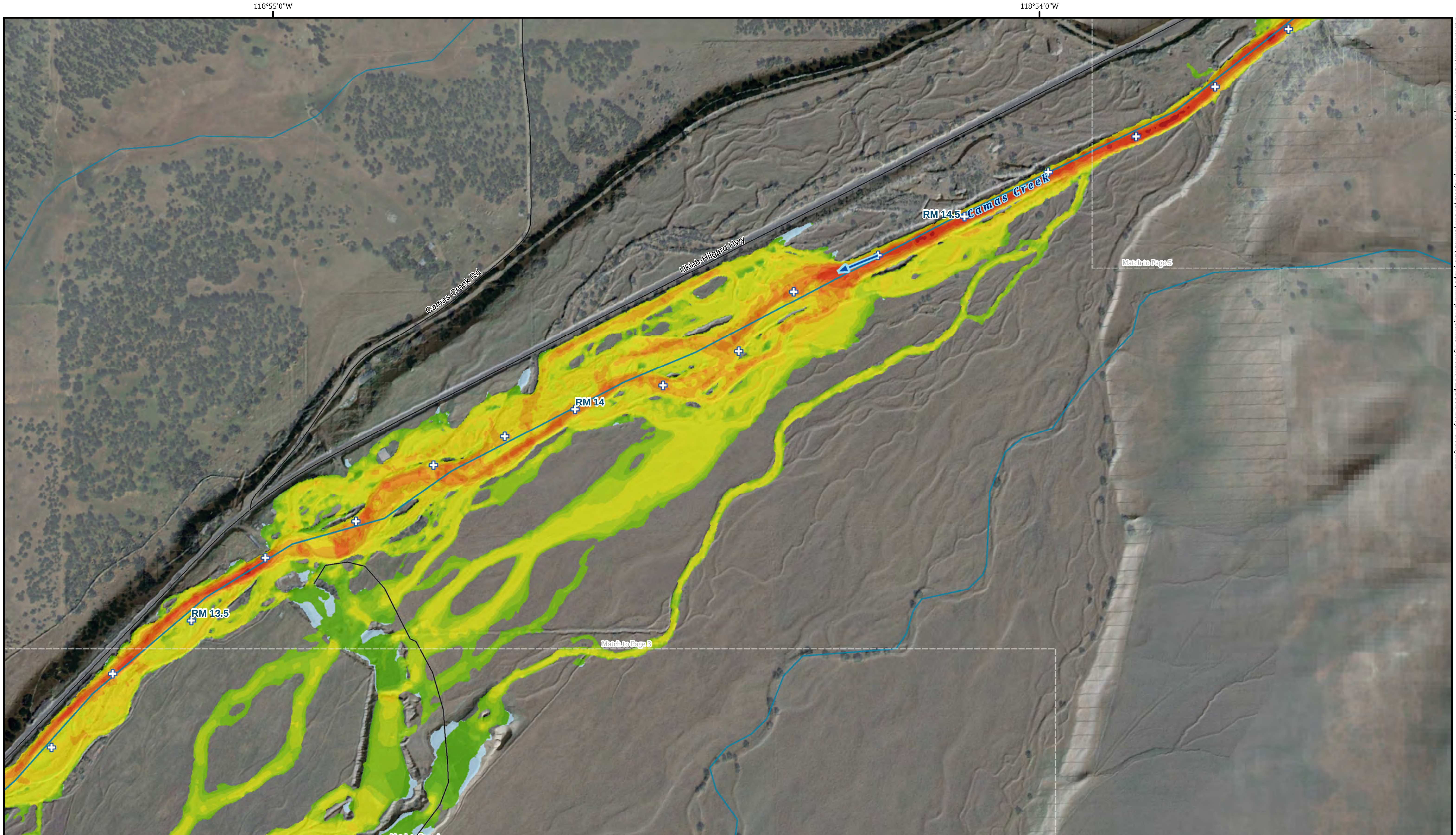
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, 12 - 15, > 15

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Velocity - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
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N

0 250 500 750 1,000 Feet

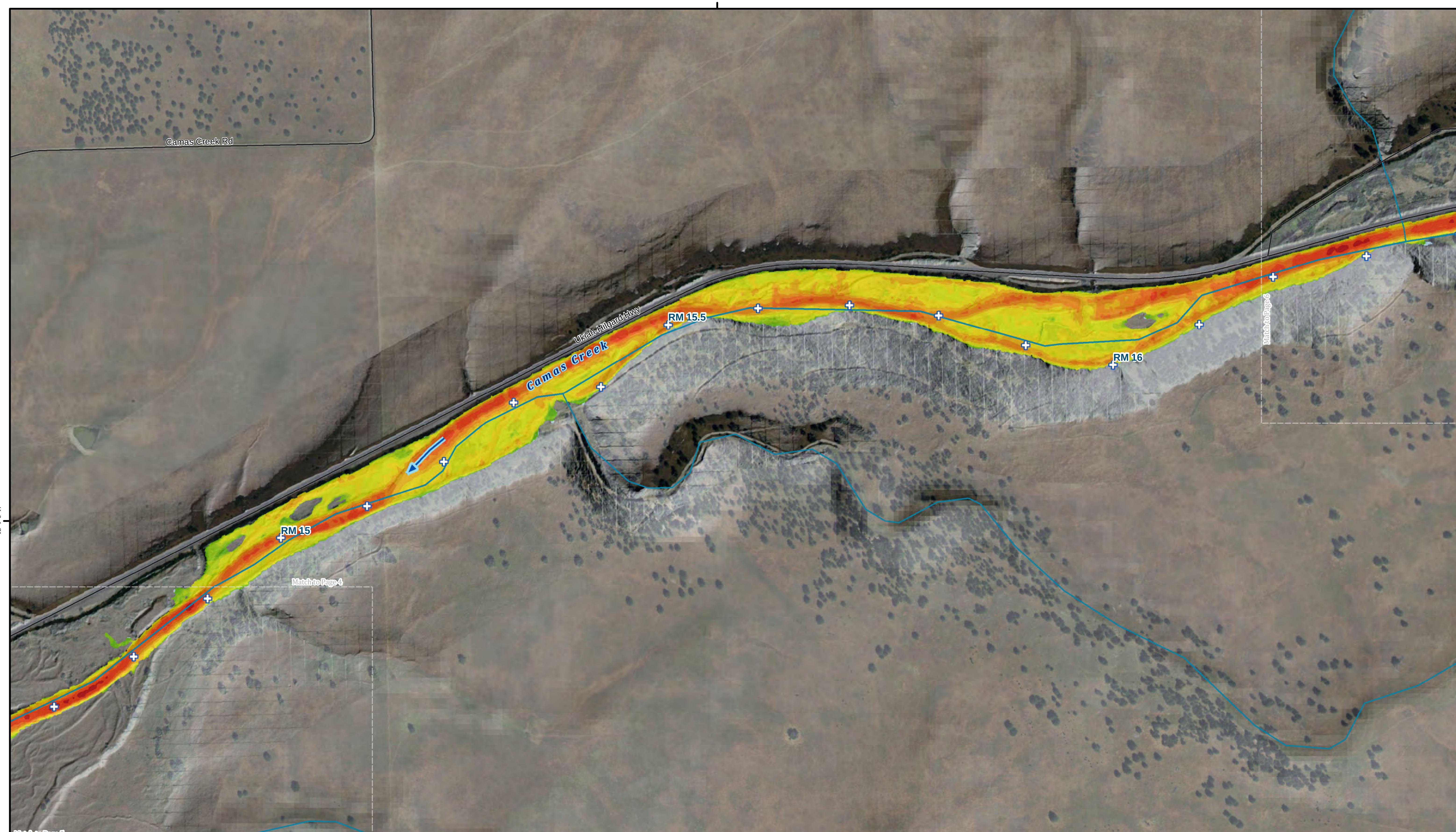
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, 12 - 15, > 15

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Velocity - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

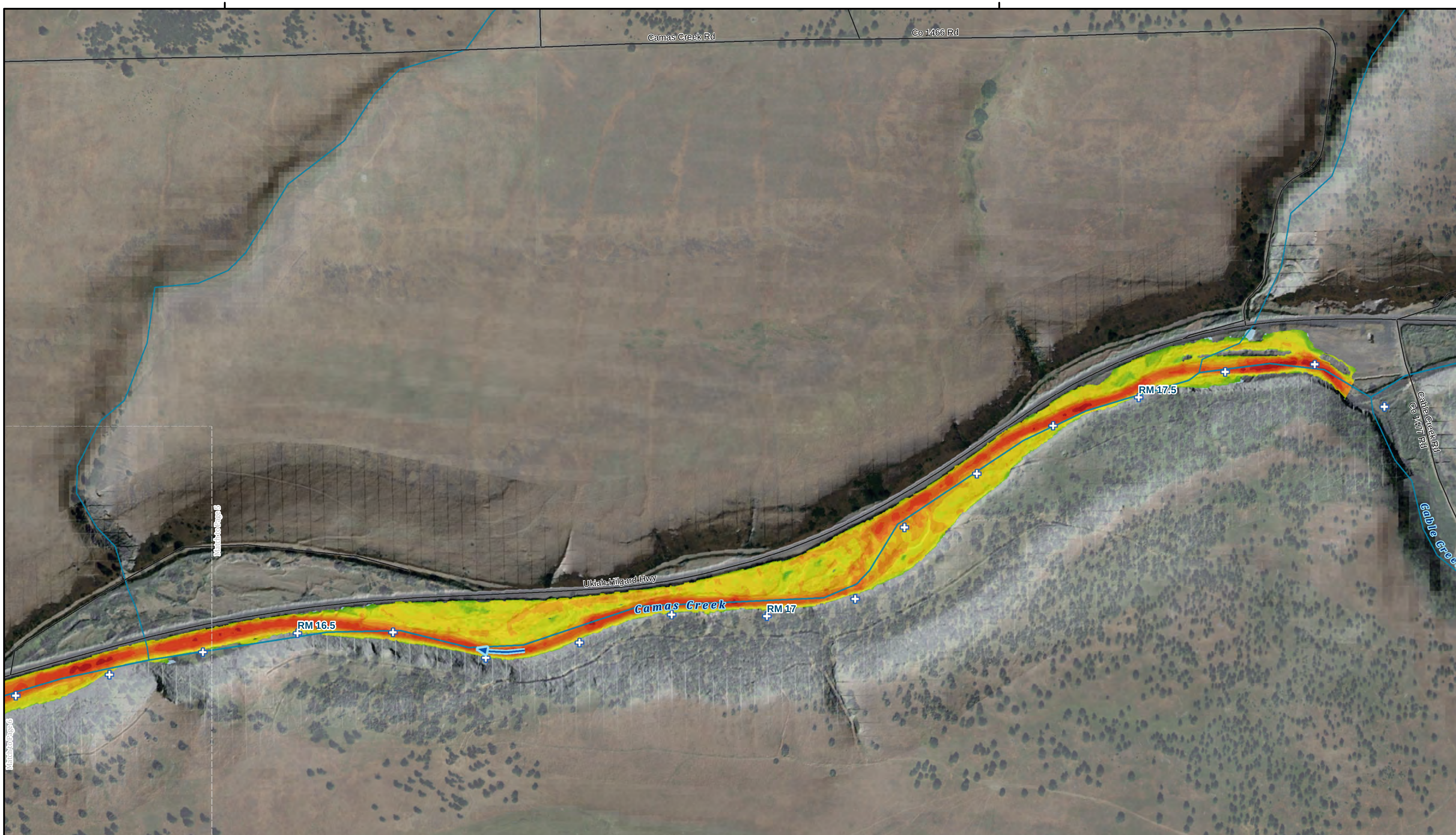
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1 | 0.1 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | 2 - 4 | 4 - 6 | 6 - 8 | 8 - 10 | 10 - 12 | 12 - 15 | > 15

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Velocity - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
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N

0 250 500 750 1,000 Feet

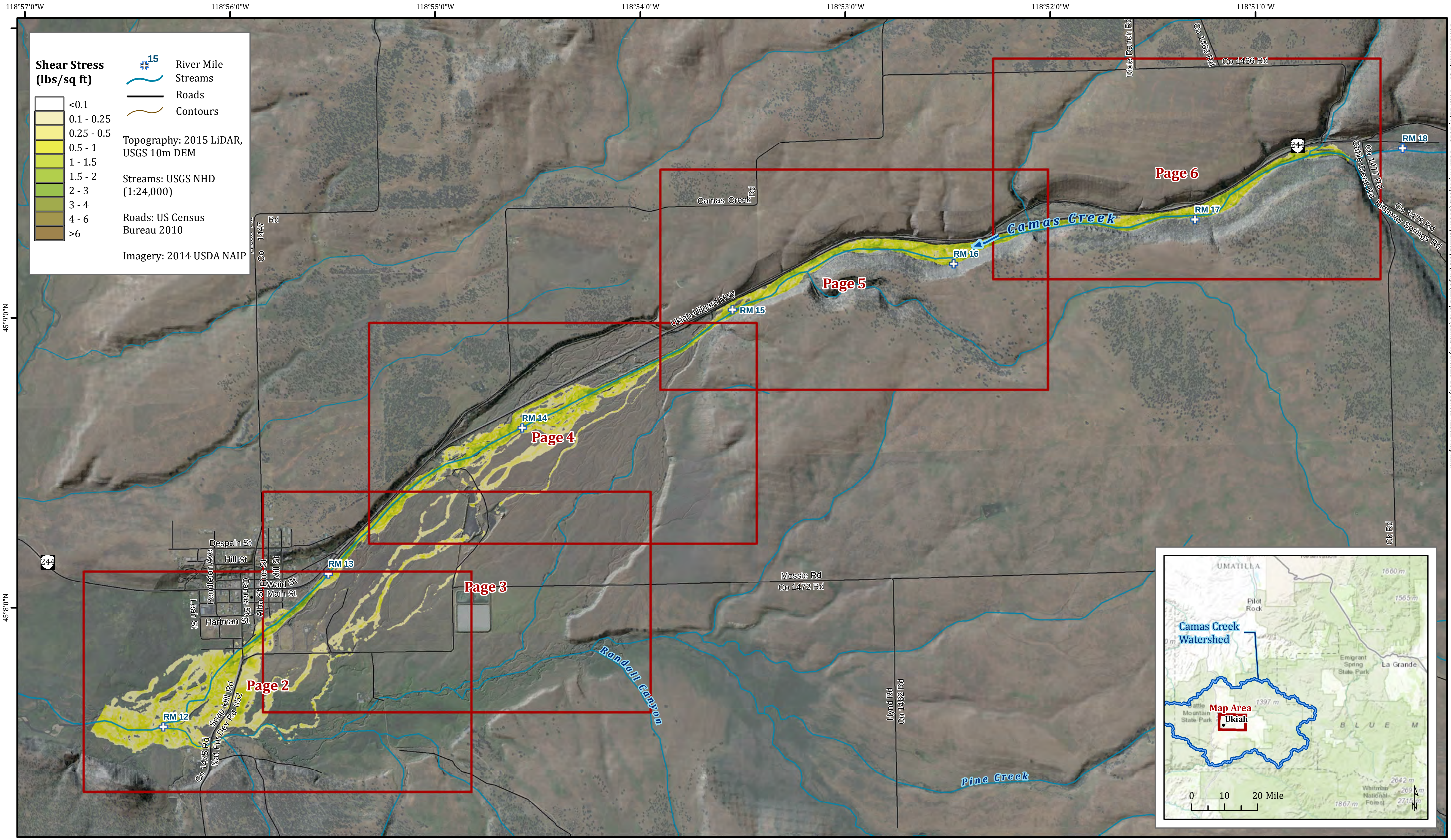
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Velocity (ft/s)

< 0.1, 0.1 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, 12 - 15, > 15

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Basal Shear Stress Map Book - Page 1 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
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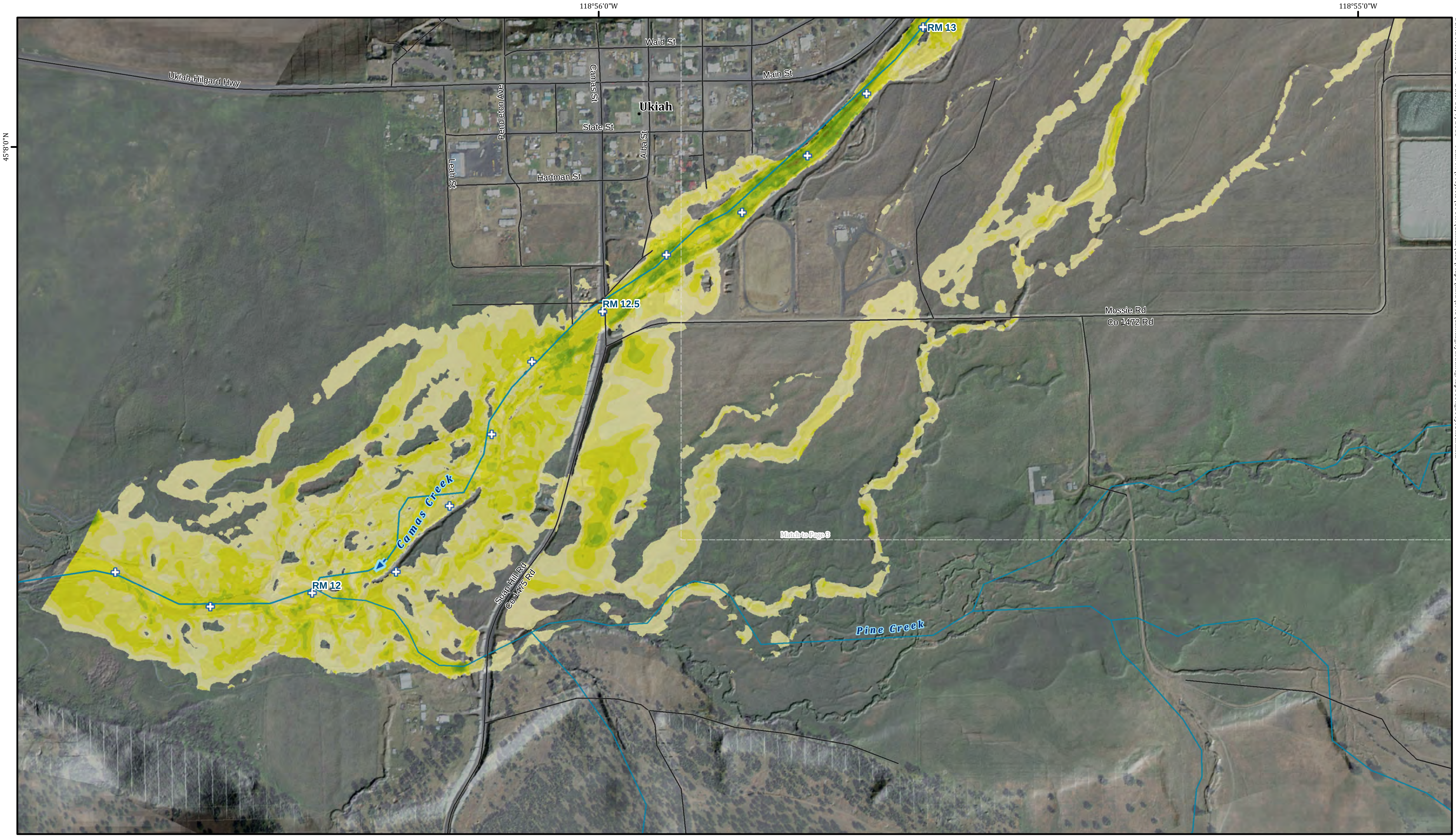
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Basal Shear Stress - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

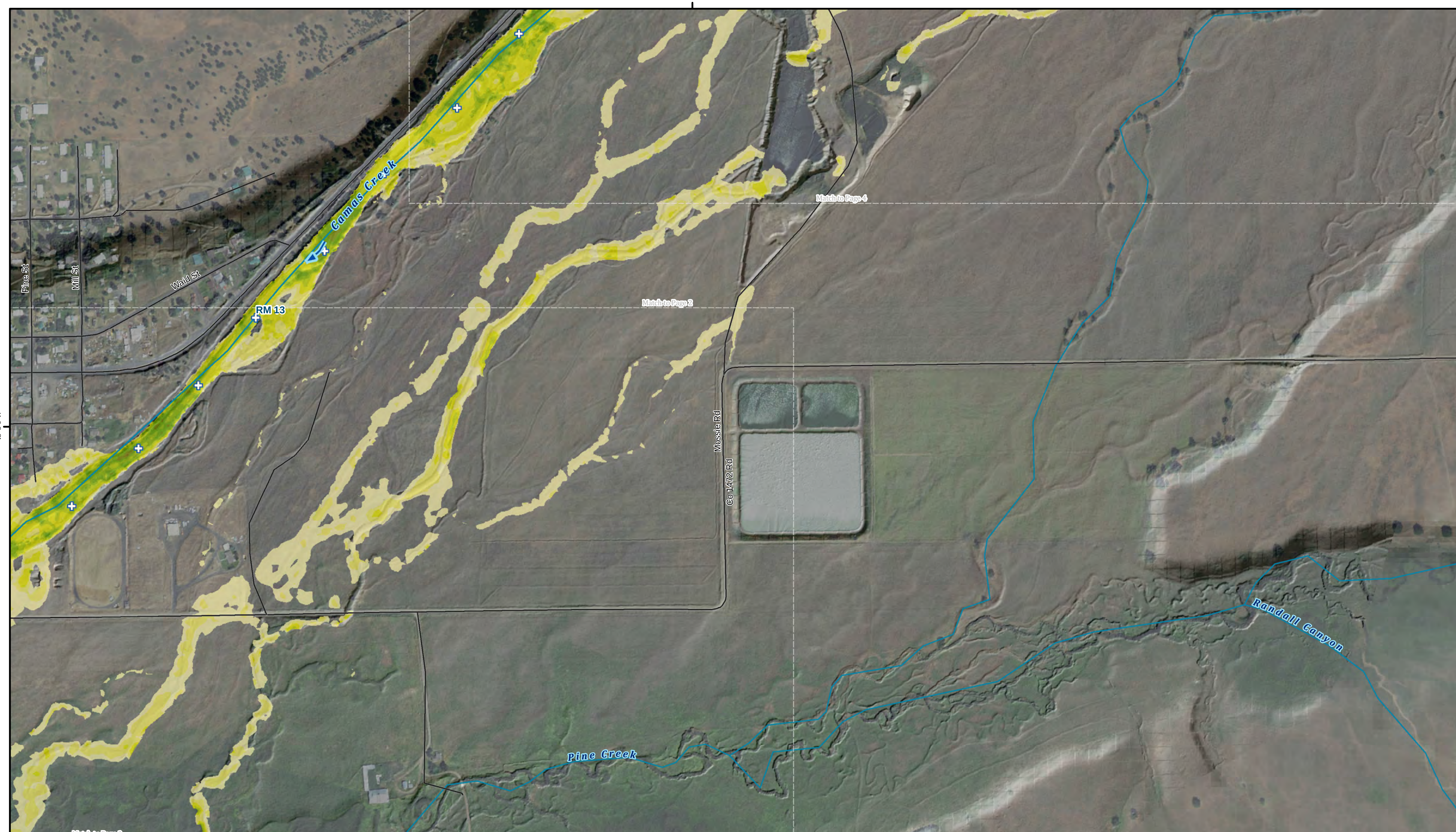
Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1 | 0.1 - 0.25 | 0.25 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | 2 - 3 | 3 - 4 | 4 - 6 | >6

15 River Mile
Streams
Roads

Natural Systems Design



David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrShear.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Basal Shear Stress - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

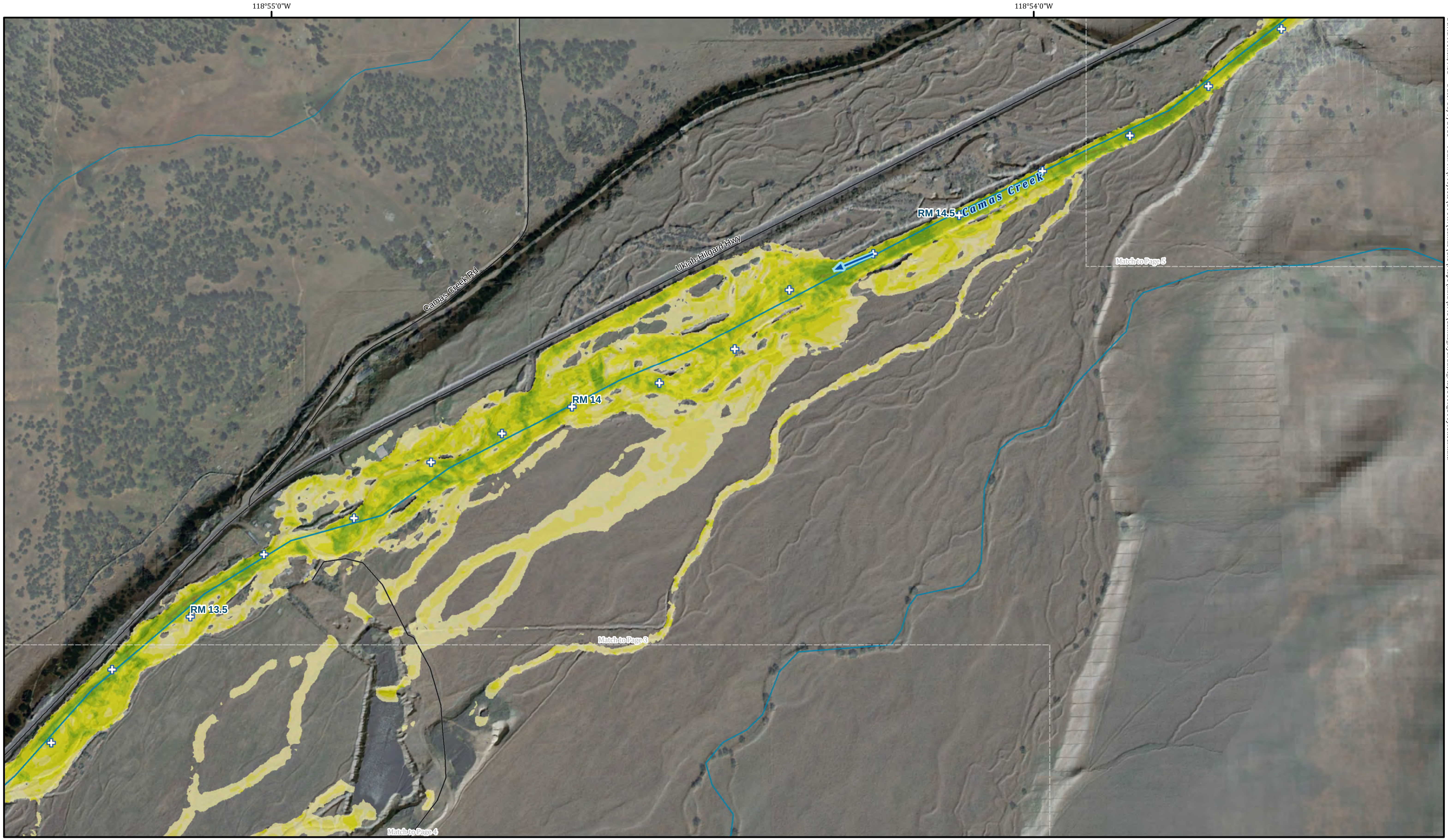
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 6, >6

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Basal Shear Stress - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

118°53'0"W

David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrShear.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Basal Shear Stress - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 6, >6

15 River Mile
Streams
Roads

Natural Systems Design

David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrShear.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Basal Shear Stress - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

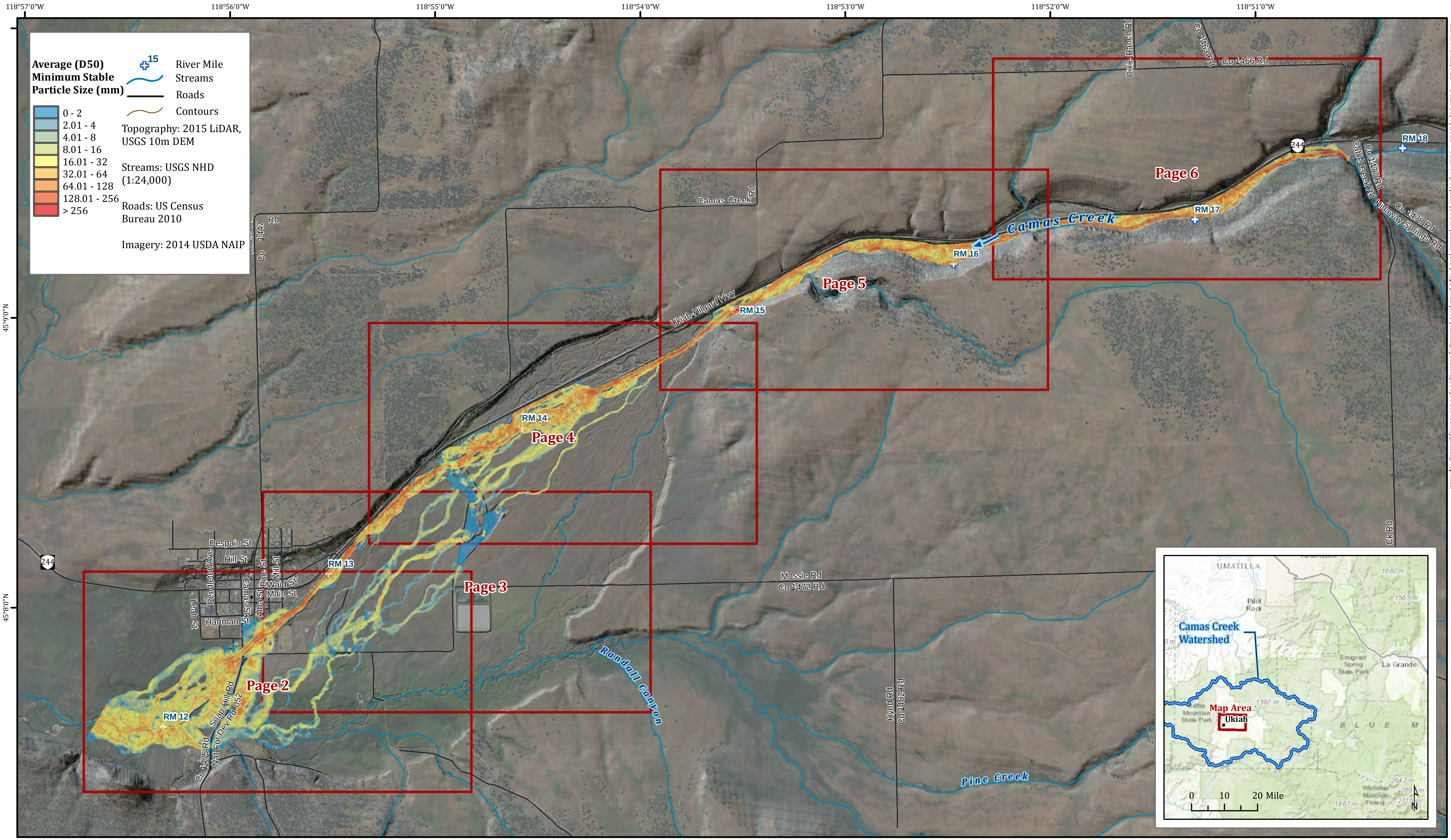
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Shear (lbs/sq ft)

<0.1, 0.1 - 0.25, 0.25 - 0.5, 0.5 - 1, 1 - 1.5, 1.5 - 2, 2 - 3, 3 - 4, 4 - 6, >6

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

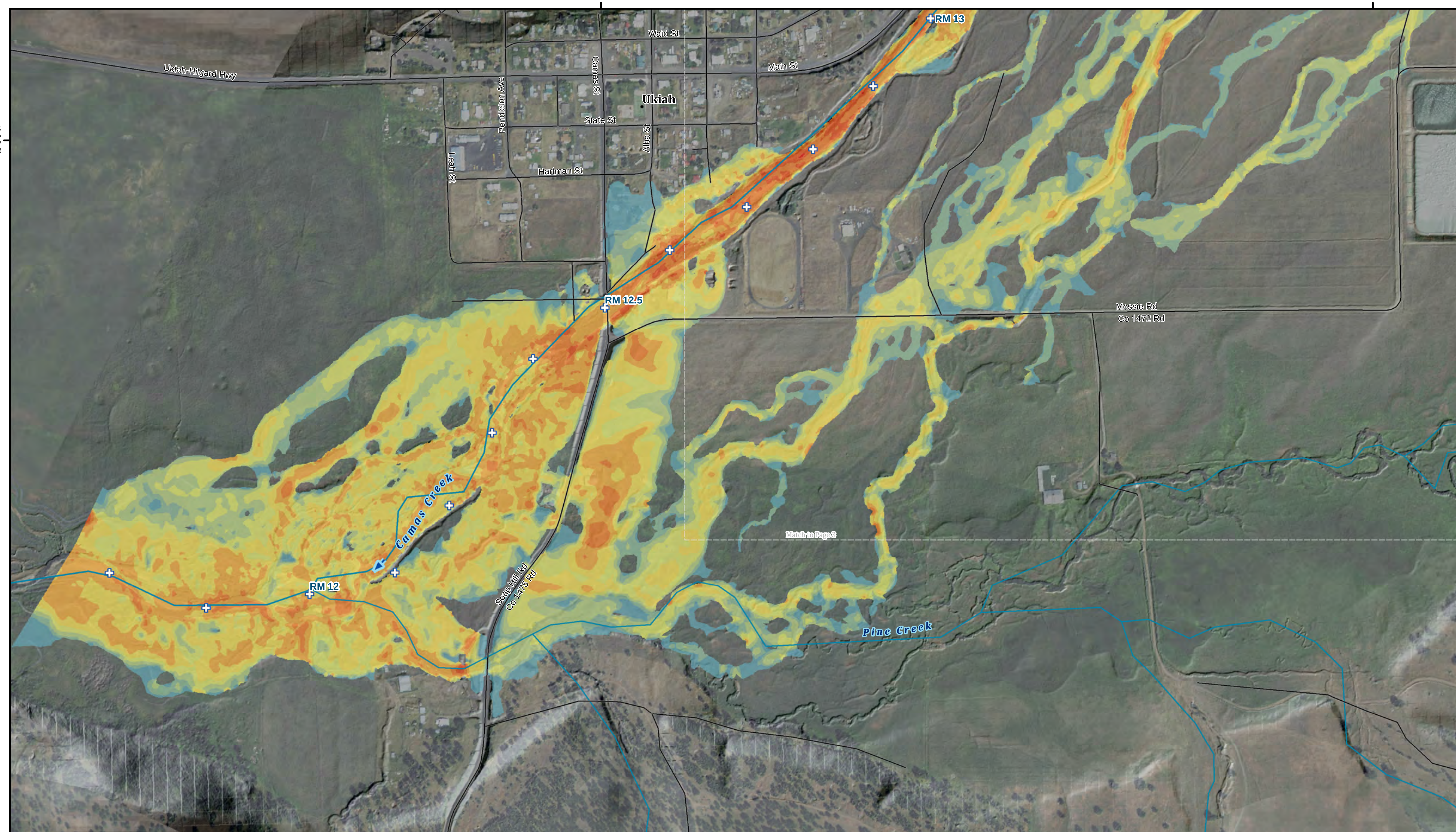
Existing Conditions 100 yr Flow Bed Mobility Map Book - Page 1 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



David French, NSD   Date: 11/9/2015   Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrBedMobility.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Bed Mobility - Page 2 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

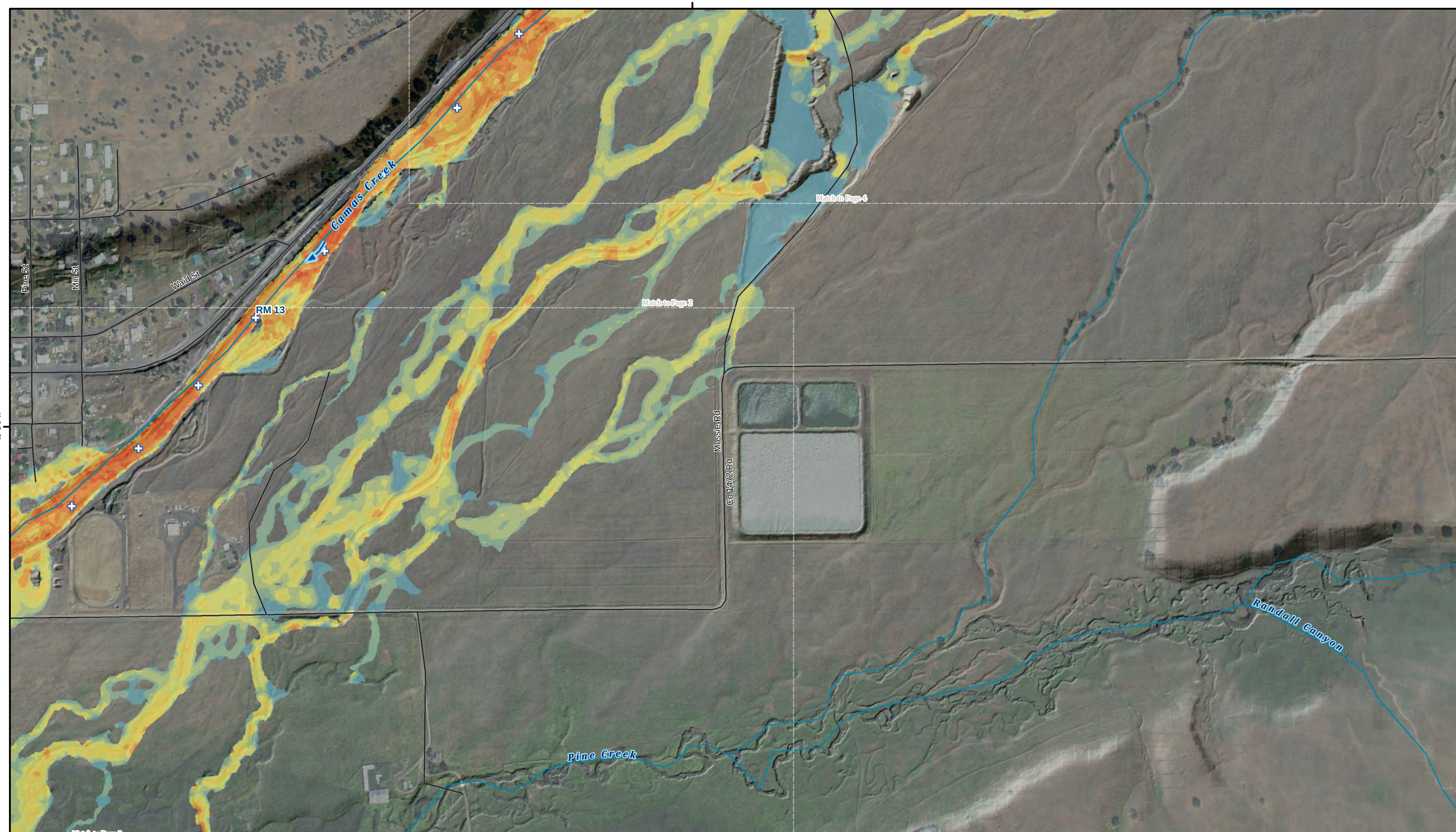
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Bed Mobility - Page 3 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

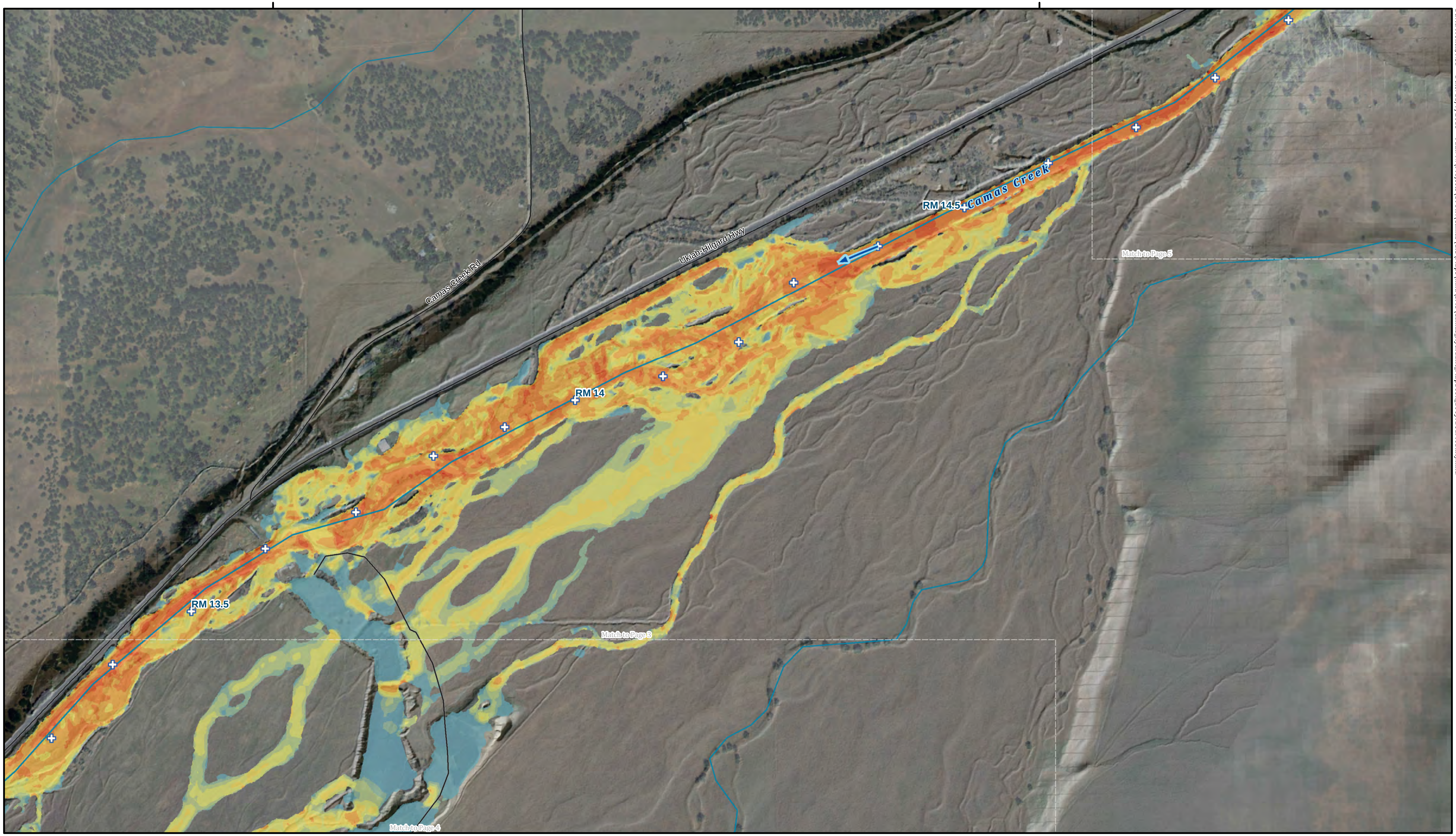
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design



David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrBedMobility.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Bed Mobility - Page 4 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design

David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrBedMobility.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Bed Mobility - Page 5 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

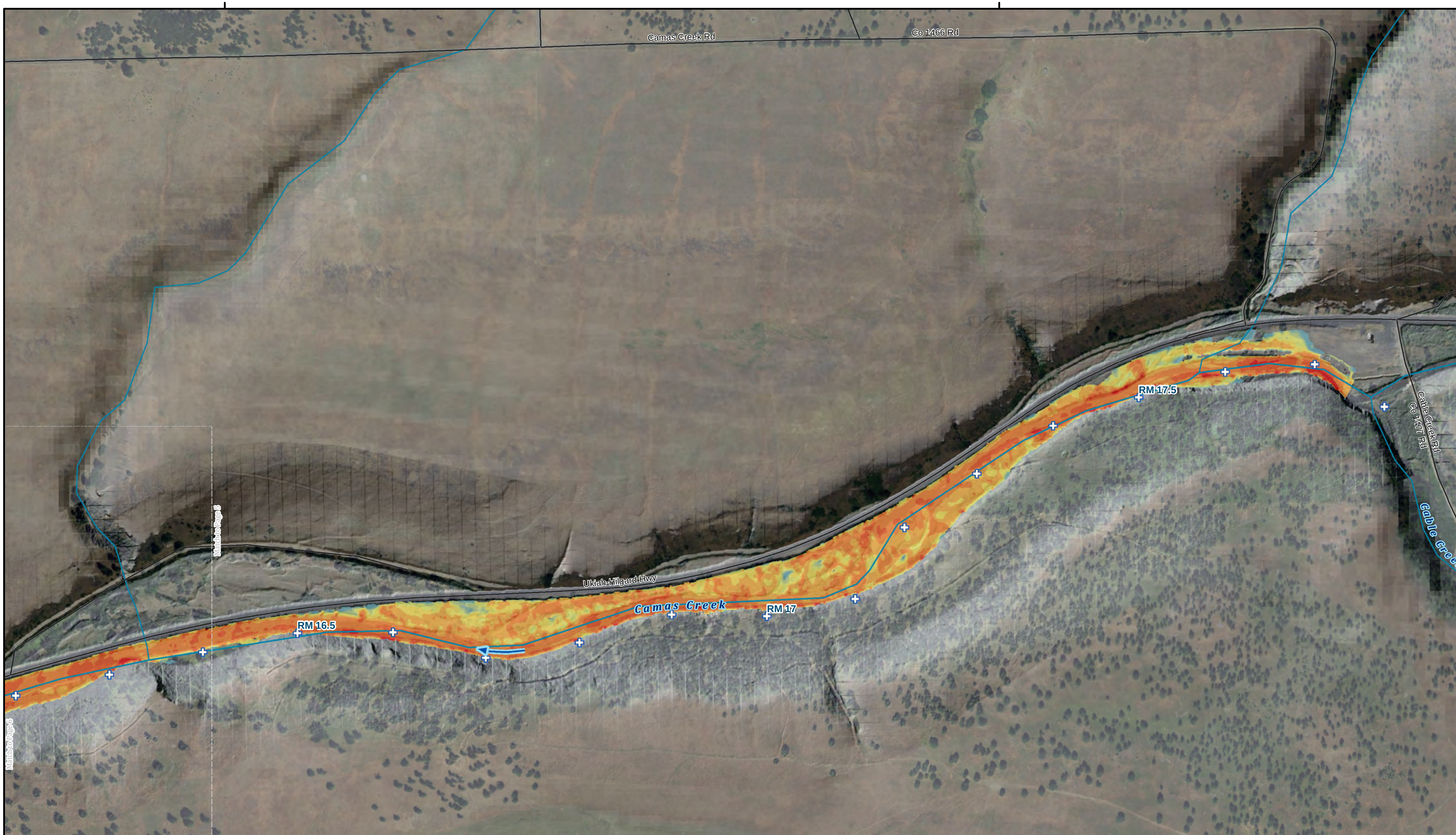
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design



David French, NSD Date: 11/9/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_Hydraulic_Mapbook_100yrBedMobility.mxd

Camas Creek Geomorphic Assessment & Action Plan

Existing Conditions 100 yr Flow Bed Mobility - Page 6 of 6

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)
Peak flow estimates used in the hydraulic analysis utilize the USGS period of record only (1914-1991).

N

0 250 500 750 1,000 Feet

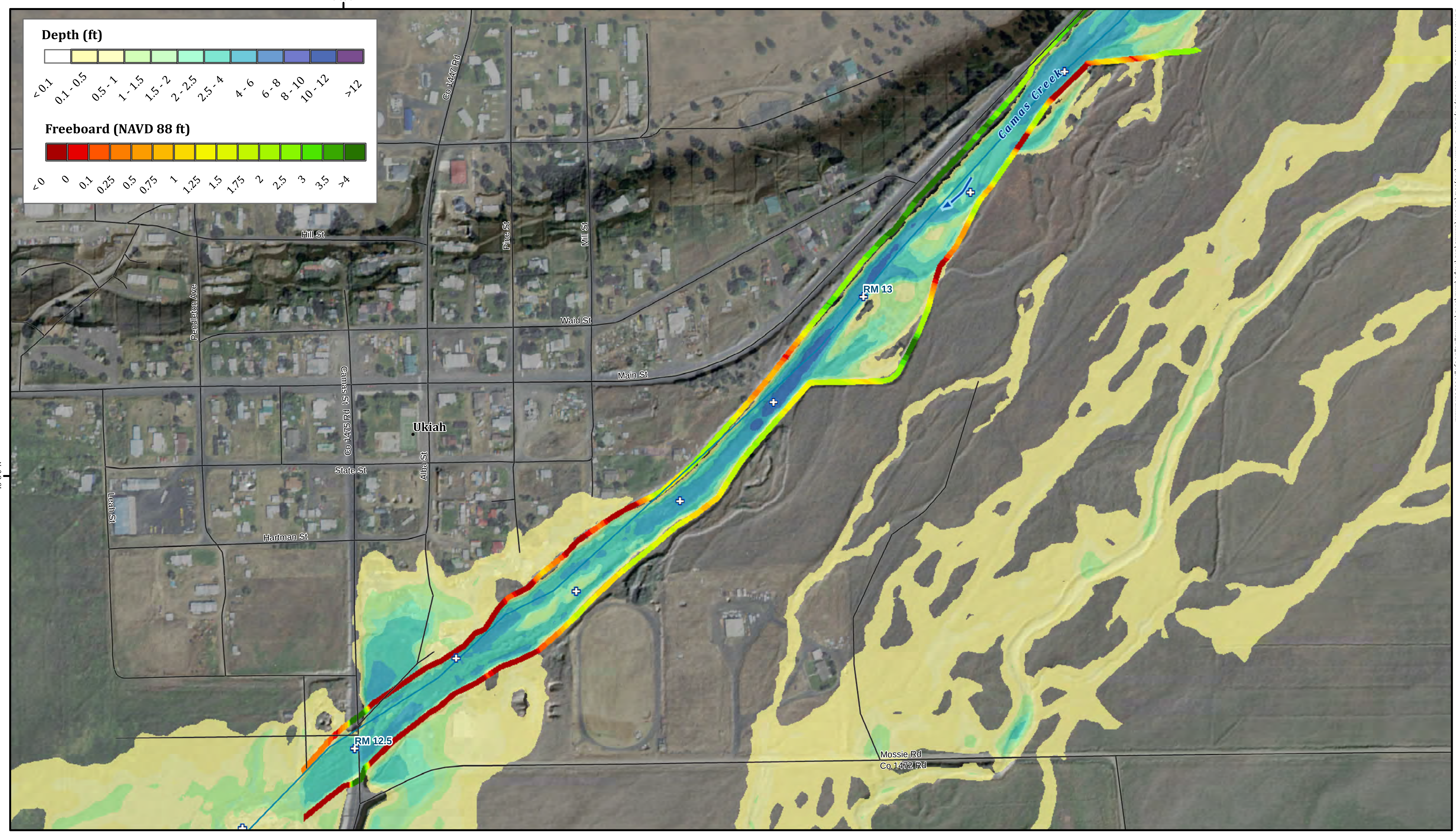
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Average (D50) Minimum Stable Partical Size (mm)

- <2 (sand)
- 2.01 - 4 (very fine gravel)
- 4.01 - 8 (fine gravel)
- 8.01 - 16 (medium gravel)
- 16.01 - 32 (coarse gravel)
- 32.01 - 64 (very coarse gravel)
- 64.01 - 128 (fine cobble)
- 128.01 - 256 (coarse cobble)
- >256 (boulder)

15 River Mile
Streams
Roads

Natural Systems Design



David French, NSD Date: 11/24/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\SMS\Camas_EC_100yr_Freeboard.mxd

Camas Creek Geomorphic Assessment & Action Plan

Levee Freeboard for 100 yr Flow Event

Hydronia RiverFlow2D Plus GPU Hydraulic Model output for 100 year (4900 cfs) flow event under existing conditions.
Freeboard is derived as the difference between levee elevations and the 100 yr water surface elevation.
Data sources: 2015 LiDAR (Quantum Spatial), USGS 10m DEM; 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)

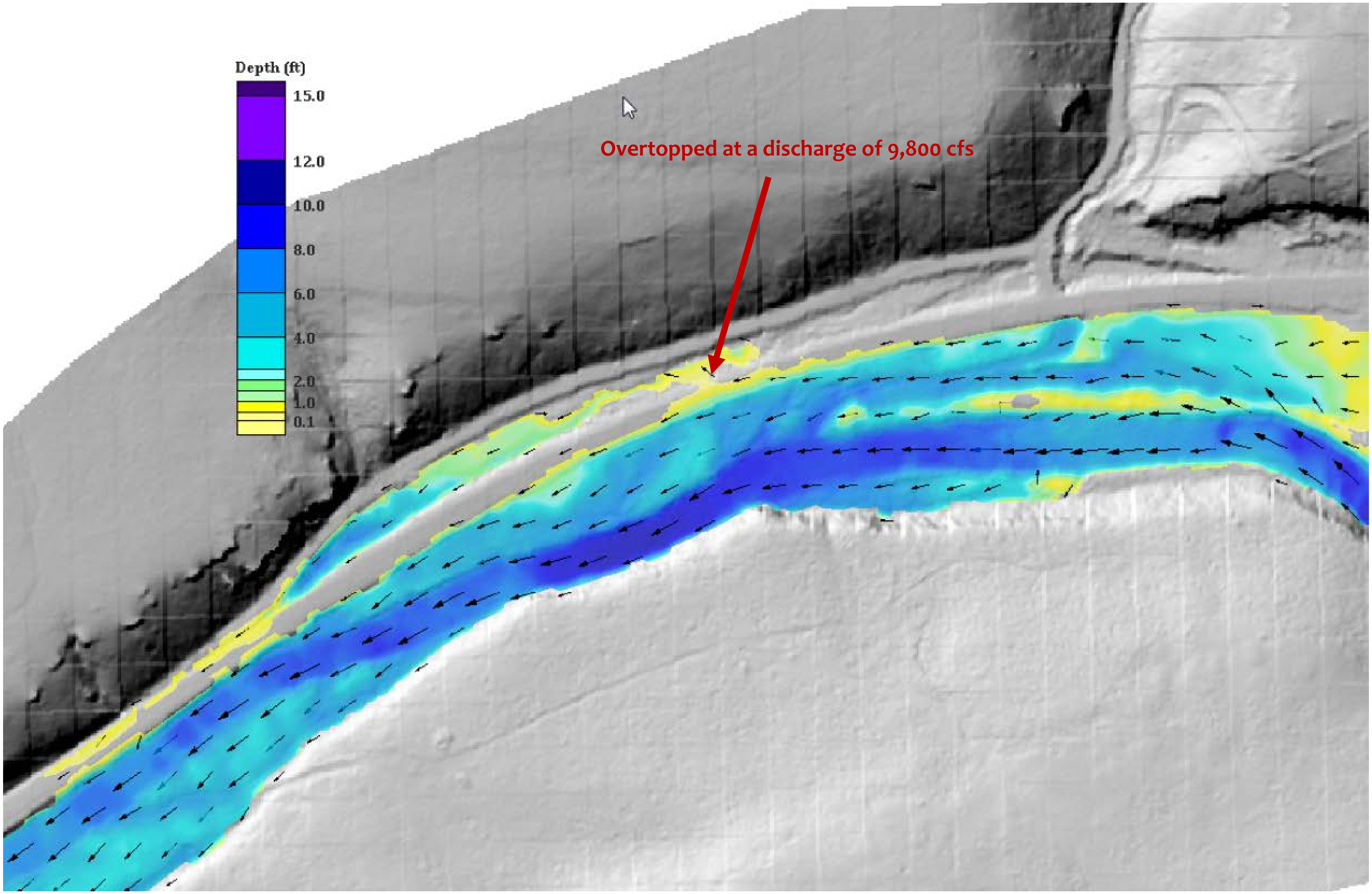
N

0 100 200 300 400 500 Feet

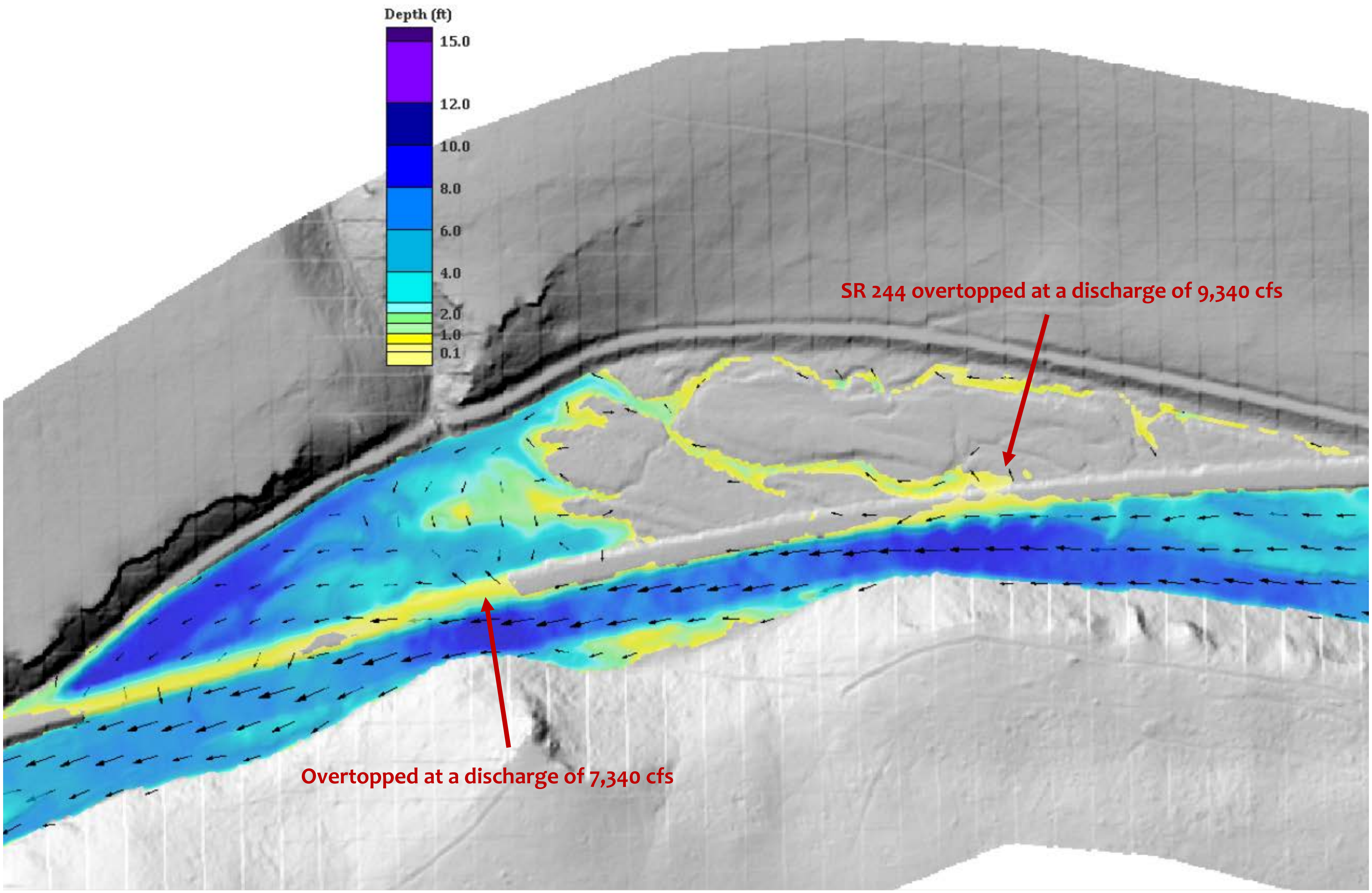
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile
Streams
Roads

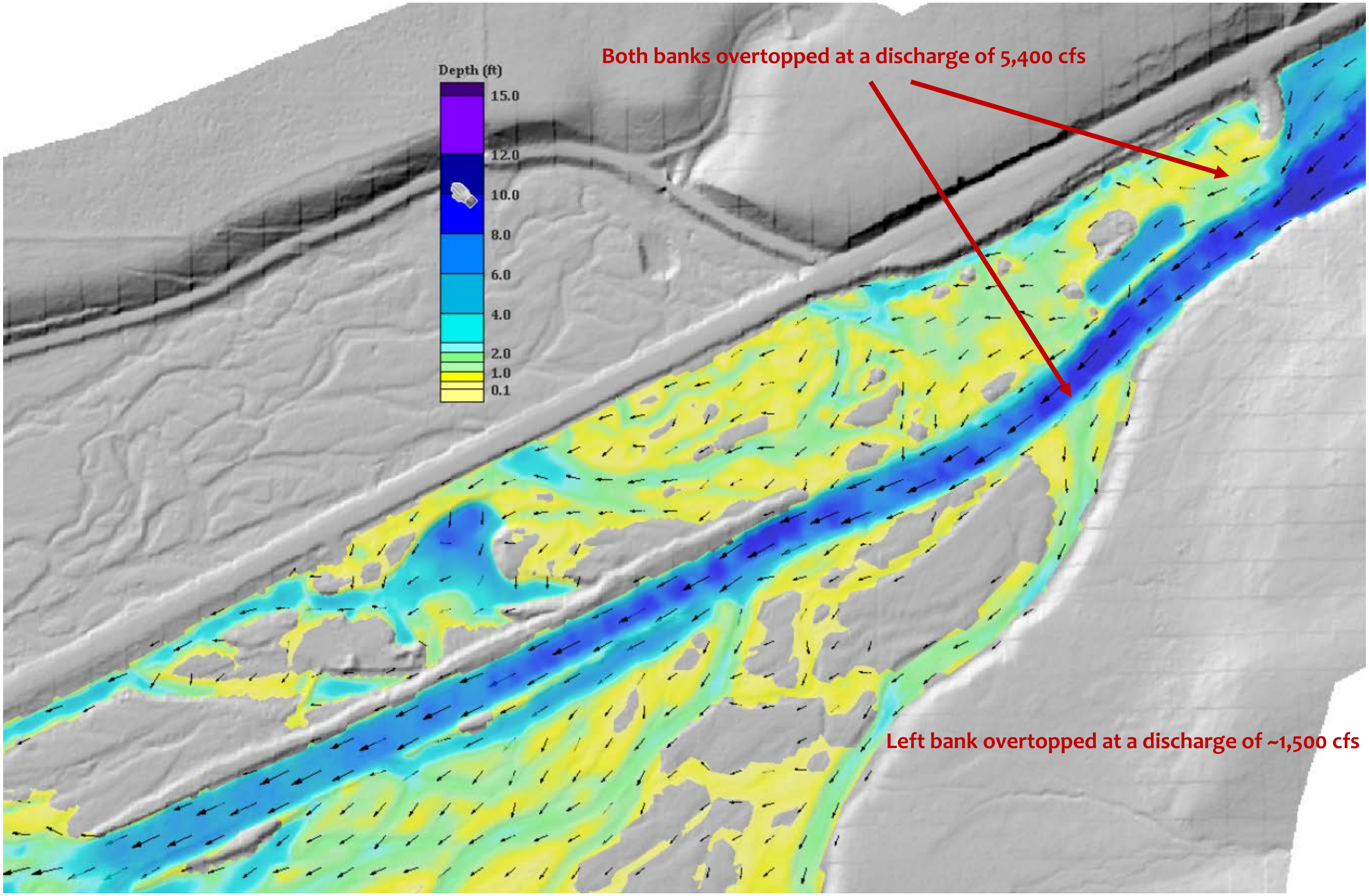
Natural Systems Design



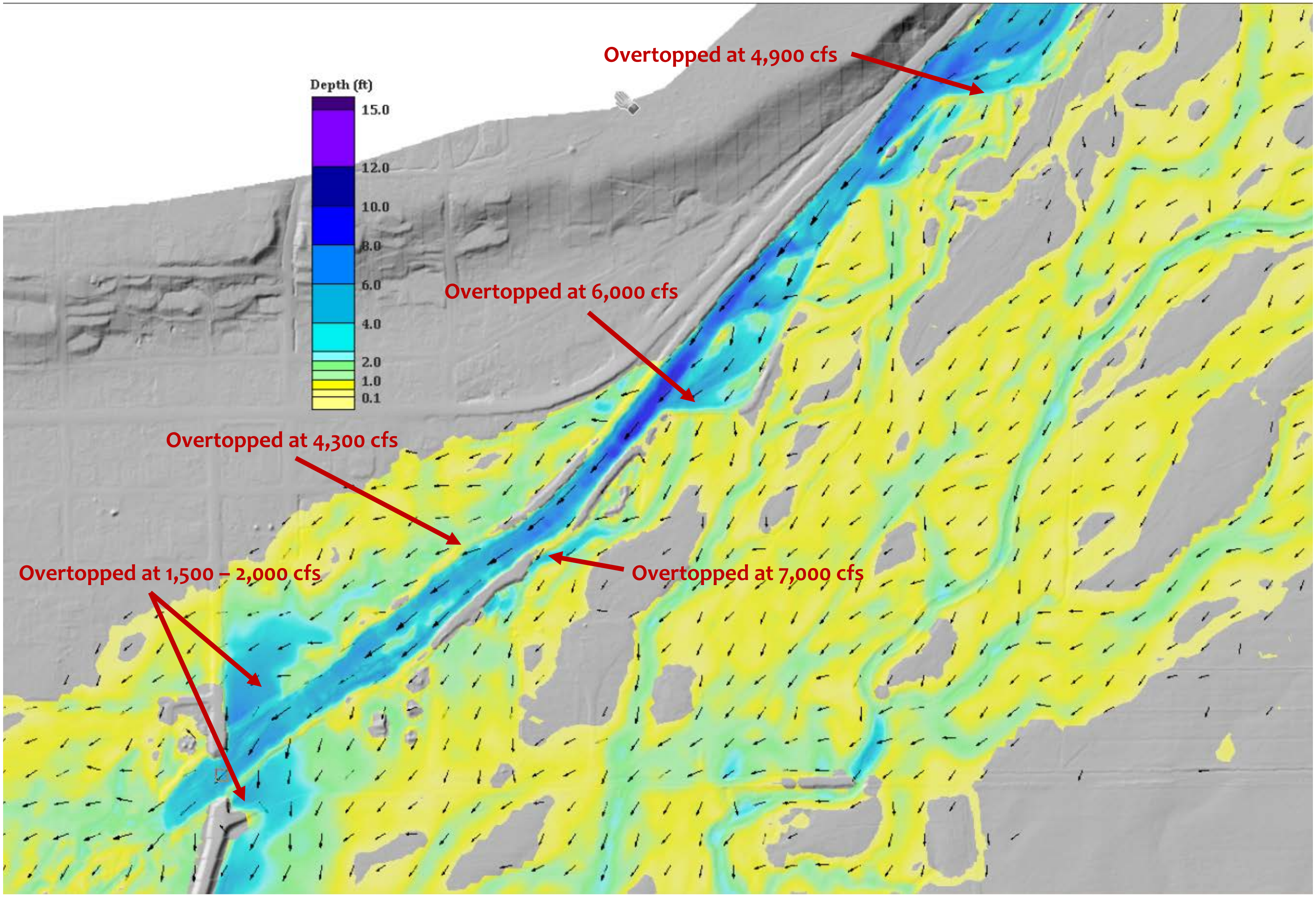
RM 17.5. Right bank along SR 244 is overtopped at a discharge of approximately 9,800 cfs.



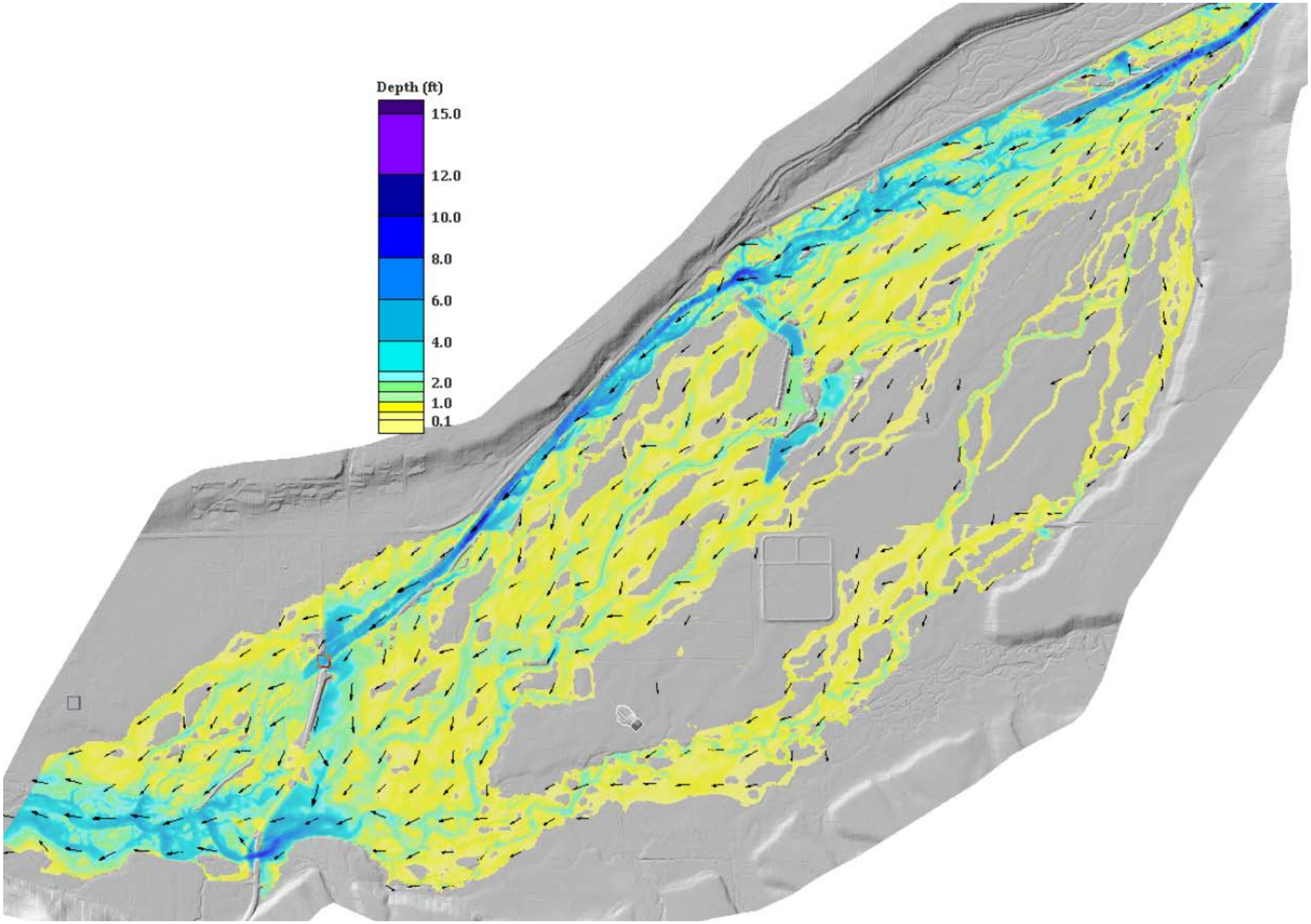
Overtopping of SR 244 initiates at RM 16.3 where the channel is constricted between the southern valley wall and the road at a discharge of 7,340 cfs. The roadway is also overtopped further upstream near RM 16.5 at a discharge of 9,340 cfs.



Flooding of the left bank floodplain at RM 14.6 where the levee has been breached initiates at approximately 1,500 cfs, with the floodplain channels fully engaged at 2,000 cfs. The left and right banks are overtopped at RM 14.8 when discharge reaches 5,400 cfs, engaging the floodplain channel along the southeastern portion of the alluvial fan.



The left bank at RM 13.25 is overtopped at a discharge of 4,900 cfs. Both the left and right banks at RM 12.9 are overtopped at 6,000 cfs. The right bank at RM 12.8 is overtopped at 4,300 cfs and the left bank at RM 12.8 is overtopped at 7,000 cfs. The left and right banks at Camas Street bridge become engaged at approximately 1,500 - 2,000 cfs.



At higher discharges, flooding of the alluvial fan initiating between RM 14.6 – 14.8 reduces the flood magnitude in Camas Creek near Ukiah. Lowering the levees at the head of the alluvial fan would help to alleviate flood risk in Ukiah, diverting peak flows to the floodplain channels and into lower Pine Creek.

Unsteady Hydraulic Model Outputs – 1,000 – 9,800 cfs

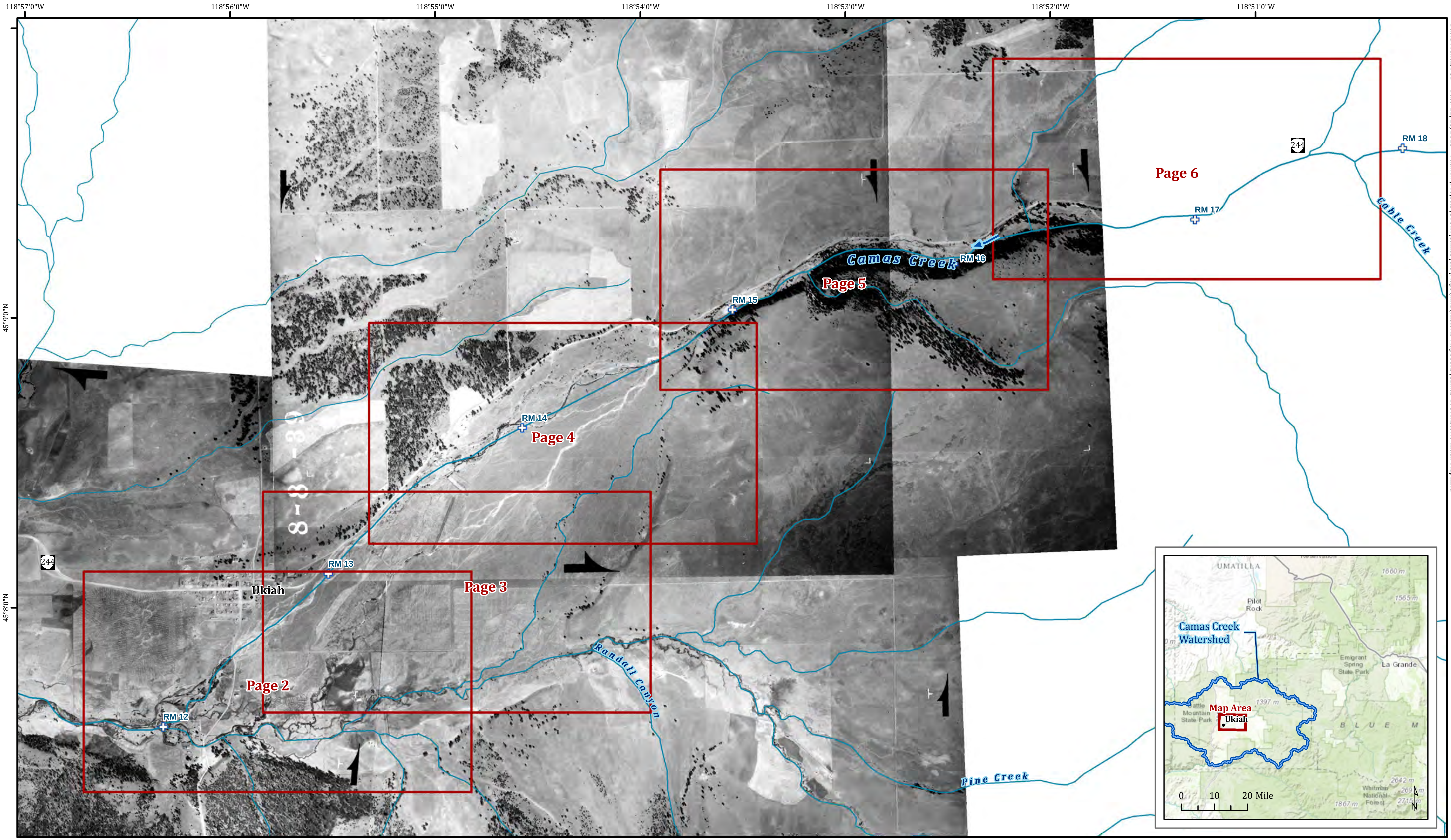
Natural Systems Design

APPENDIX B

Historic Aerial Photograph Maps

Natural Systems Design

P.O. Box 15609, Seattle, WA 98105 T: (206) 834-0175



Camas Creek Geomorphic Assessment & Action Plan

1939 Aerial Photo Map Book - Page 1 of 6

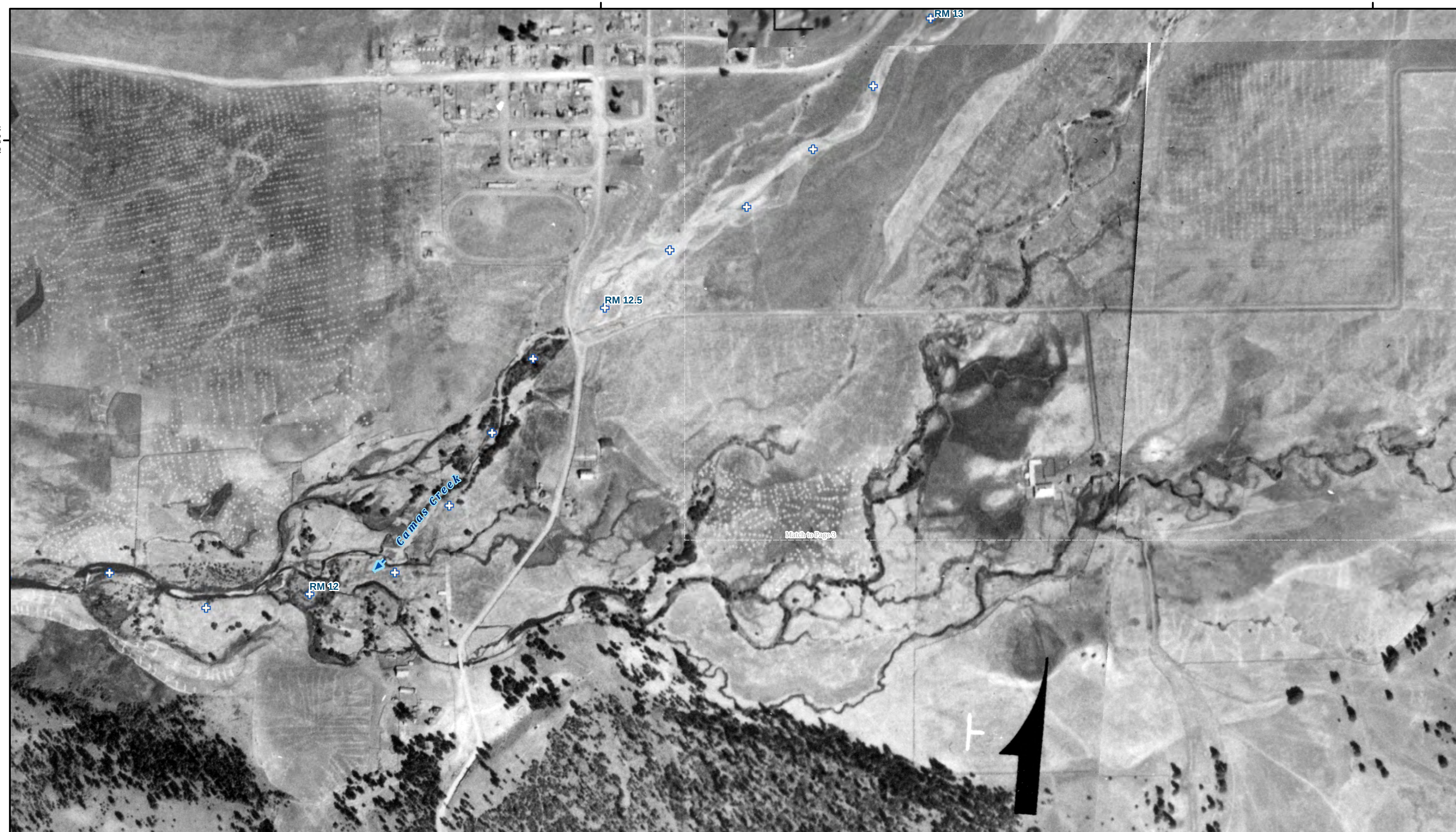
Data source: 1939 aerial imagery obtained from CTUIR

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1939Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1939 Aerial Photo Map Book - Page 2 of 6

Data source: 1939 aerial imagery obtained from CTUIR

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1939Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1939 Aerial Photo Map Book - Page 3 of 6

Data source: 1939 aerial imagery obtained from CTUIR

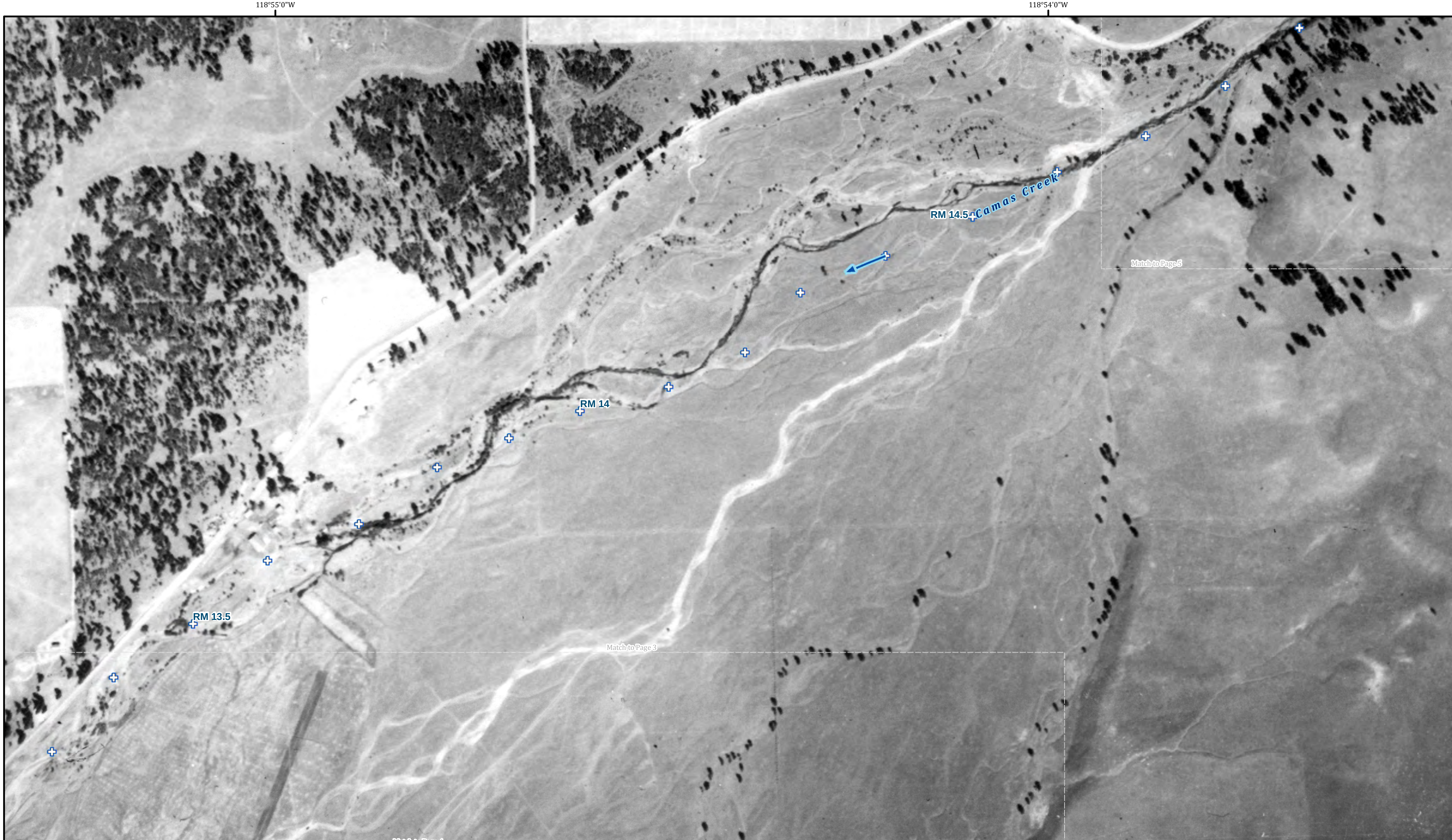
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1939Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1939 Aerial Photo Map Book - Page 4 of 6

Data source: 1939 aerial imagery obtained from CTUIR

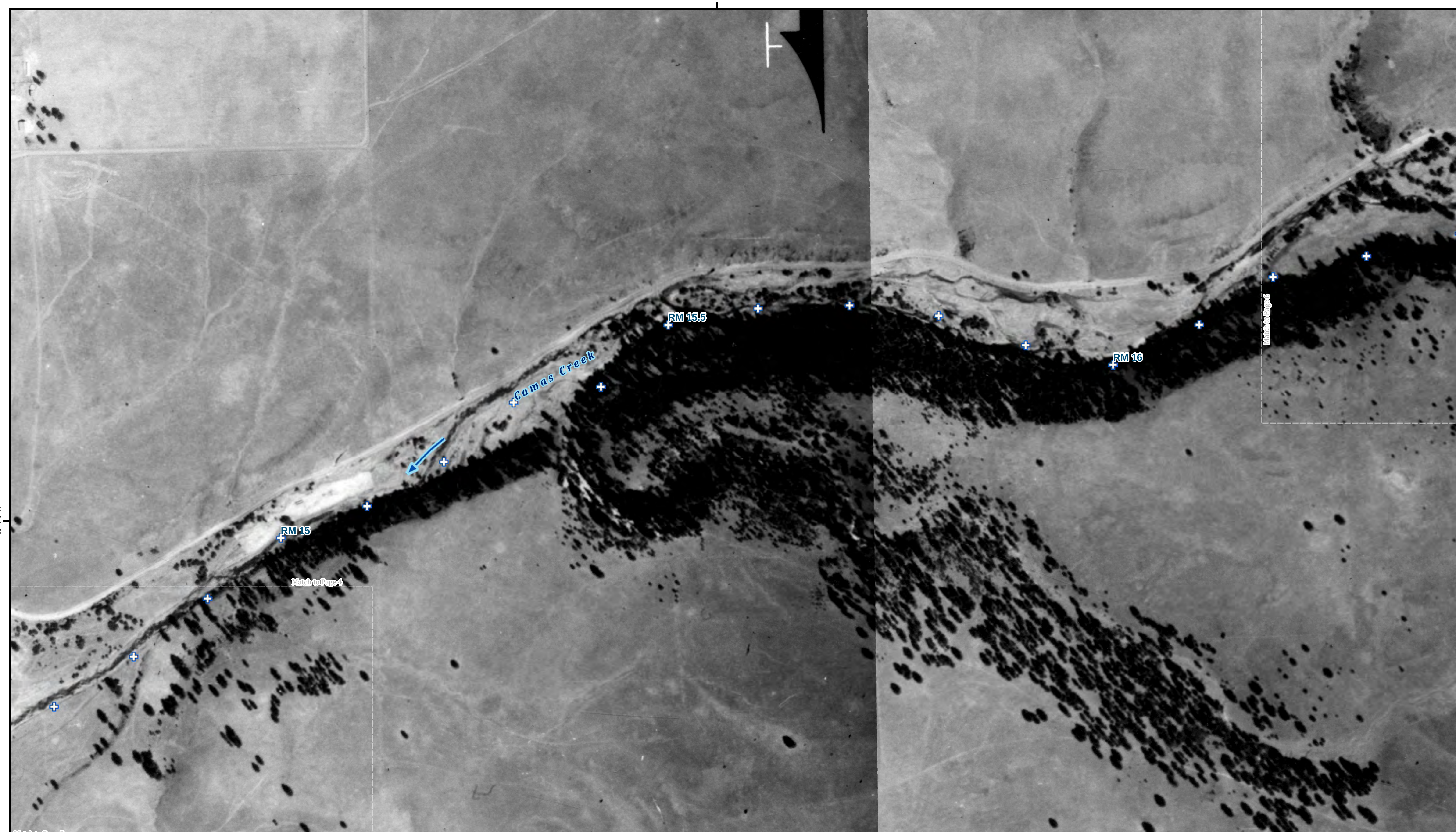
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1939Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1939 Aerial Photo Map Book - Page 5 of 6

Data source: 1939 aerial imagery obtained from CTUIR

N

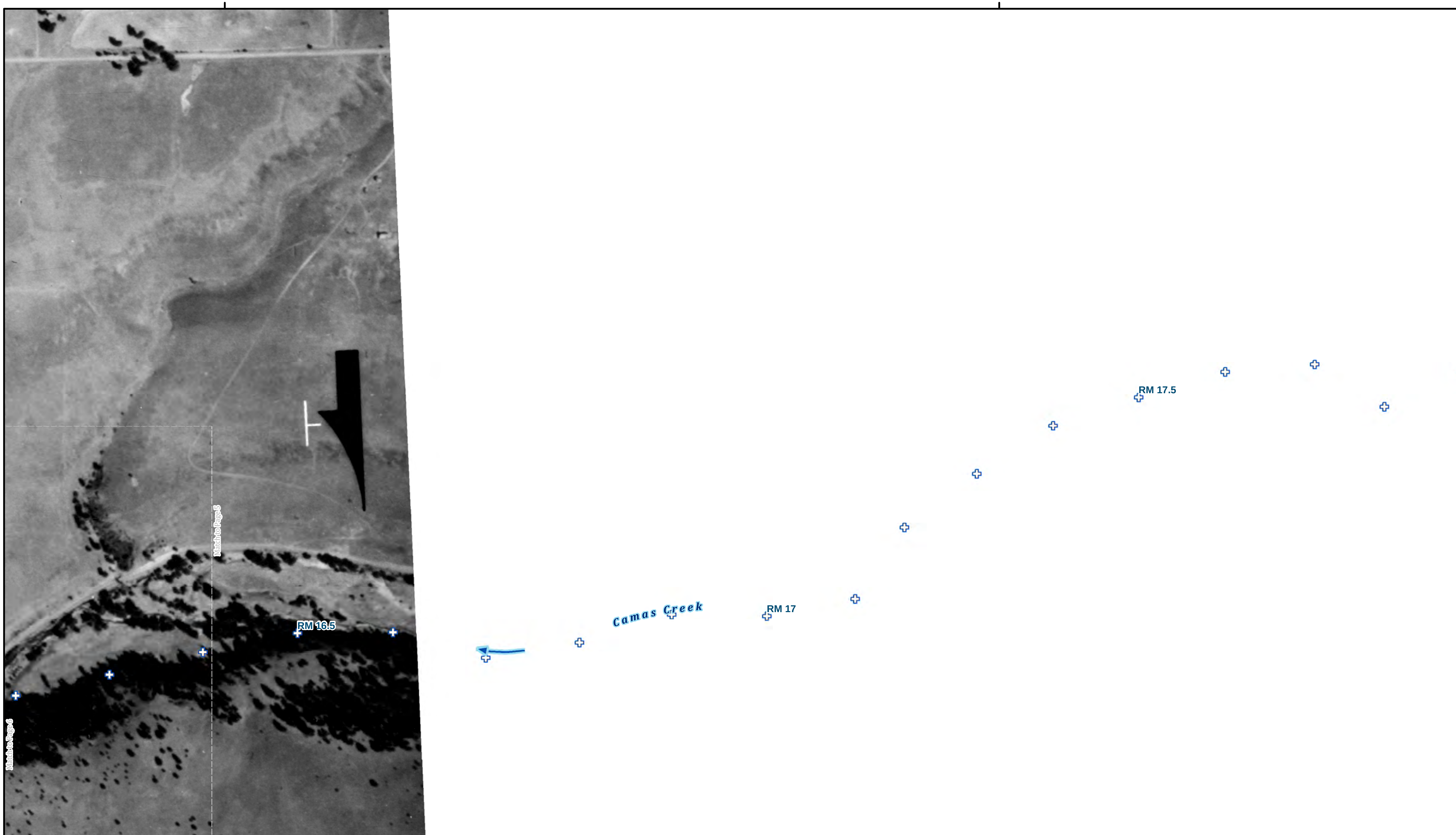
0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°52'0"W 118°51'0"W



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Camas Creek Geomorphic Assessment & Action Plan

1939 Aerial Photo Map Book - Page 6 of 6

Data source: 1939 aerial imagery obtained from CTUIR

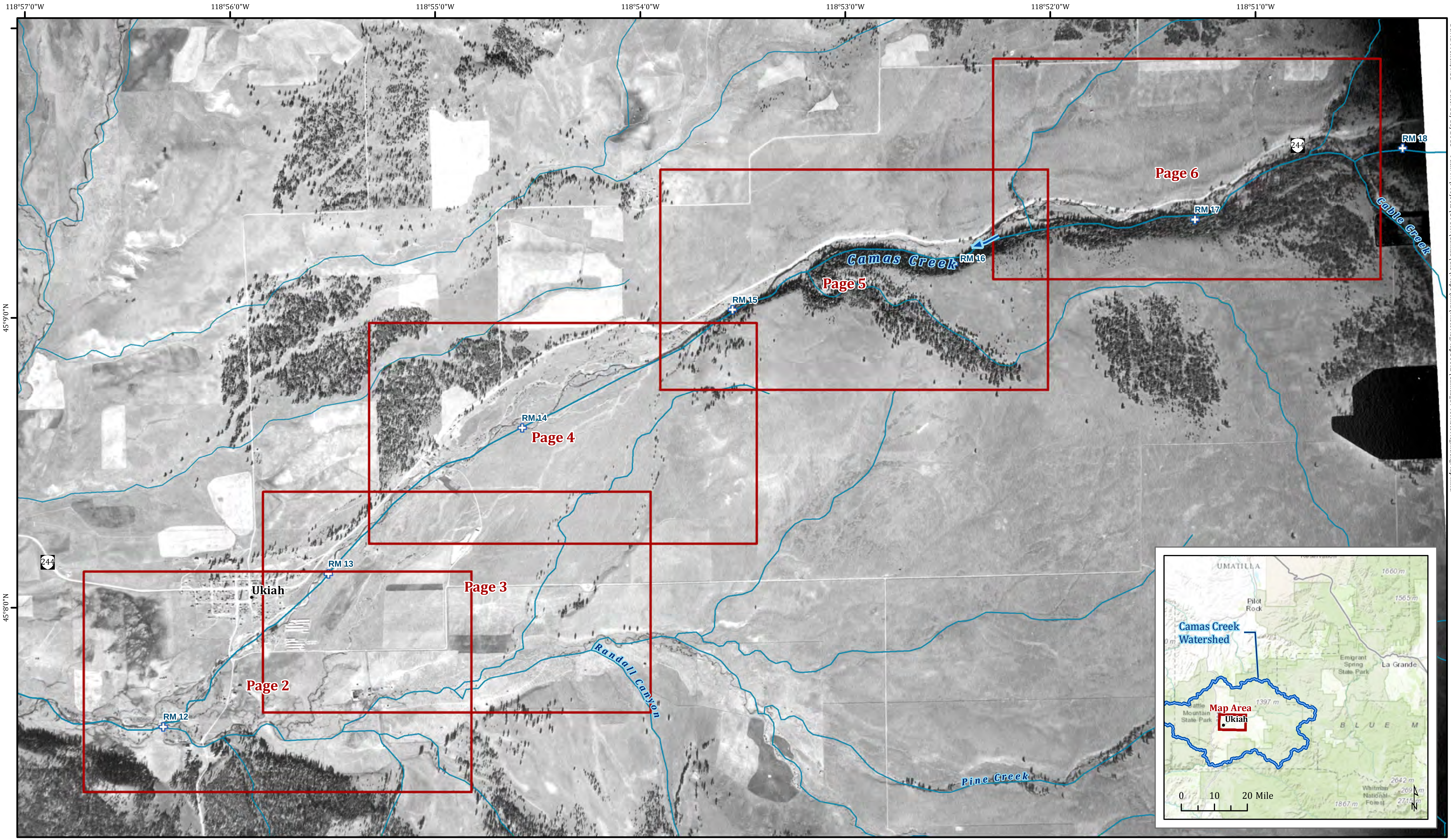
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1946 Aerial Photo Map Book - Page 1 of 6

Data source: 1946 aerial imagery obtained from CTUIR

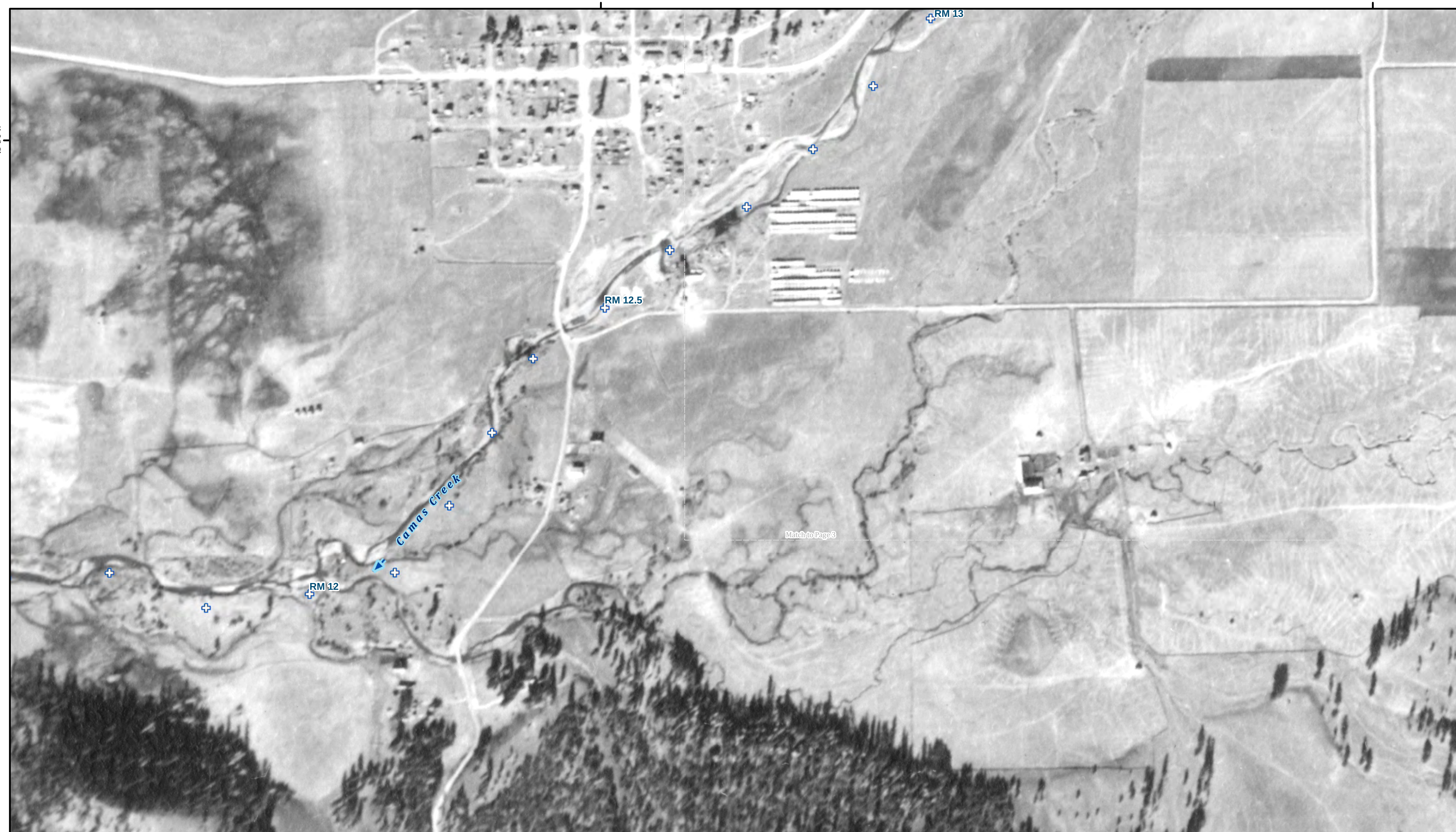
N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1946 Aerial Photo Map Book - Page 2 of 6

Data source: 1946 aerial imagery obtained from CTUIR

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

Camas Creek Geomorphic Assessment & Action Plan

1946 Aerial Photo Map Book - Page 3 of 6

Data source: 1946 aerial imagery obtained from CTUIR

N

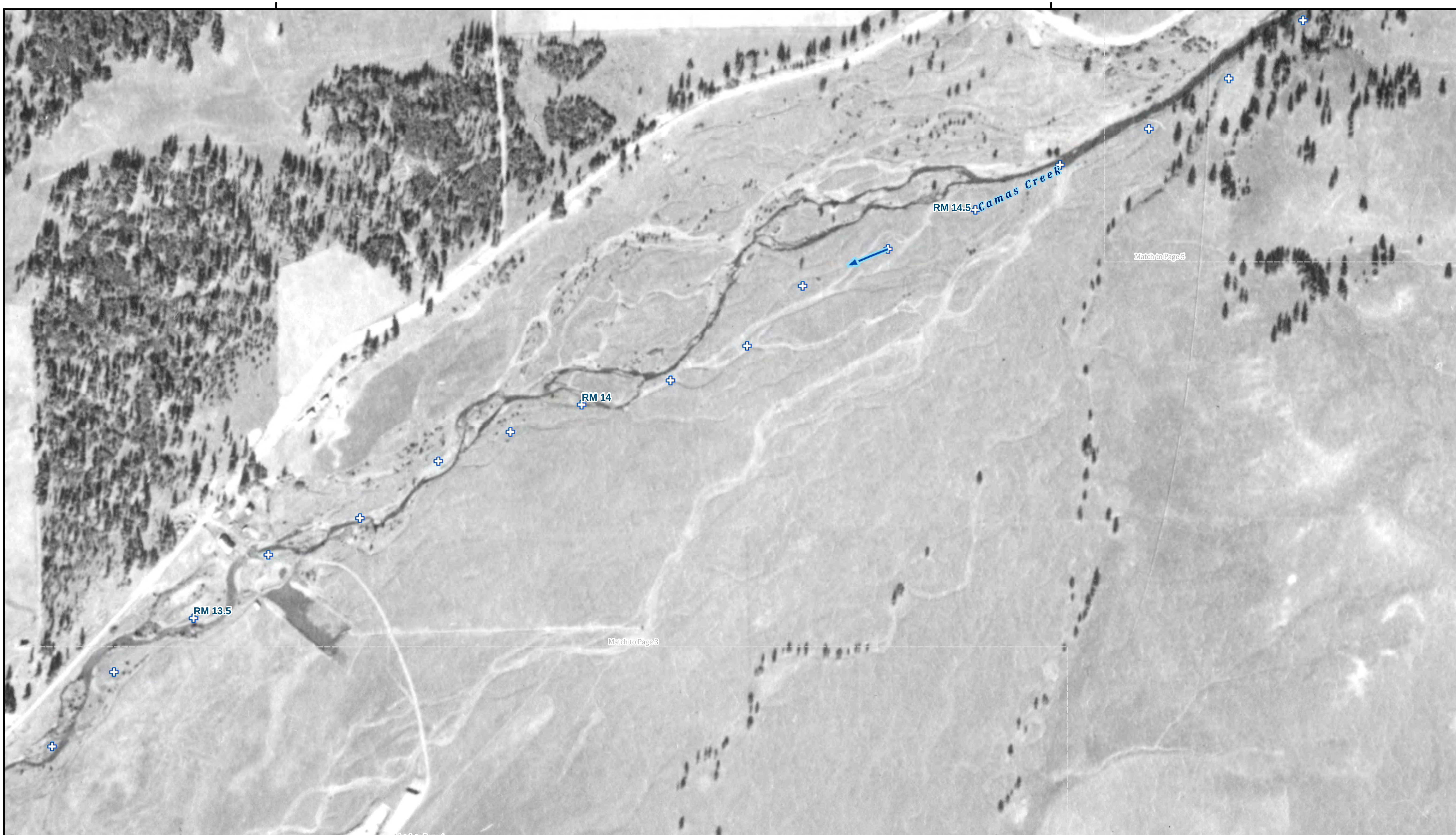
0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°55'0"W 118°54'0"W



David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1946Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1946 Aerial Photo Map Book - Page 4 of 6

Data source: 1946 aerial imagery obtained from CTUIR

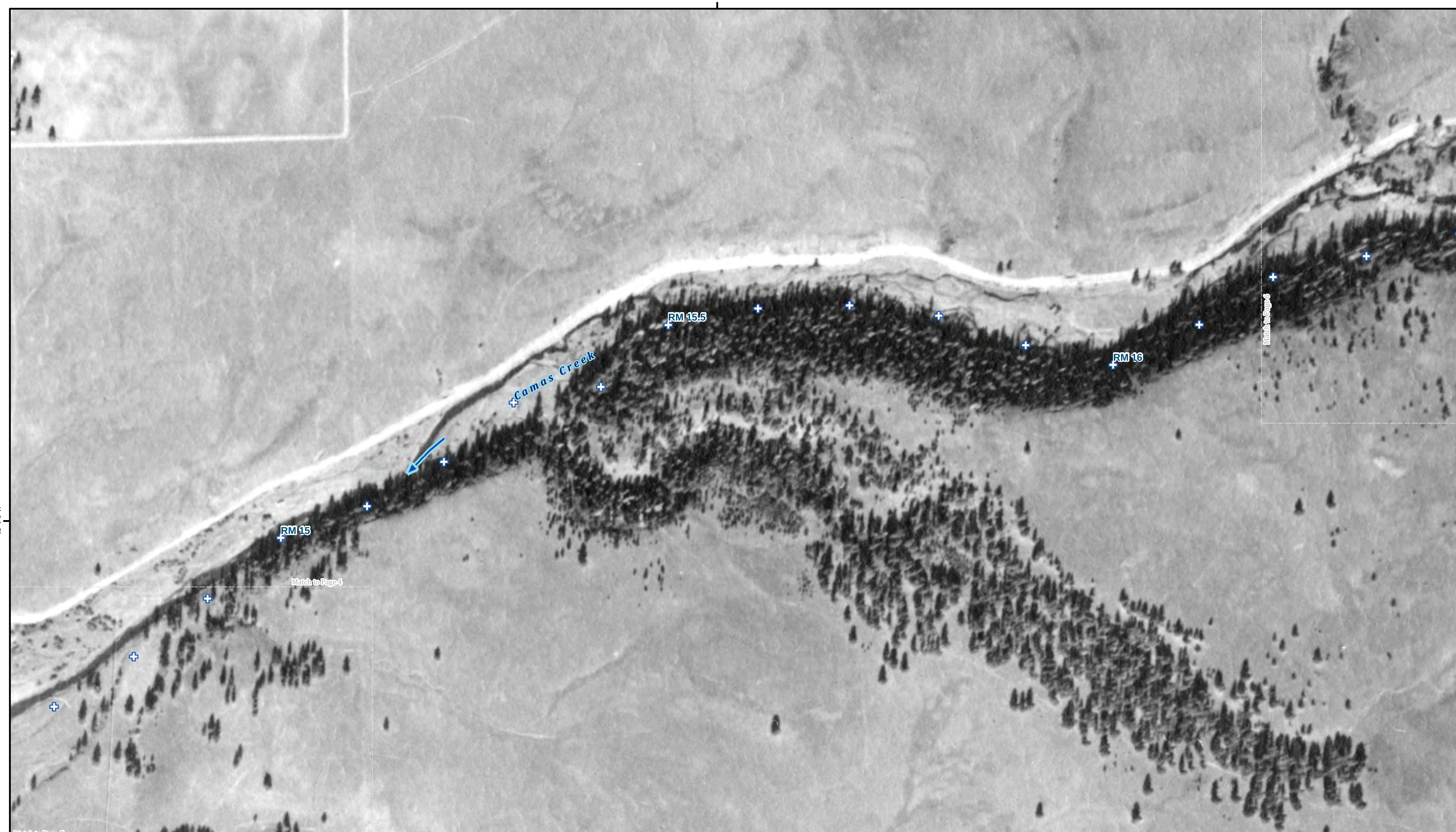
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1946 Aerial Photo Map Book - Page 5 of 6

Data source: 1946 aerial imagery obtained from CTUIR

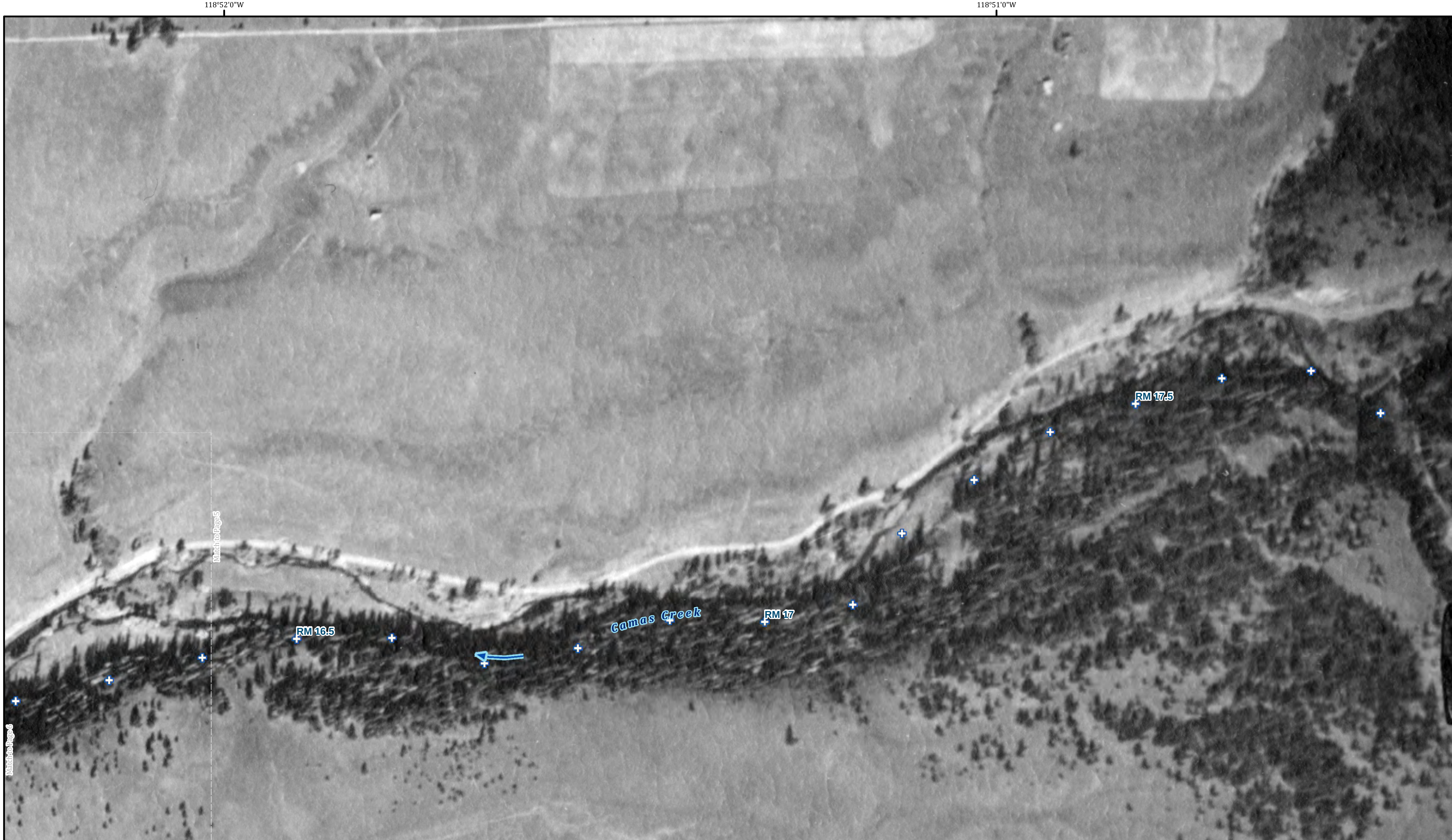
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1946 Aerial Photo Map Book - Page 6 of 6

Data source: 1946 aerial imagery obtained from CTUIR

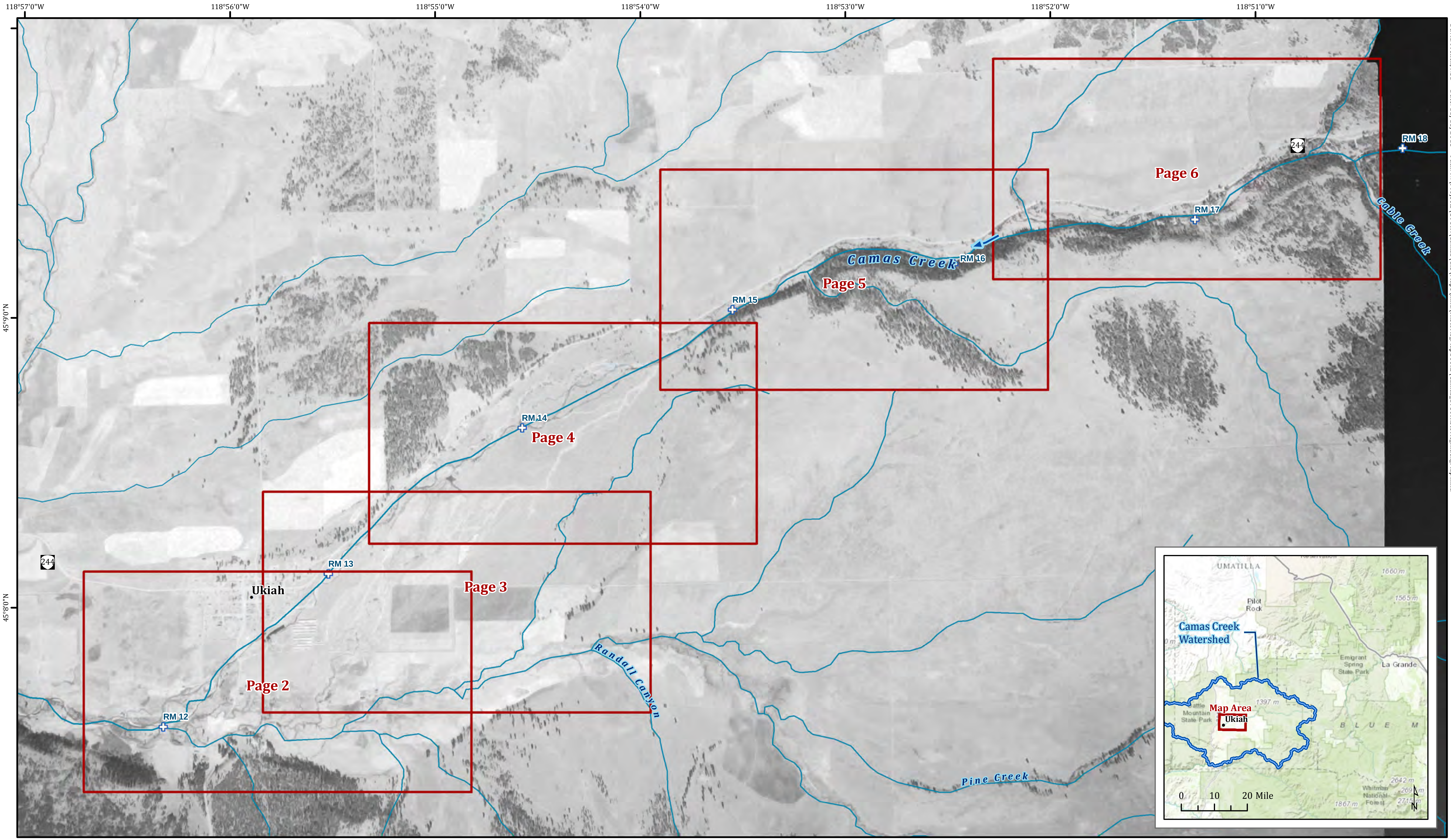
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1950 Aerial Photo Map Book - Page 1 of 6

Data source: 1950 aerial imagery obtained from USGS Earth Explorer

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

Camas Creek Geomorphic Assessment & Action Plan

1950 Aerial Photo Map Book - Page 2 of 6

Data source: 1950 aerial imagery obtained from USGS Earth Explorer

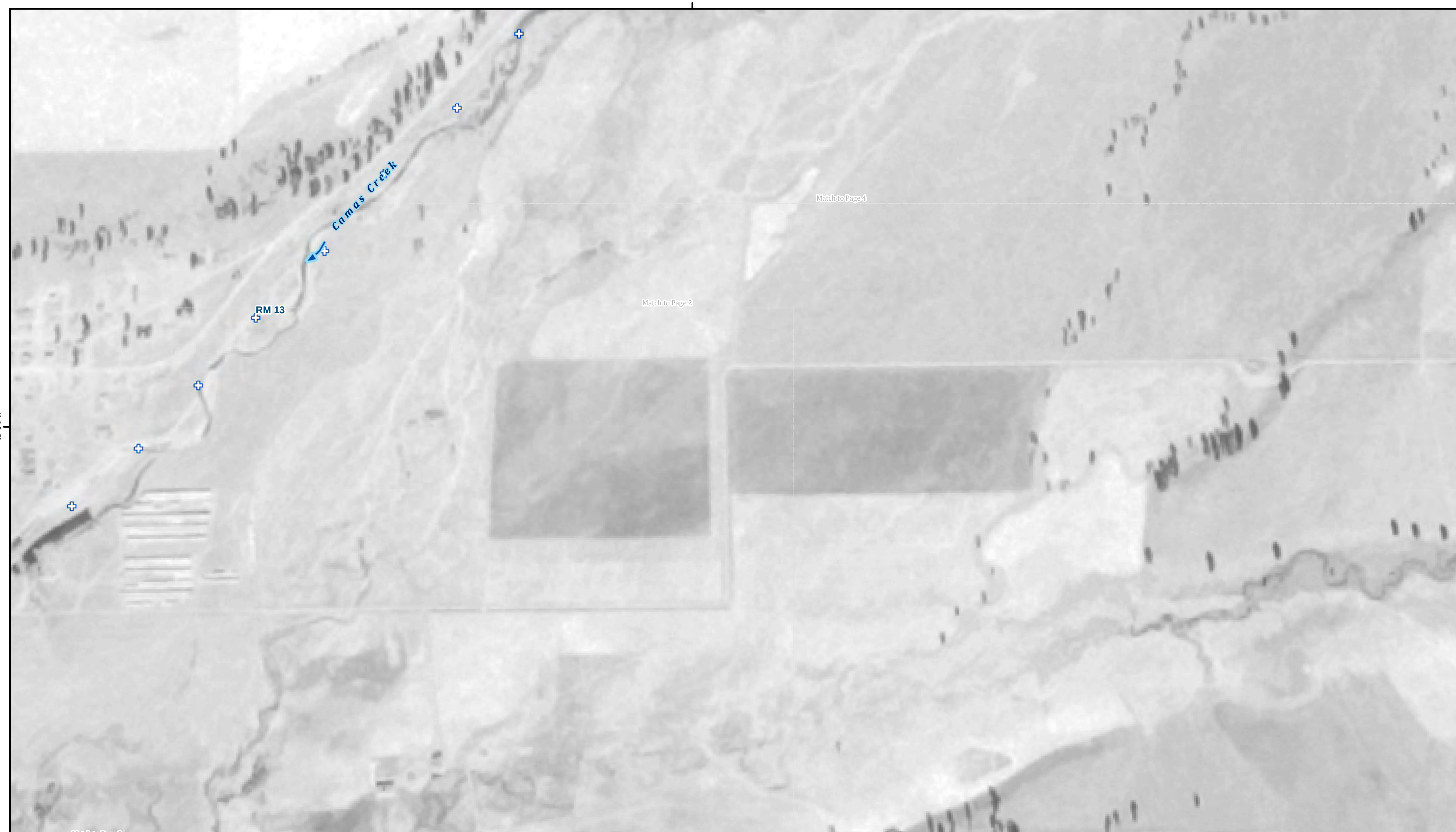
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1950 Aerial Photo Map Book - Page 3 of 6

Data source: 1950 aerial imagery obtained from USGS Earth Explorer

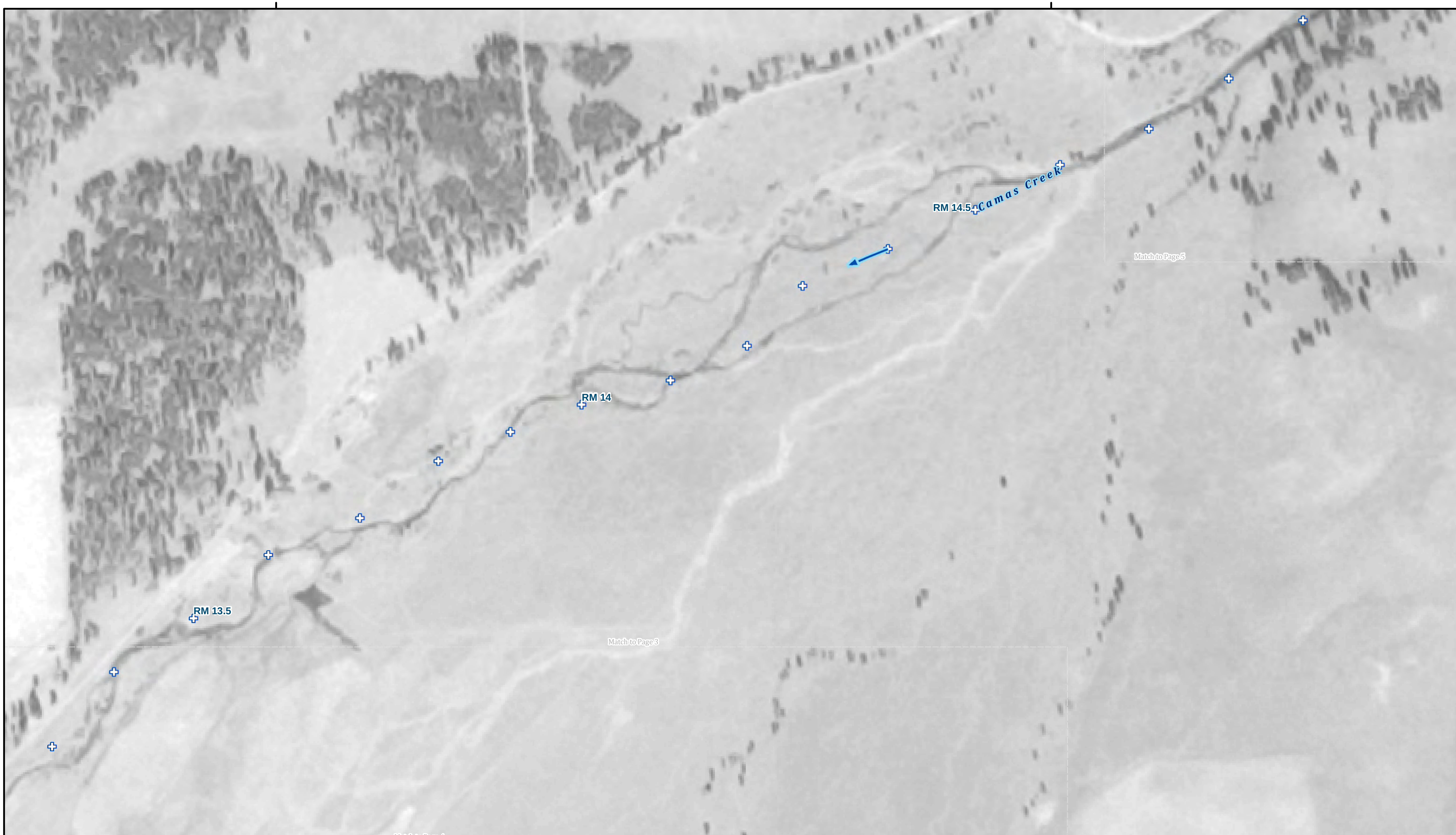
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1950 Aerial Photo Map Book - Page 4 of 6

Data source: 1950 aerial imagery obtained from USGS Earth Explorer

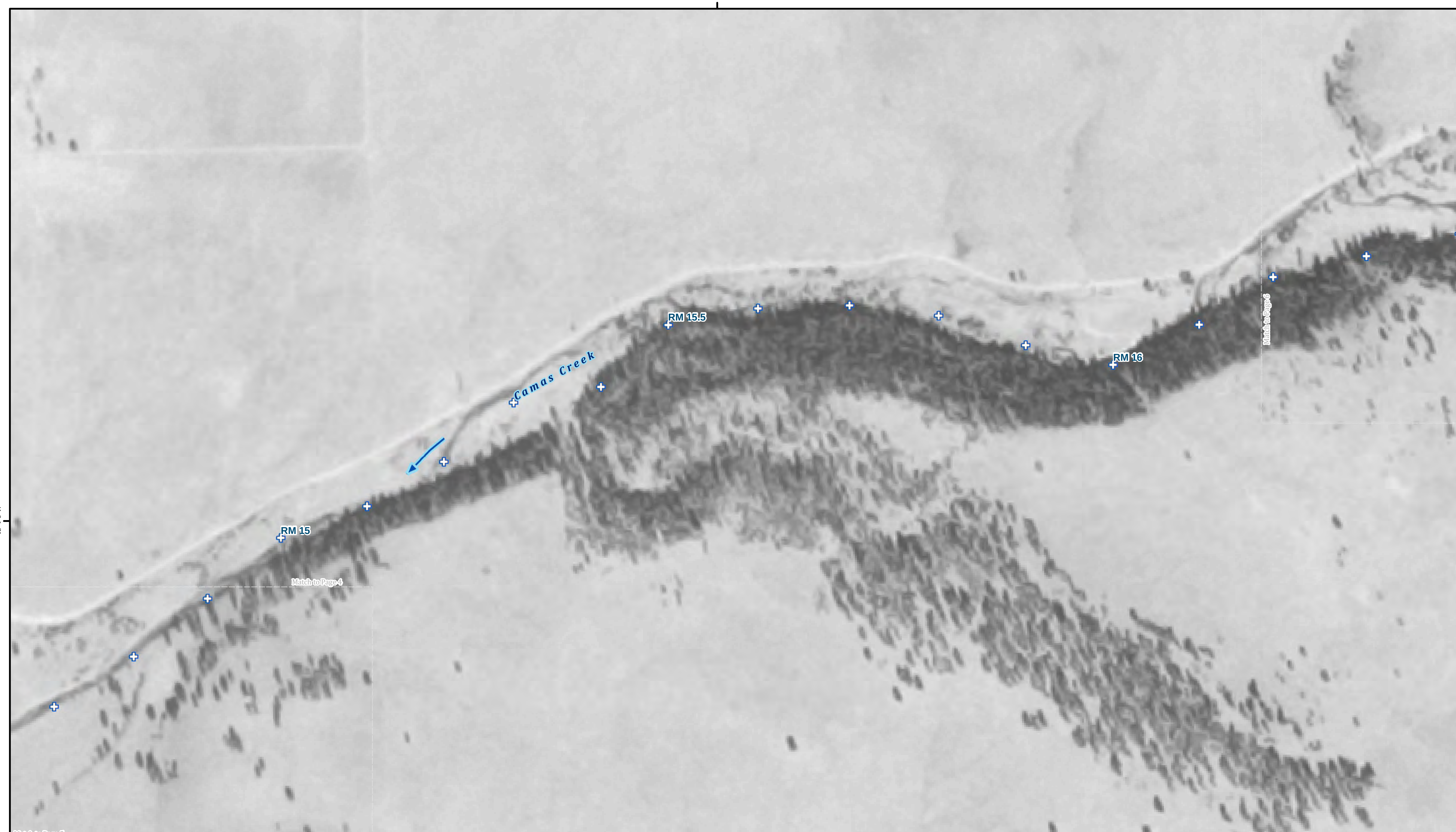
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1950 Aerial Photo Map Book - Page 5 of 6

Data source: 1950 aerial imagery obtained from USGS Earth Explorer

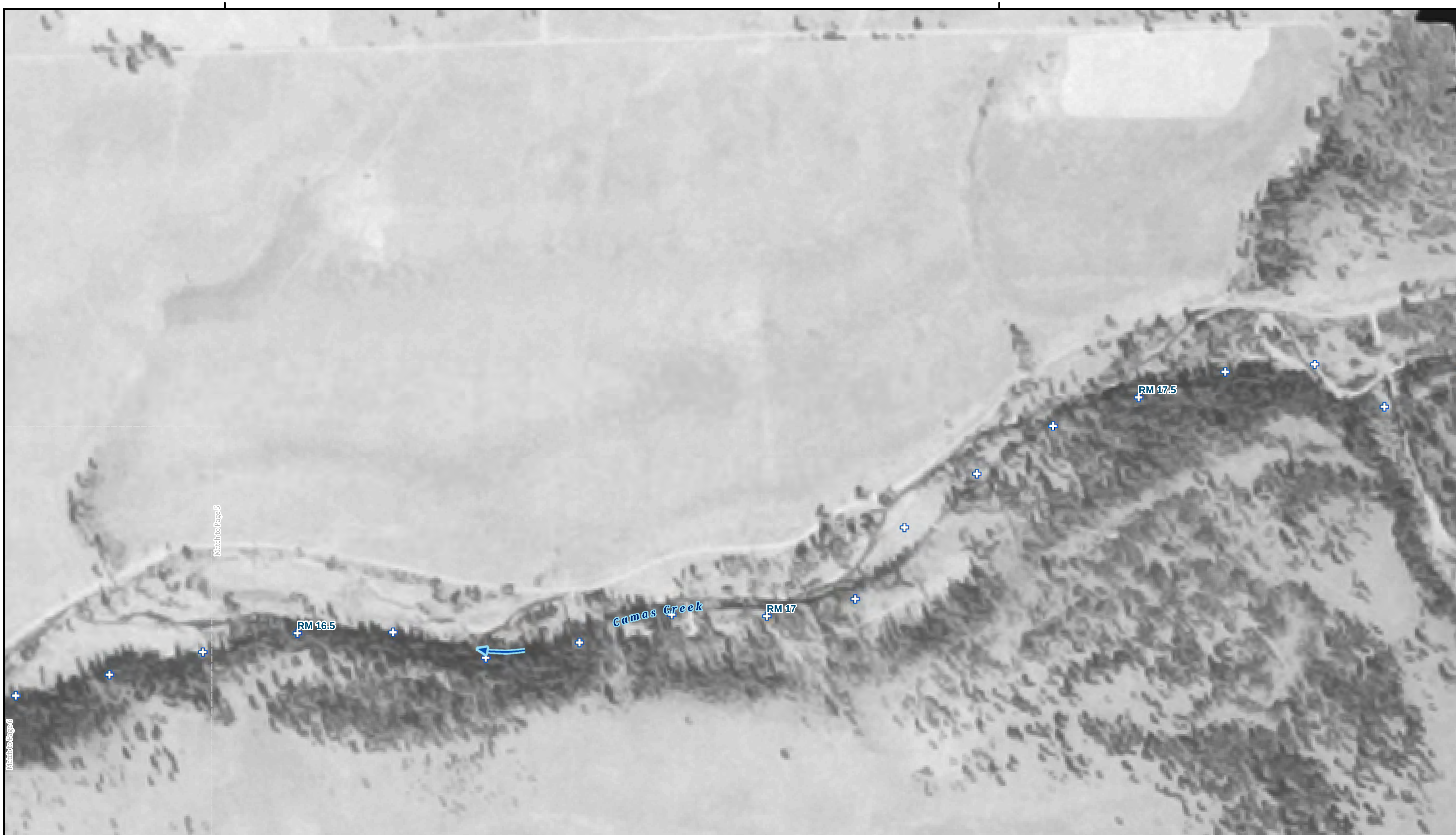
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1950 Aerial Photo Map Book - Page 6 of 6

Data source: 1950 aerial imagery obtained from USGS Earth Explorer

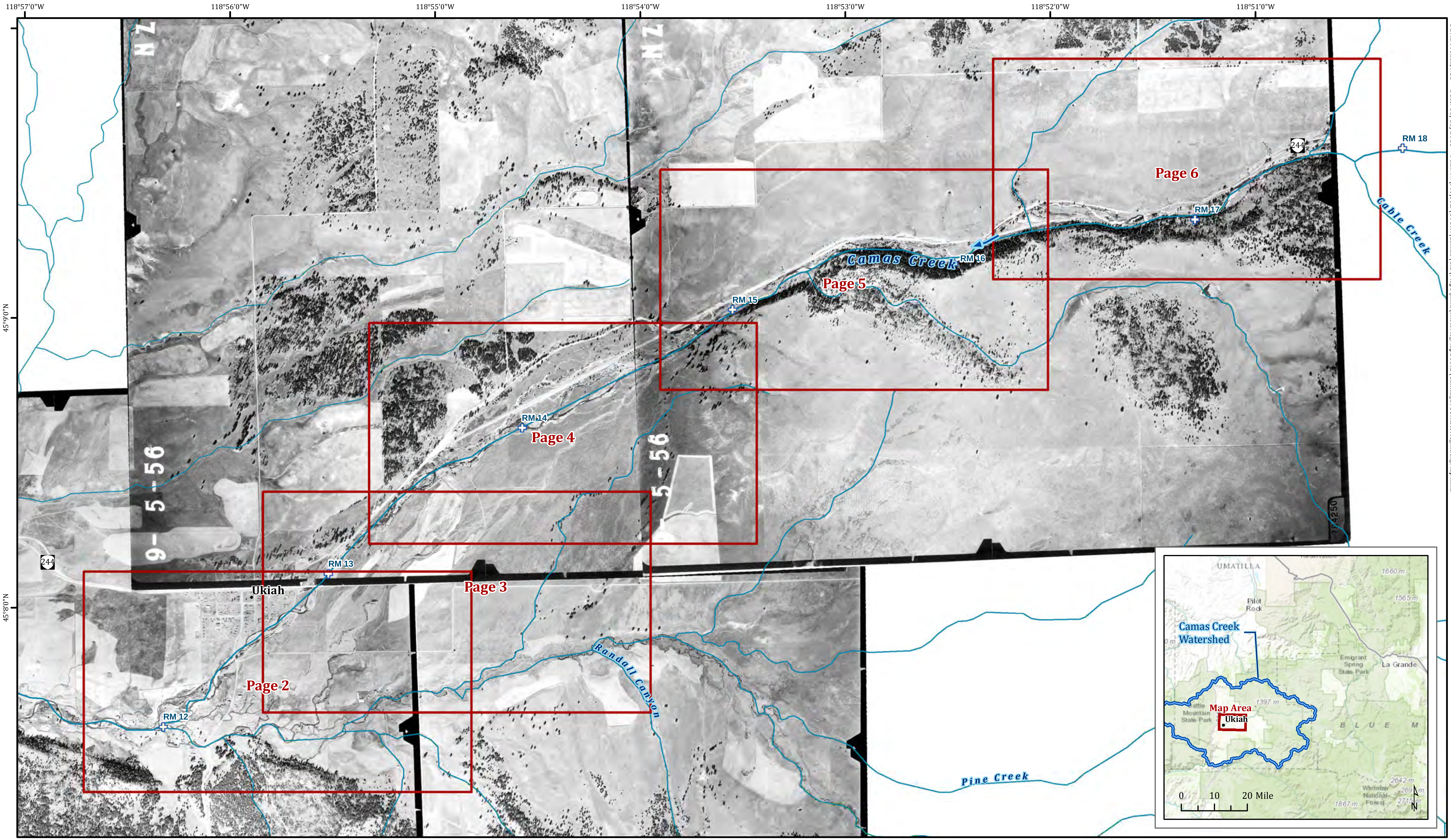
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1956 Aerial Photo Map Book - Page 1 of 6

Data source: 1956 aerial imagery obtained from CTUIR

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1956Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1956 Aerial Photo Map Book - Page 2 of 6

Data source: 1956 aerial imagery obtained from CTUIR

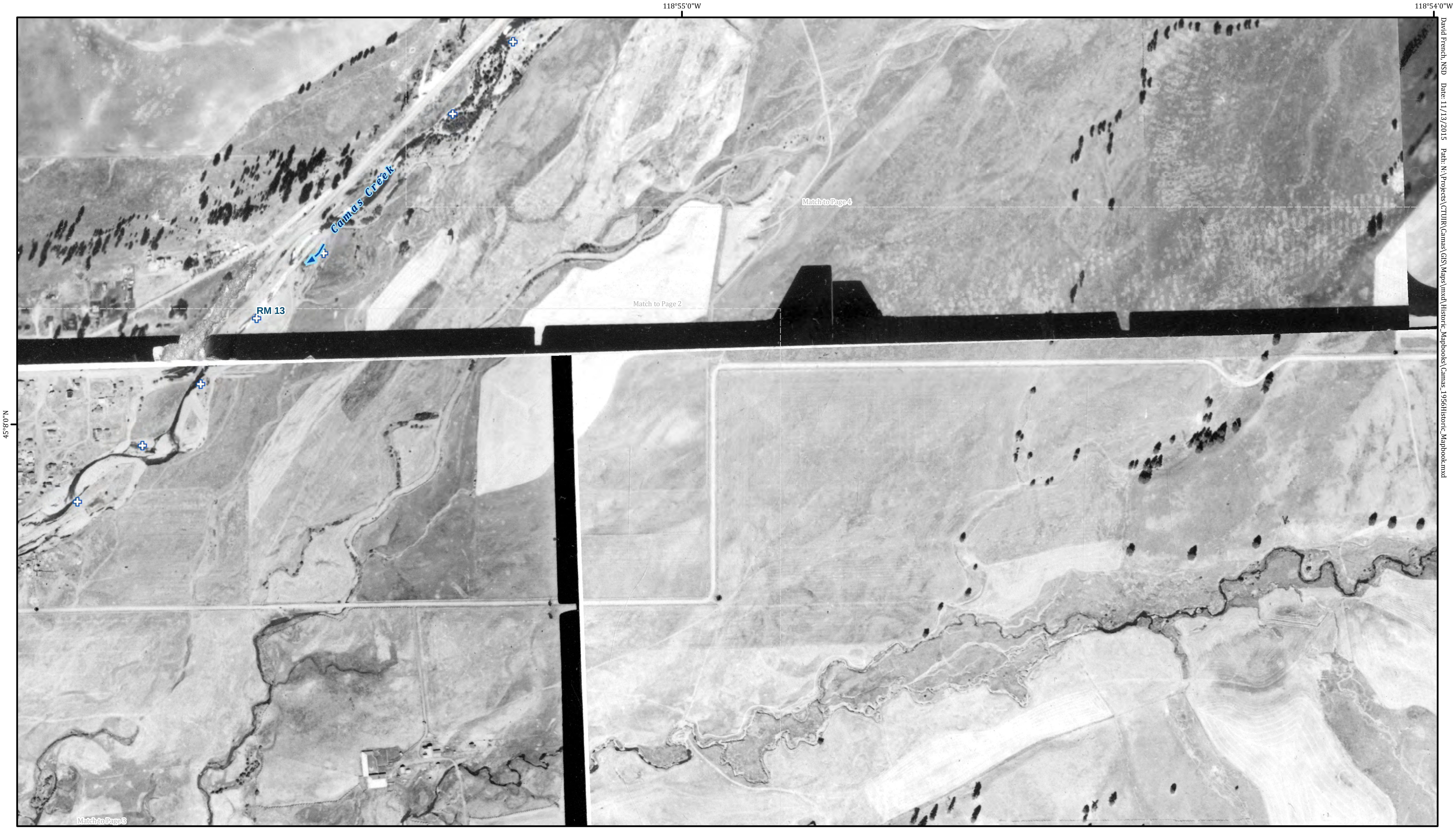
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1956 Aerial Photo Map Book - Page 3 of 6

Data source: 1956 aerial imagery obtained from CTUIR

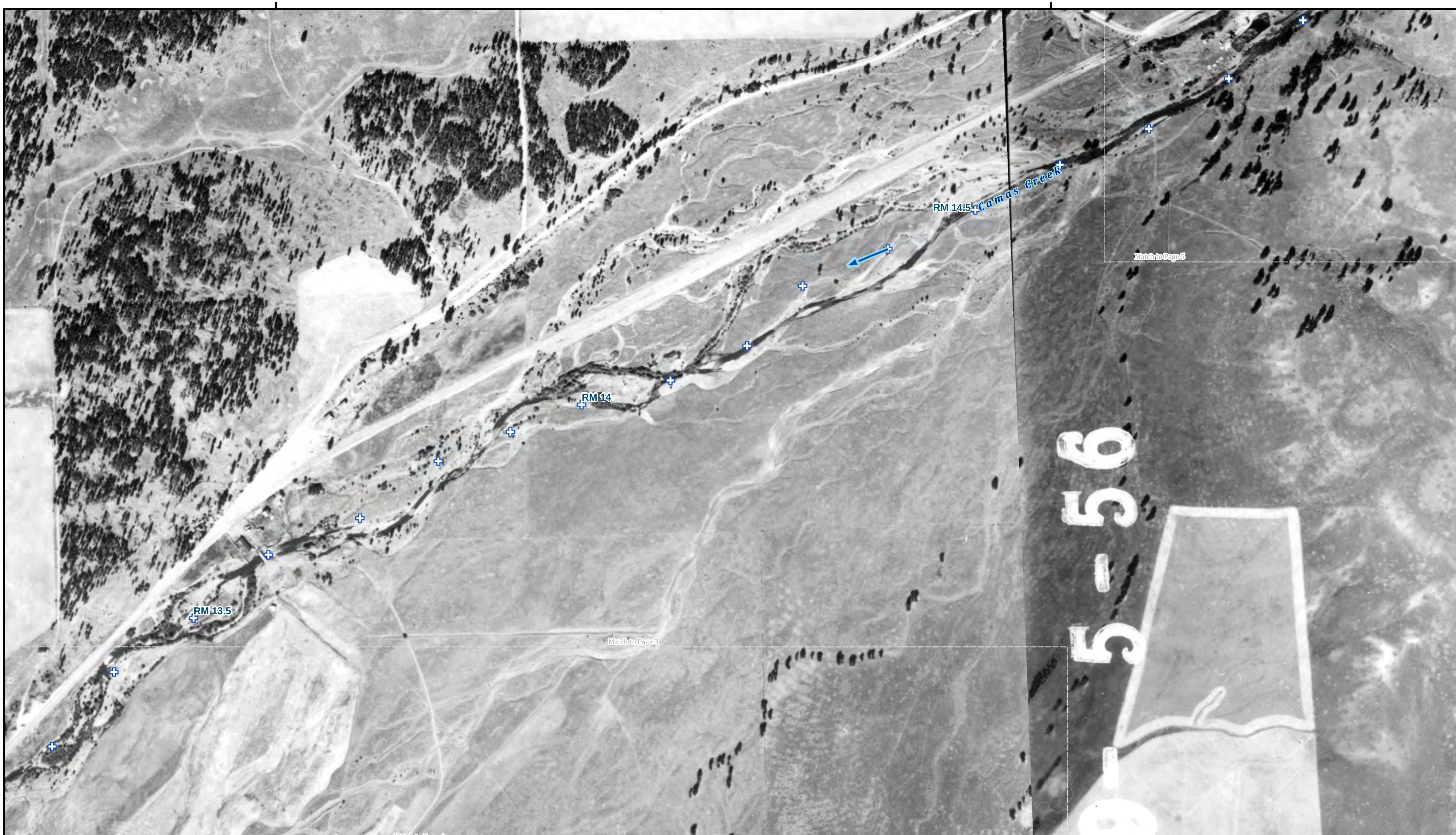
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1956 Aerial Photo Map Book - Page 4 of 6

Data source: 1956 aerial imagery obtained from CTUIR

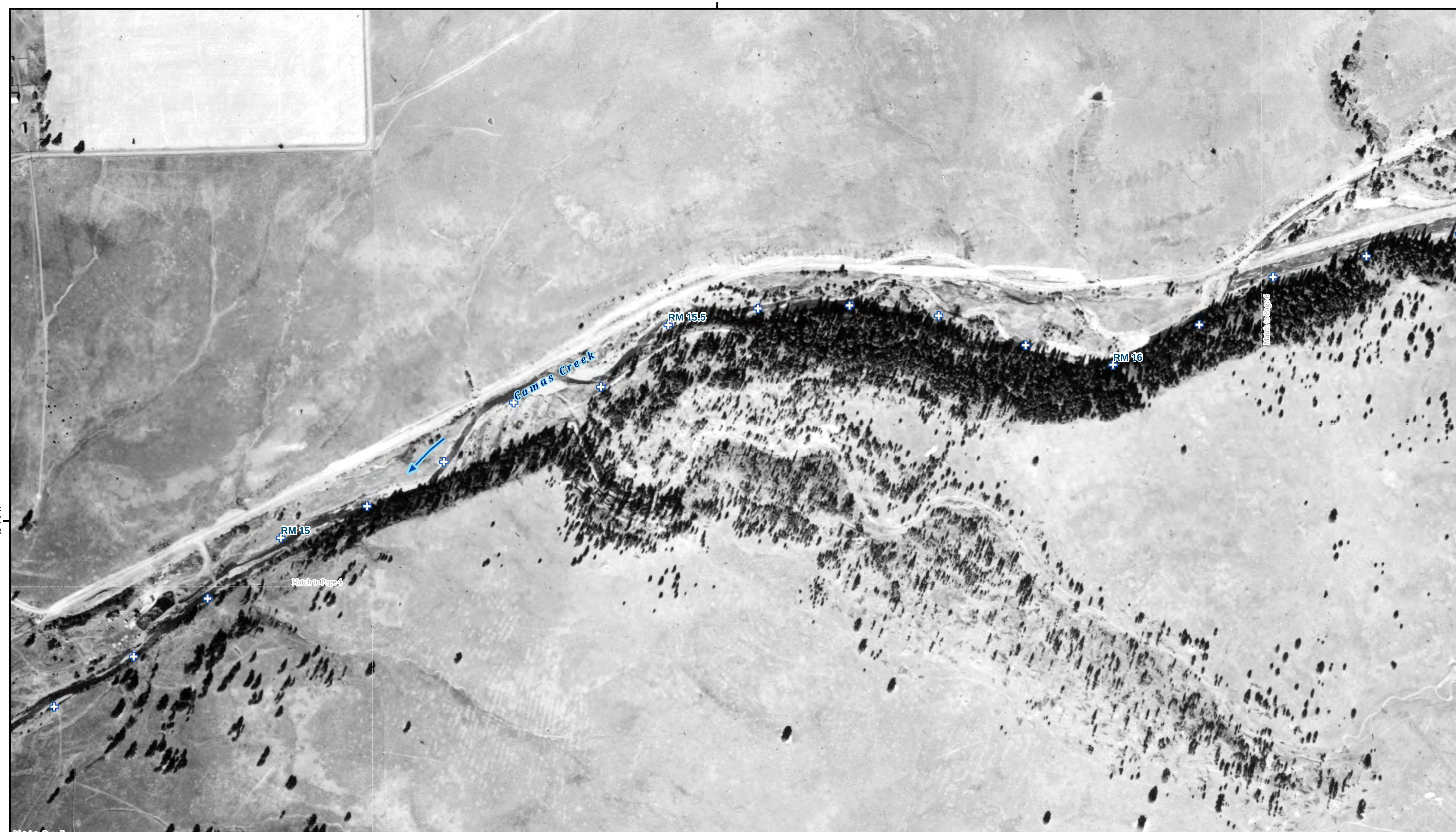
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1956 Aerial Photo Map Book - Page 5 of 6

Data source: 1956 aerial imagery obtained from CTUIR

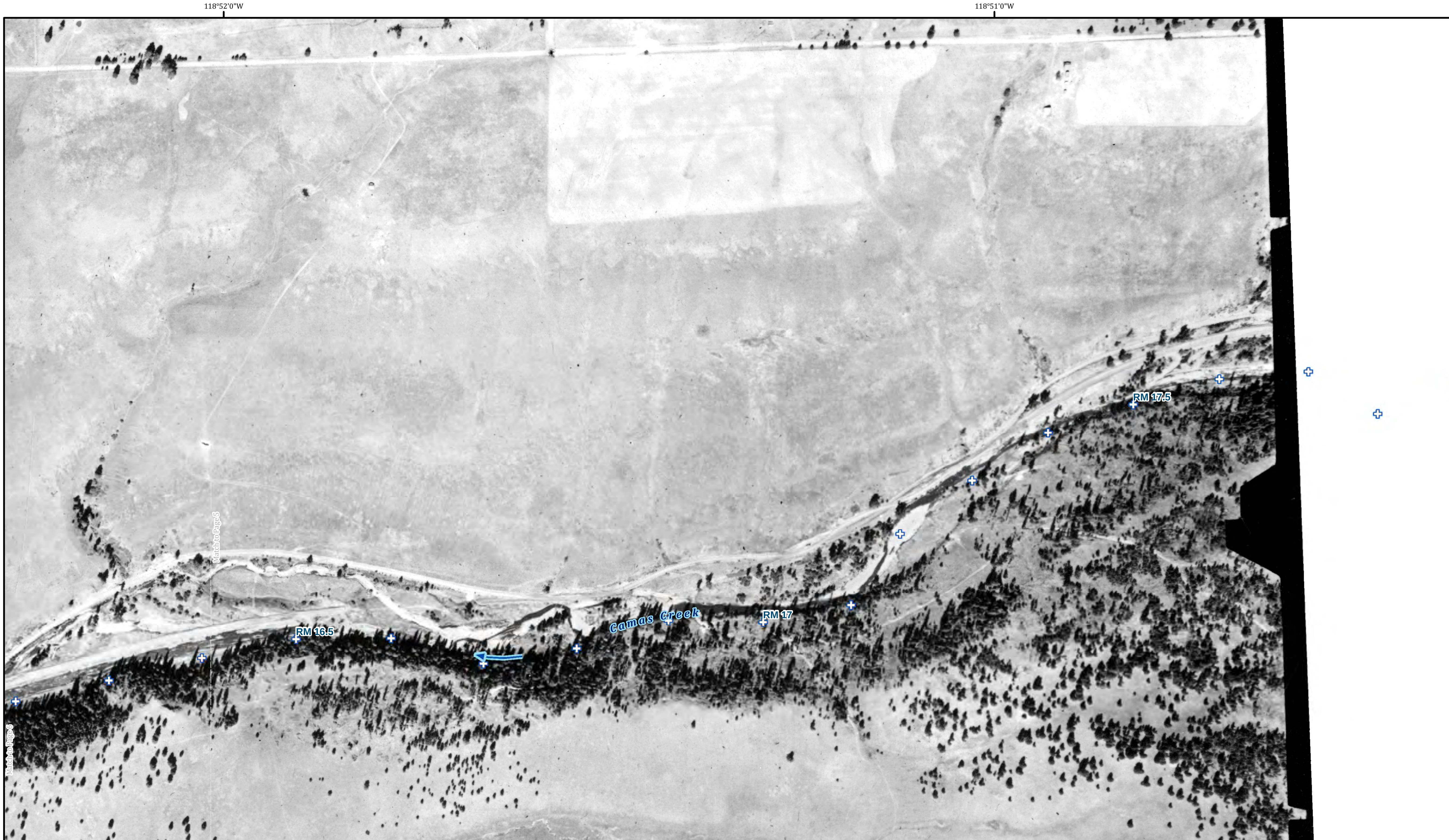
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1956 Aerial Photo Map Book - Page 6 of 6

Data source: 1956 aerial imagery obtained from CTUIR

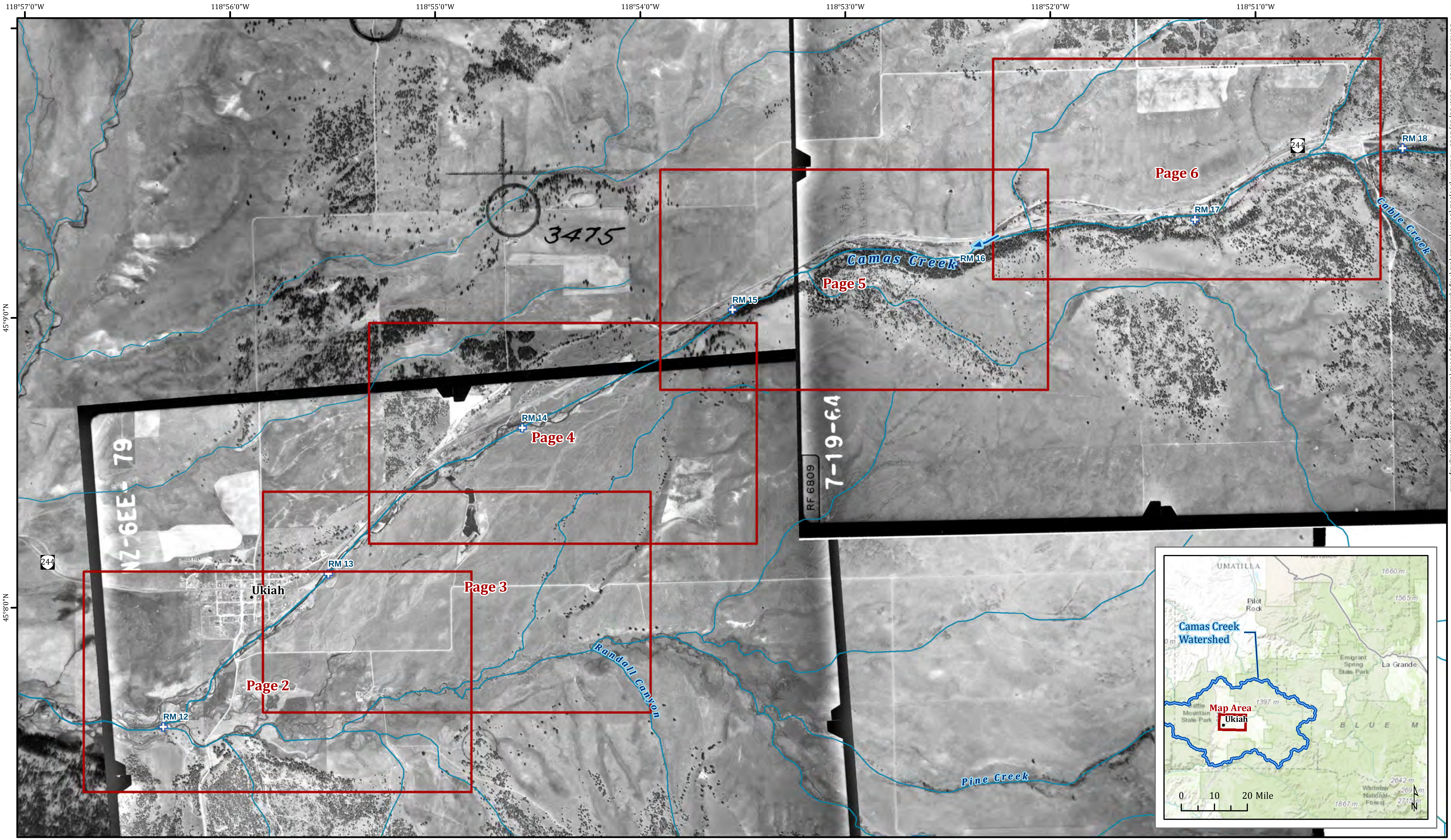
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1964 Aerial Photo Map Book - Page 1 of 6

Data source: 1964 aerial imagery obtained from CTUIR

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1964Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1964 Aerial Photo Map Book - Page 2 of 6

Data source: 1964 aerial imagery obtained from CTUIR

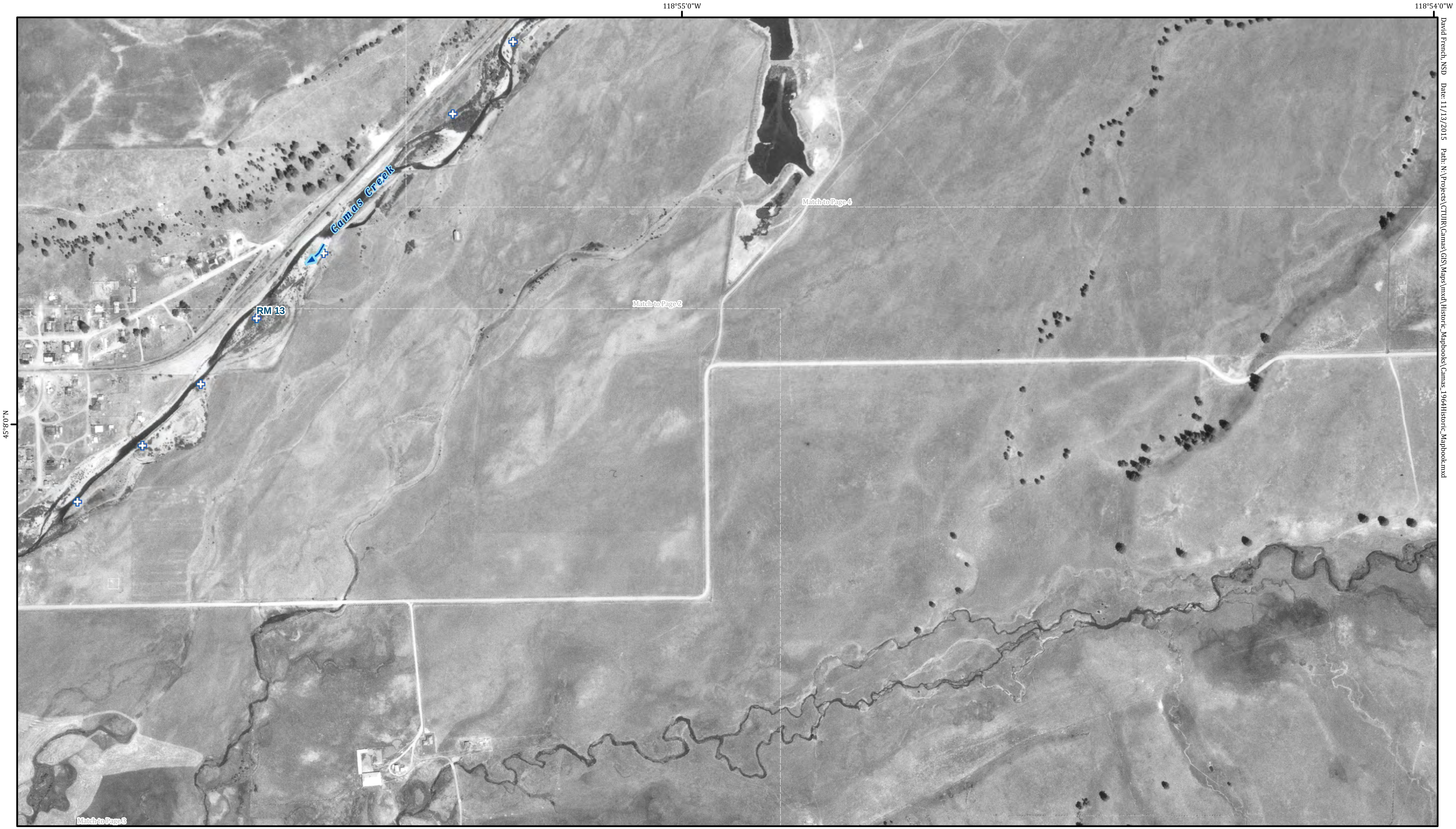
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1964 Aerial Photo Map Book - Page 3 of 6

Data source: 1964 aerial imagery obtained from CTUIR

N

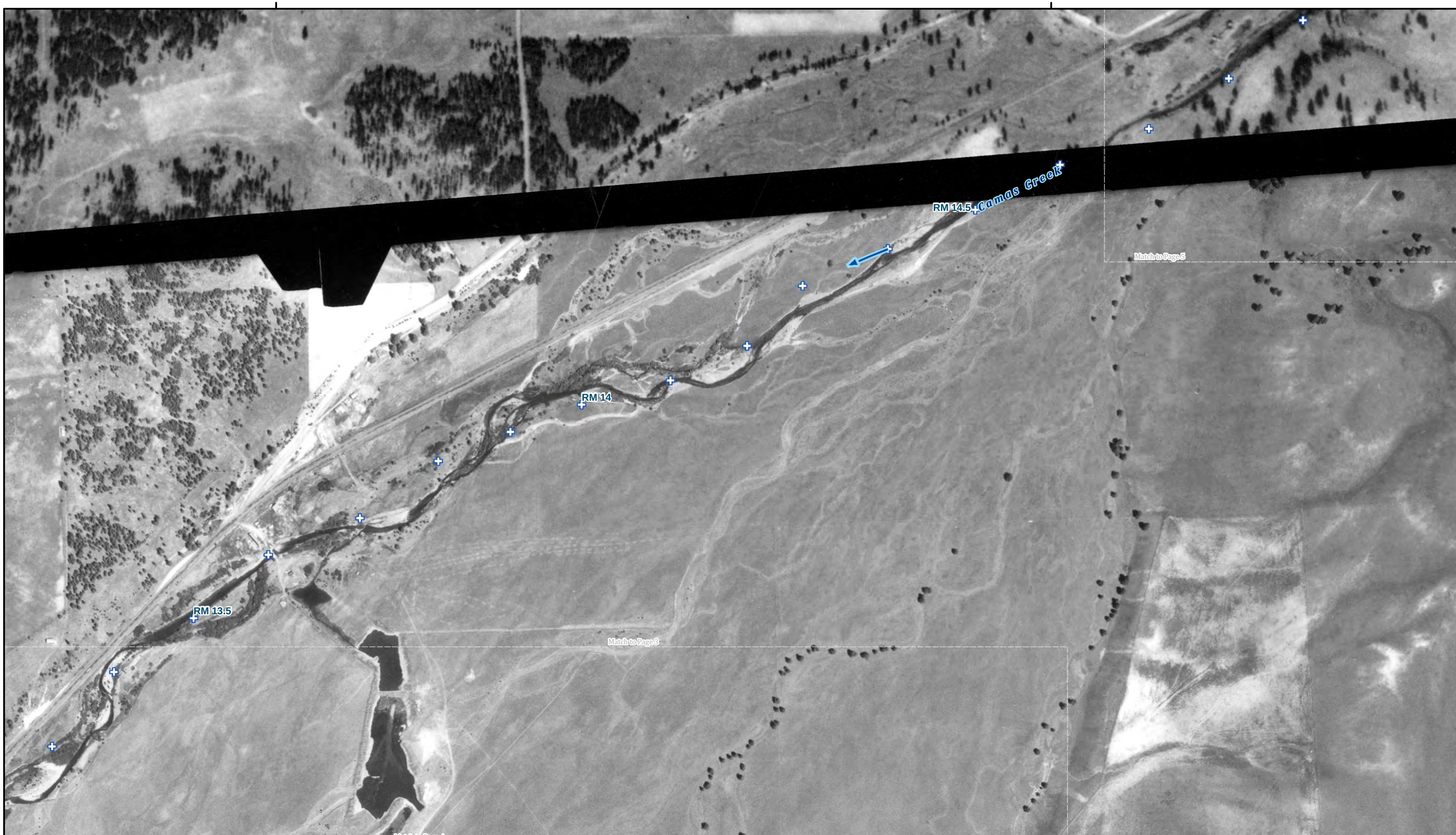
0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°55'0"W
118°54'0"W



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Camas Creek Geomorphic Assessment & Action Plan

1964 Aerial Photo Map Book - Page 4 of 6

Data source: 1964 aerial imagery obtained from CTUIR

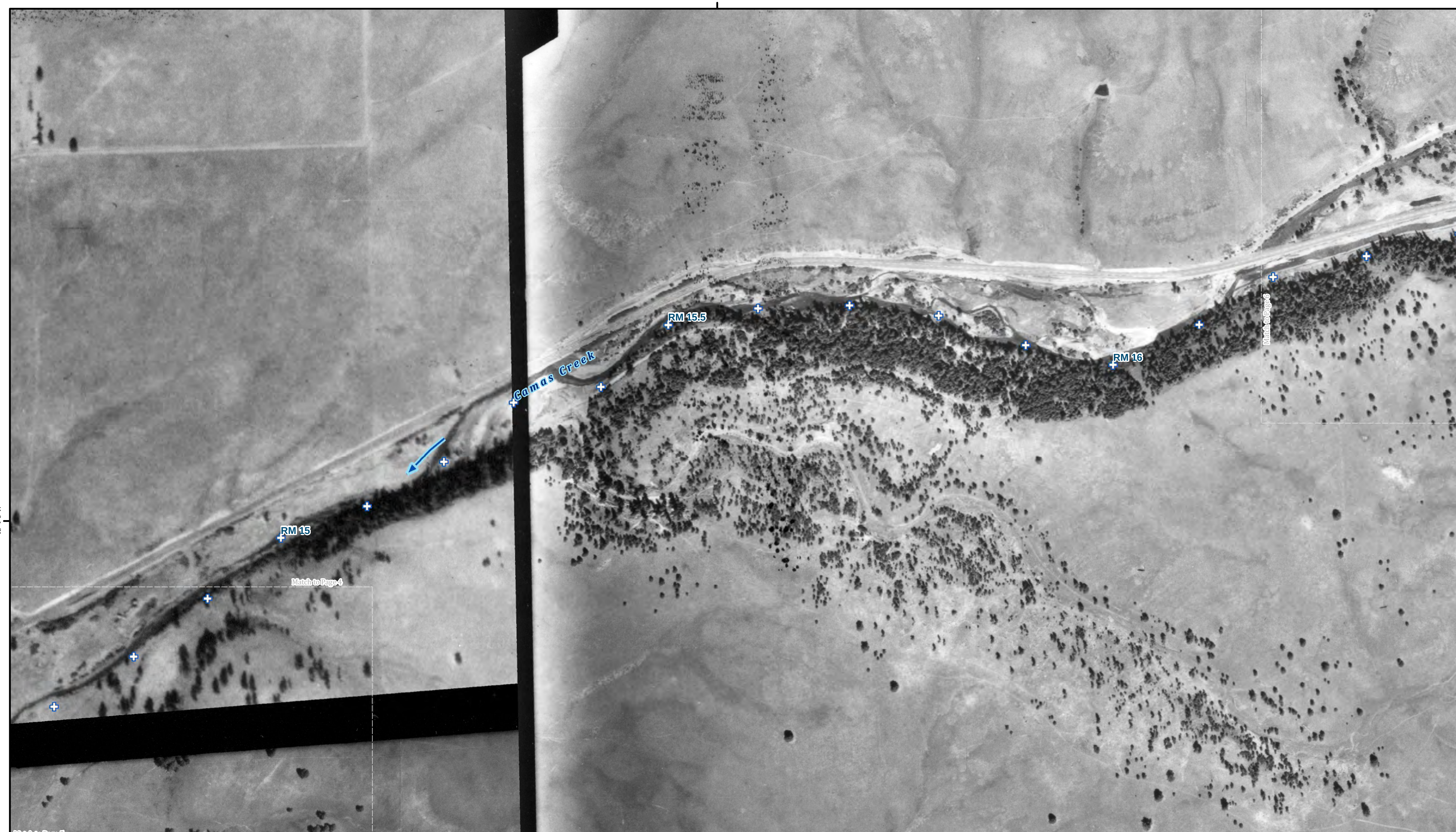
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1964 Aerial Photo Map Book - Page 5 of 6

Data source: 1964 aerial imagery obtained from CTUIR

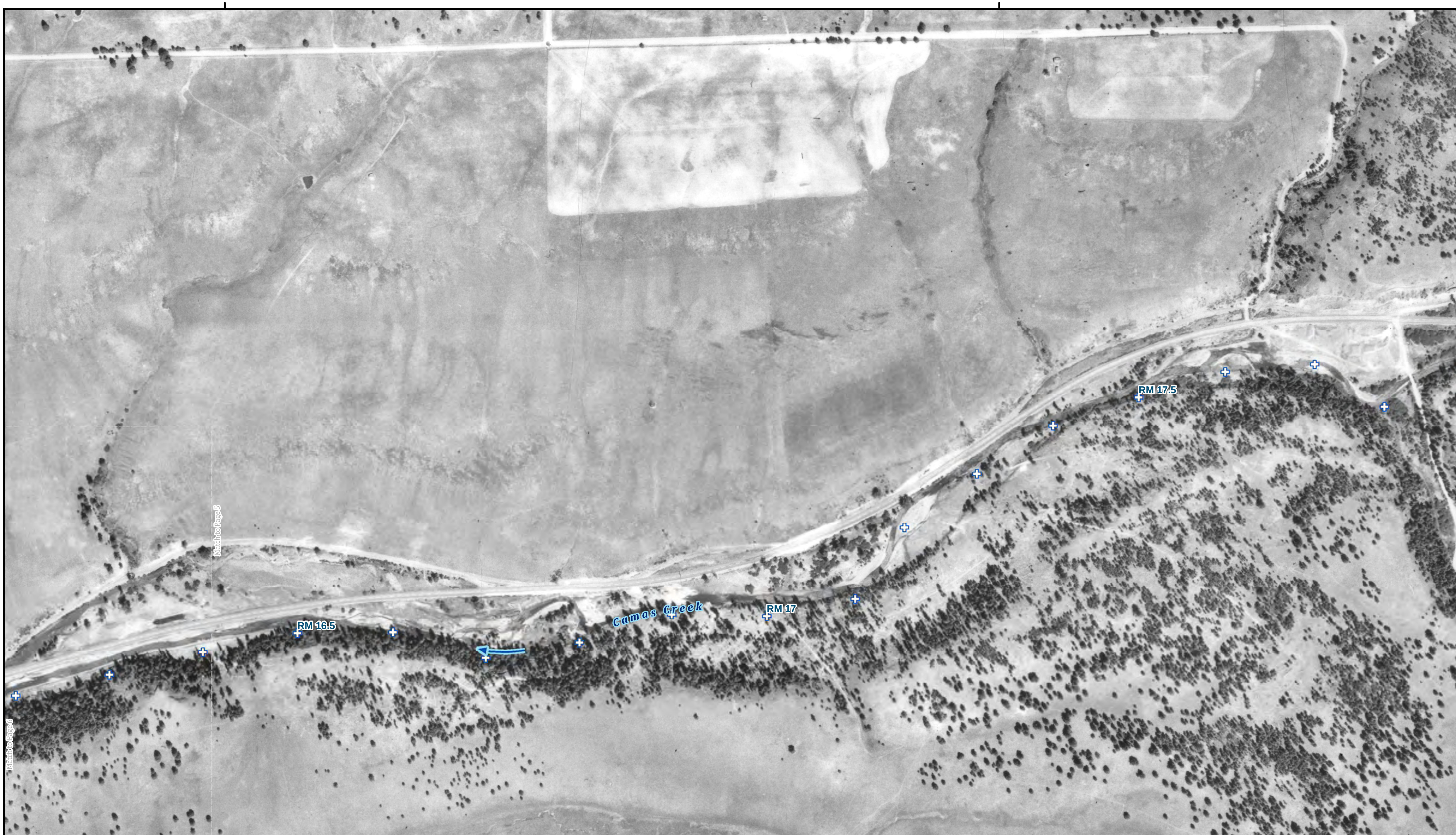
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1964 Aerial Photo Map Book - Page 6 of 6

Data source: 1964 aerial imagery obtained from CTUIR

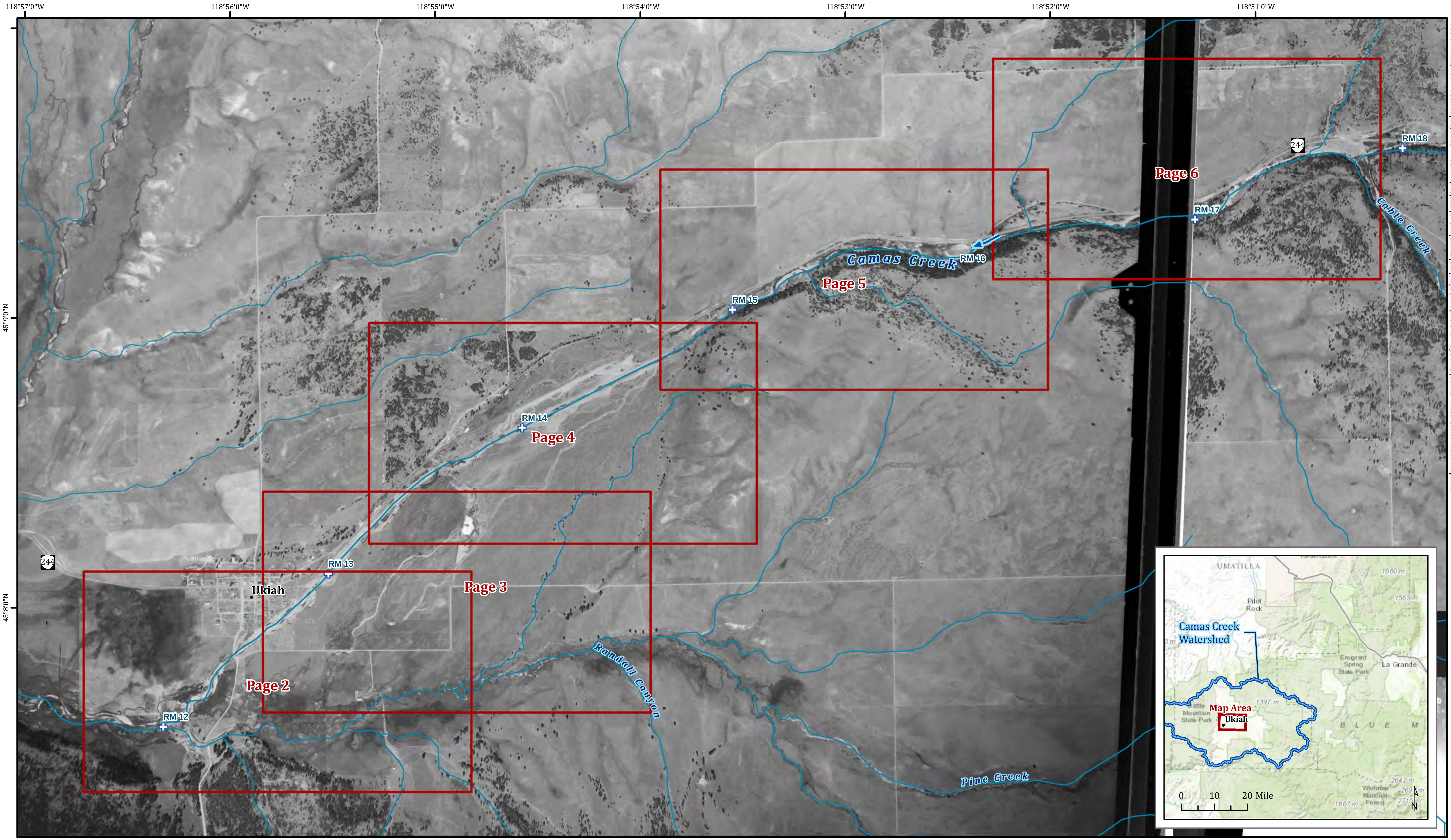
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1965 Aerial Photo Map Book - Page 1 of 6

Data source: 1965 aerial imagery obtained from USGS Earth Explorer

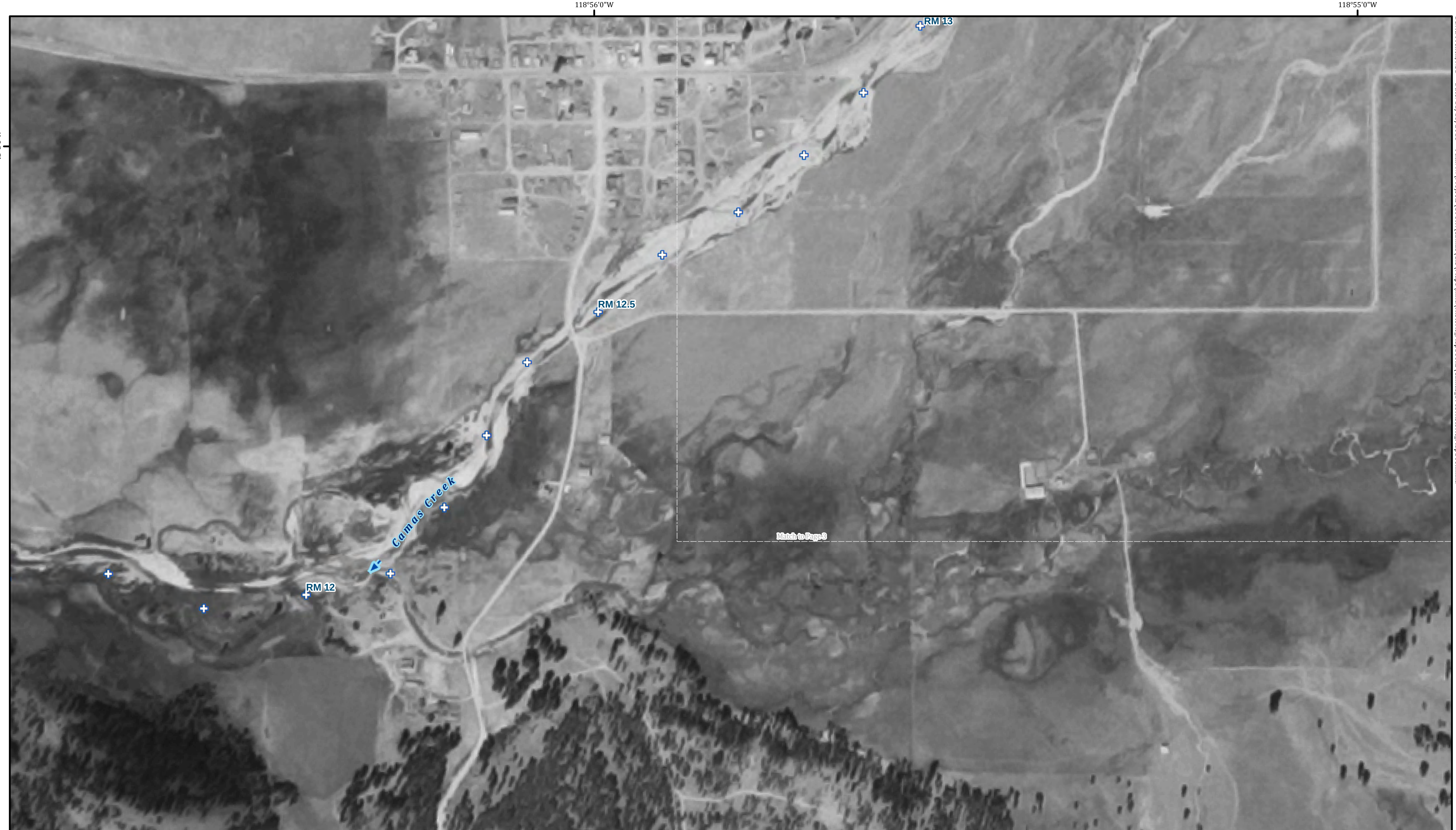
N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1965 Aerial Photo Map Book - Page 2 of 6

Data source: 1965 aerial imagery obtained from USGS Earth Explorer

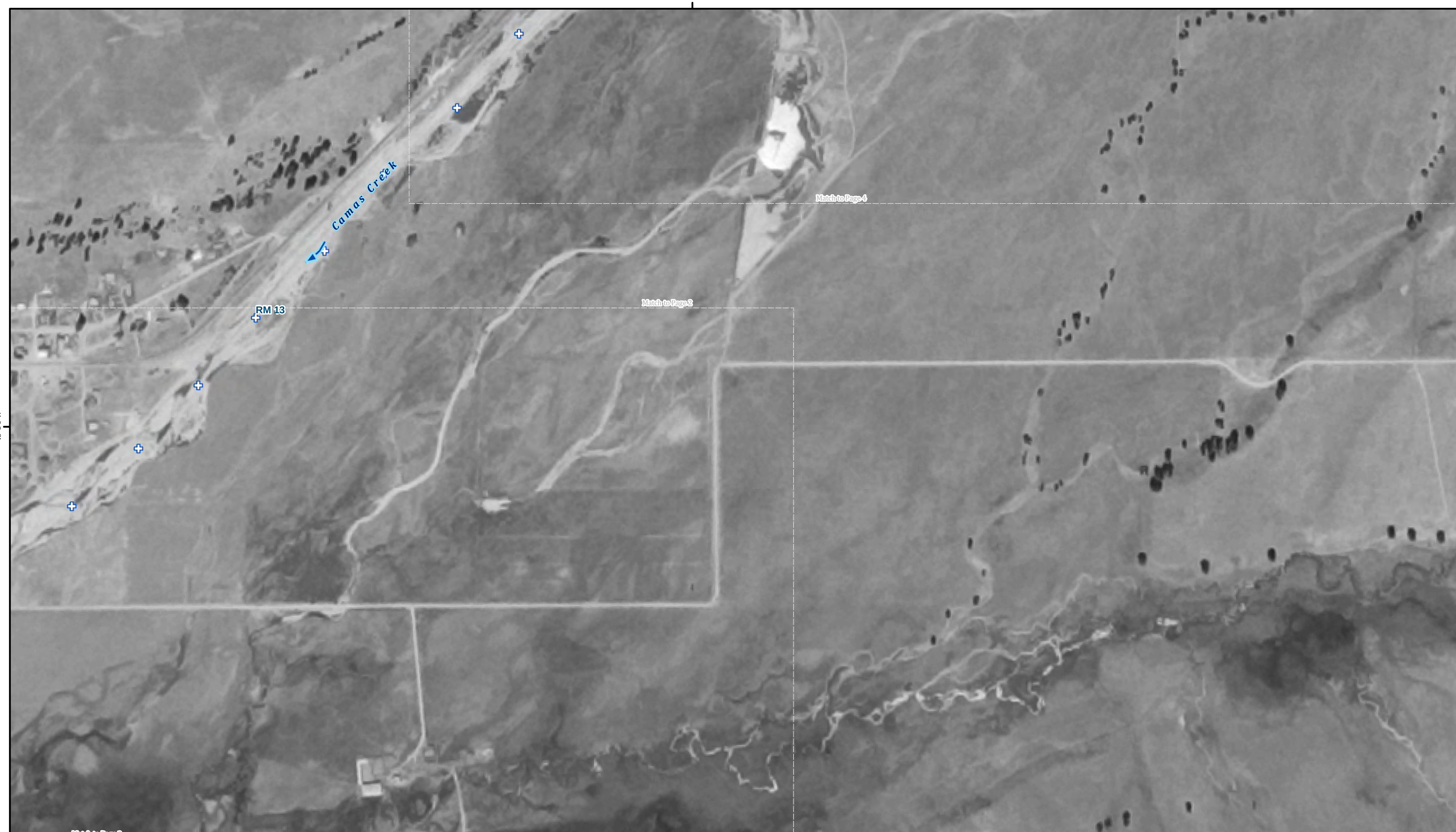
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1965 Aerial Photo Map Book - Page 3 of 6

Data source: 1965 aerial imagery obtained from USGS Earth Explorer

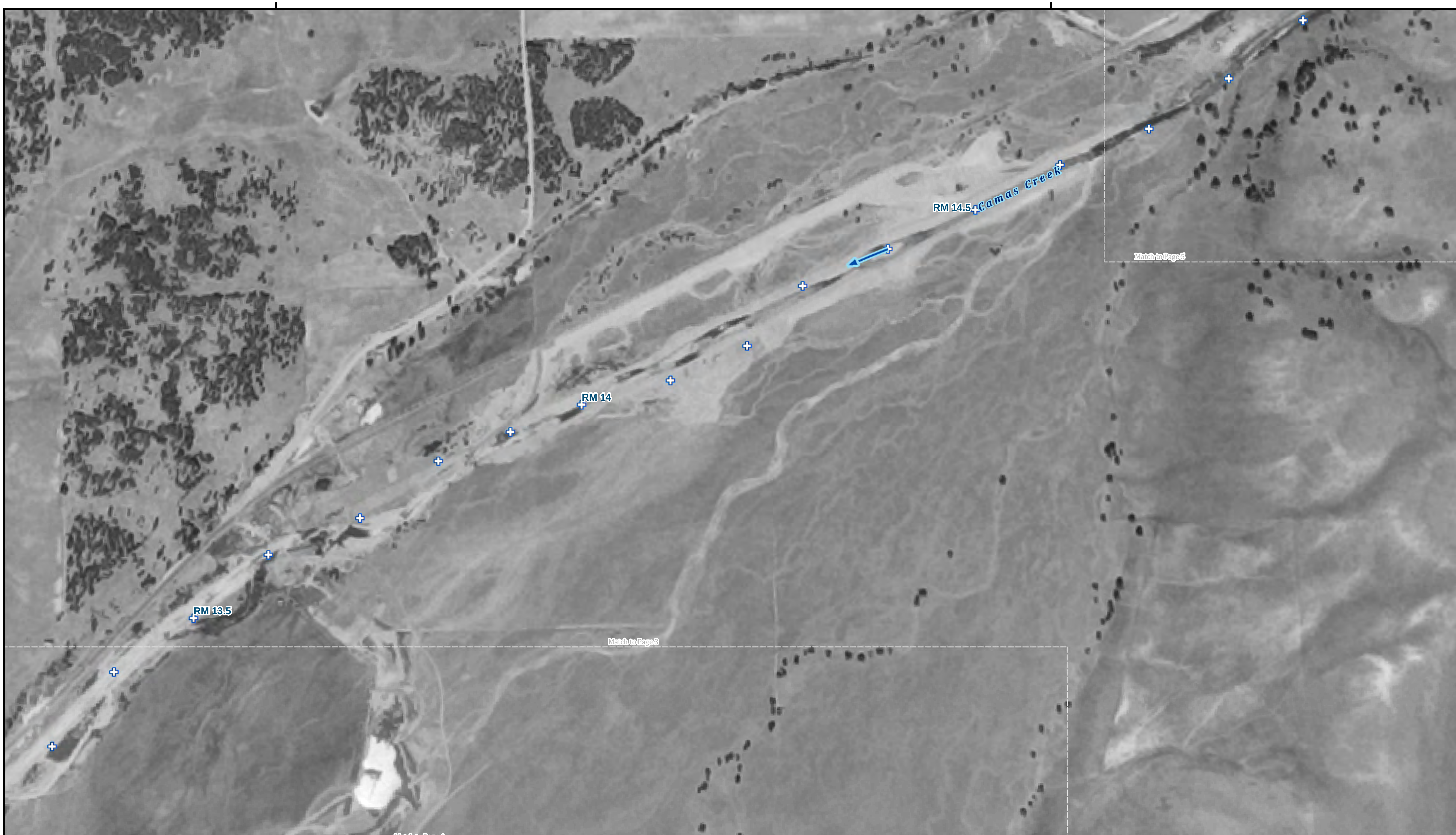
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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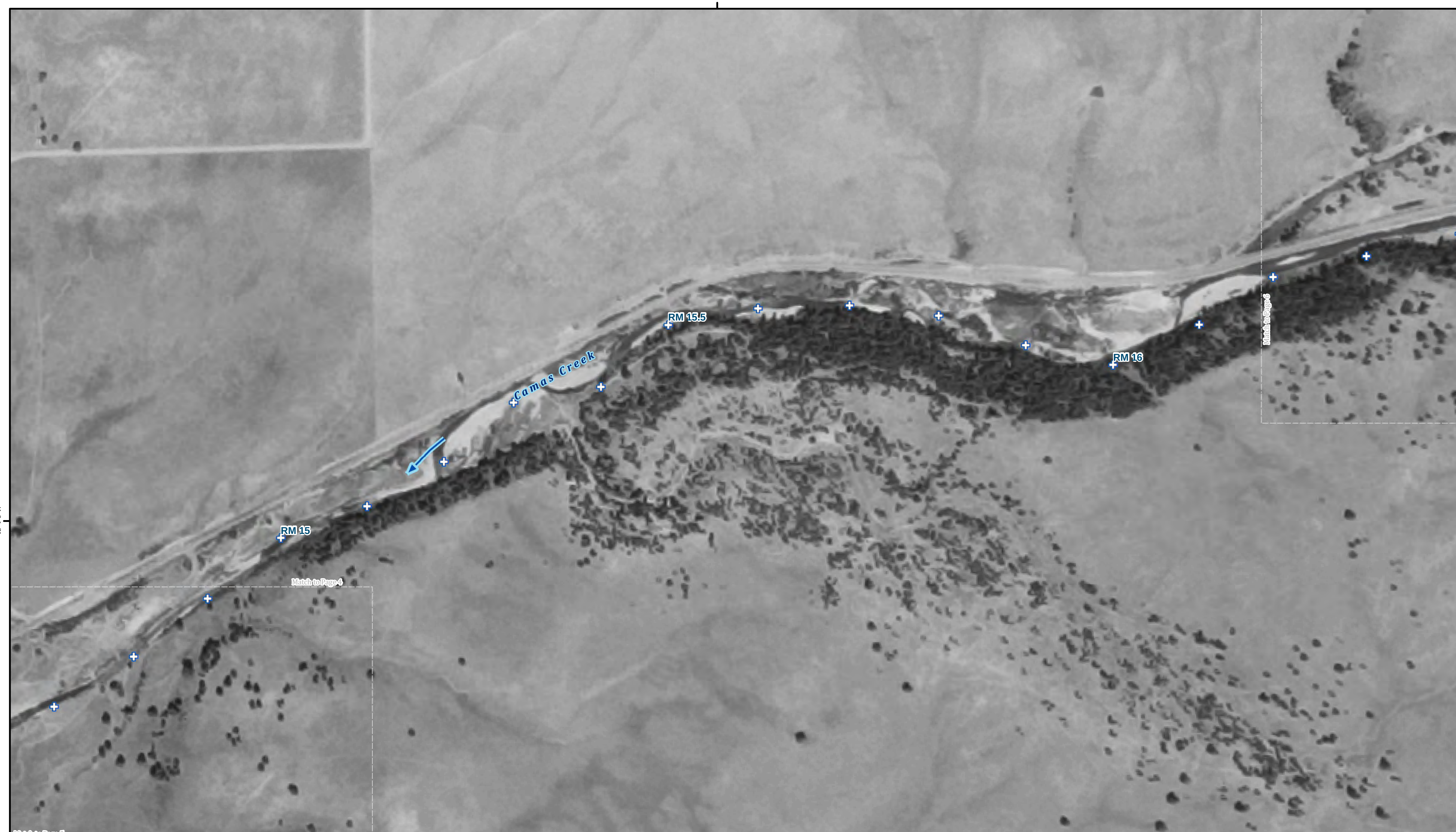
Camas Creek Geomorphic Assessment & Action Plan

1965 Aerial Photo Map Book - Page 4 of 6

Data source: 1965 aerial imagery obtained from USGS Earth Explorer

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)



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Camas Creek Geomorphic Assessment & Action Plan

1965 Aerial Photo Map Book - Page 5 of 6

Data source: 1965 aerial imagery obtained from USGS Earth Explorer

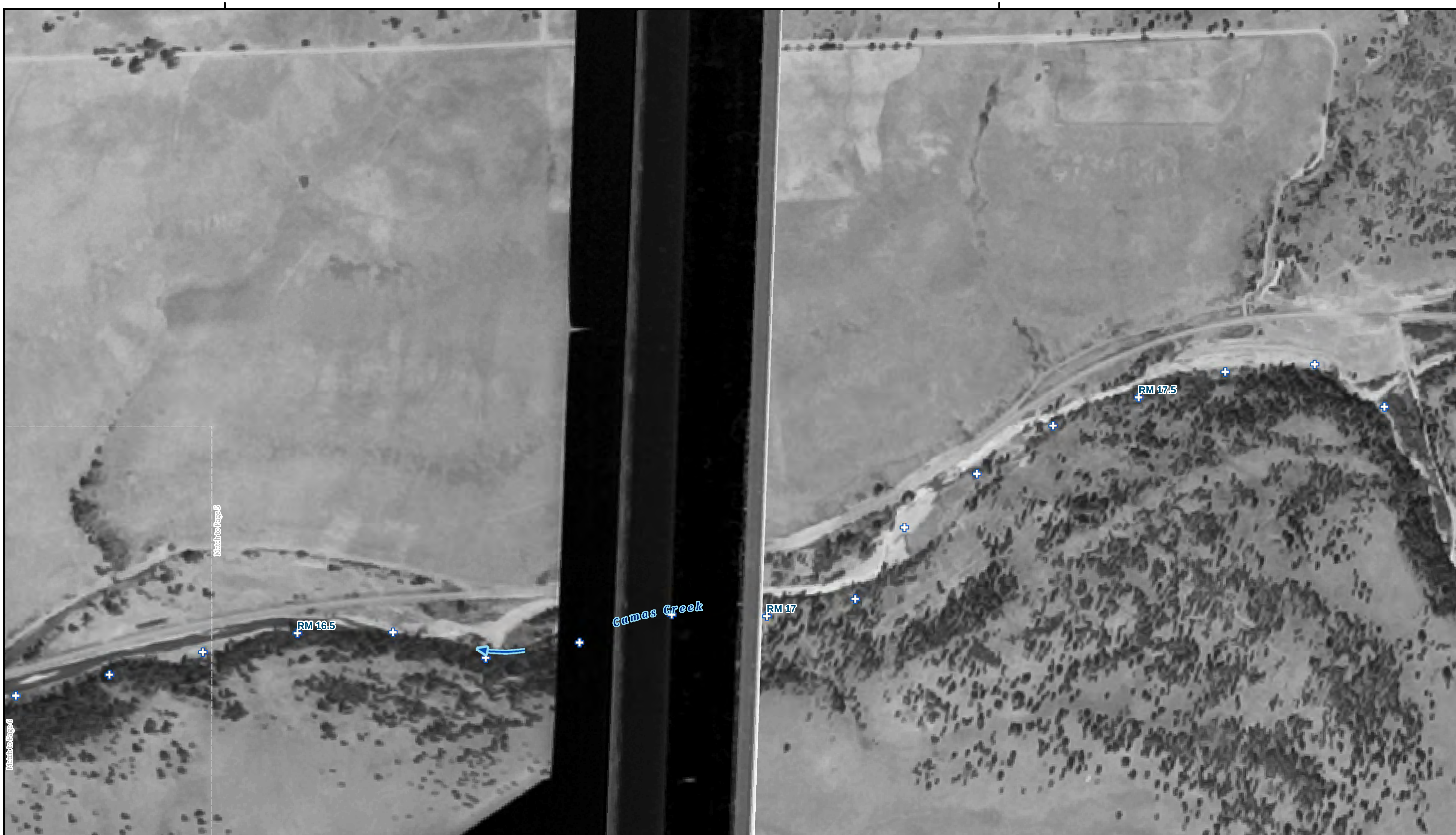
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1965Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1965 Aerial Photo Map Book - Page 6 of 6

Data source: 1965 aerial imagery obtained from USGS Earth Explorer

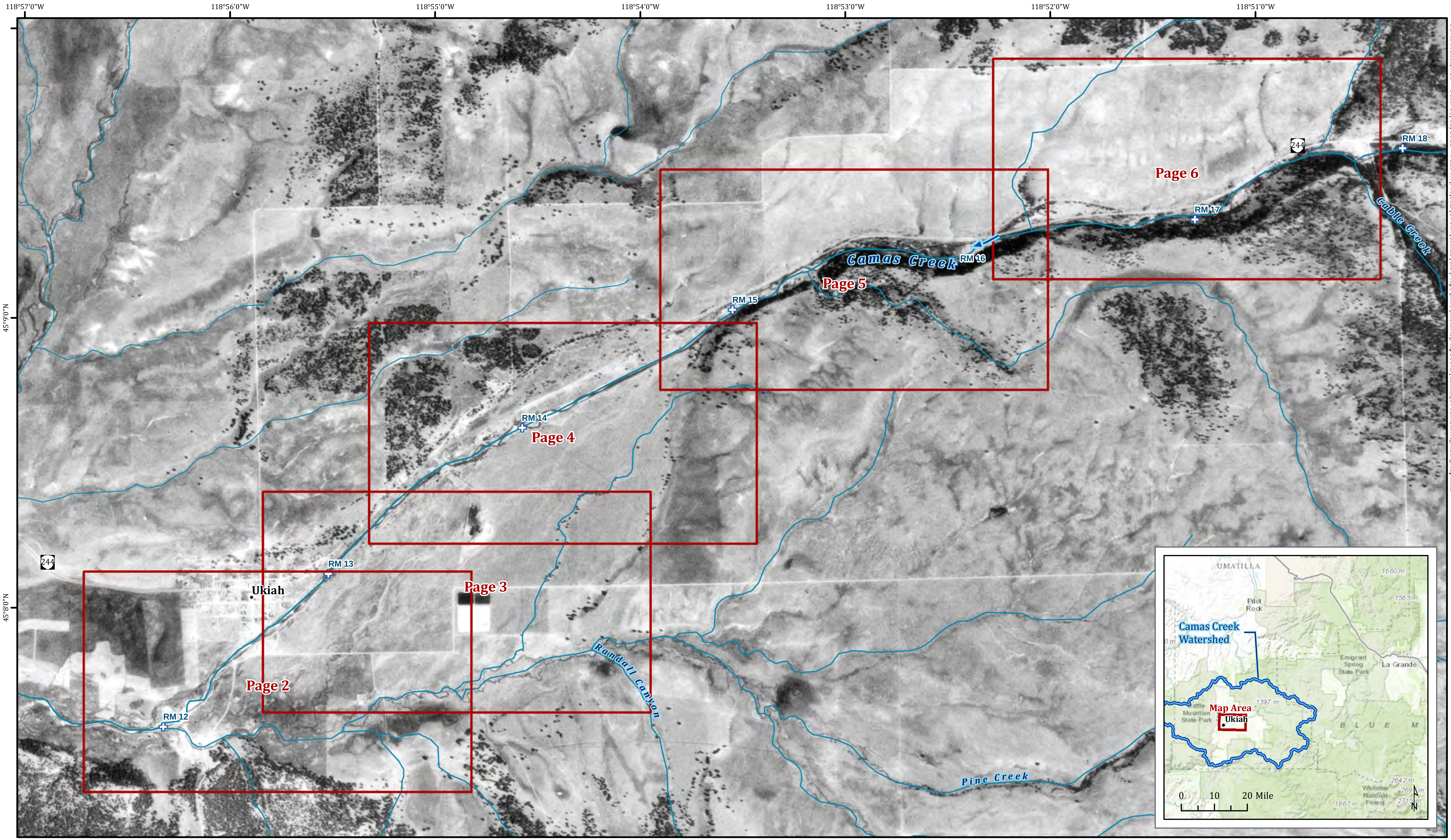
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1981 Aerial Photo Map Book - Page 1 of 6

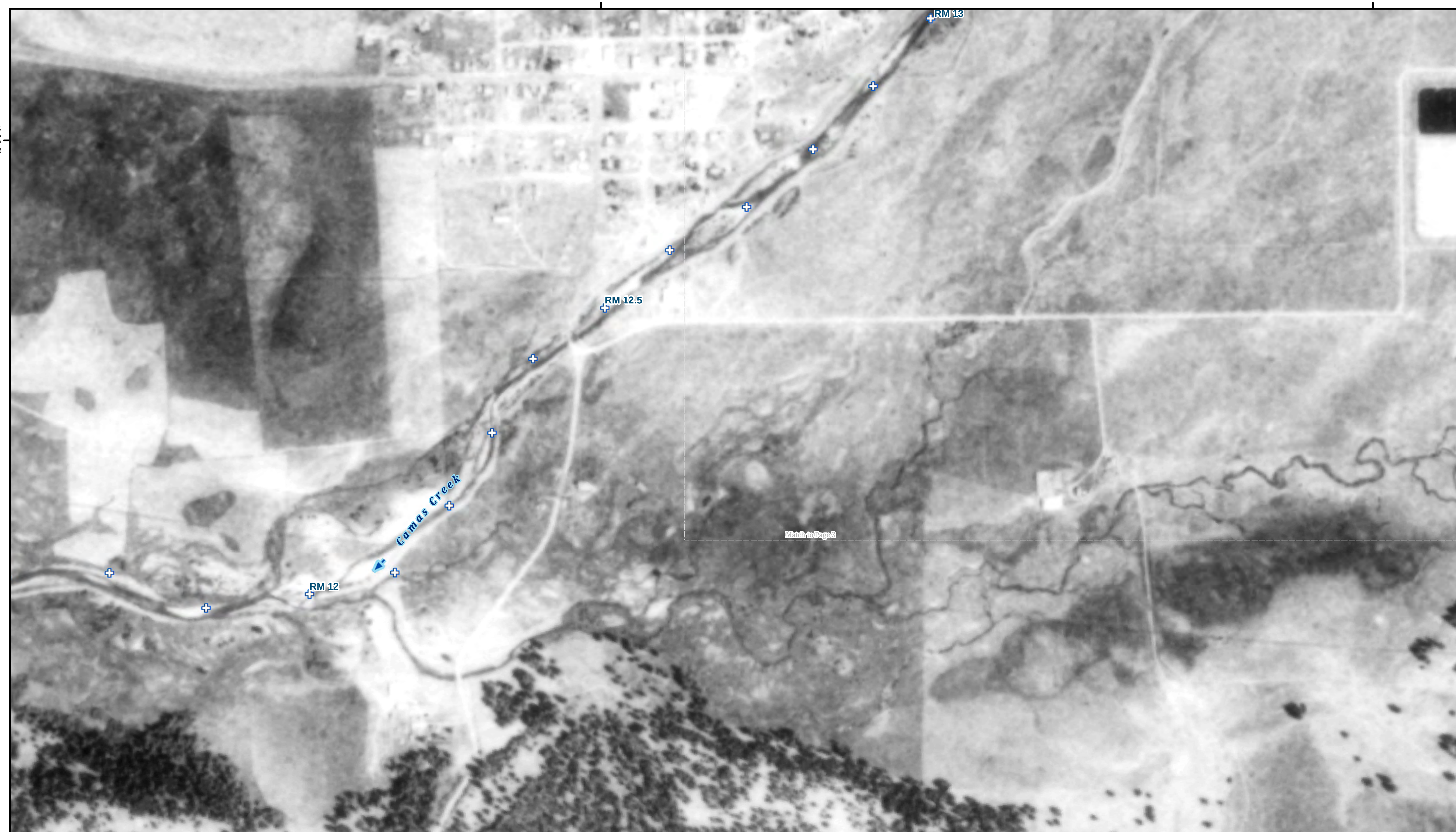
Data source: 1981 aerial imagery obtained from CTUIR

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1981 Aerial Photo Map Book - Page 2 of 6

Data source: 1981 aerial imagery obtained from CTUIR

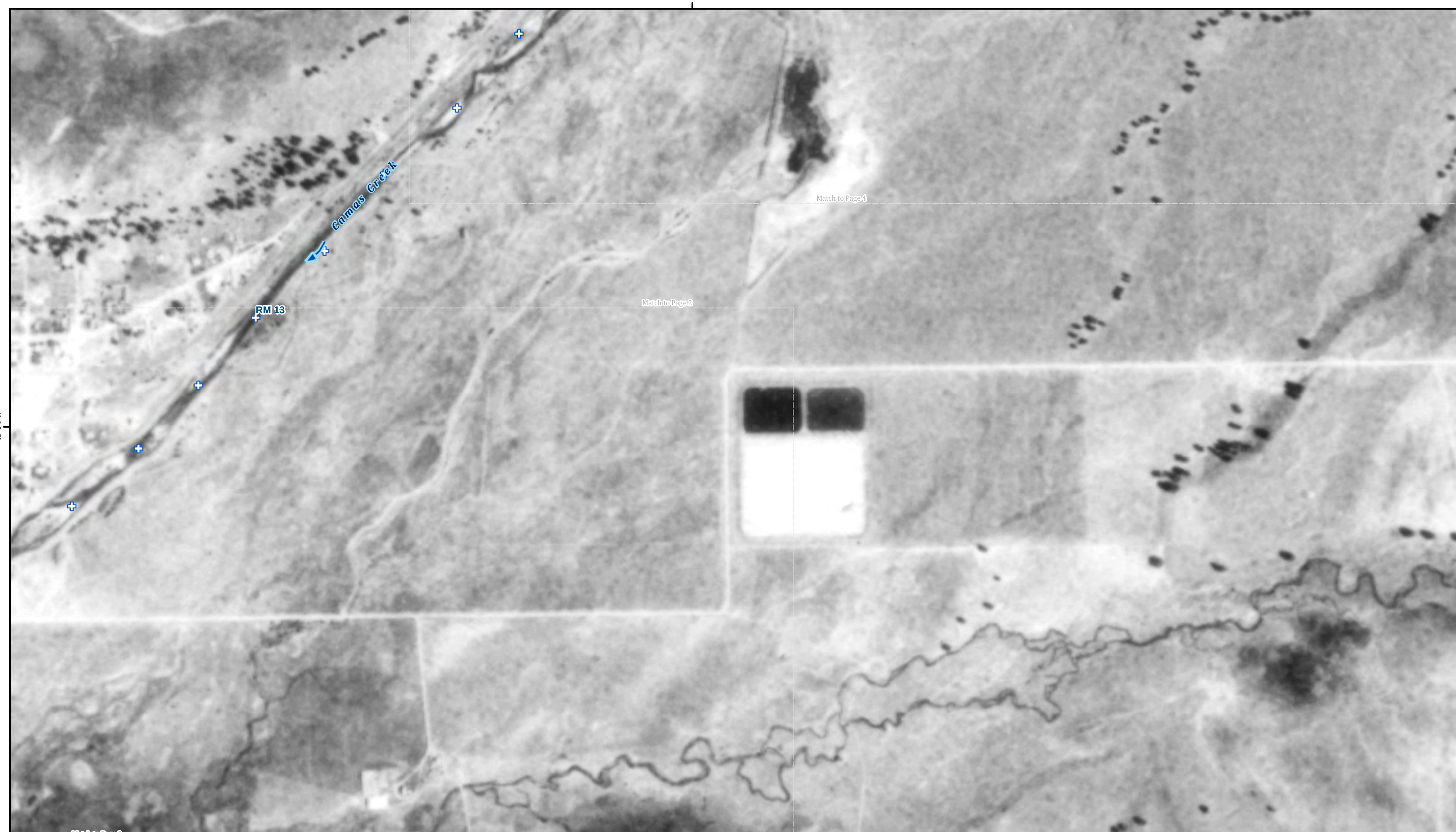
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1981 Aerial Photo Map Book - Page 3 of 6

Data source: 1981 aerial imagery obtained from CTUIR

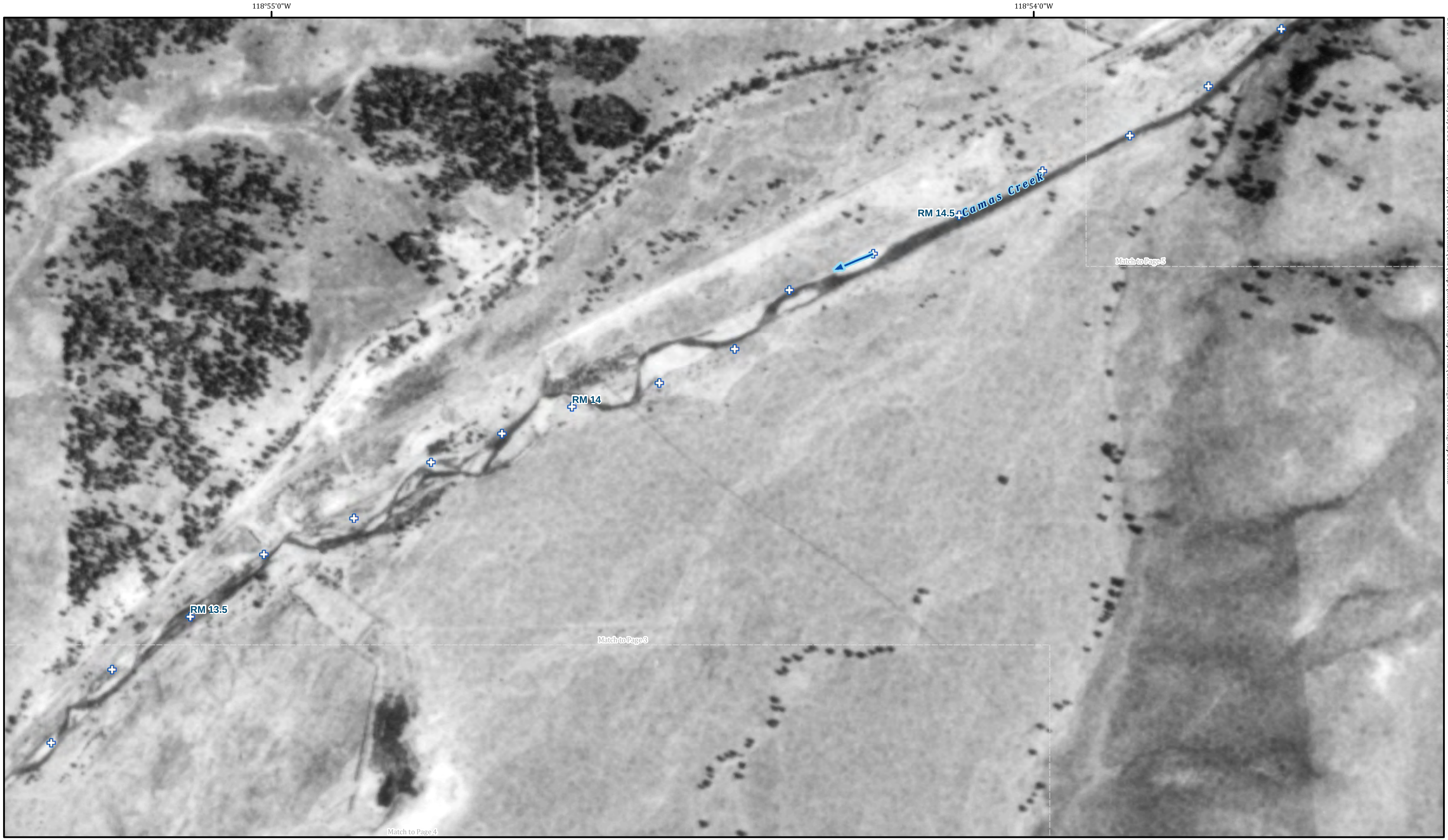
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1981 Aerial Photo Map Book - Page 4 of 6

Data source: 1981 aerial imagery obtained from CTUIR

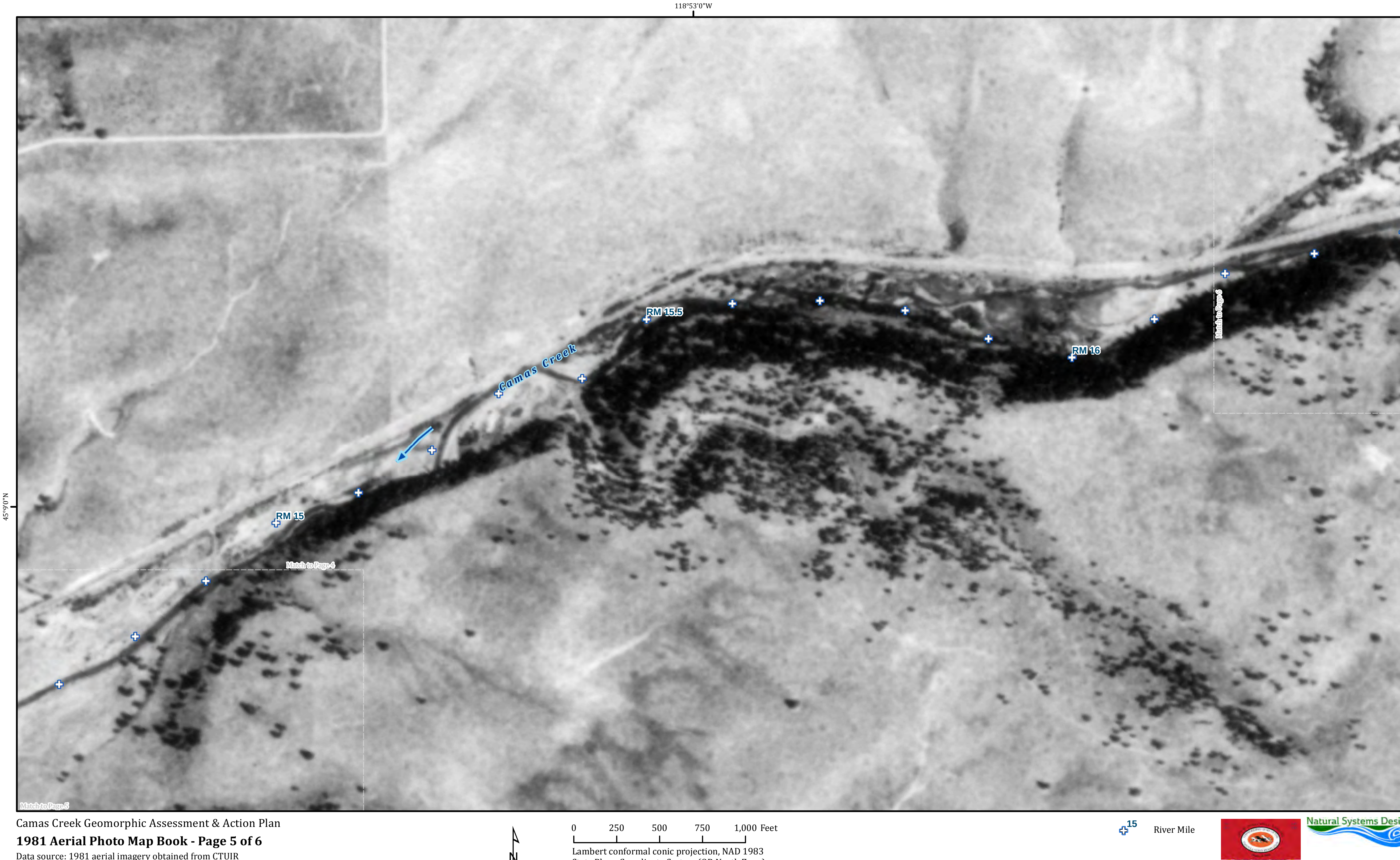
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1981 Aerial Photo Map Book - Page 5 of 6

Data source: 1981 aerial imagery obtained from CTUIR

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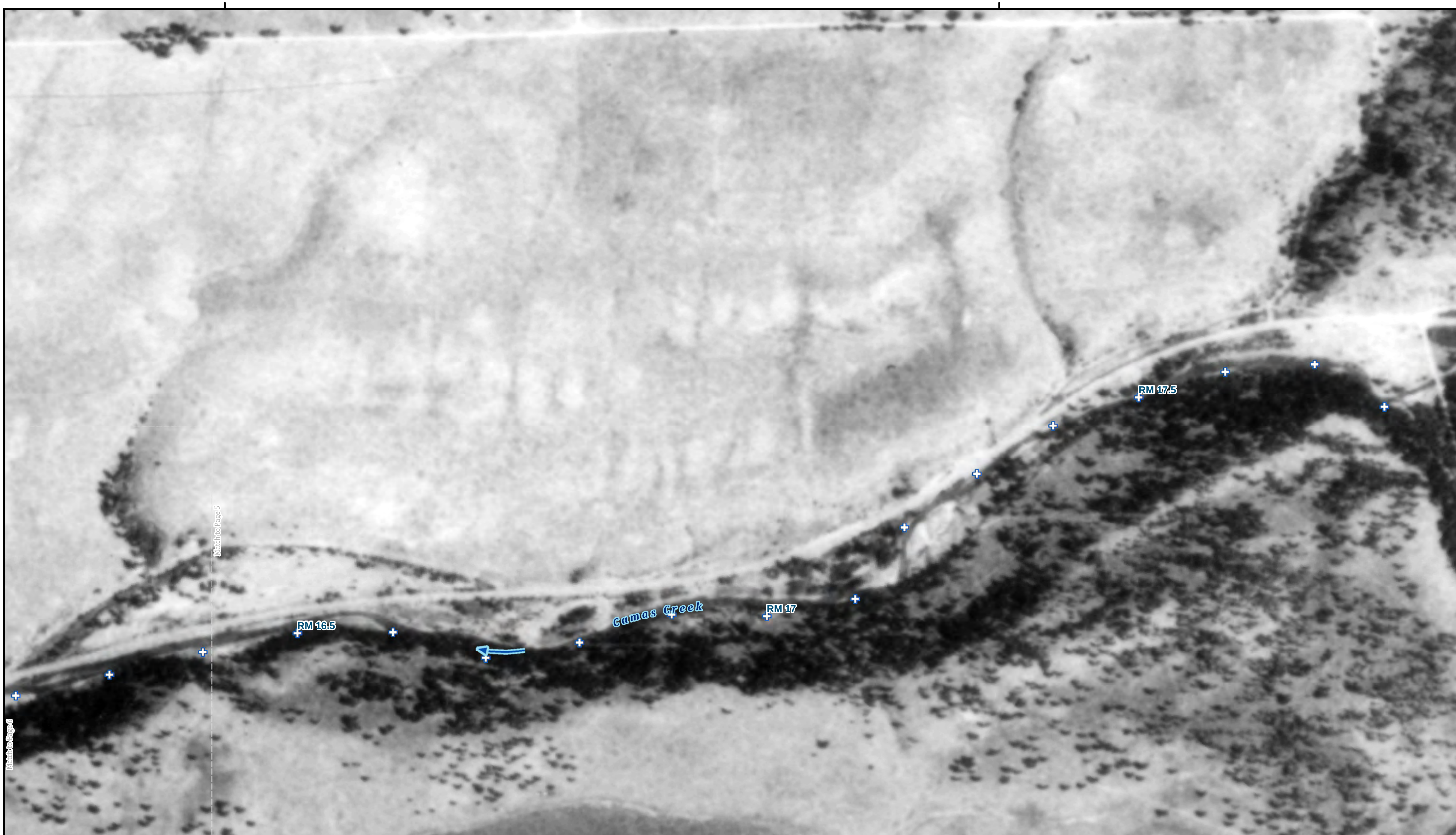


Camas Creek Geomorphic Assessment & Action Plan

1981 Aerial Photo Map Book - Page 6 of 6

Data source: 1981 aerial imagery obtained from CTUIR

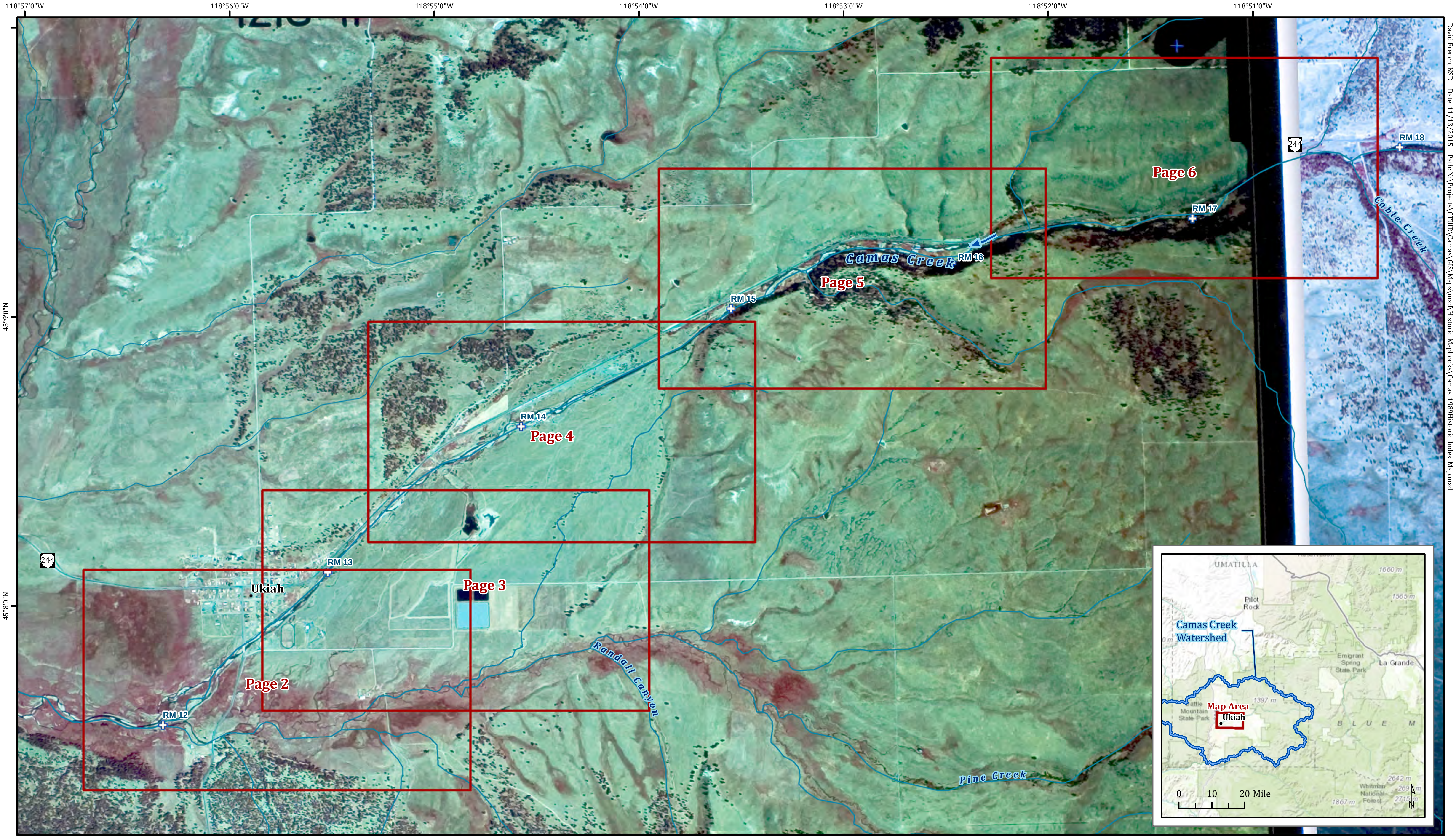
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1989 Aerial Photo Map Book - Page 1 of 6

Data source: 1989 aerial imagery obtained from USGS Earth Explorer

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

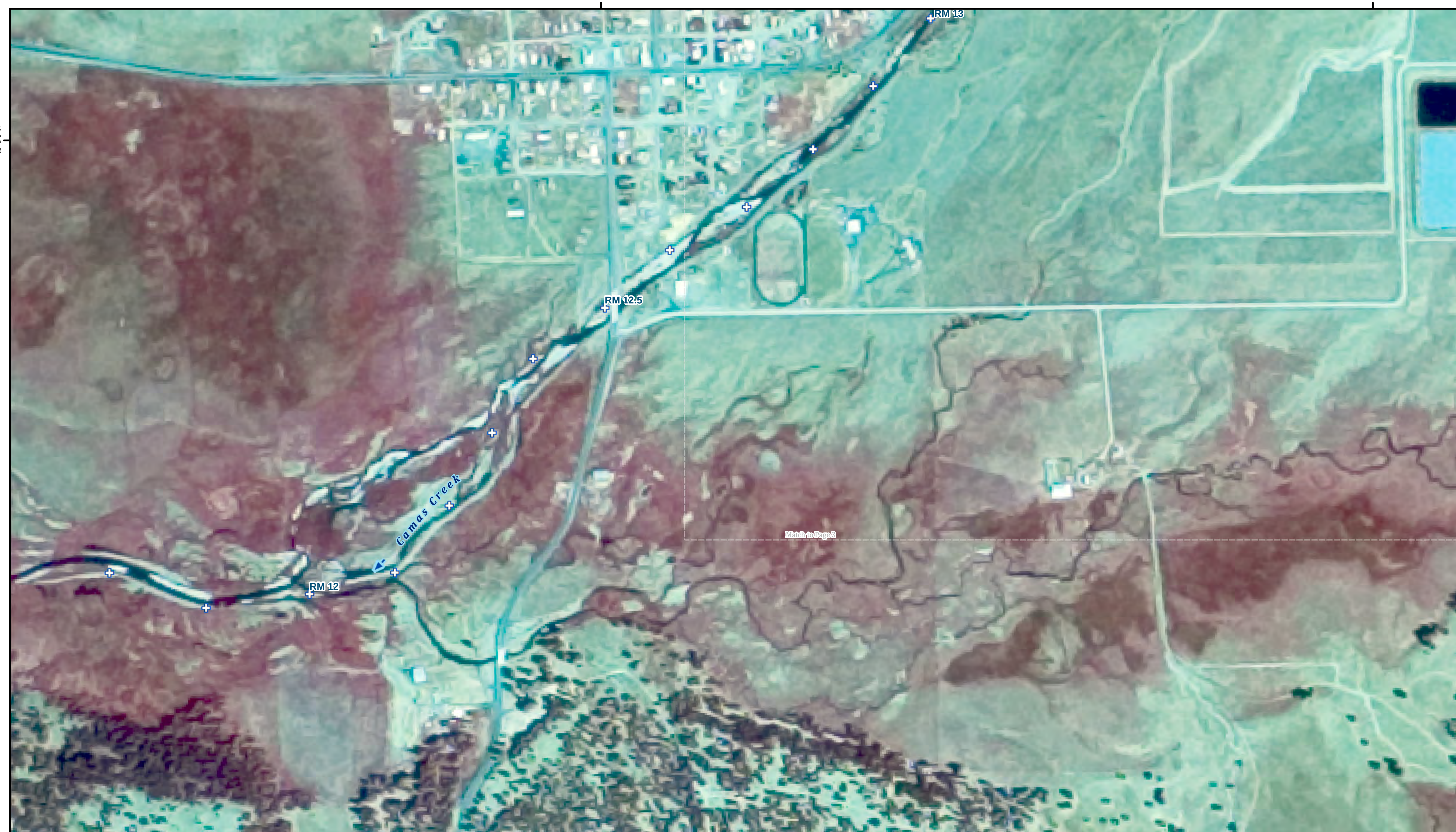
15 River Mile

Natural Systems Design

118°56'0"W

118°55'0"W

45°8'0"N



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Camas Creek Geomorphic Assessment & Action Plan

1989 Aerial Photo Map Book - Page 2 of 6

Data source: 1989 aerial imagery obtained from USGS Earth Explorer

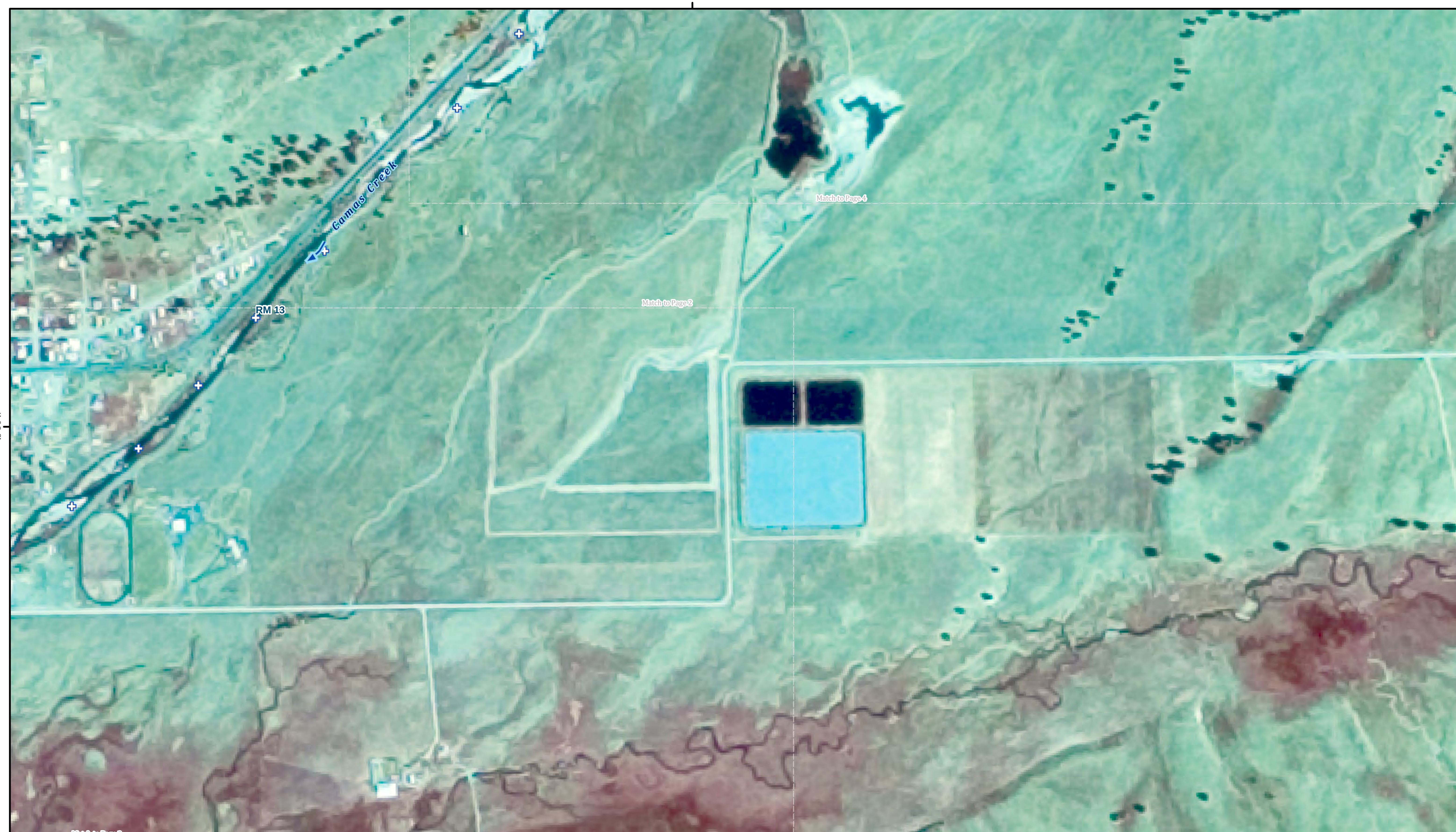
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1989 Aerial Photo Map Book - Page 3 of 6

Data source: 1989 aerial imagery obtained from USGS Earth Explorer

N

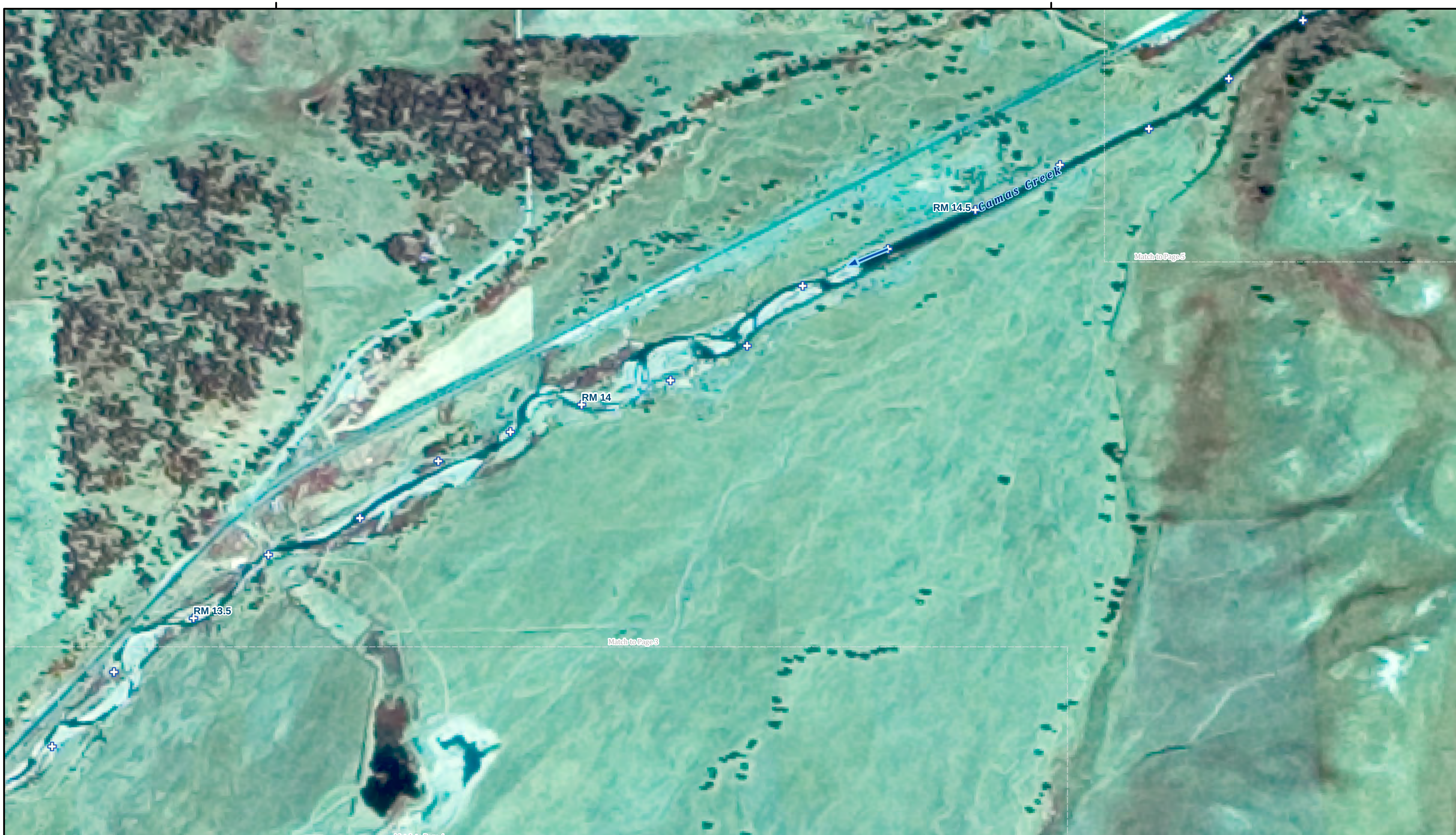
0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°55'0"W 118°54'0"W



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Camas Creek Geomorphic Assessment & Action Plan

1989 Aerial Photo Map Book - Page 4 of 6

Data source: 1989 aerial imagery obtained from USGS Earth Explorer

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1989Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1989 Aerial Photo Map Book - Page 5 of 6

Data source: 1989 aerial imagery obtained from USGS Earth Explorer

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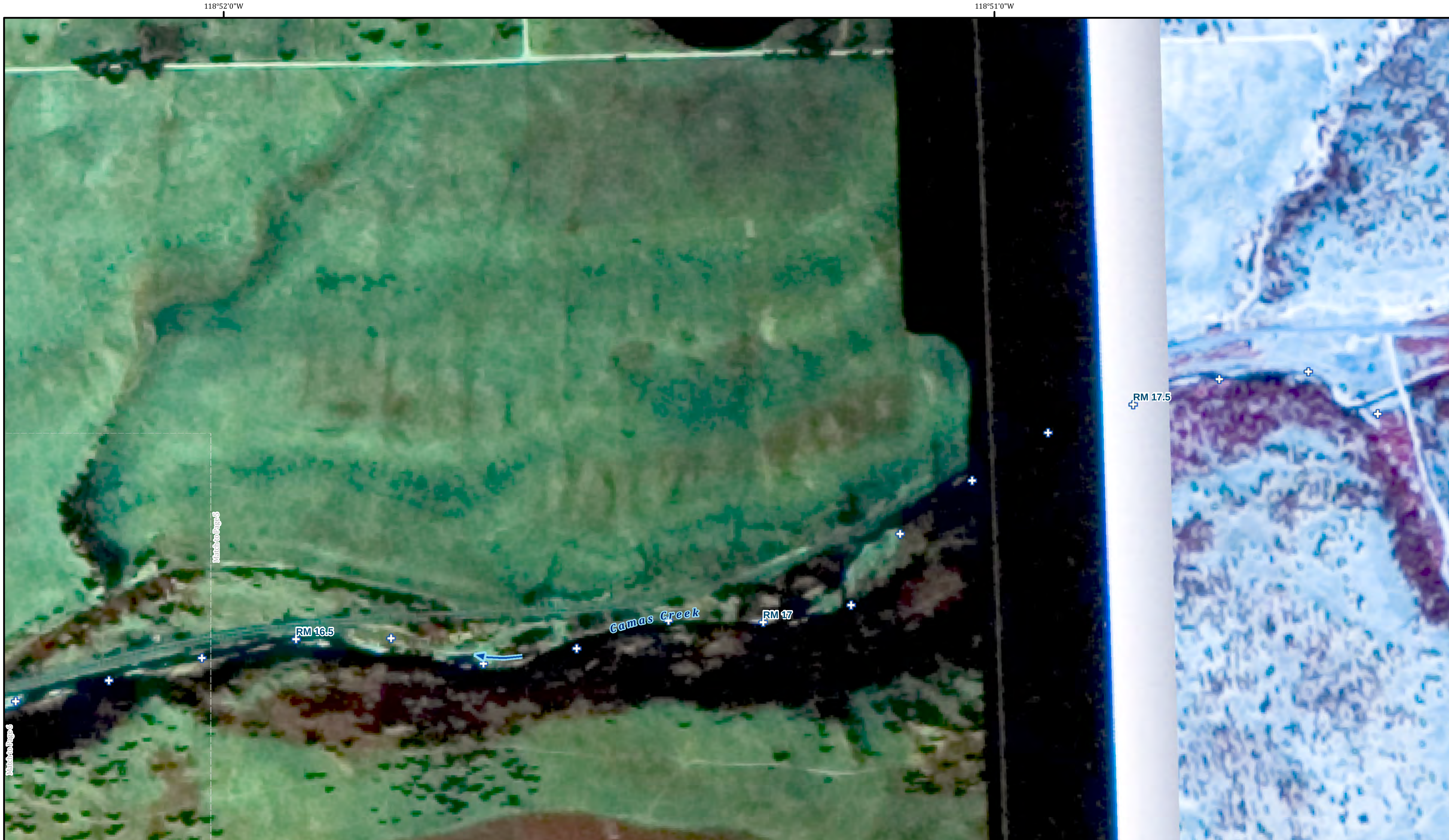
0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1989 Aerial Photo Map Book - Page 6 of 6

Data source: 1989 aerial imagery obtained from USGS Earth Explorer

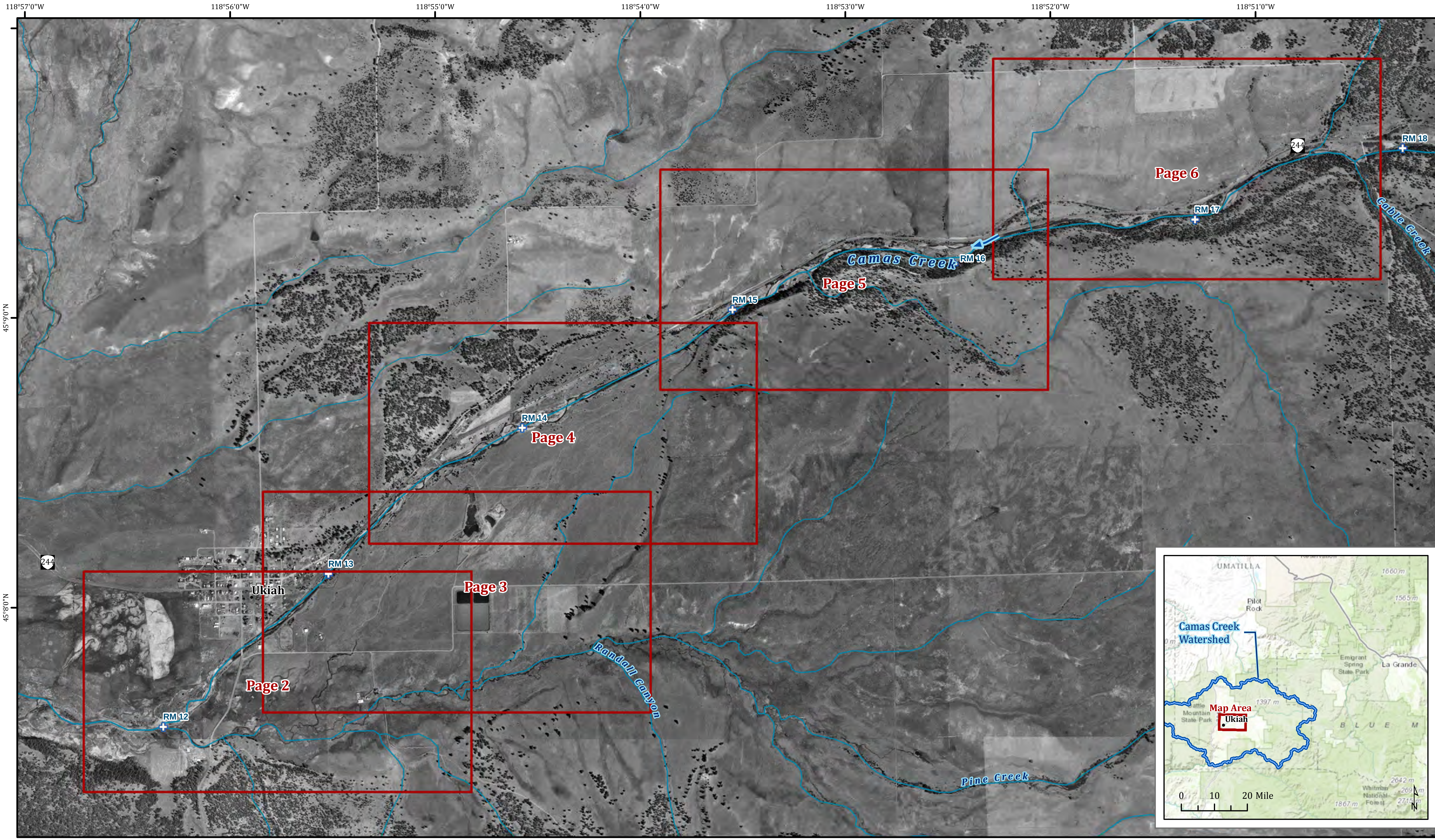
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1995 Aerial Photo Map Book - Page 1 of 6

Data source: 1995 aerial imagery obtained from USGS Earth Explorer

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°56'0"W
118°55'0"W
45°8'0"N

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_1995Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

1995 Aerial Photo Map Book - Page 2 of 6

Data source: 1995 aerial imagery obtained from USGS Earth Explorer

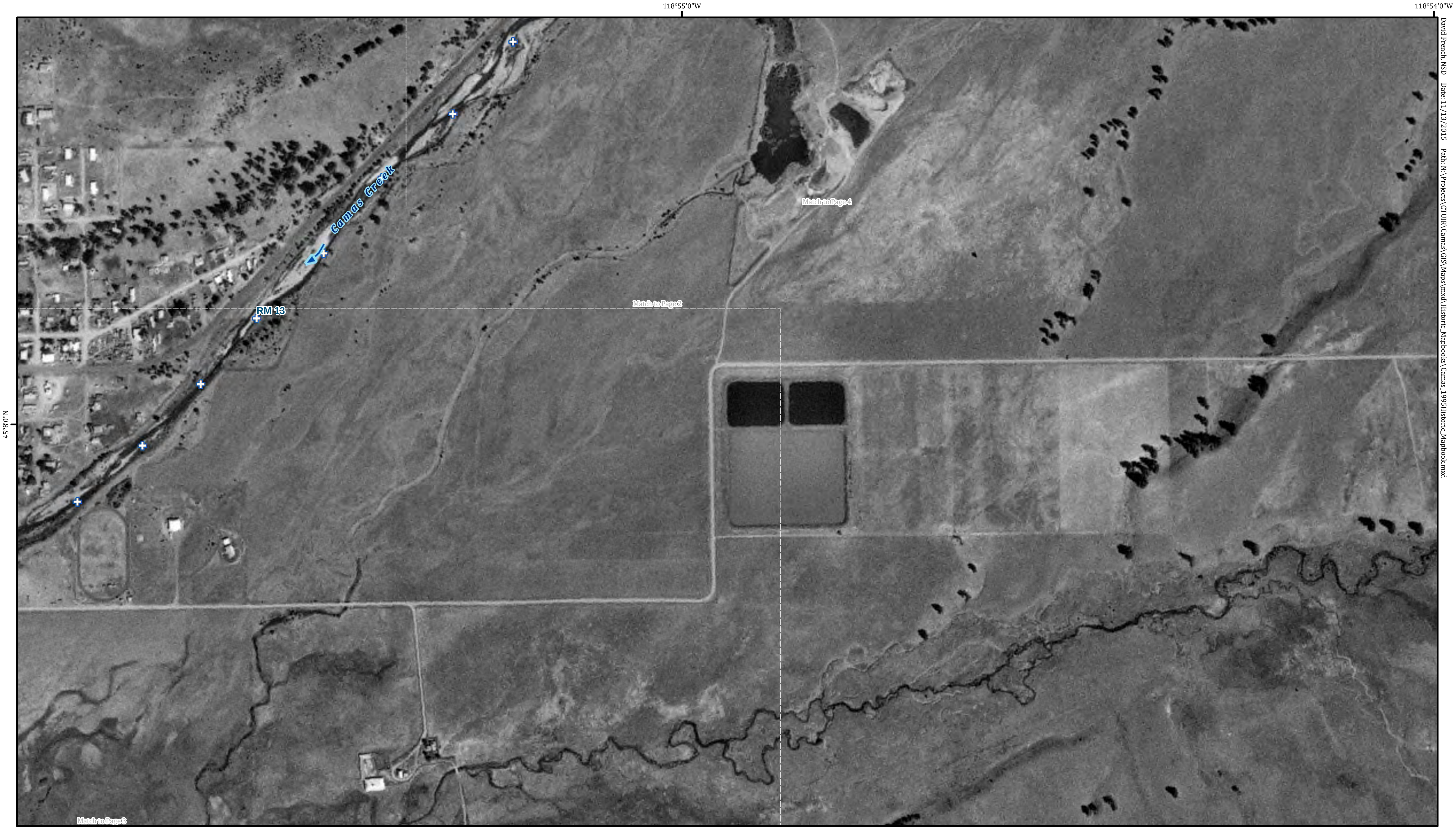
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

1995 Aerial Photo Map Book - Page 3 of 6

Data source: 1995 aerial imagery obtained from USGS Earth Explorer

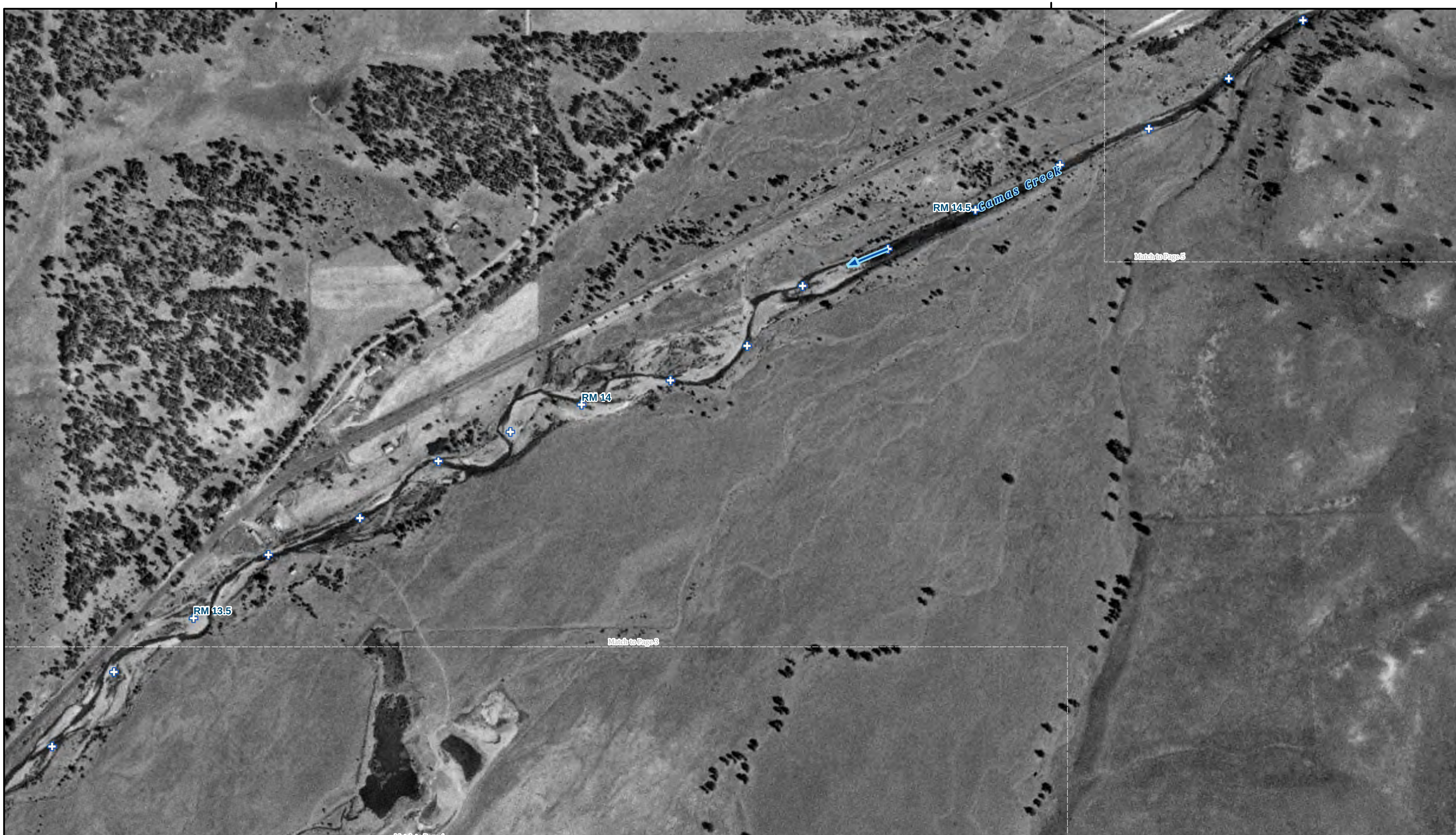
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1995 Aerial Photo Map Book - Page 4 of 6

Data source: 1995 aerial imagery obtained from USGS Earth Explorer

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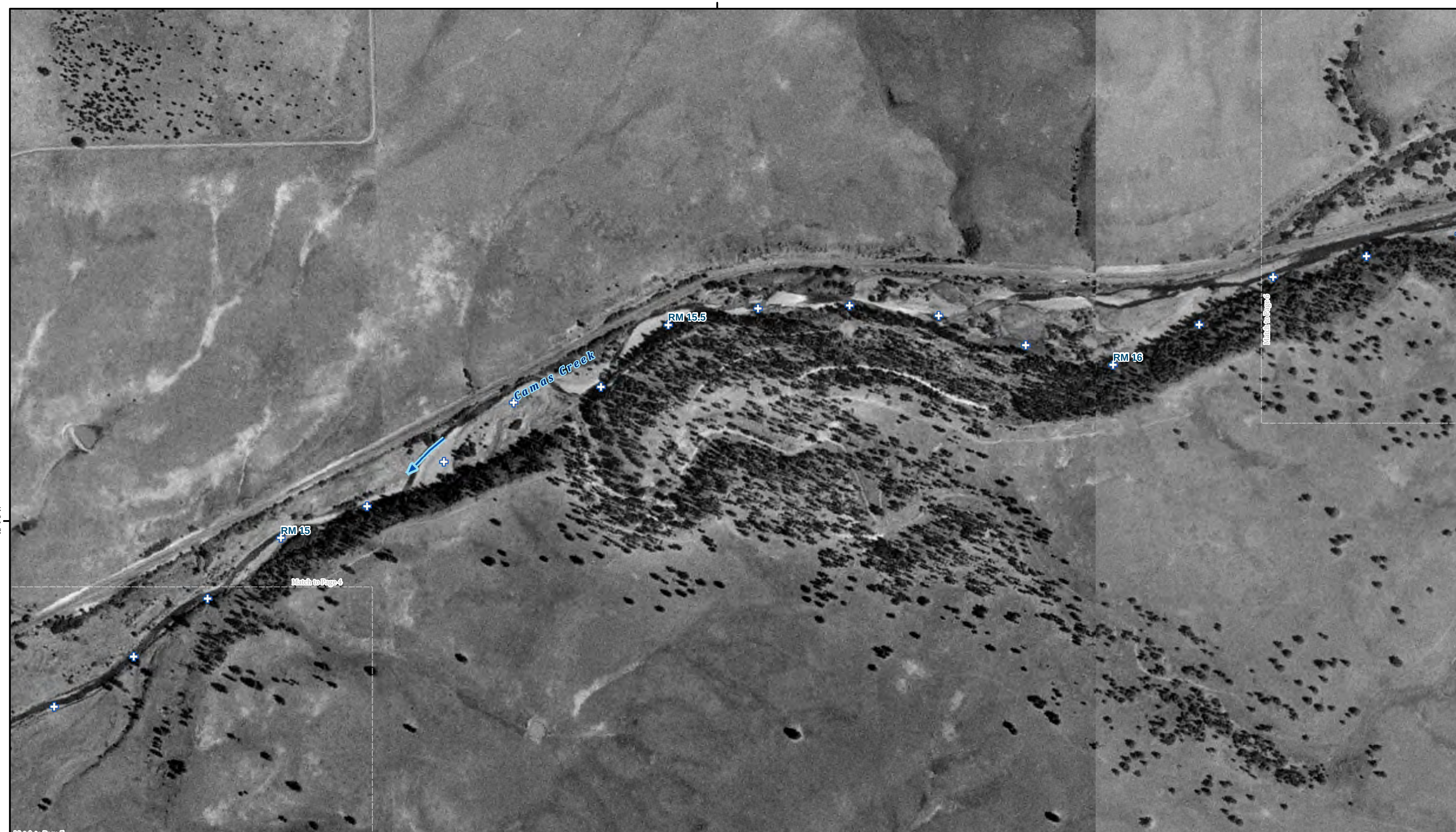
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1995 Aerial Photo Map Book - Page 5 of 6

Data source: 1995 aerial imagery obtained from USGS Earth Explorer

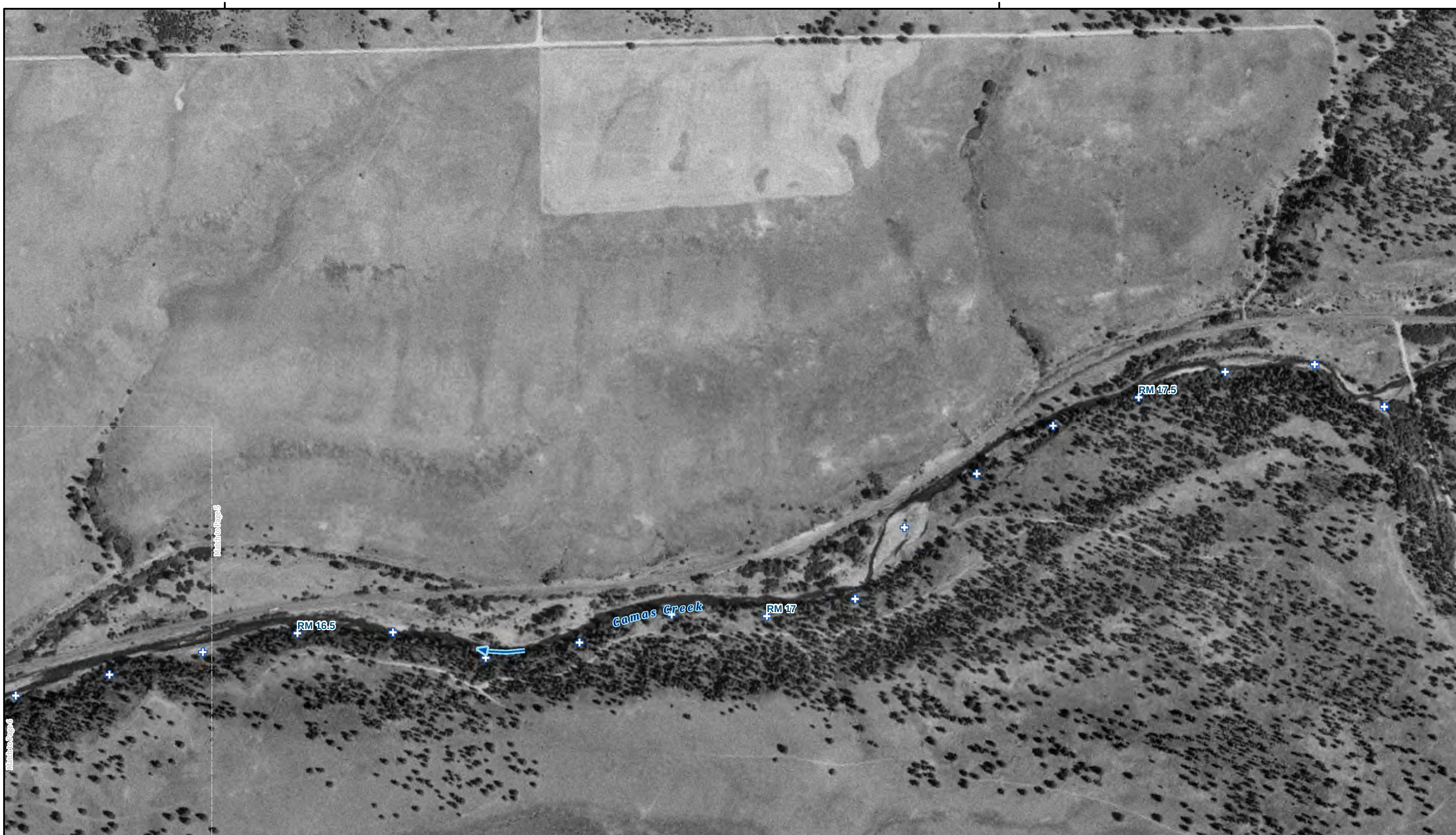
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

1995 Aerial Photo Map Book - Page 6 of 6

Data source: 1995 aerial imagery obtained from USGS Earth Explorer

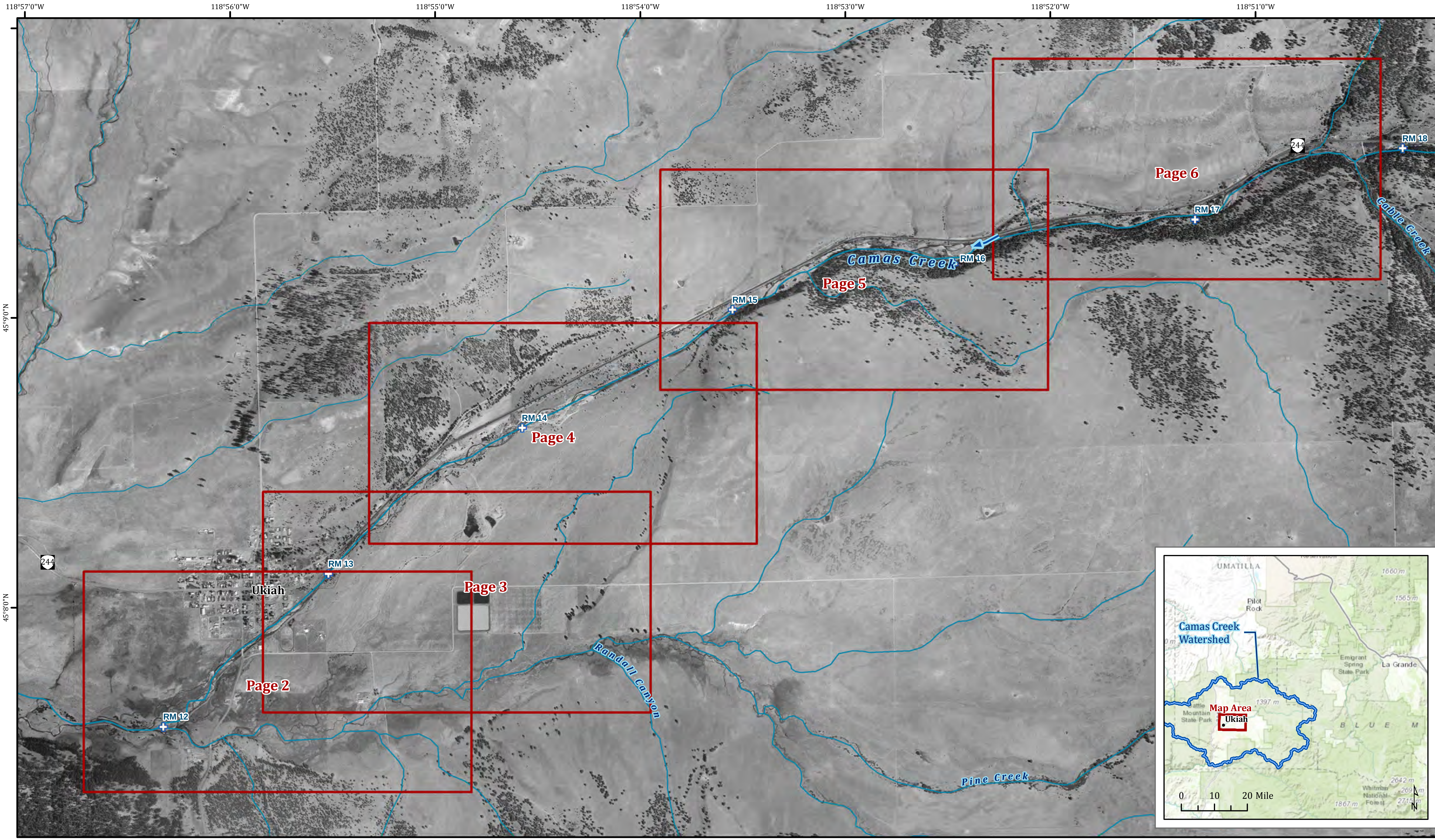
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2000 Aerial Photo Map Book - Page 1 of 6

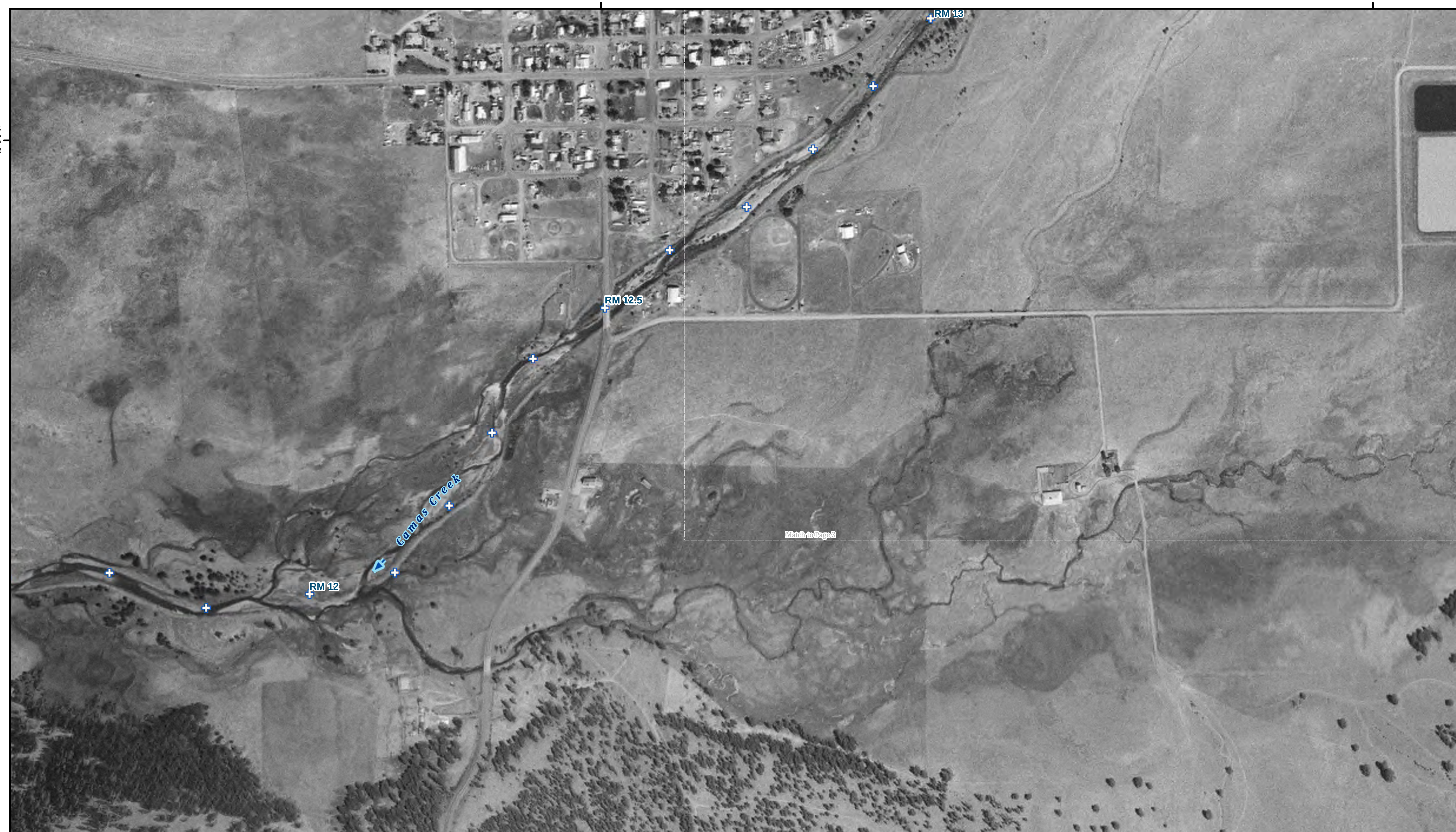
Data source: 2000 aerial imagery obtained from USGS Earth Explorer

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2000 Aerial Photo Map Book - Page 2 of 6

Data source: 2000 aerial imagery obtained from USGS Earth Explorer

N

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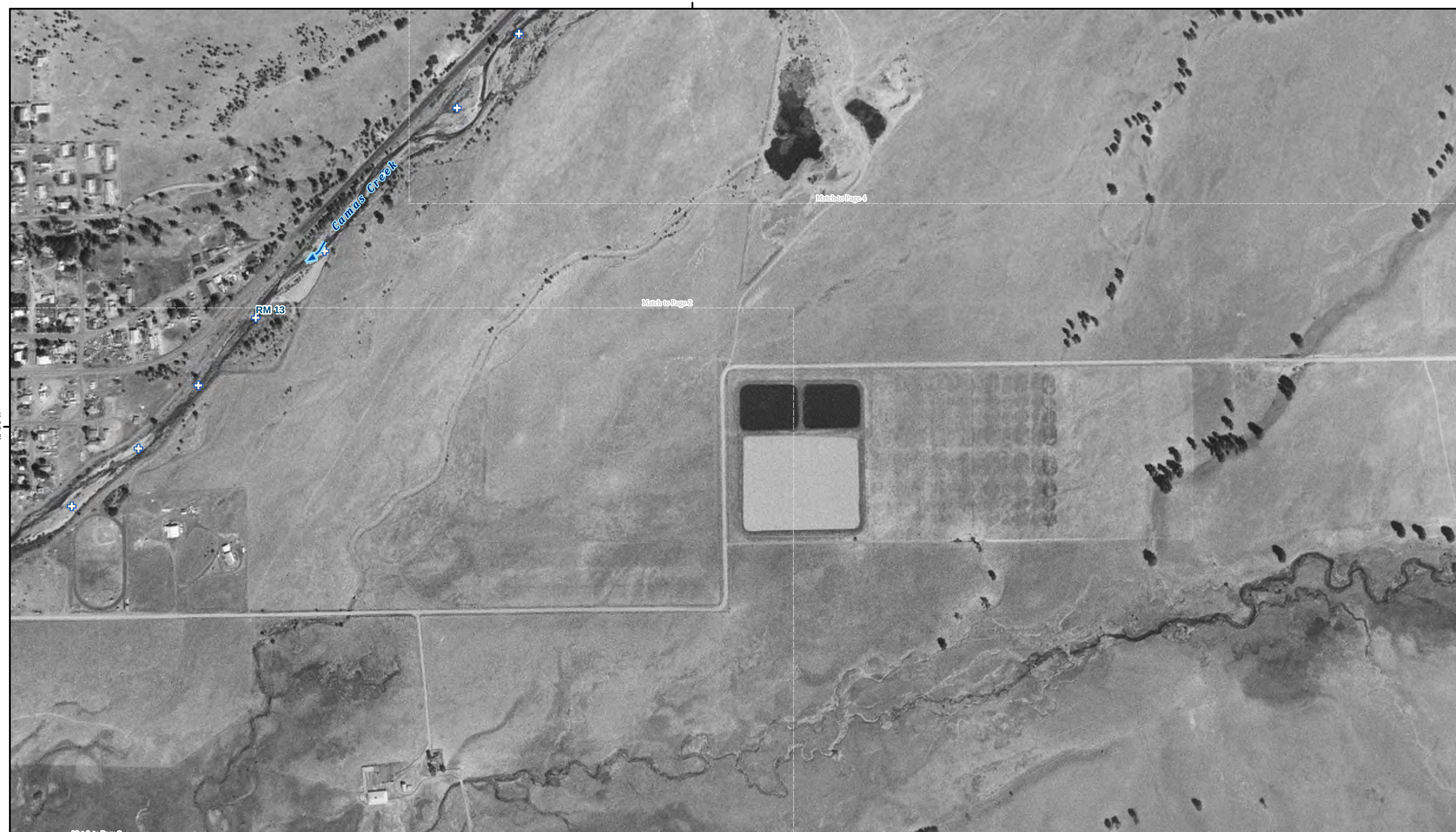
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

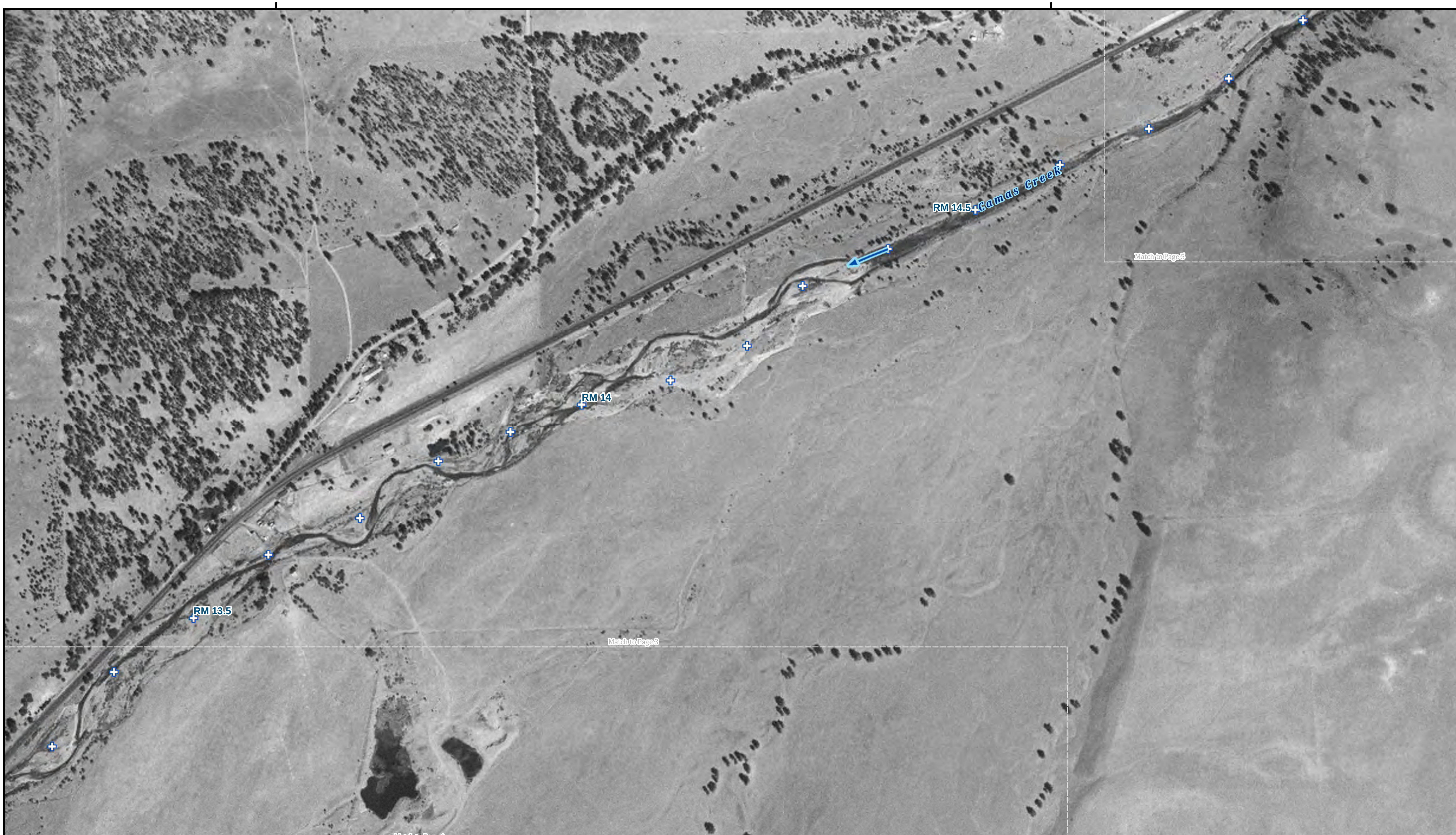


Camas Creek Geomorphic Assessment & Action Plan

2000 Aerial Photo Map Book - Page 3 of 6

Data source: 2000 aerial imagery obtained from USGS Earth Explorer

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)



Camas Creek Geomorphic Assessment & Action Plan

2000 Aerial Photo Map Book - Page 4 of 6

Data source: 2000 aerial imagery obtained from USGS Earth Explorer

N

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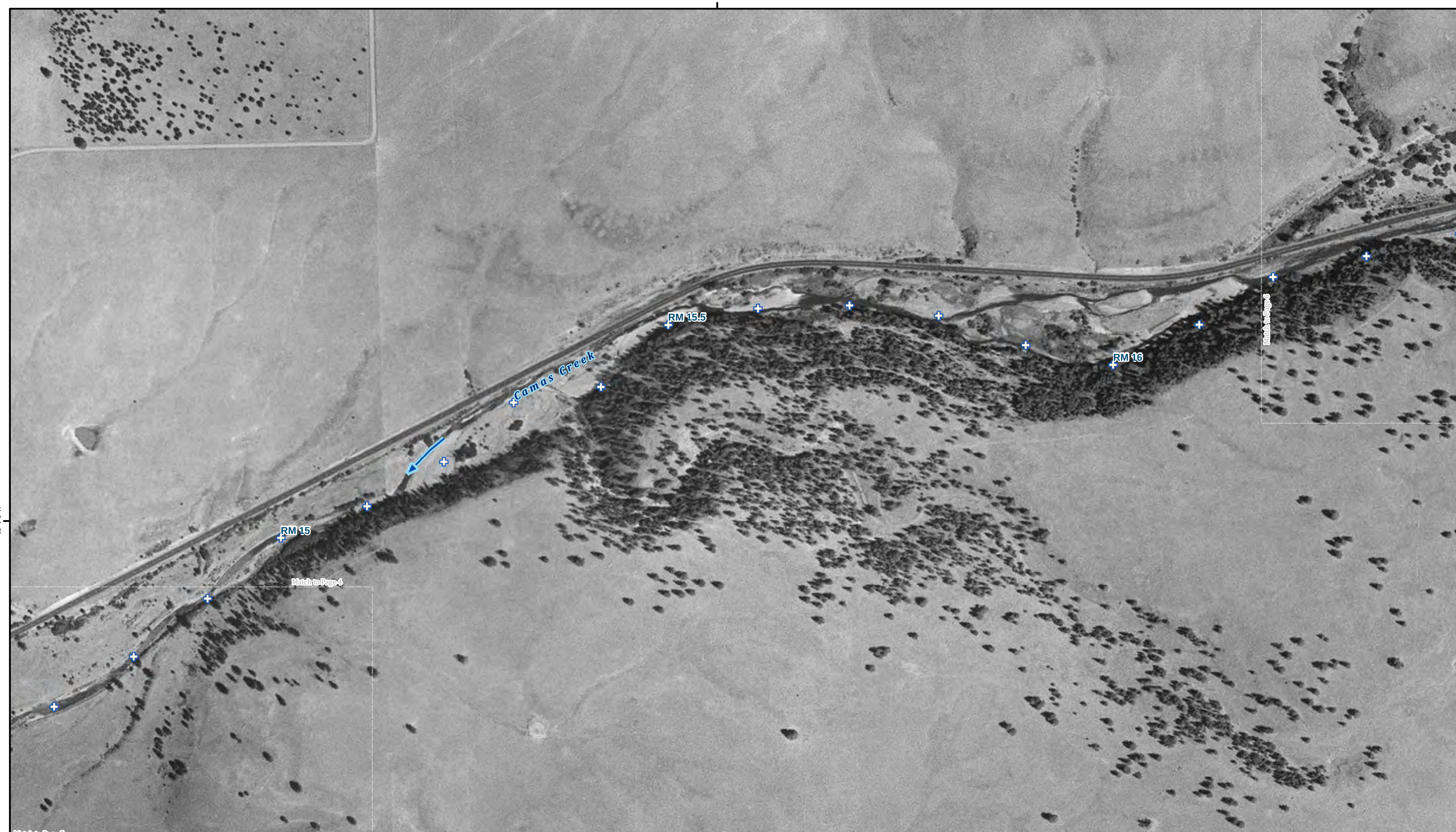
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°53'0"W



45°9'0"N

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Camas Creek Geomorphic Assessment & Action Plan

2000 Aerial Photo Map Book - Page 5 of 6

Data source: 2000 aerial imagery obtained from USGS Earth Explorer

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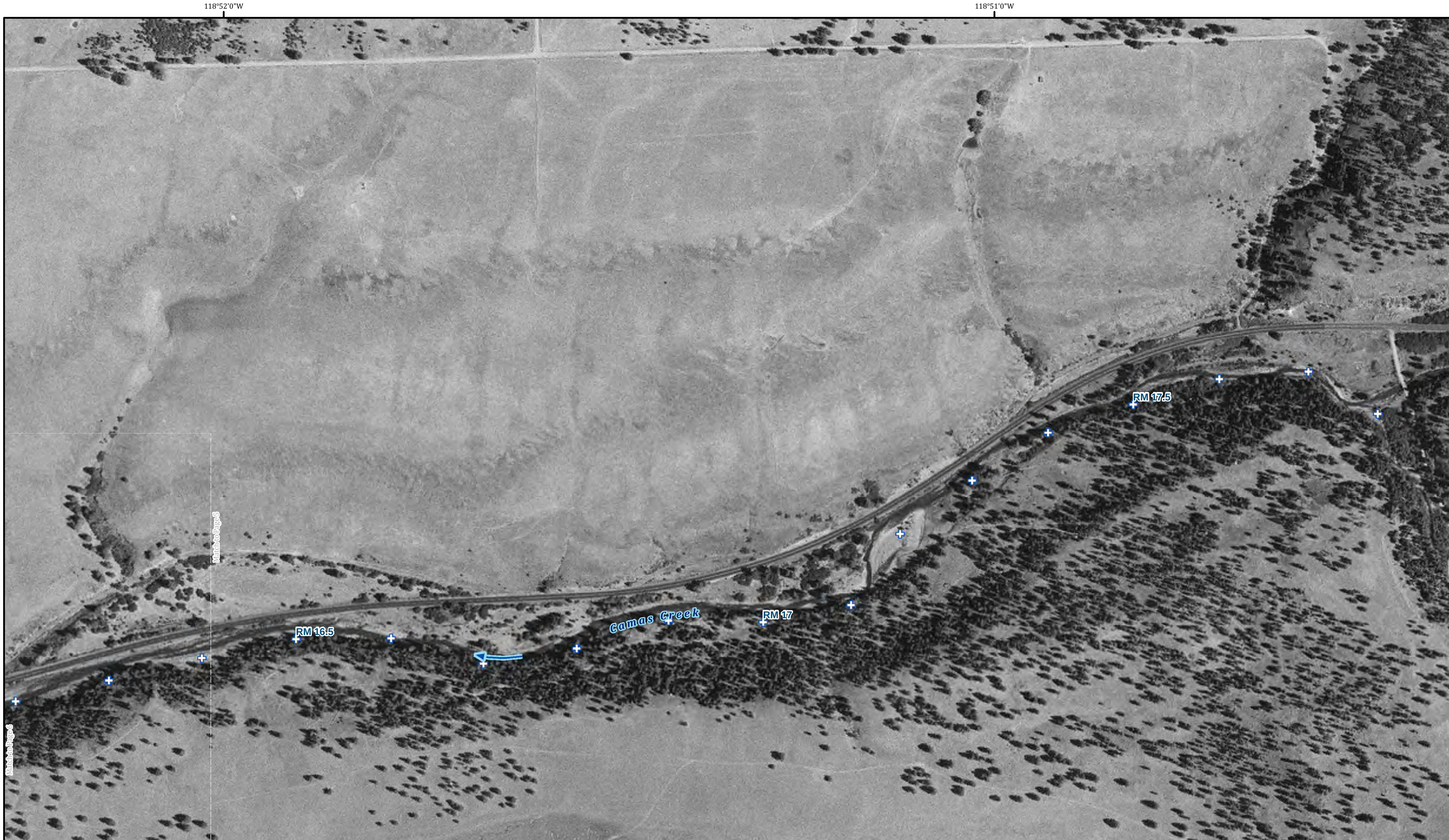
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2000 Aerial Photo Map Book - Page 6 of 6

Data source: 2000 aerial imagery obtained from USGS Earth Explorer

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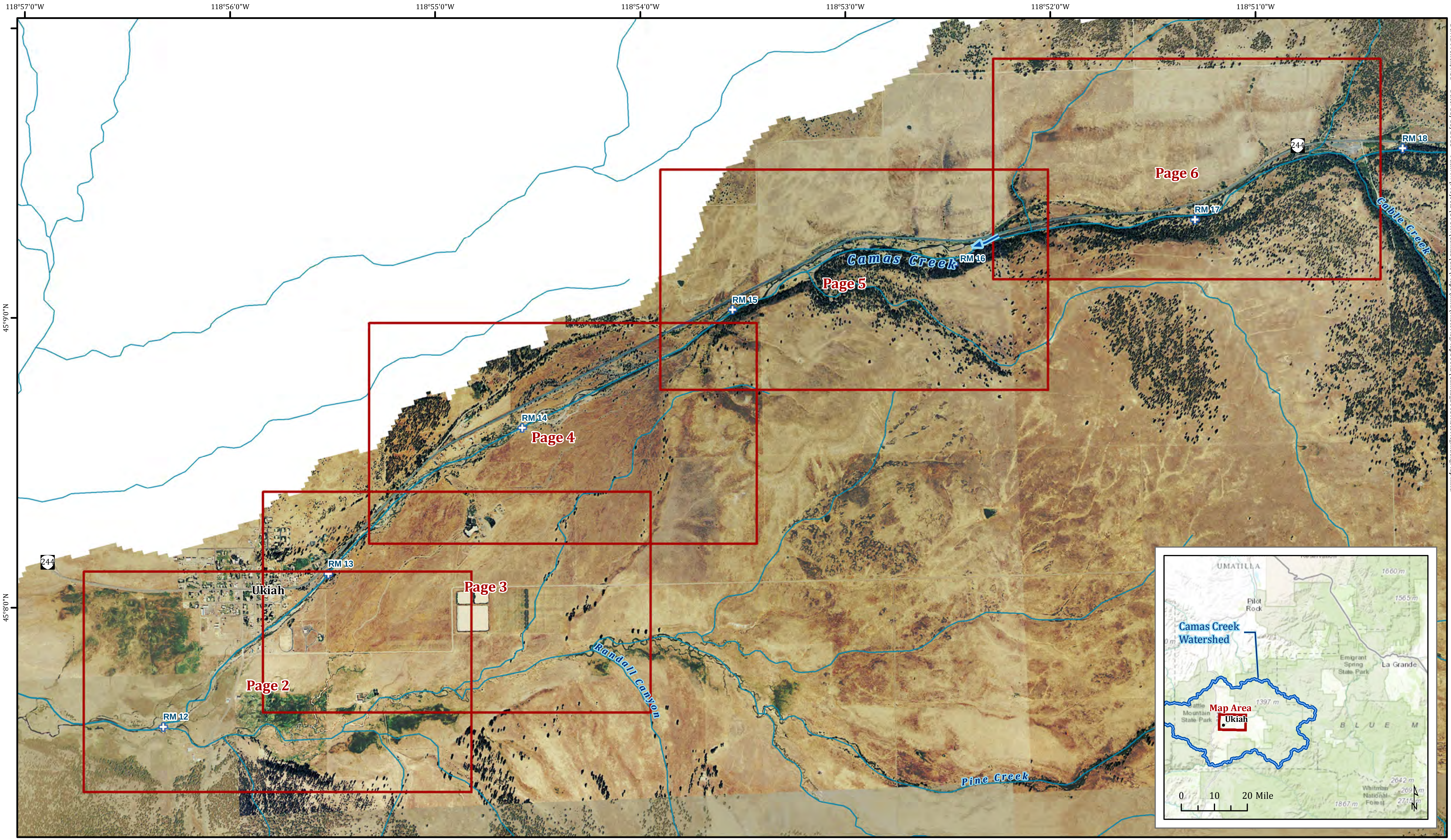
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2003 Aerial Photo Map Book - Page 1 of 6

Data source: 2003 NAIP aerial imagery obtained from USDA

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2003Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2003 Aerial Photo Map Book - Page 2 of 6

Data source: 2003 NAIP aerial imagery obtained from USDA

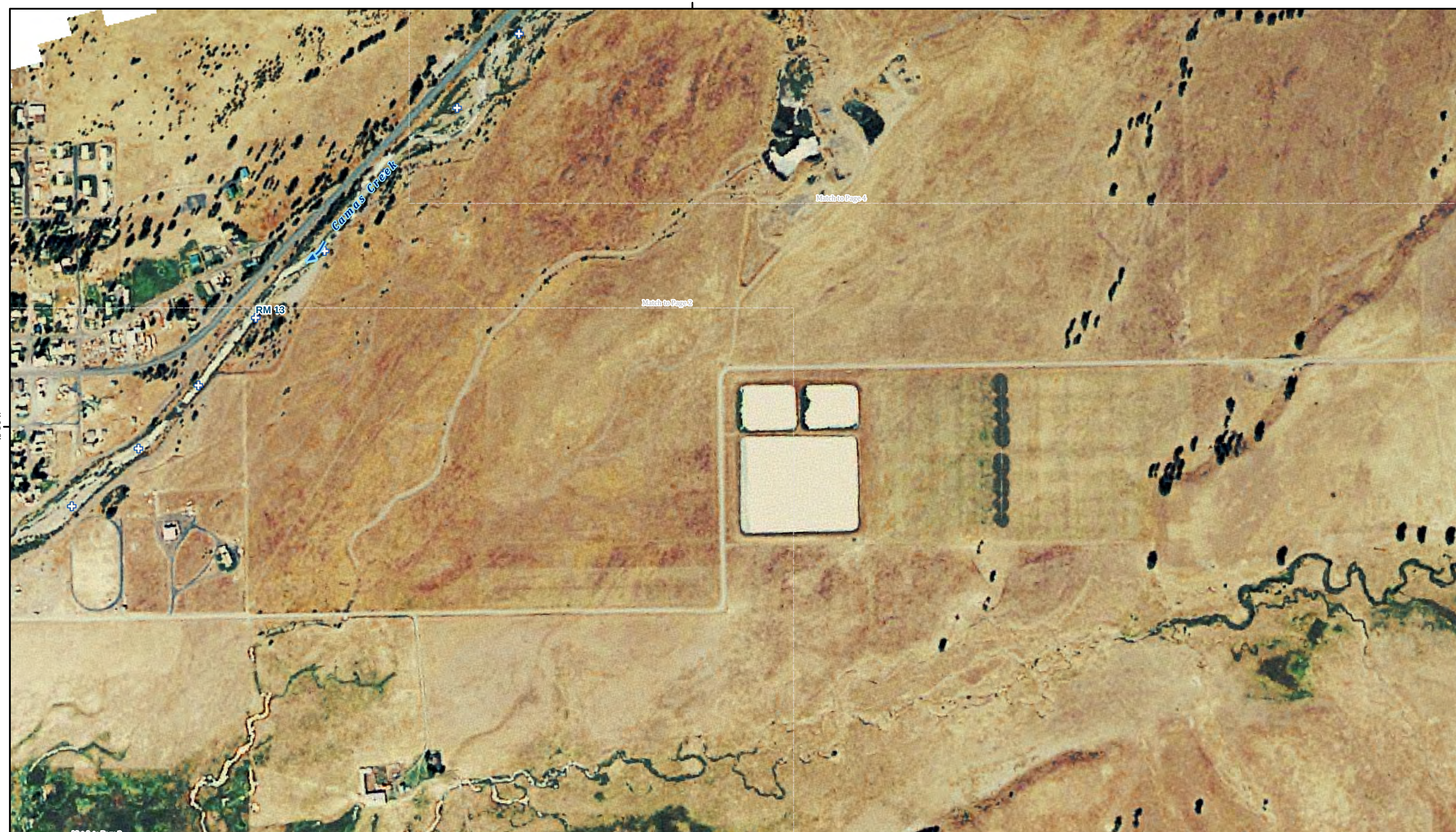
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2003 Aerial Photo Map Book - Page 3 of 6

Data source: 2003 NAIP aerial imagery obtained from USDA

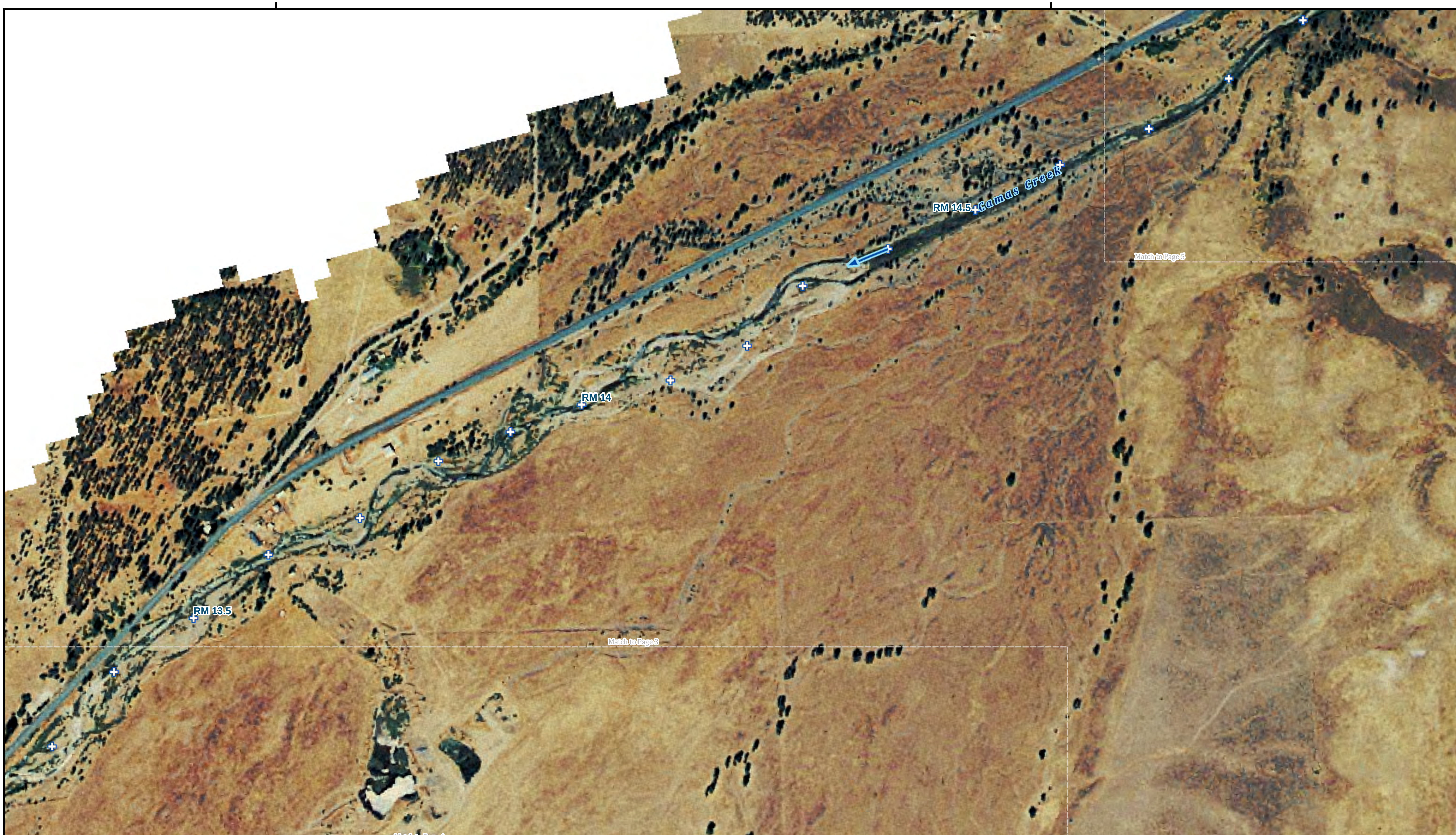
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2003 Aerial Photo Map Book - Page 4 of 6

Data source: 2003 NAIP aerial imagery obtained from USDA

N

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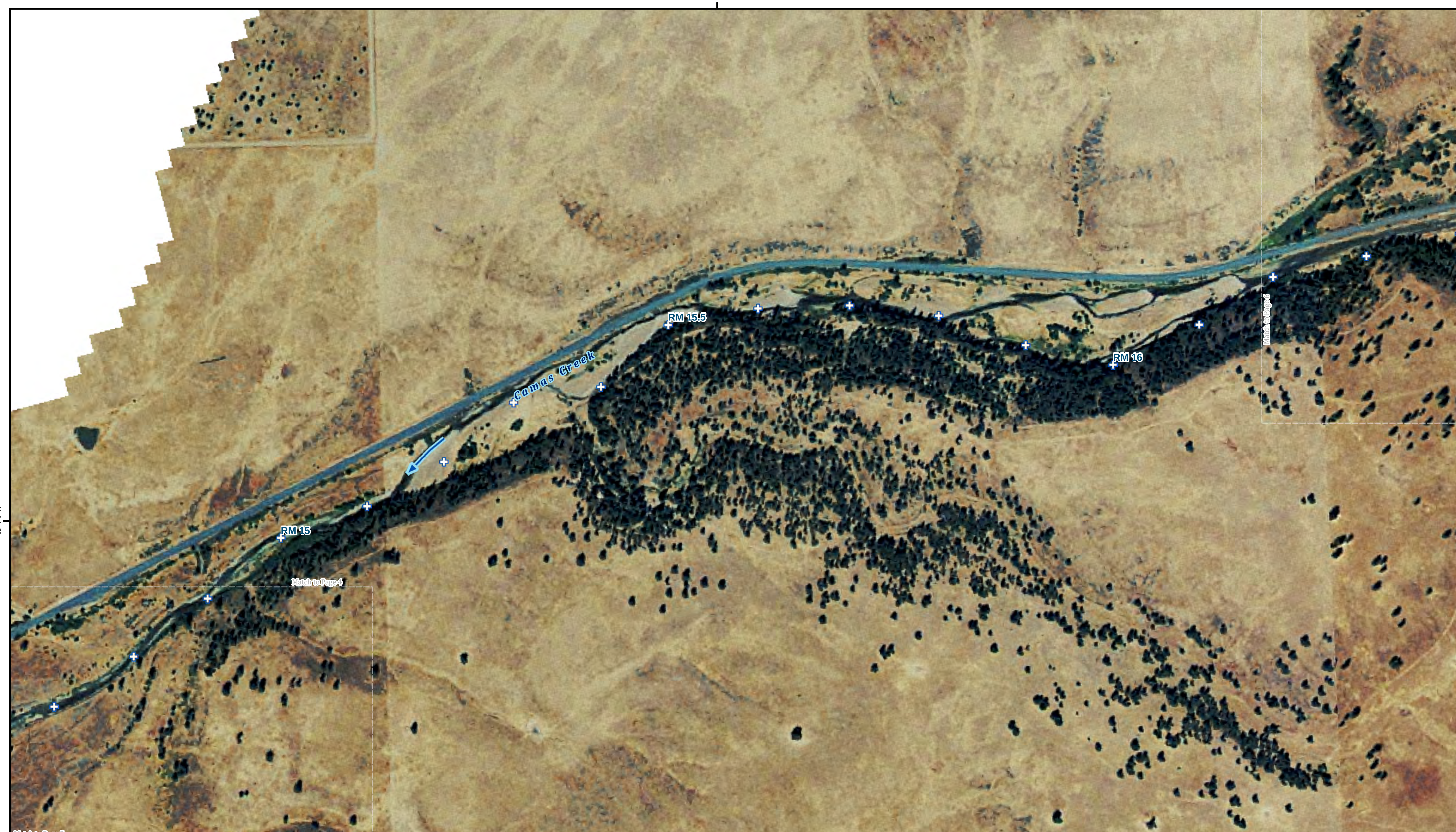
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2003 Aerial Photo Map Book - Page 5 of 6

Data source: 2003 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2003Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2003 Aerial Photo Map Book - Page 6 of 6

Data source: 2003 NAIP aerial imagery obtained from USDA

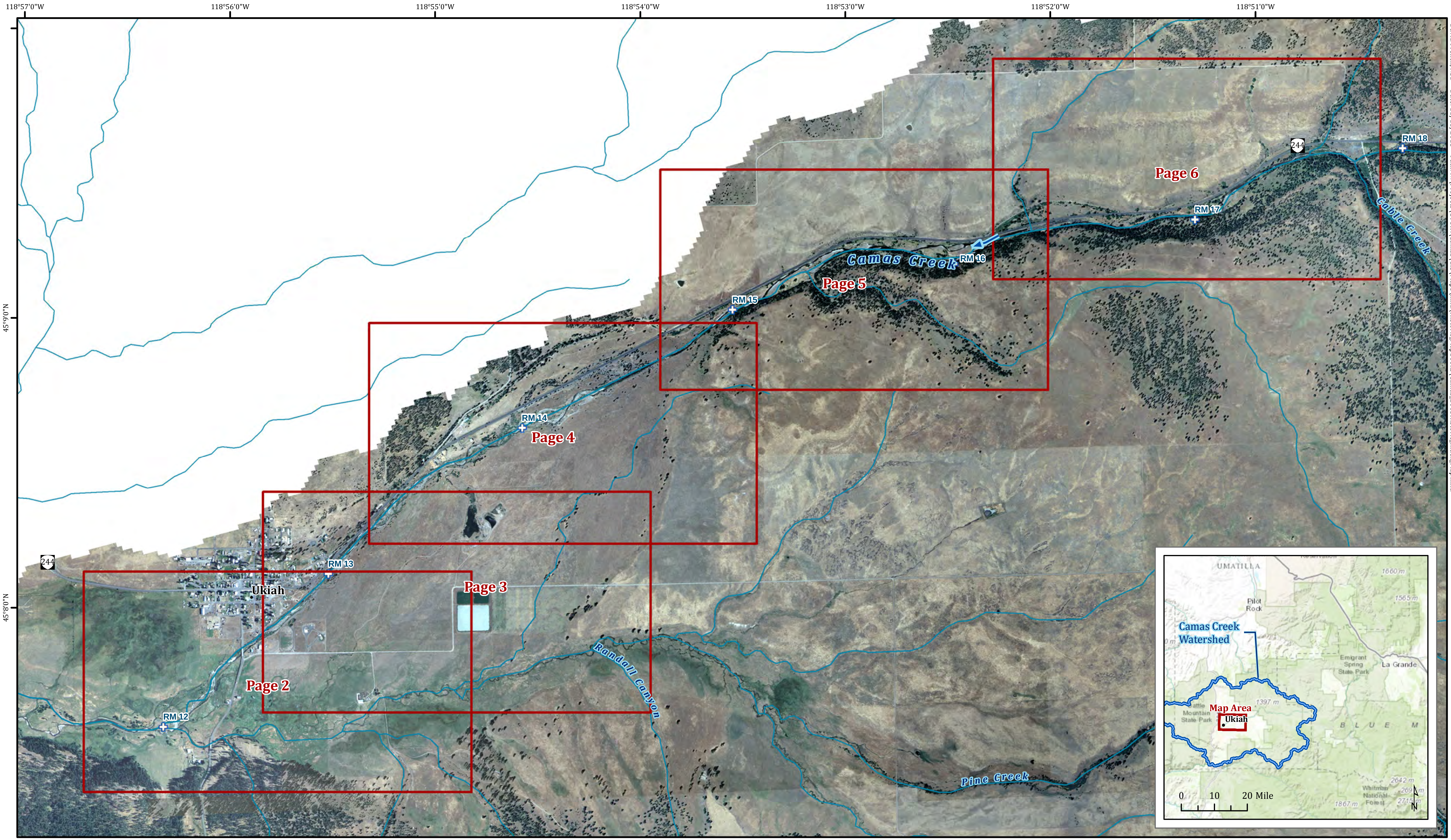
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2005 Aerial Photo Map Book - Page 1 of 6

Data source: 2005 NAIP aerial imagery obtained from USDA

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2005Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2005 Aerial Photo Map Book - Page 2 of 6

Data source: 2005 NAIP aerial imagery obtained from USDA

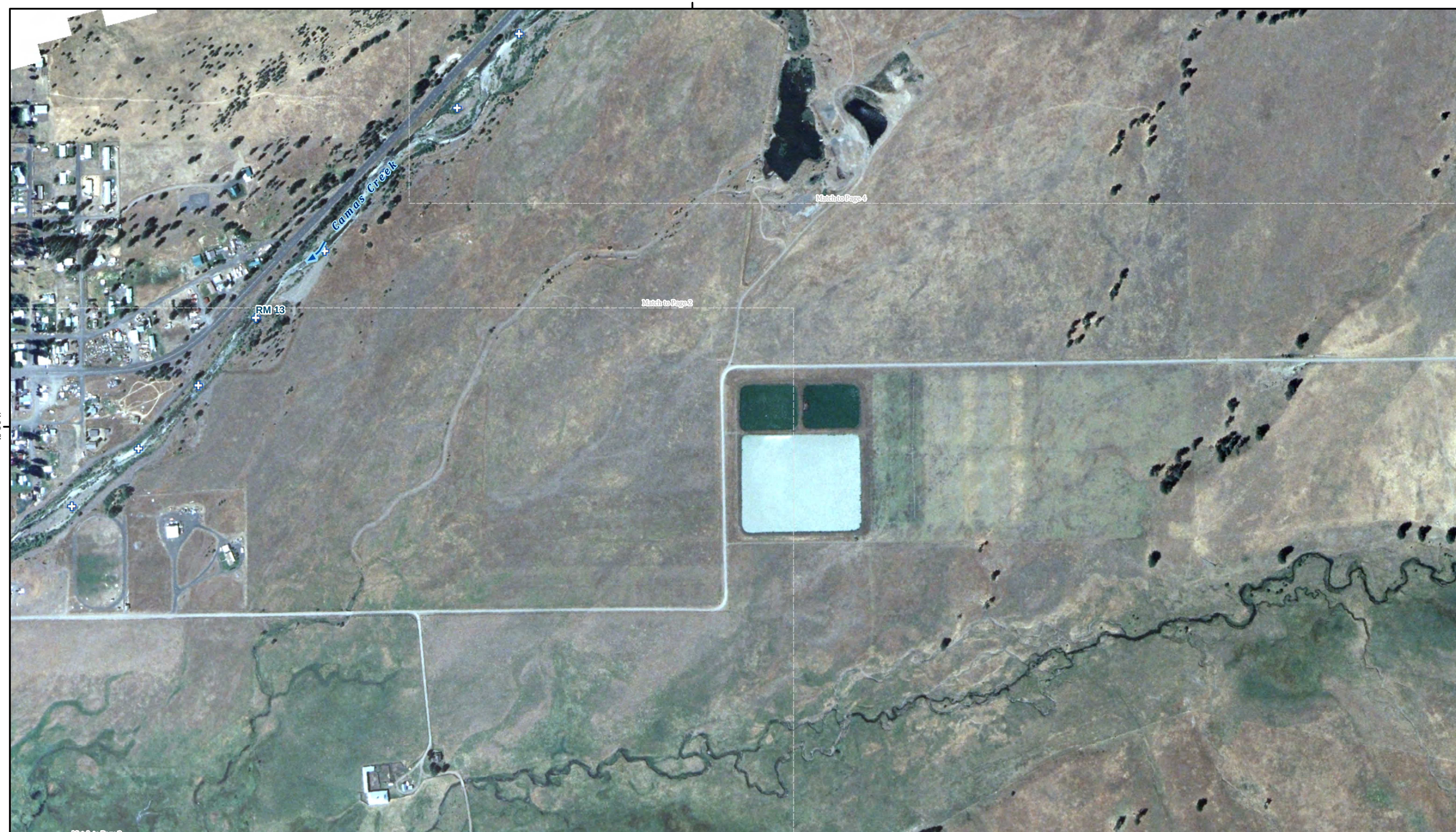
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2005 Aerial Photo Map Book - Page 3 of 6

Data source: 2005 NAIP aerial imagery obtained from USDA

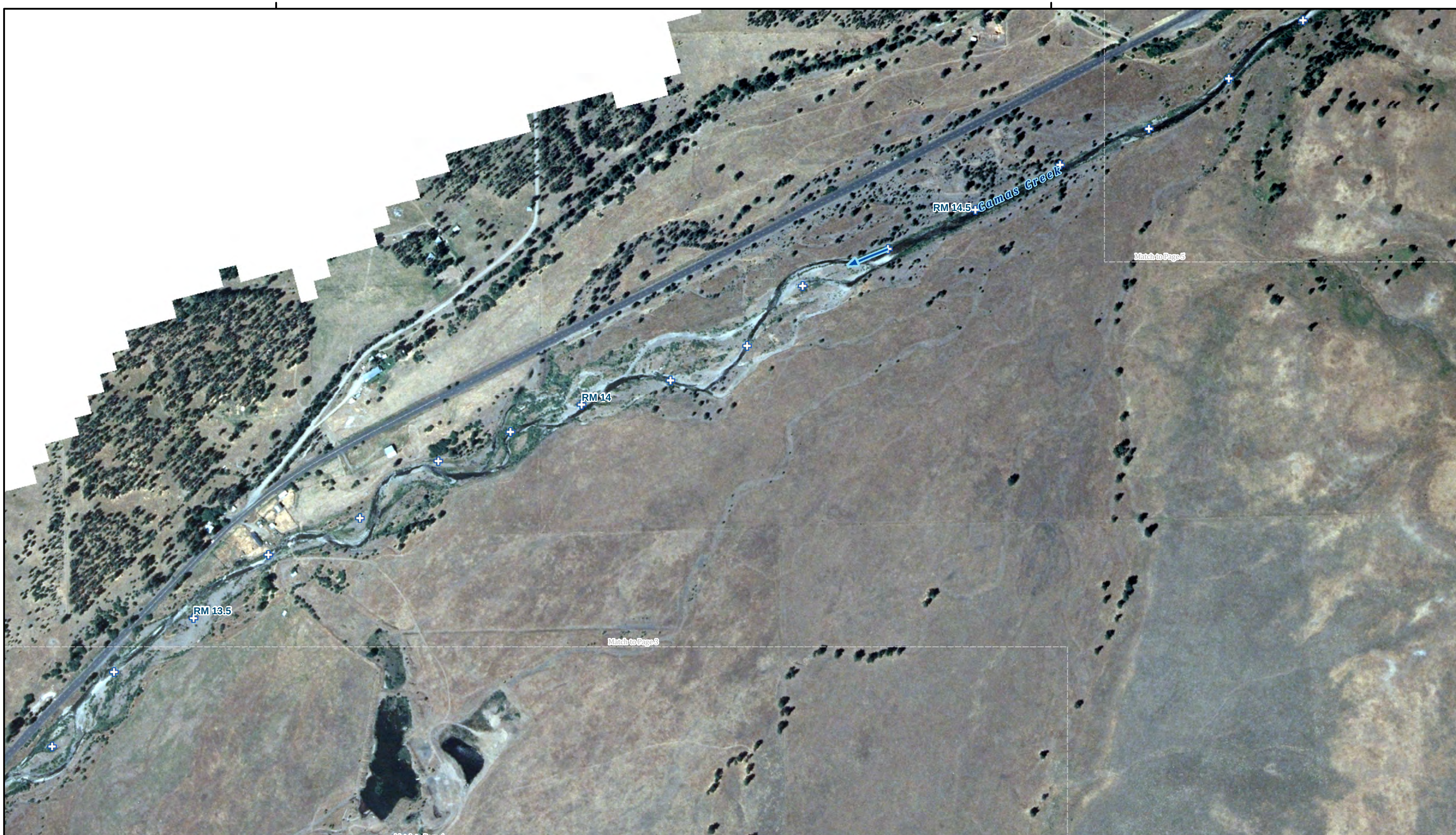
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2005 Aerial Photo Map Book - Page 4 of 6

Data source: 2005 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2005Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2005 Aerial Photo Map Book - Page 5 of 6

Data source: 2005 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2005Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2005 Aerial Photo Map Book - Page 6 of 6

Data source: 2005 NAIP aerial imagery obtained from USDA

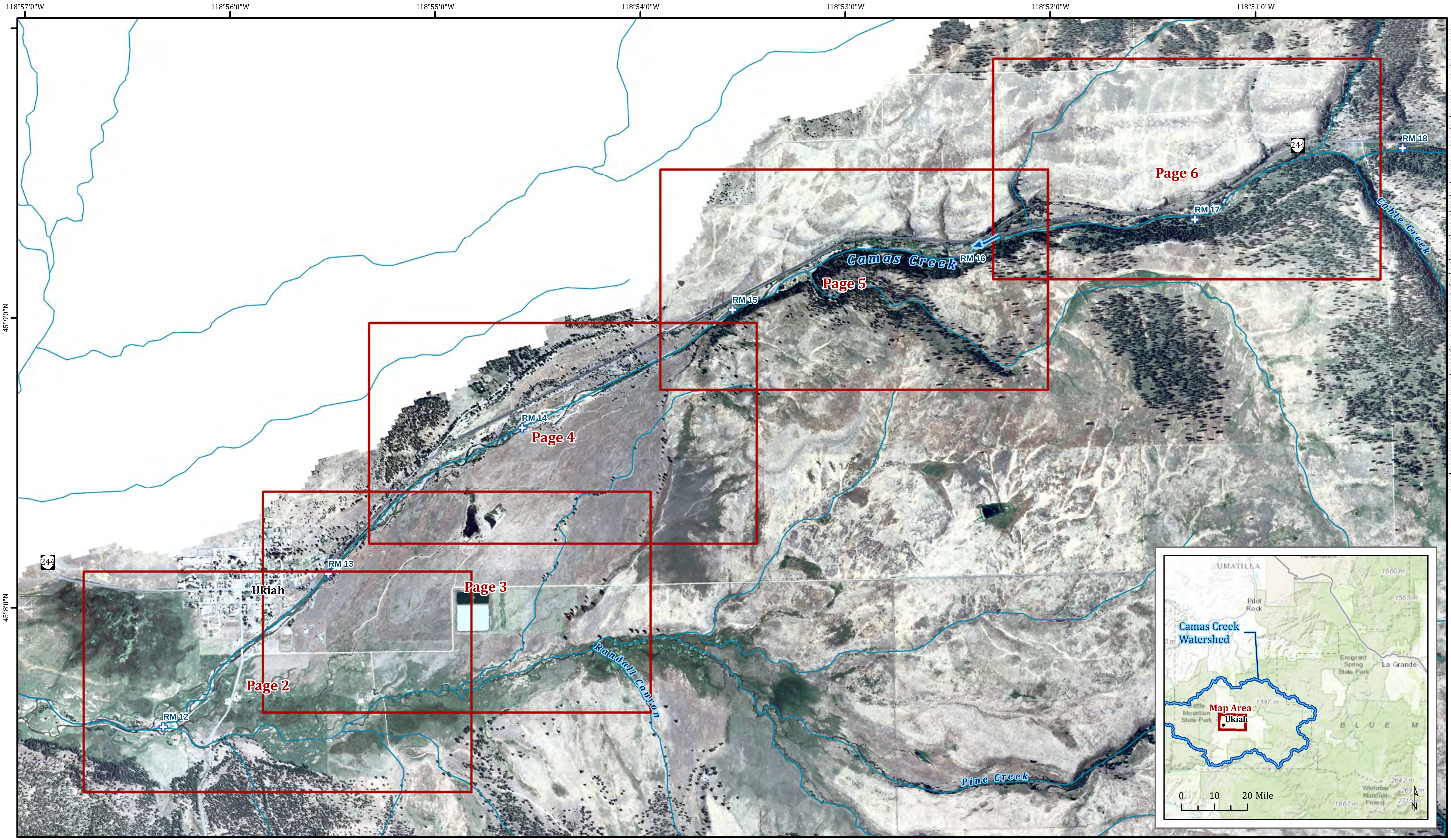
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2006 Aerial Photo Map Book - Page 1 of 6

Data source: 2006 NAIP aerial imagery obtained from USDA

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

Camas Creek Geomorphic Assessment & Action Plan

2006 Aerial Photo Map Book - Page 2 of 6

Data source: 2006 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

Camas Creek Geomorphic Assessment & Action Plan

2006 Aerial Photo Map Book - Page 3 of 6

Data source: 2006 NAIP aerial imagery obtained from USDA

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Camas Creek Geomorphic Assessment & Action Plan

2006 Aerial Photo Map Book - Page 4 of 6

Data source: 2006 NAIP aerial imagery obtained from USDA

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2006Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2006 Aerial Photo Map Book - Page 5 of 6

Data source: 2006 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD   Date: 11/13/2015   Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2006Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2006 Aerial Photo Map Book - Page 6 of 6

Data source: 2006 NAIP aerial imagery obtained from USDA

N

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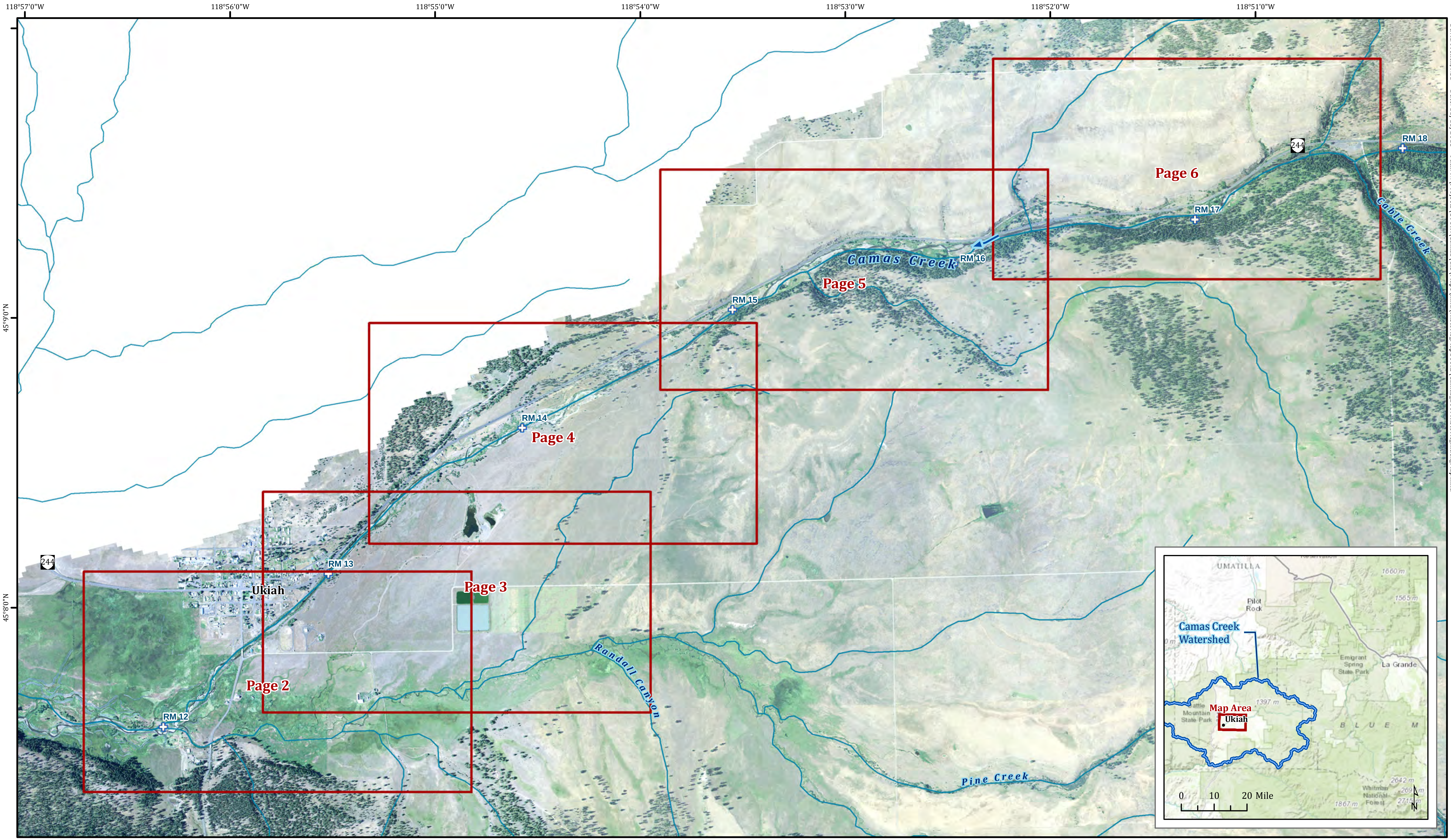
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2009 Aerial Photo Map Book - Page 1 of 6

Data source: 2009 NAIP aerial imagery obtained from USDA

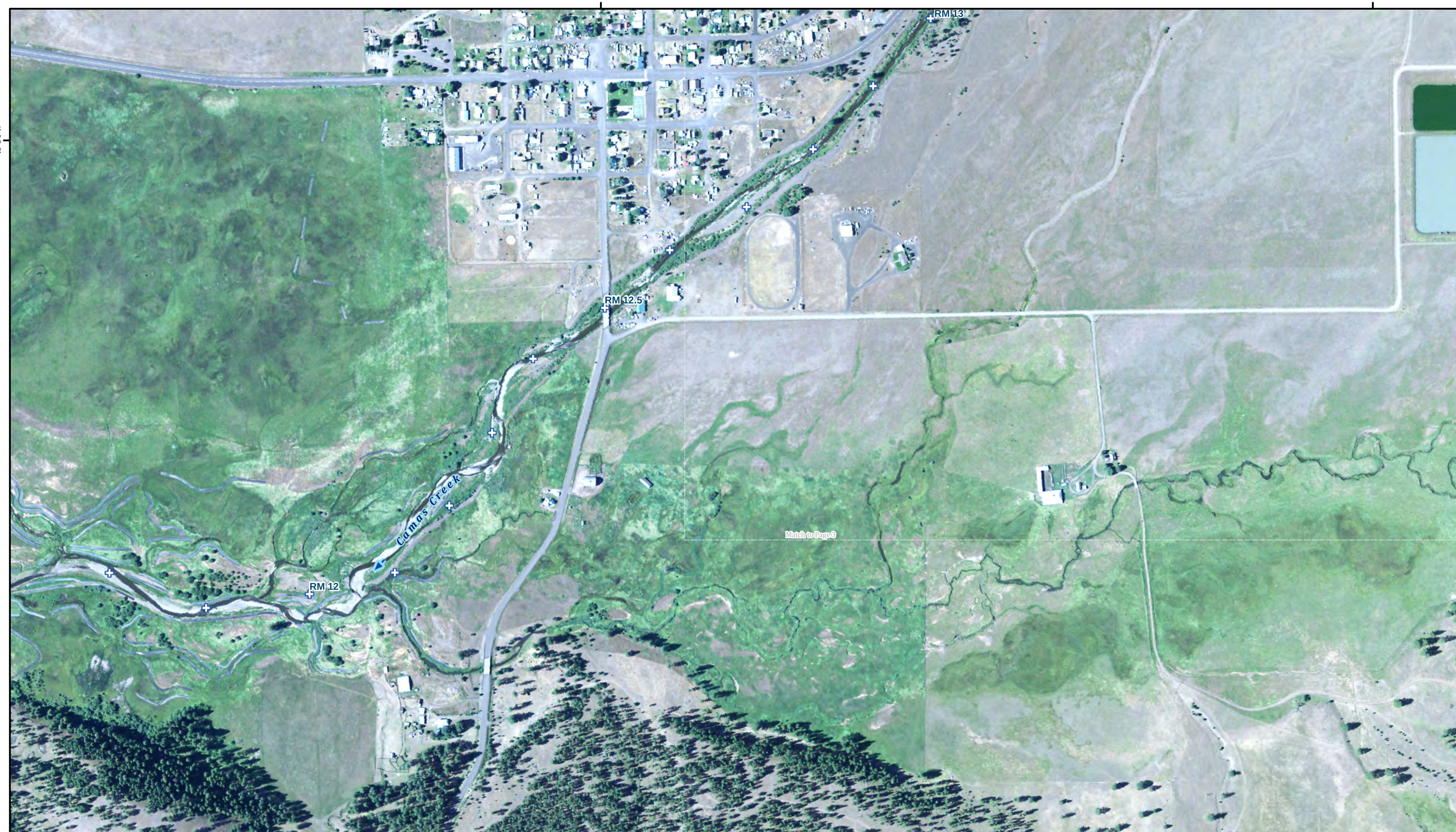
N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2009 Aerial Photo Map Book - Page 2 of 6

Data source: 2009 NAIP aerial imagery obtained from USDA

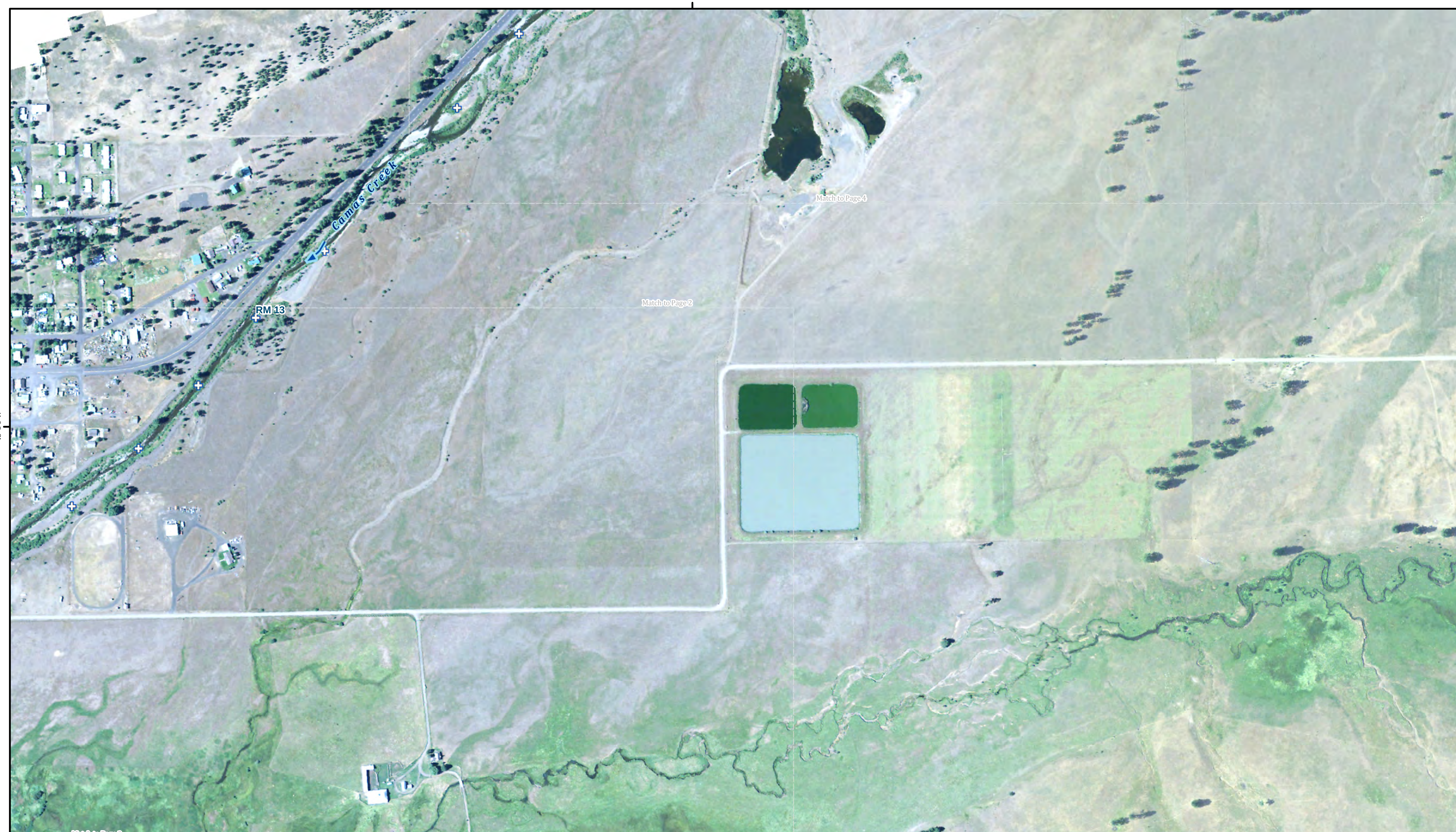
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2009 Aerial Photo Map Book - Page 3 of 6

Data source: 2009 NAIP aerial imagery obtained from USDA

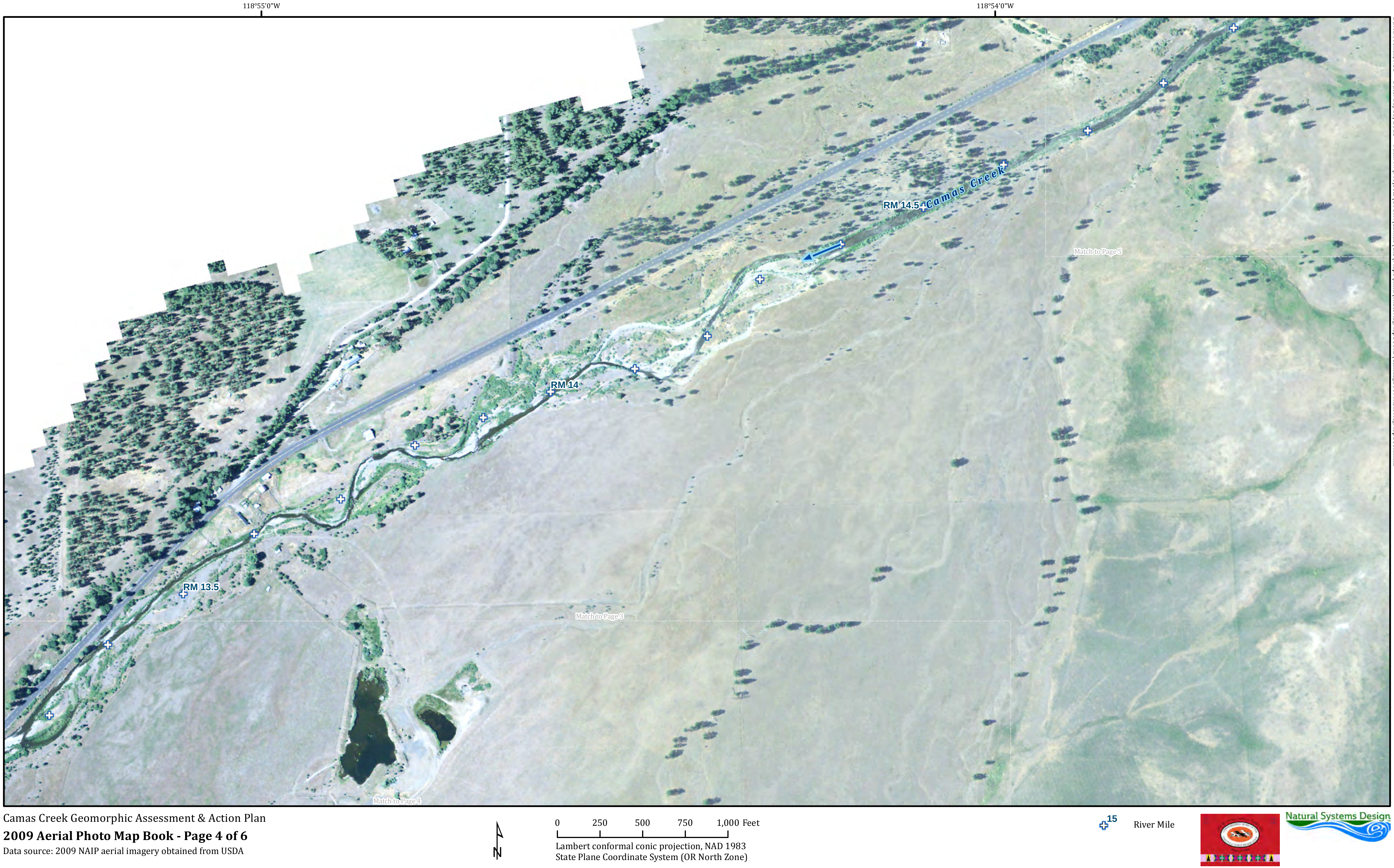
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2009 Aerial Photo Map Book - Page 4 of 6

Data source: 2009 NAIP aerial imagery obtained from USDA

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

118°53'0"W

45°9'0"N

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2009Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2009 Aerial Photo Map Book - Page 5 of 6

Data source: 2009 NAIP aerial imagery obtained from USDA

N

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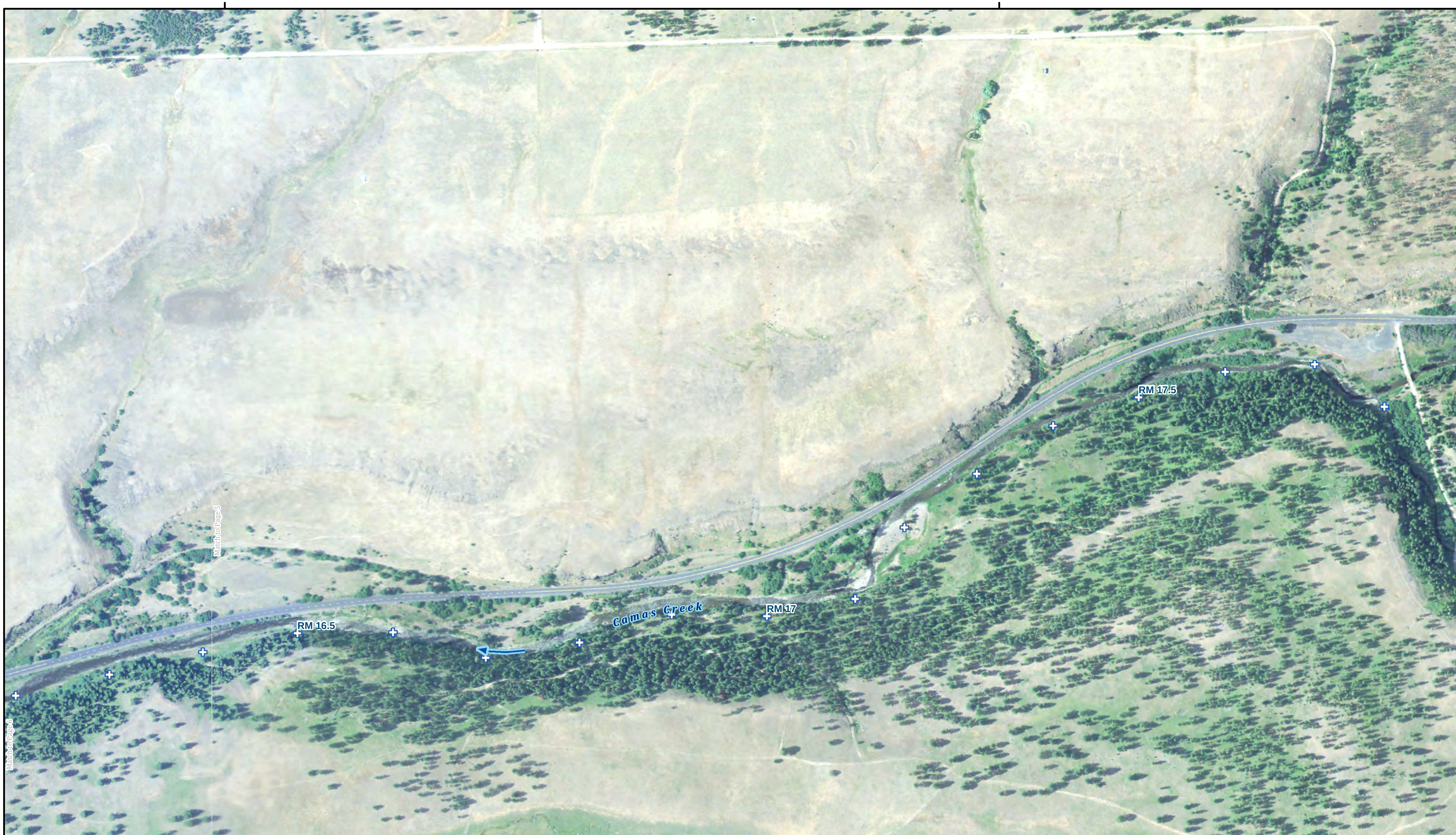
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2009 Aerial Photo Map Book - Page 6 of 6

Data source: 2009 NAIP aerial imagery obtained from USDA

N

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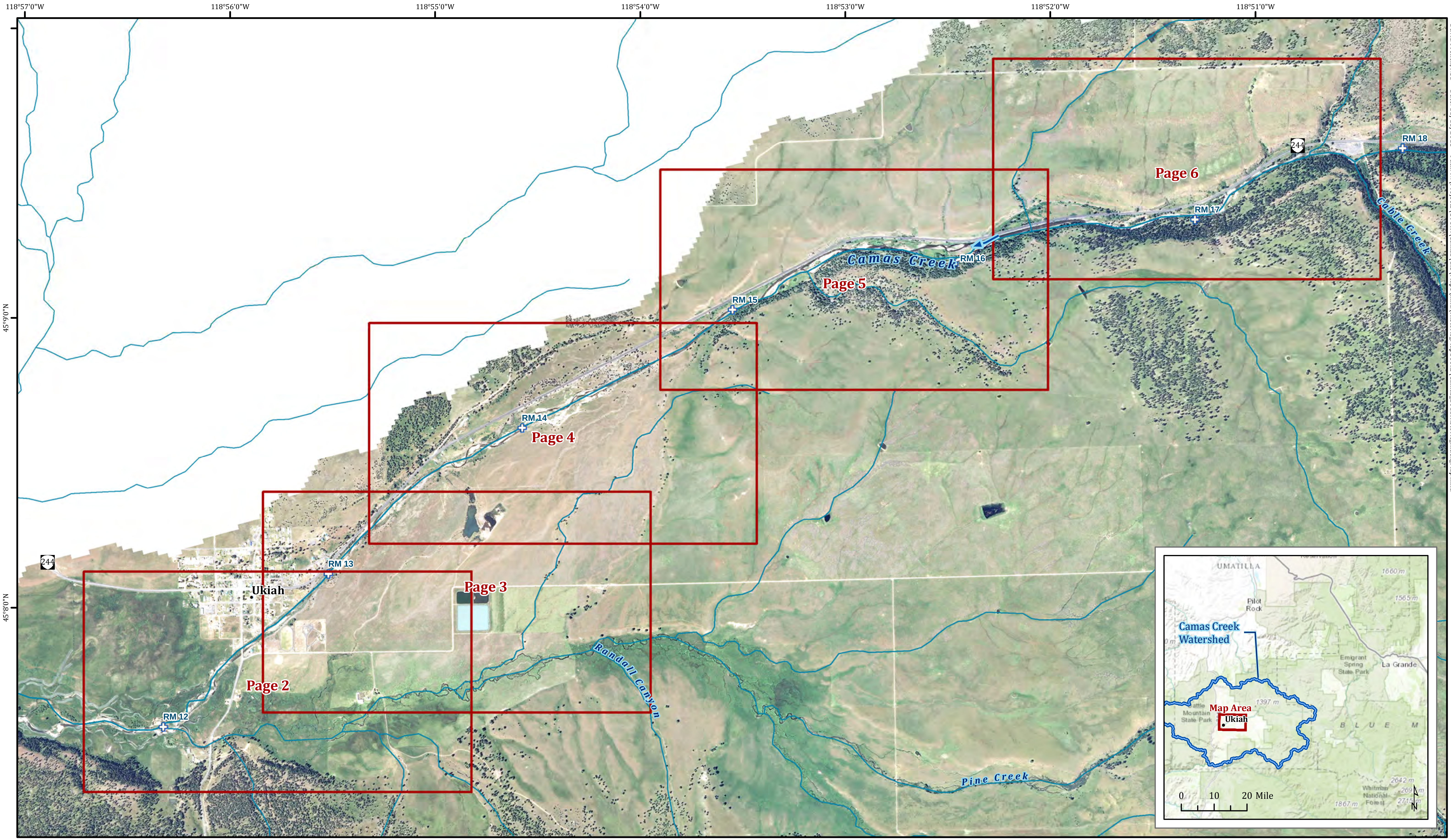
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2011 Aerial Photo Map Book - Page 1 of 6

Data source: 2011 NAIP aerial imagery obtained from USDA

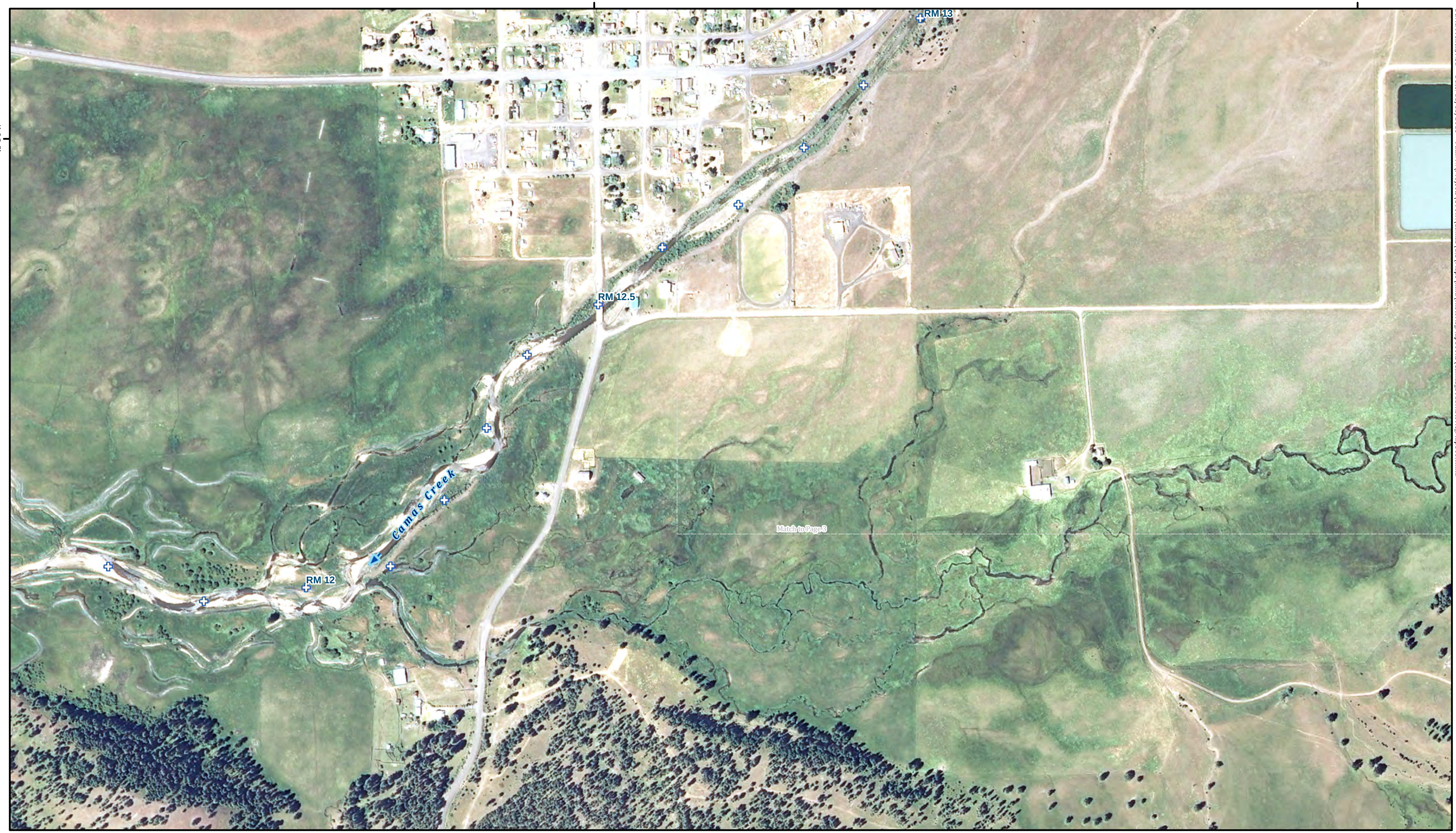
N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2011 Aerial Photo Map Book - Page 2 of 6

Data source: 2011 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2011Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2011 Aerial Photo Map Book - Page 3 of 6

Data source: 2011 NAIP aerial imagery obtained from USDA

N

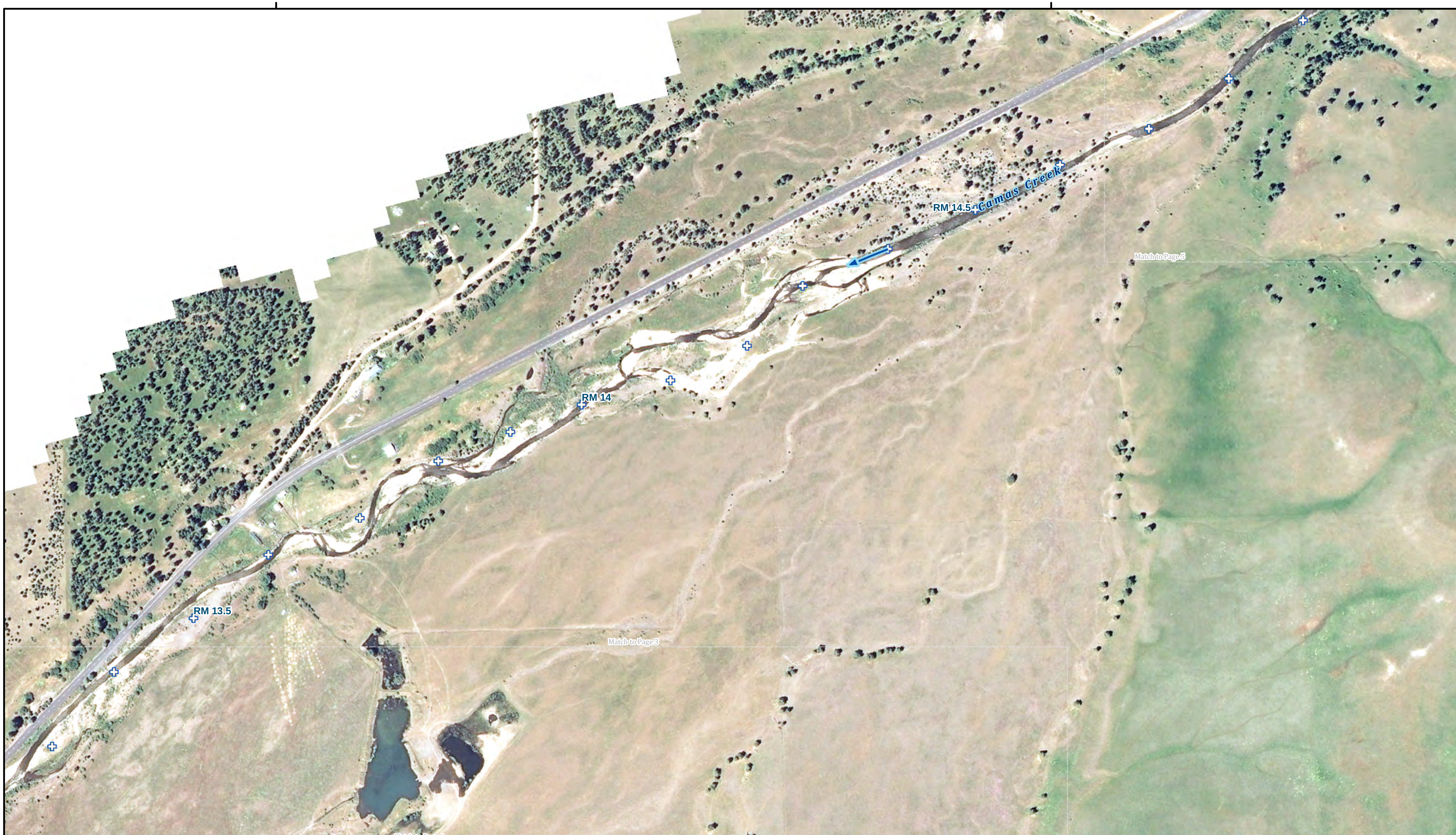
0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

118°55'0"W
118°54'0"W



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Camas Creek Geomorphic Assessment & Action Plan

2011 Aerial Photo Map Book - Page 4 of 6

Data source: 2011 NAIP aerial imagery obtained from USDA

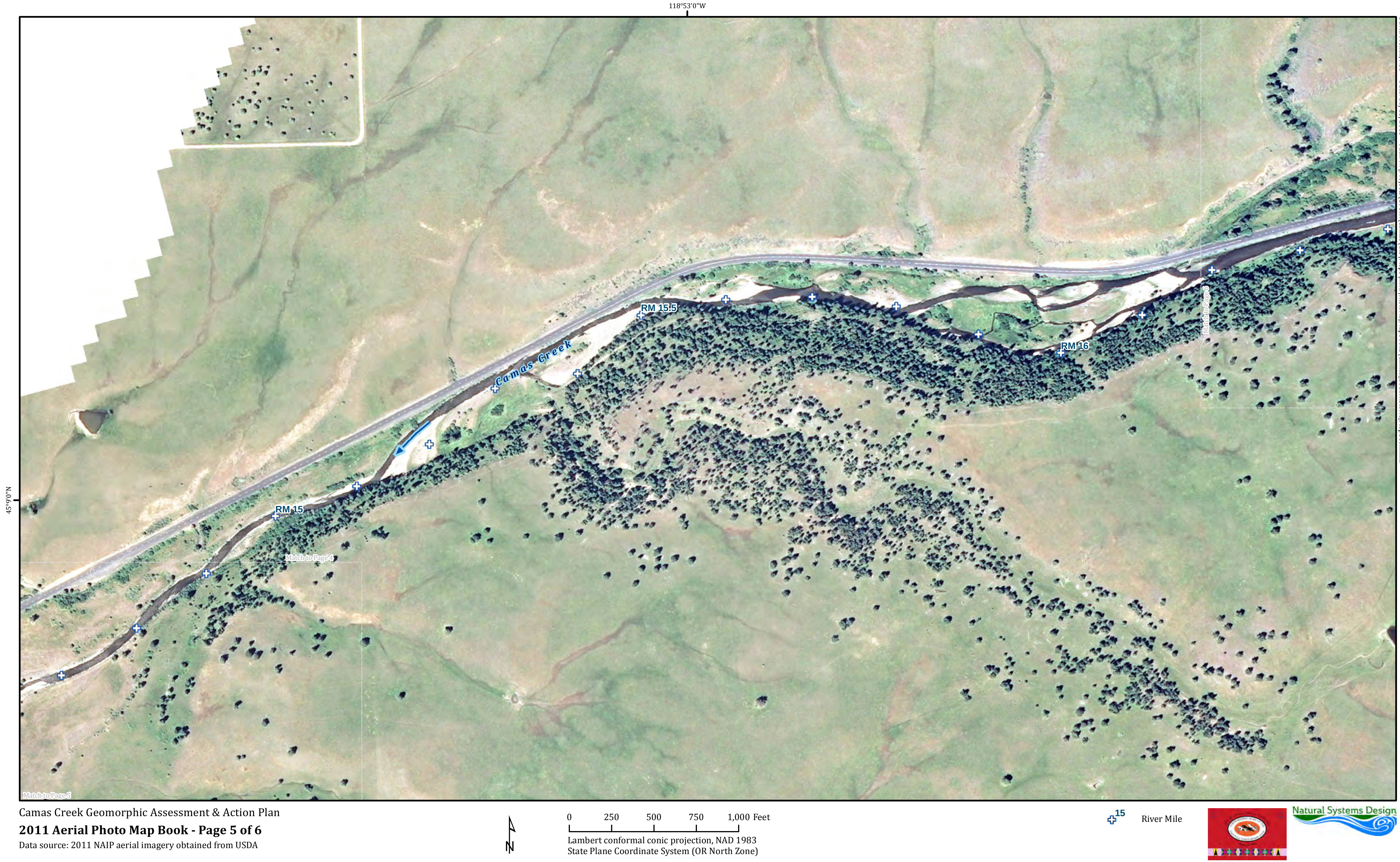
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

2011 Aerial Photo Map Book - Page 5 of 6

Data source: 2011 NAIP aerial imagery obtained from USDA

Camas Creek Geomorphic Assessment & Action Plan

2011 Aerial Photo Map Book - Page 6 of 6

Data source: 2011 NAIP aerial imagery obtained from USDA

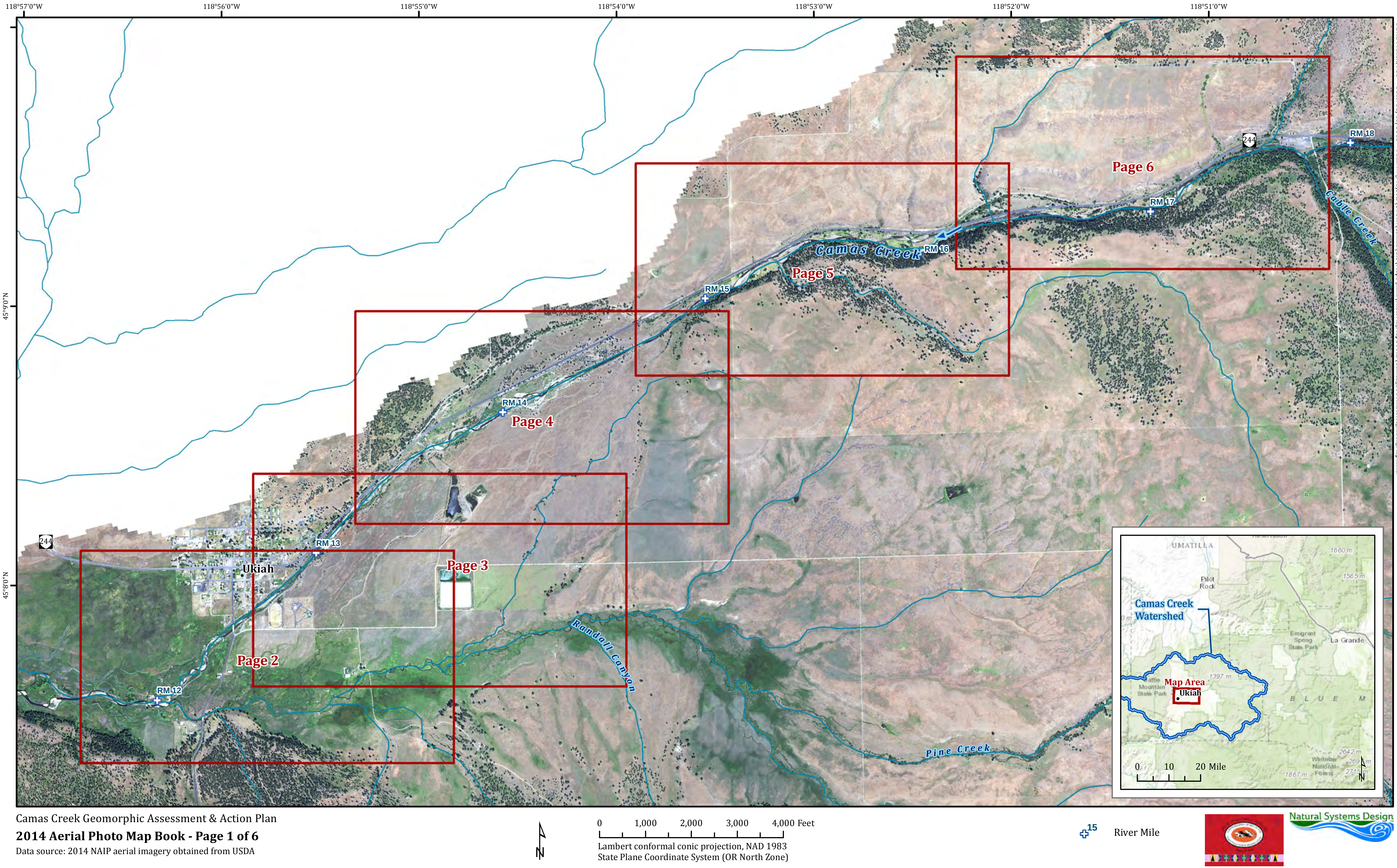
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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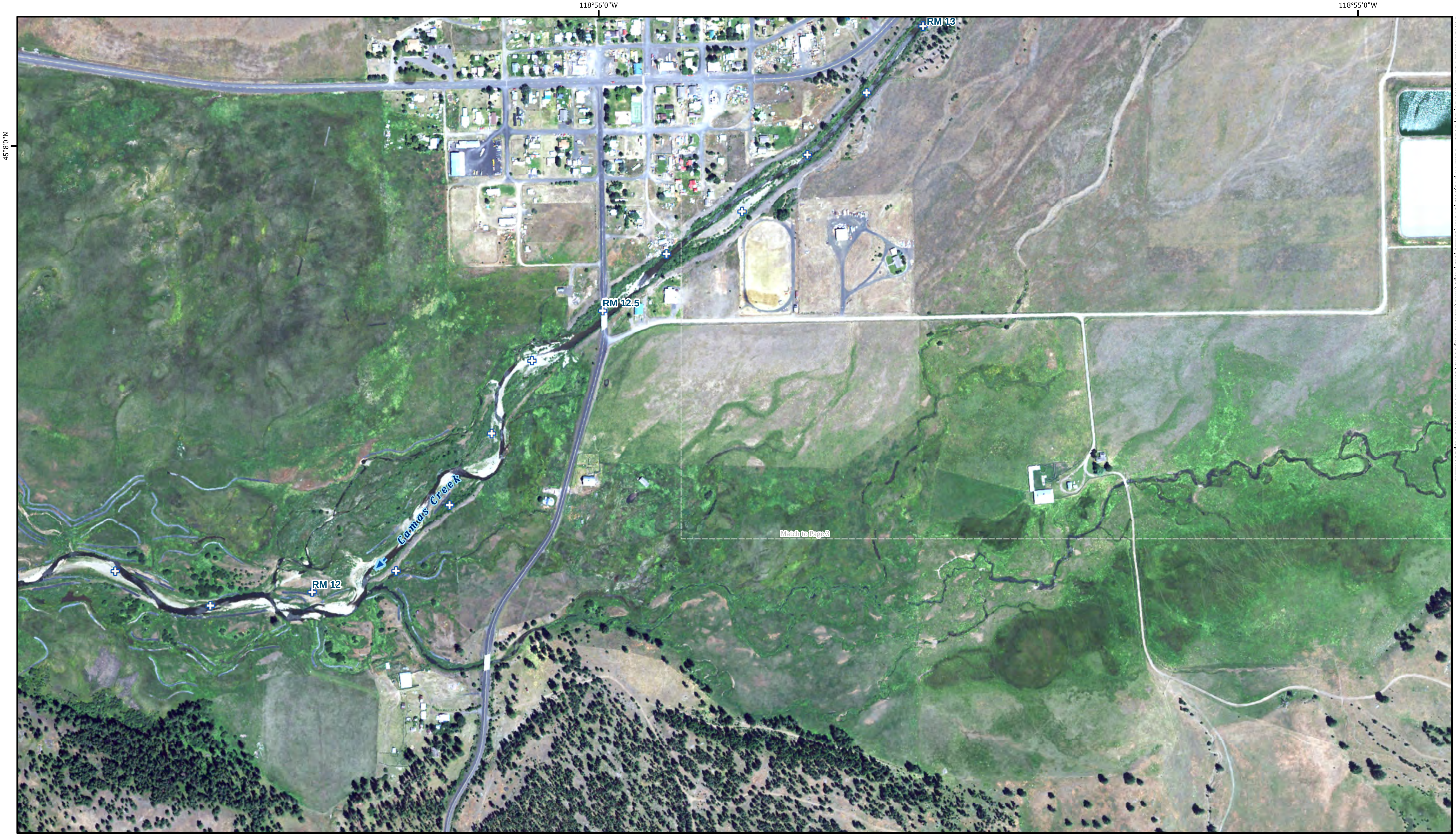
Camas Creek Geomorphic Assessment & Action Plan

2014 Aerial Photo Map Book - Page 1 of 6

Data source: 2014 NAIP aerial imagery obtained from USDA

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)



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Camas Creek Geomorphic Assessment & Action Plan

2014 Aerial Photo Map Book - Page 2 of 6

Data source: 2014 NAIP aerial imagery obtained from USDA

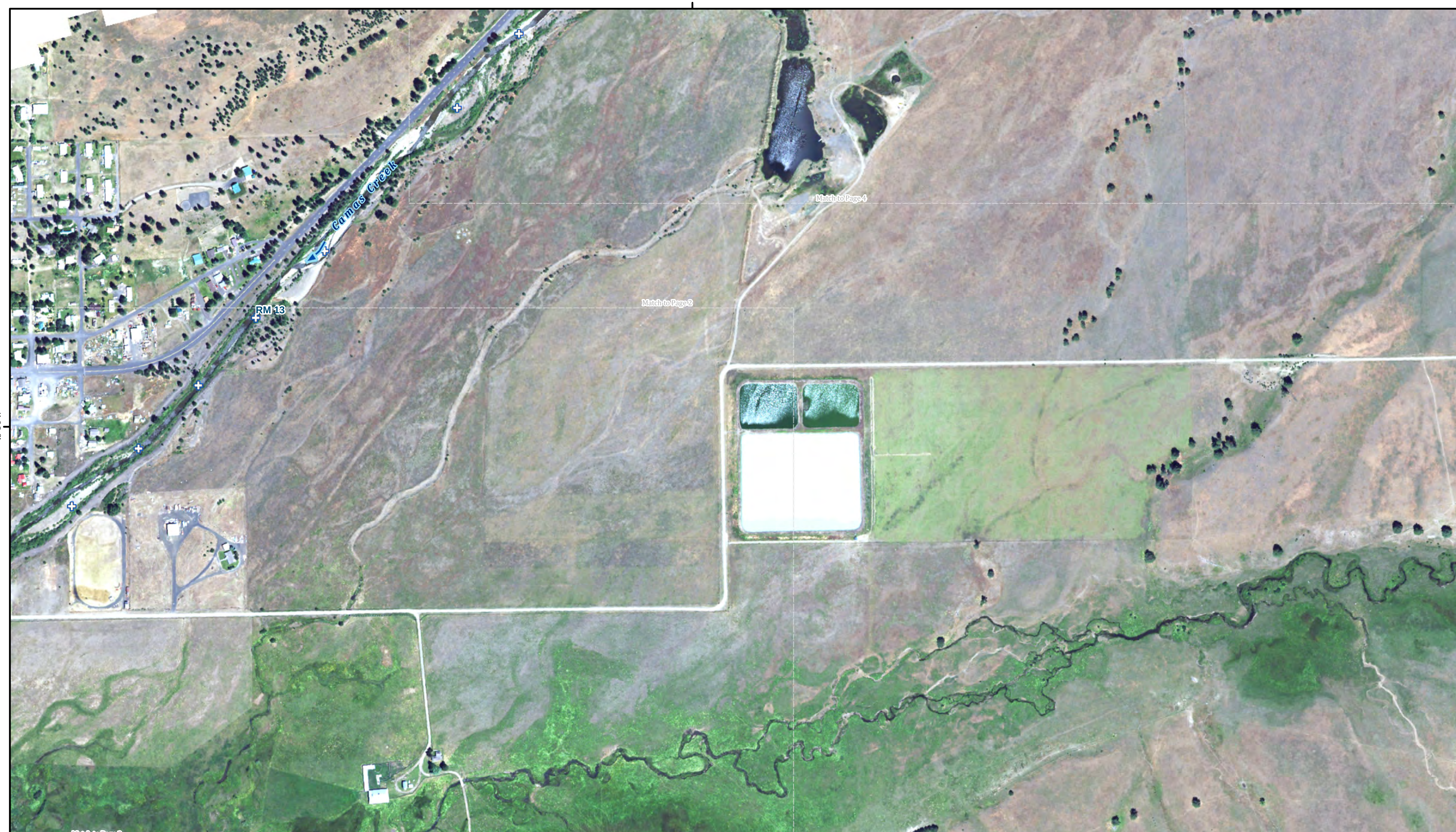
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2014 Aerial Photo Map Book - Page 3 of 6

Data source: 2014 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

Camas Creek Geomorphic Assessment & Action Plan

2014 Aerial Photo Map Book - Page 4 of 6

Data source: 2014 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

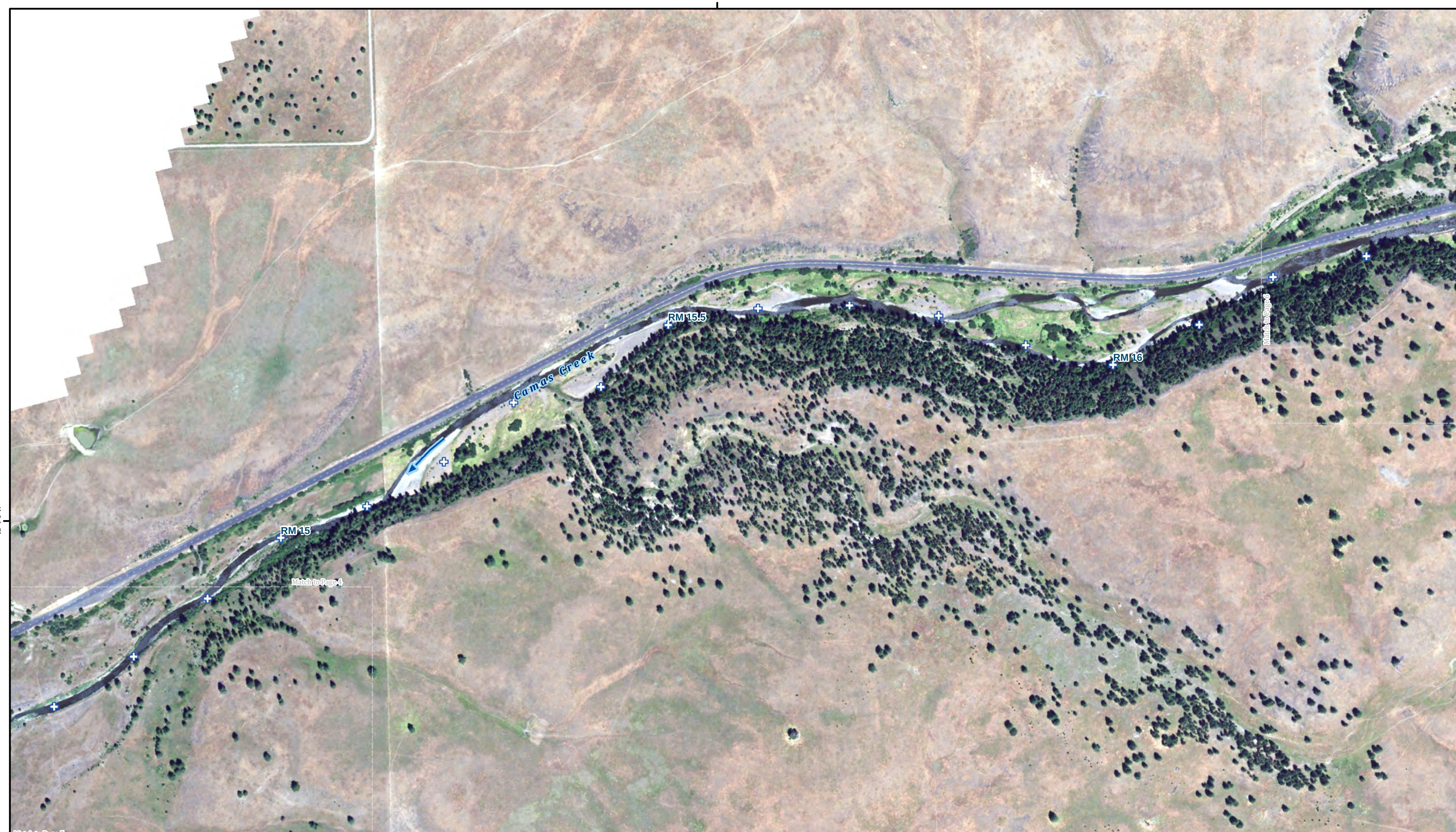
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2014Historic_Mapbook.mxd

118°53'0"W



45°9'0"N

David French, NSD Date: 11/13/2015 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Historic_Mapbooks\Camas_2014Historic_Mapbook.mxd

Camas Creek Geomorphic Assessment & Action Plan

2014 Aerial Photo Map Book - Page 5 of 6

Data source: 2014 NAIP aerial imagery obtained from USDA

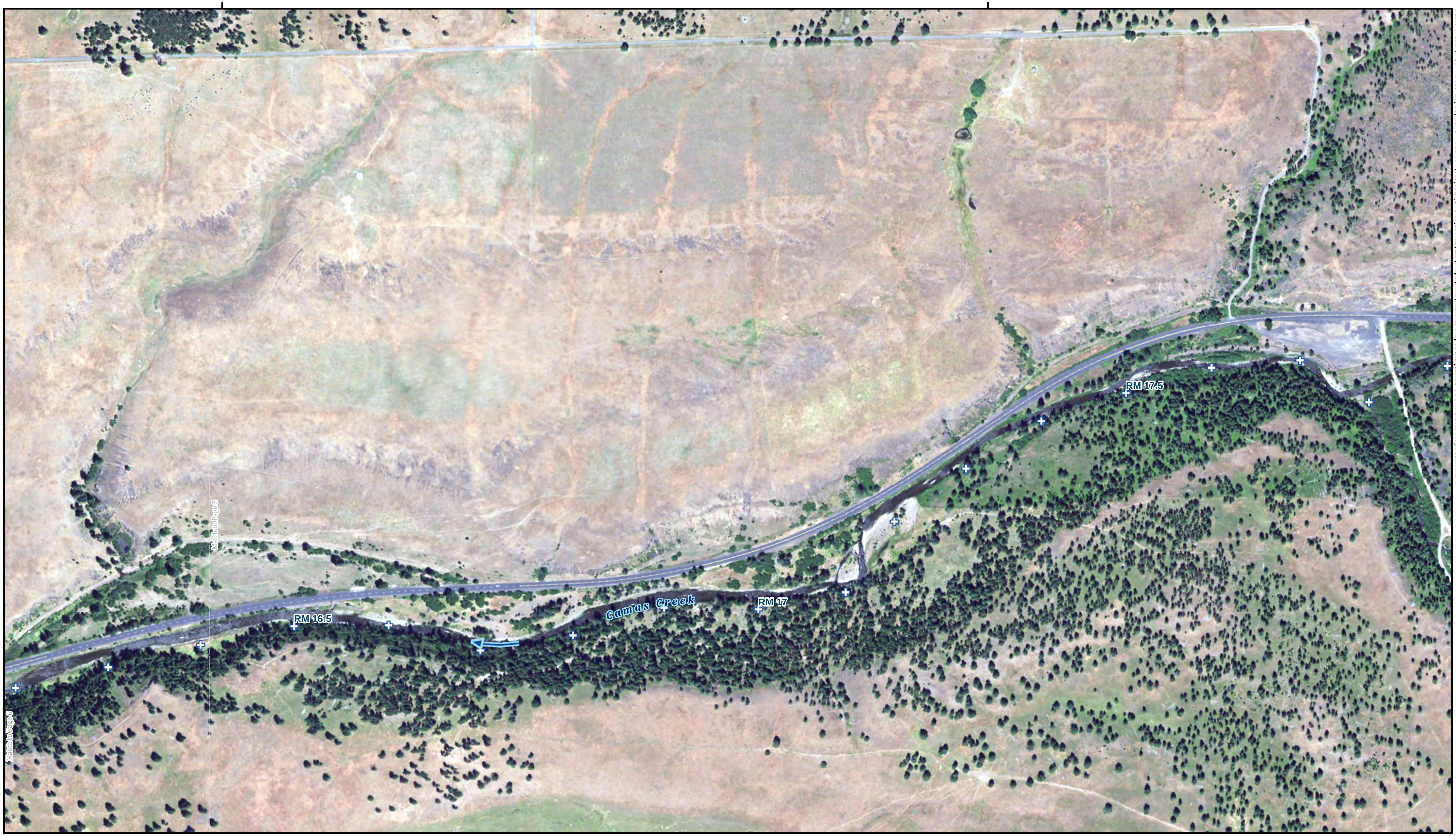
N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

2014 Aerial Photo Map Book - Page 6 of 6

Data source: 2014 NAIP aerial imagery obtained from USDA

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

15 River Mile

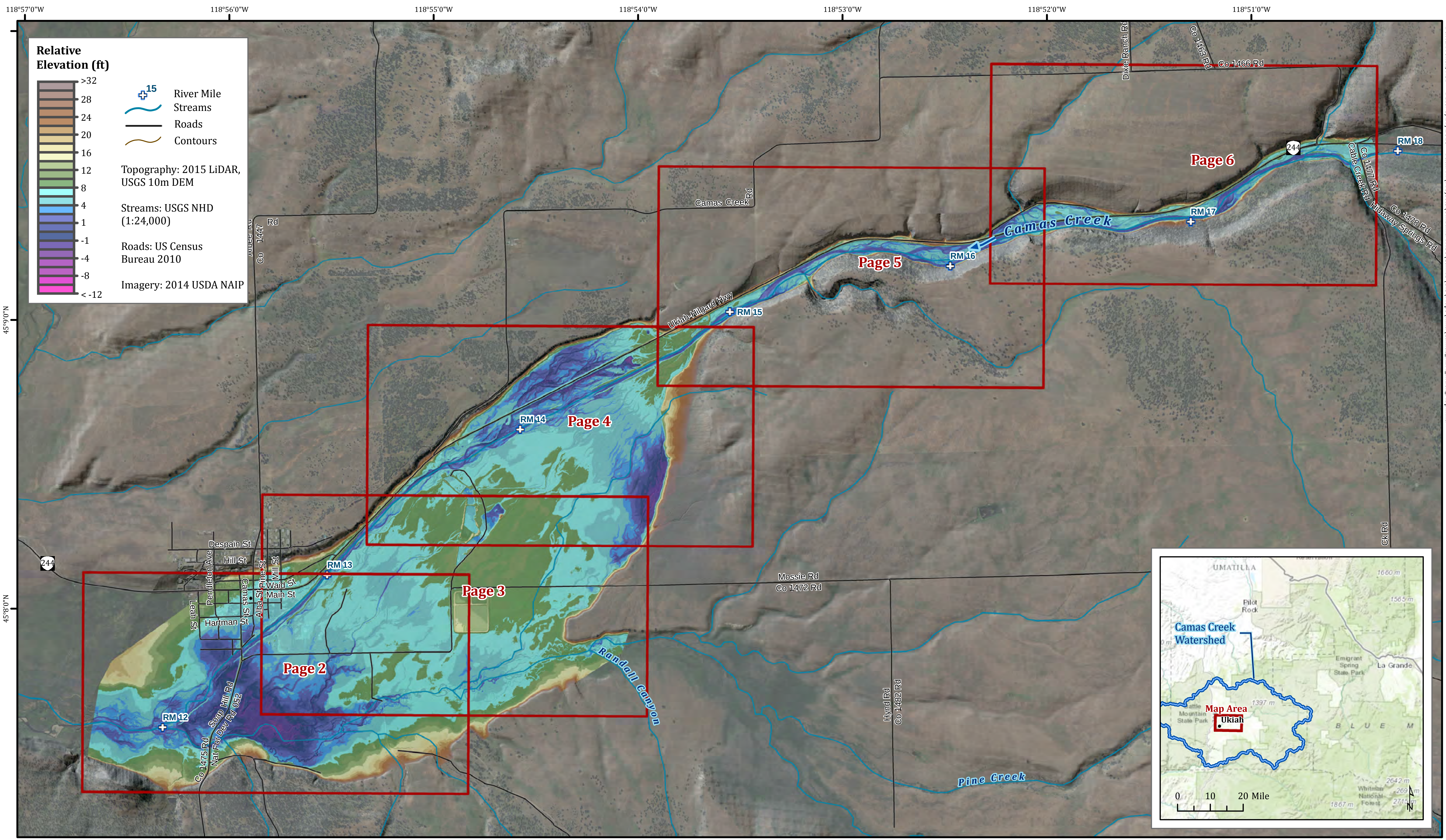
Natural Systems Design

APPENDIX C

Relative Elevation Mapbook

Natural Systems Design

P.O. Box 15609, Seattle, WA 98105 T: (206) 834-0175



Camas Creek Geomorphic Assessment & Action Plan

Relative Elevation Map Book - Page 1 of 6

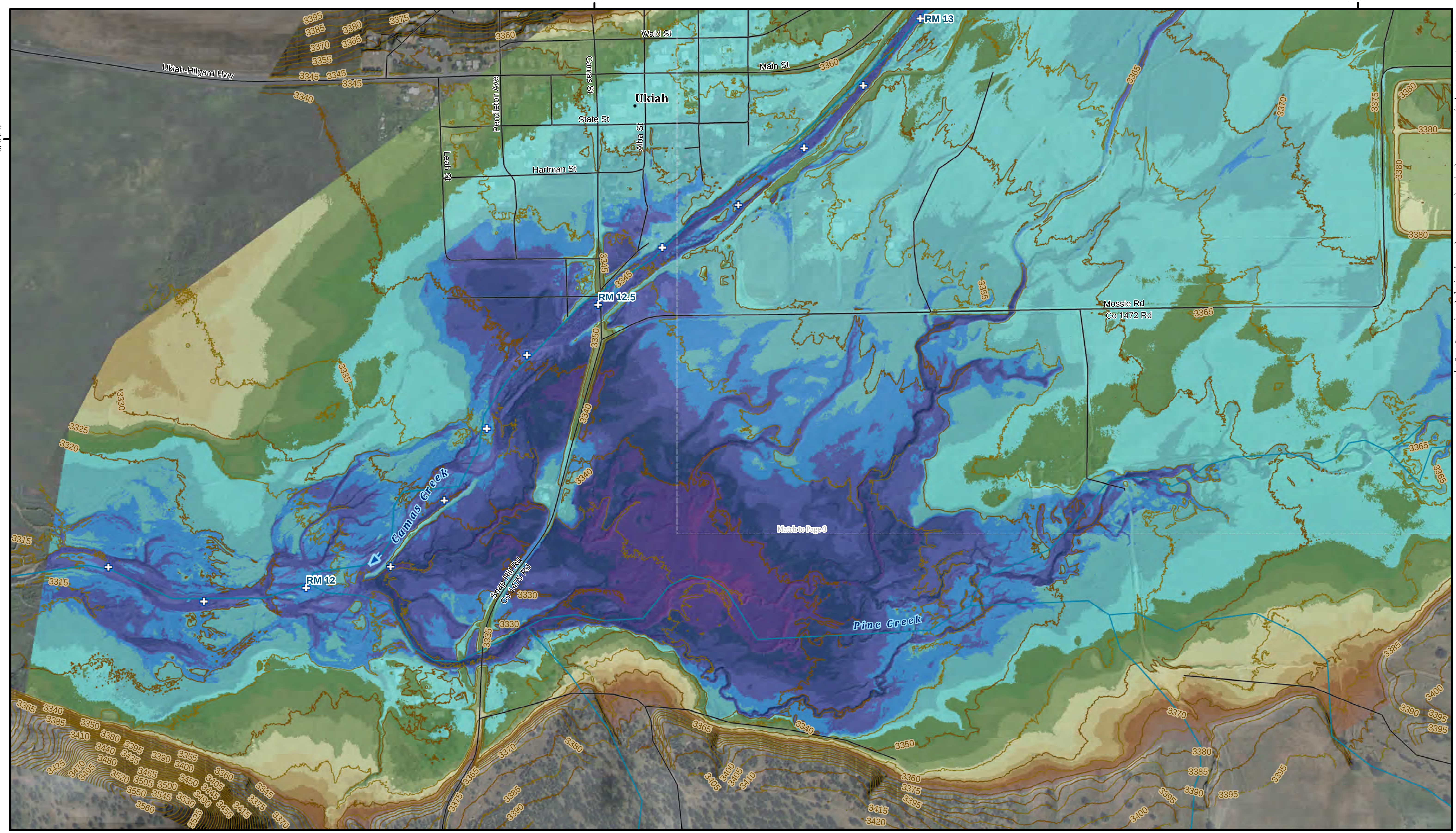
Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM. Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 5 ft

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Relative Elevation Map Book - Page 2 of 6

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.
Data sources: 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)

N

0 250 500 750 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 5 ft

Relative Elevation (ft)

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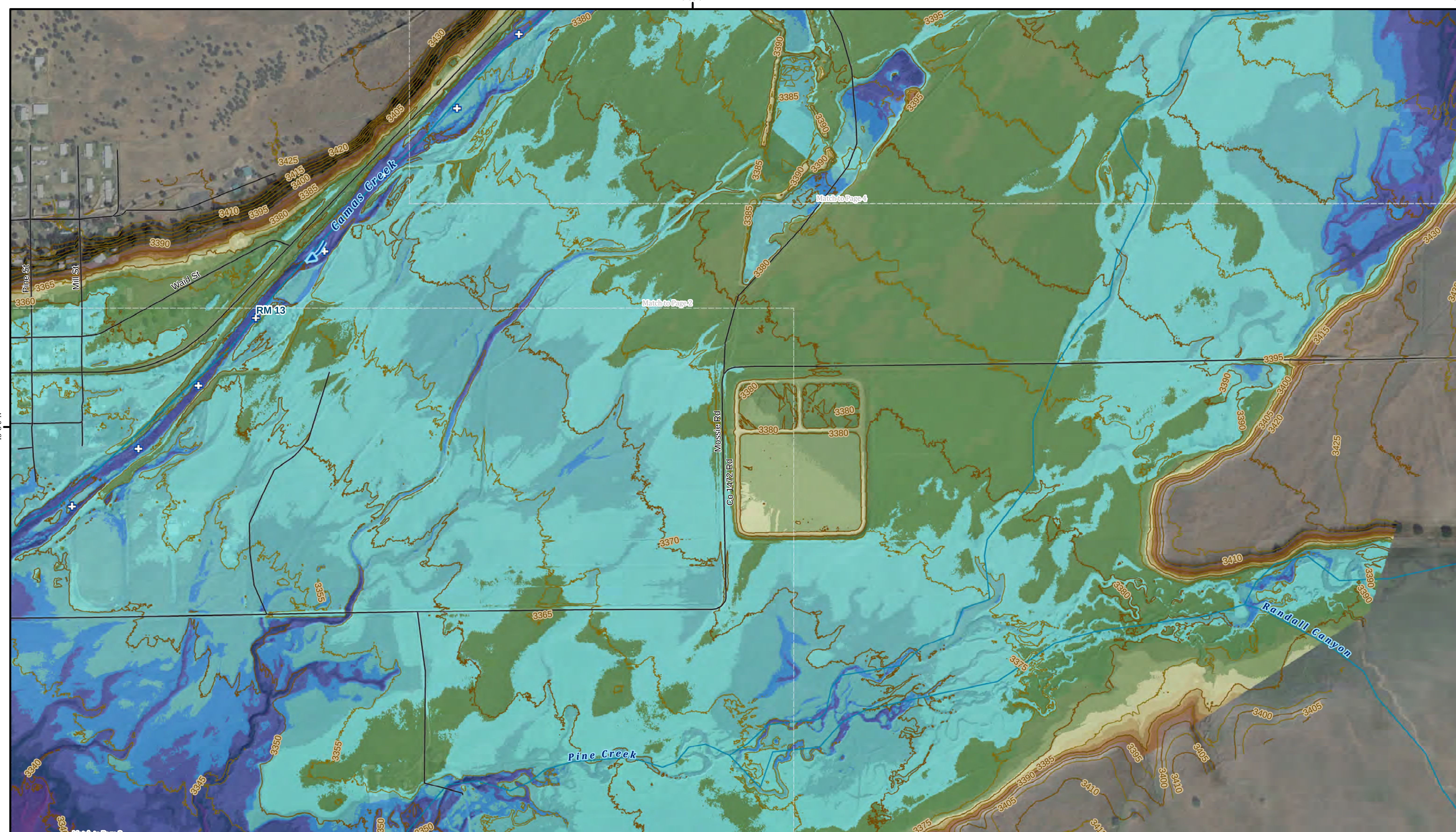
15 River Mile
Streams
Roads
Contours

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Relative Elevation Map Book - Page 3 of 6

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.
Data sources: 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)

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Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

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Relative Elevation (ft)

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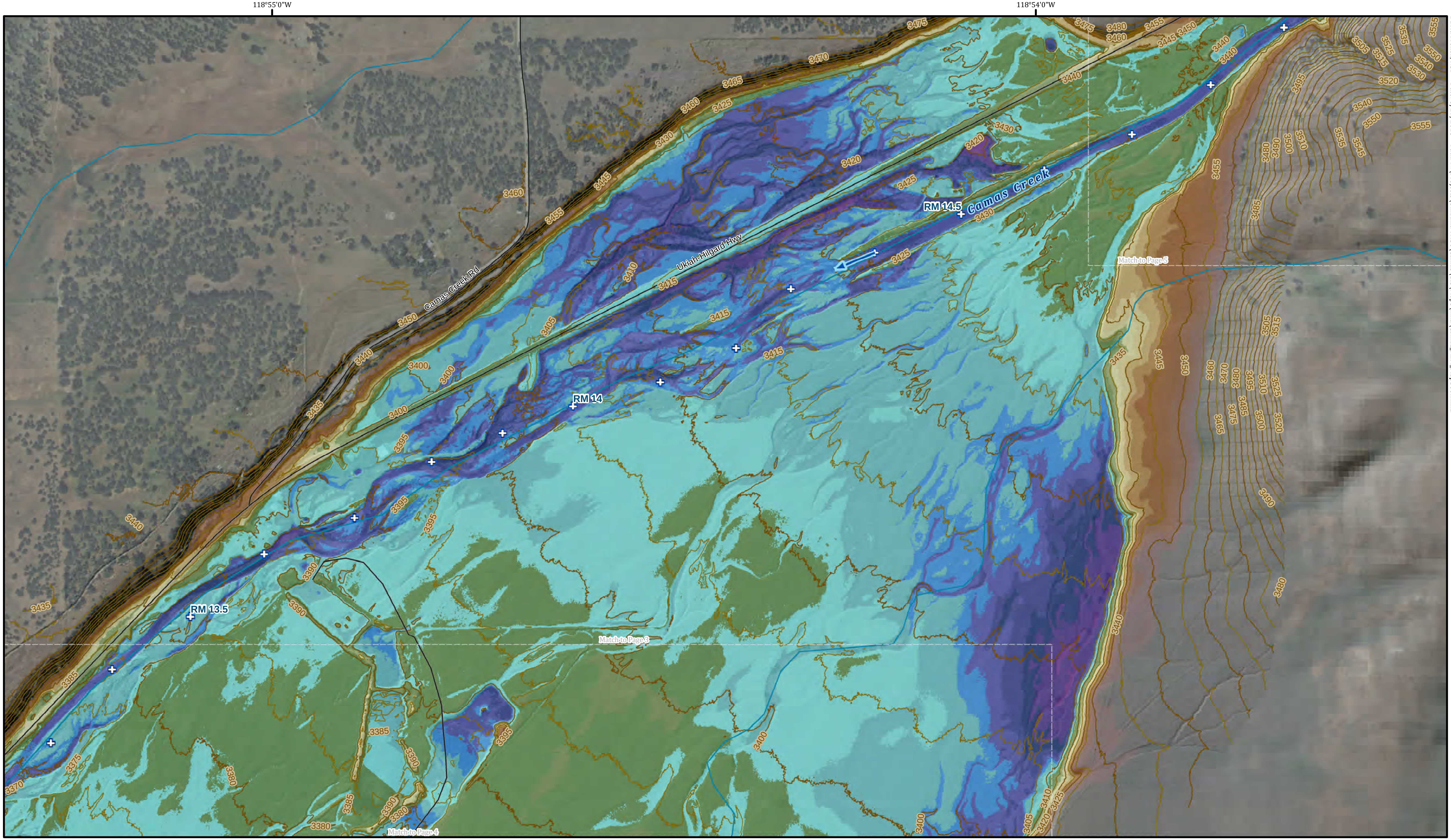
15 River Mile
Streams
Roads
Contours

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Relative Elevation Map Book - Page 4 of 6

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.
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Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 5 ft

Relative Elevation (ft)
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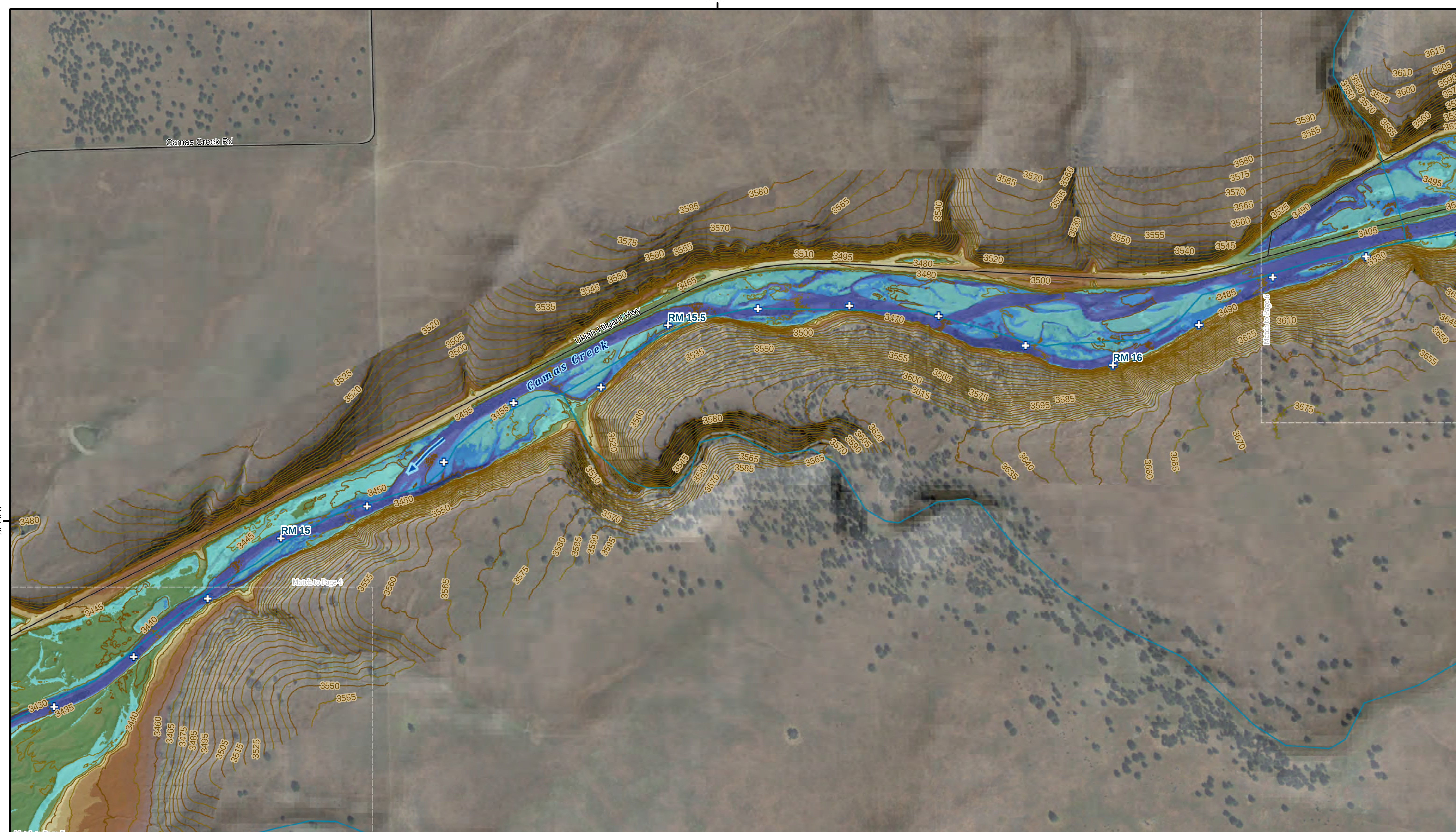
15 River Mile
Streams
Roads
Contours

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Relative Elevation Map Book - Page 5 of 6

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.
Data sources: 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)

N

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Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 5 ft

Relative Elevation (ft)

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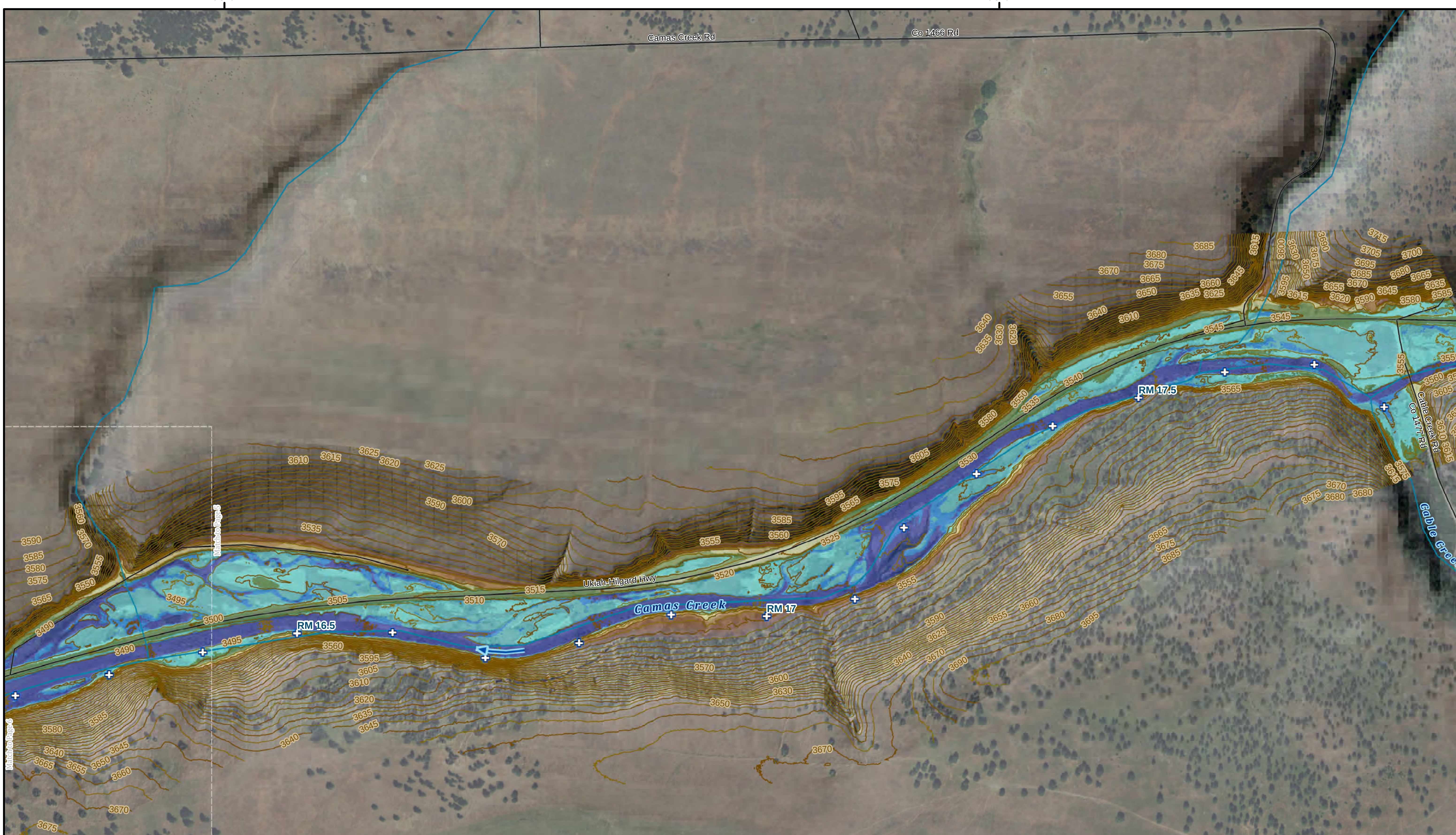
15 River Mile
Streams
Roads
Contours

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Relative Elevation Map Book - Page 6 of 6

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.
Data sources: 2014 USDA NAIP, US Census Bureau 2010, USGS NHD (1:24,000)

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Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (OR North Zone)

Contour Interval = 5 ft

Relative Elevation (ft)

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15 River Mile
Streams
Roads
Contours

Natural Systems Design

APPENDIX D

Alluvial Fan Profiles and Valley Cross Sections

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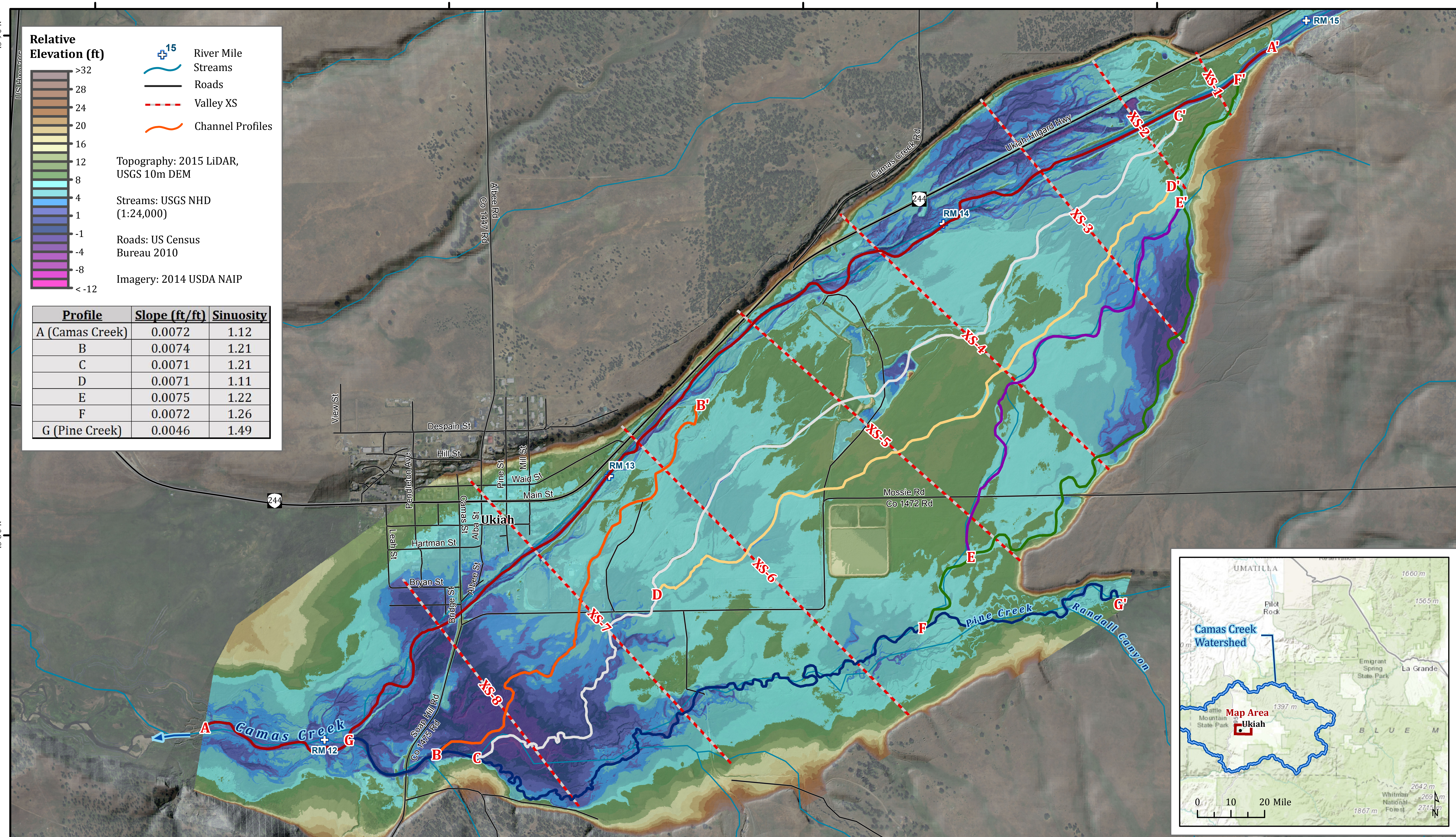


Profile	Slope (ft/ft)	Sinuosity
A (Camas Creek)	0.0072	1.12
B	0.0074	1.21
C	0.0071	1.21
D	0.0071	1.11
E	0.0075	1.22
F	0.0072	1.26
G (Pine Creek)	0.0046	1.49

David French, NSD Date: 6/29/2015 Path: N:\Projects\Umatilla Tribe\Camas\GIS\Maps\mxd\Camas_Fan_Profiles_Map.mxd

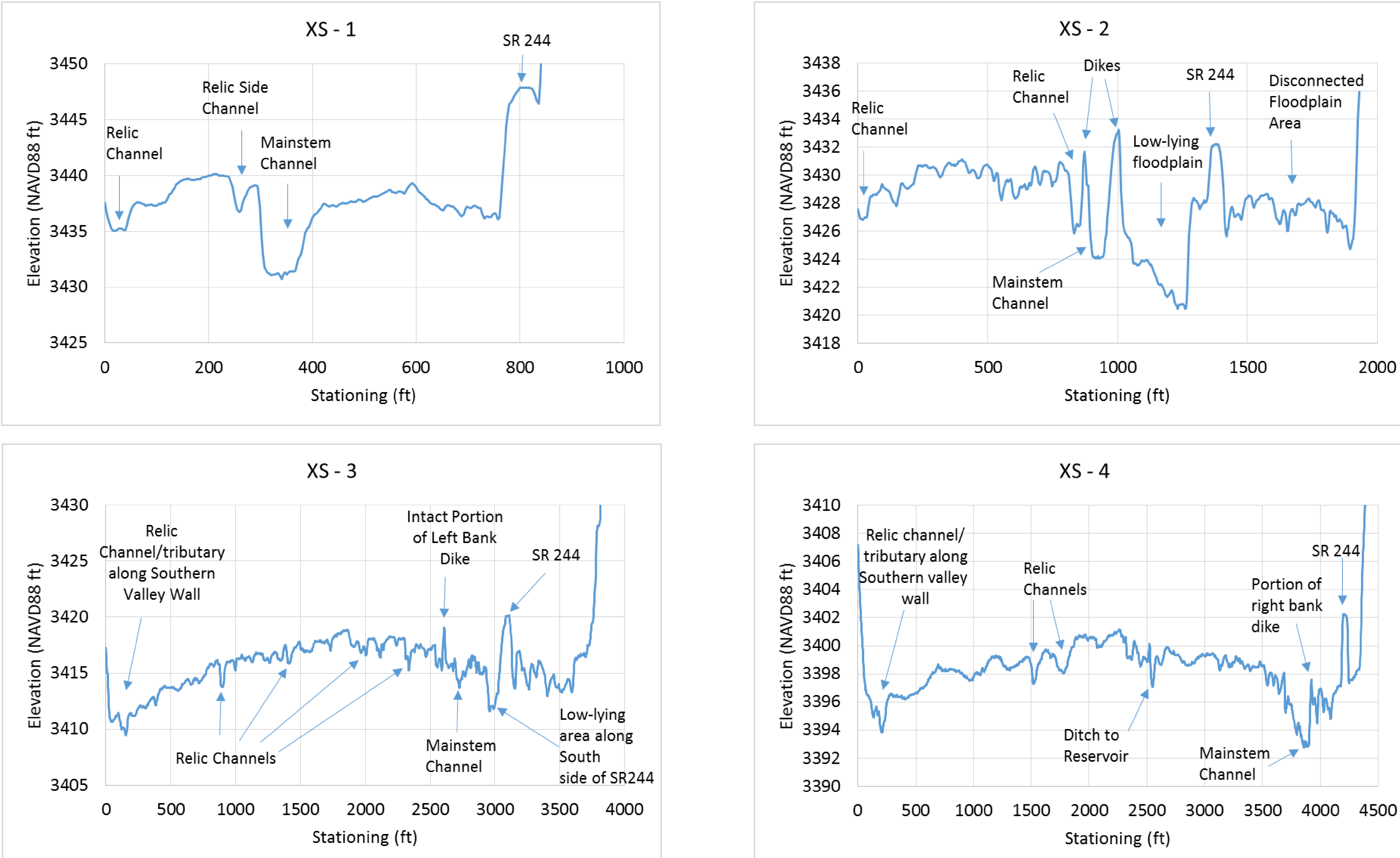
Camas Creek Geomorphic Assessment & Action Plan

Valley Cross Section and Channel Profile Locations

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM. Relative elevation is derived as the difference between bare earth elevations and a reference plane representing the low flow water surface.

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Valley-scale cross sections derived from 2015 LiDAR bare earth DEM (see Valley Cross Section and Channel Profile Locations map for specific XS locations)

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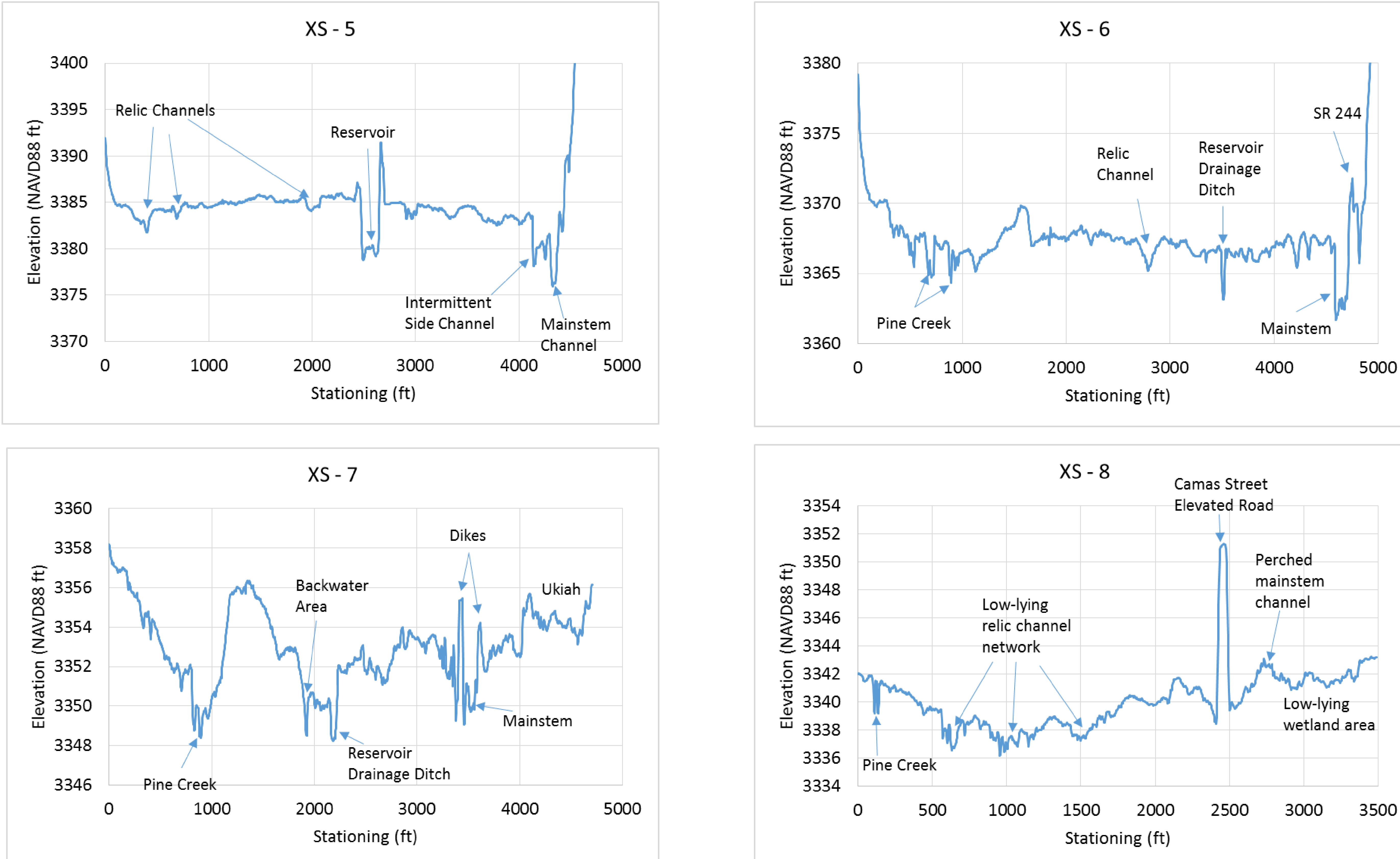
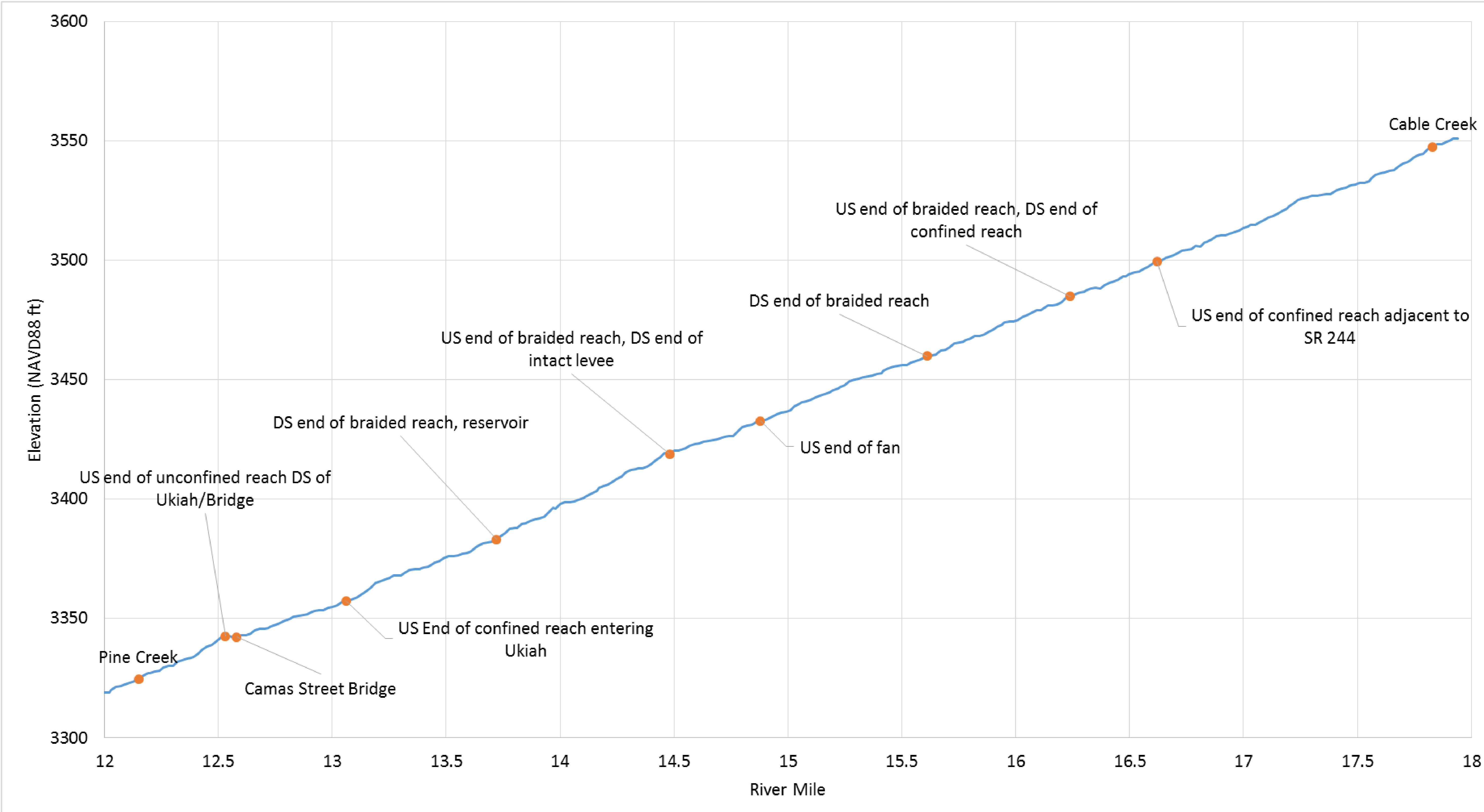


Valley-scale cross sections derived from 2015 LiDAR bare earth DEM (see Valley Cross Section and Channel Profile Locations map for specific XS locations)

Natural Systems Design
P.O. Box 15609
Seattle, WA 98115



Longitudinal channel profile derived from 2015 LiDAR bare earth DEM

Camas Creek Geomorphic Assessment & Action Plan

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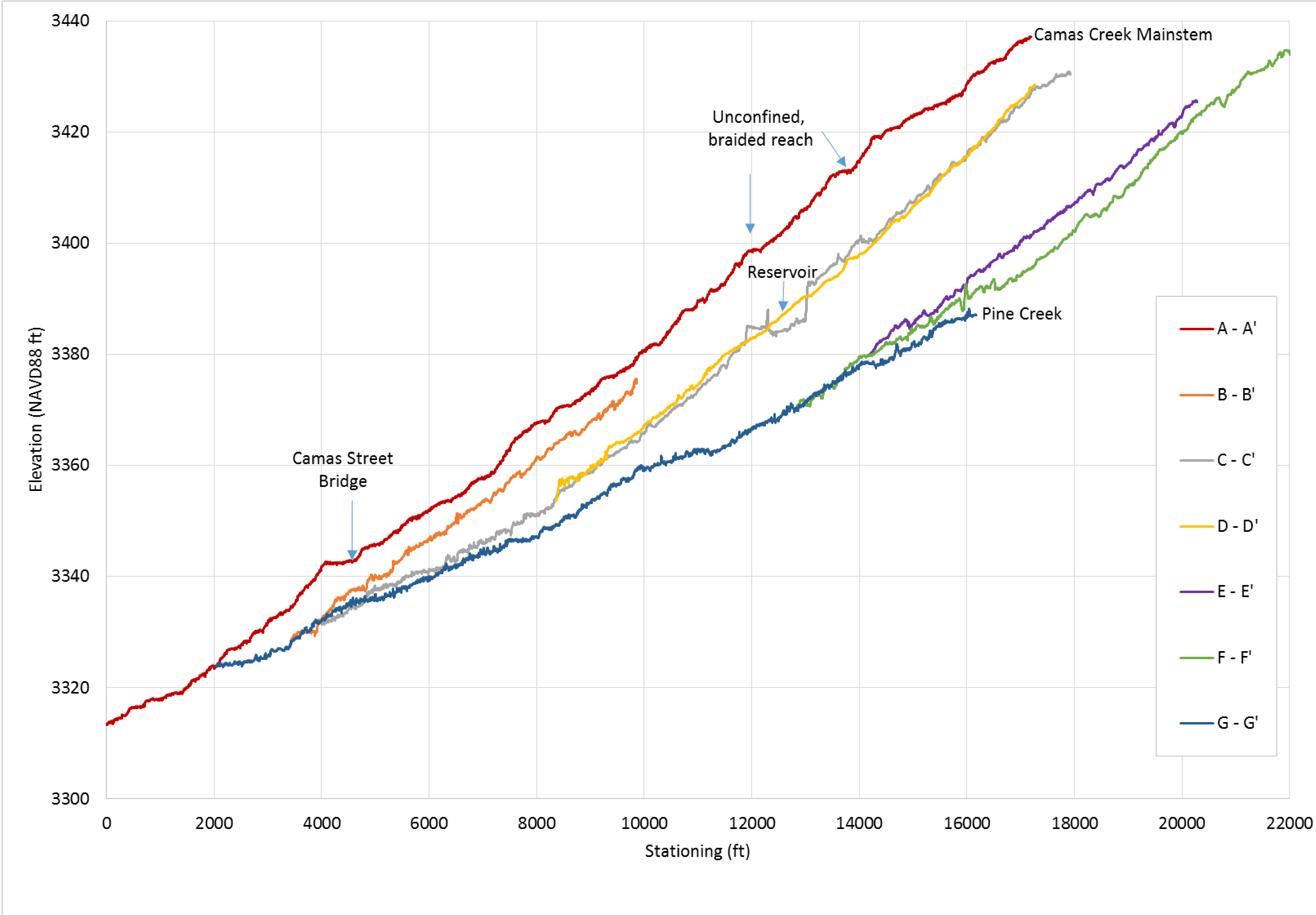

Longitudinal channel profiles derived from 2015 LiDAR bare earth DEM (see Valley Cross Section and Channel Profile Locations map for specific XS locations)

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Seattle, WA 98115

APPENDIX E

Sediment Gradations

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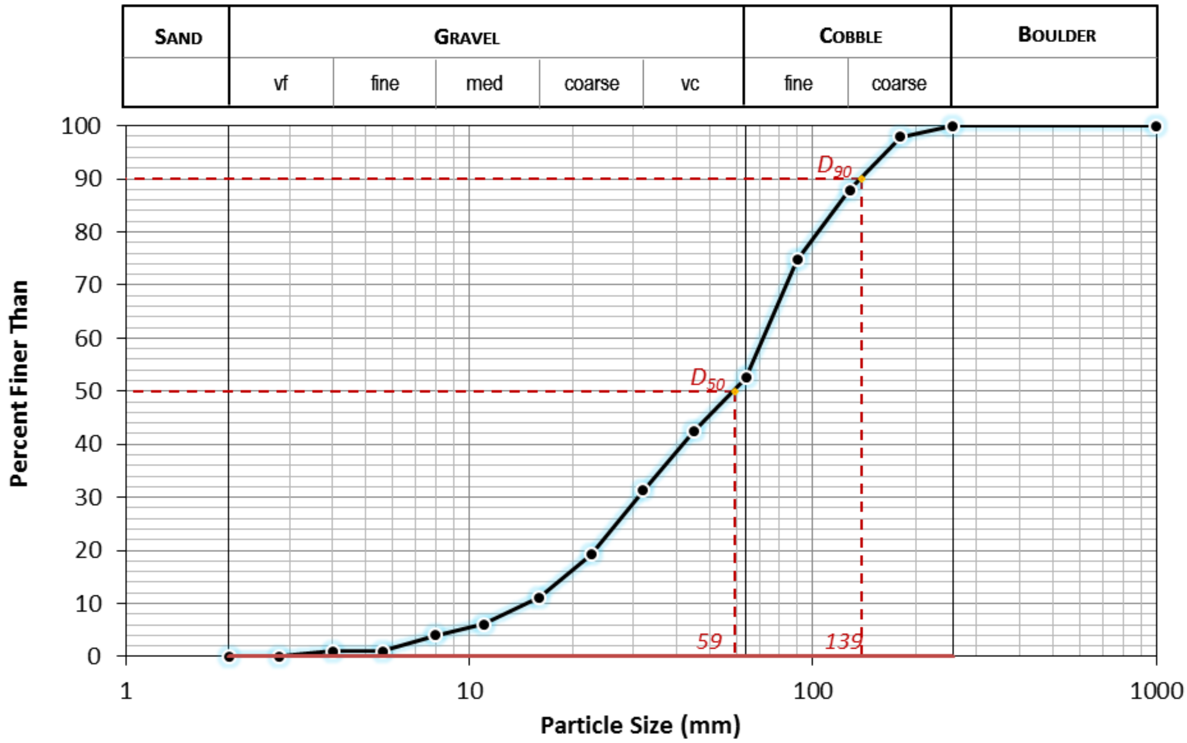
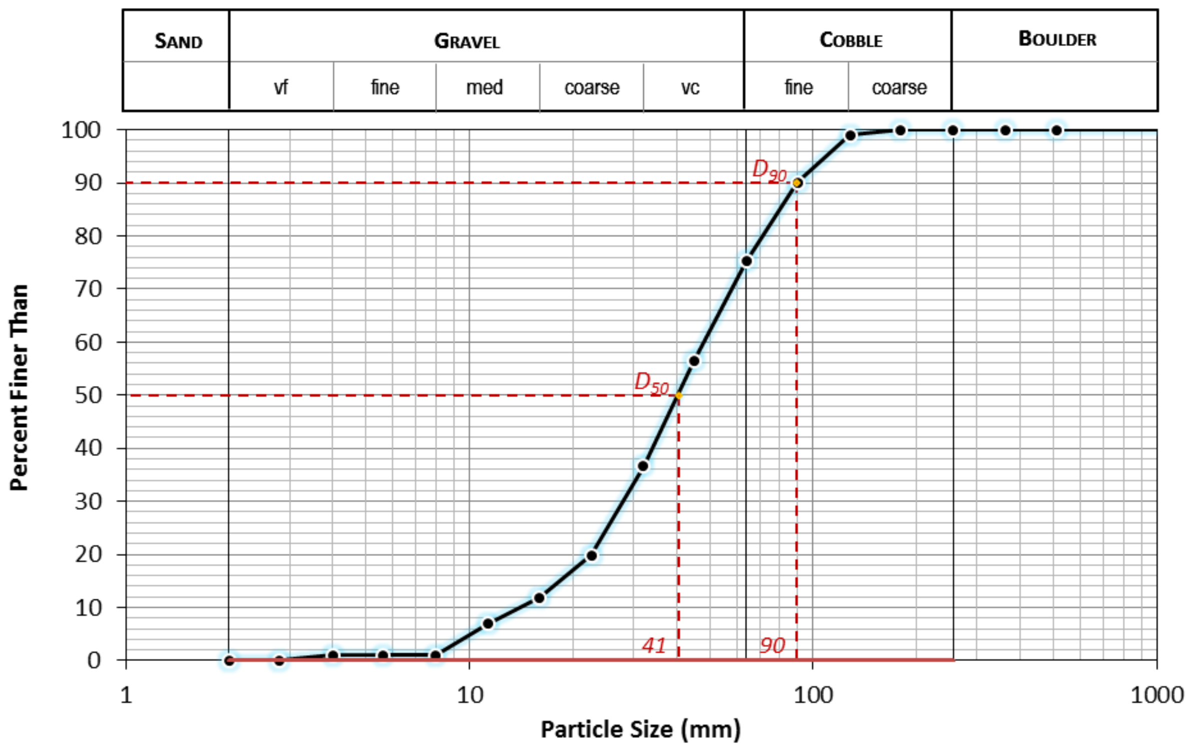
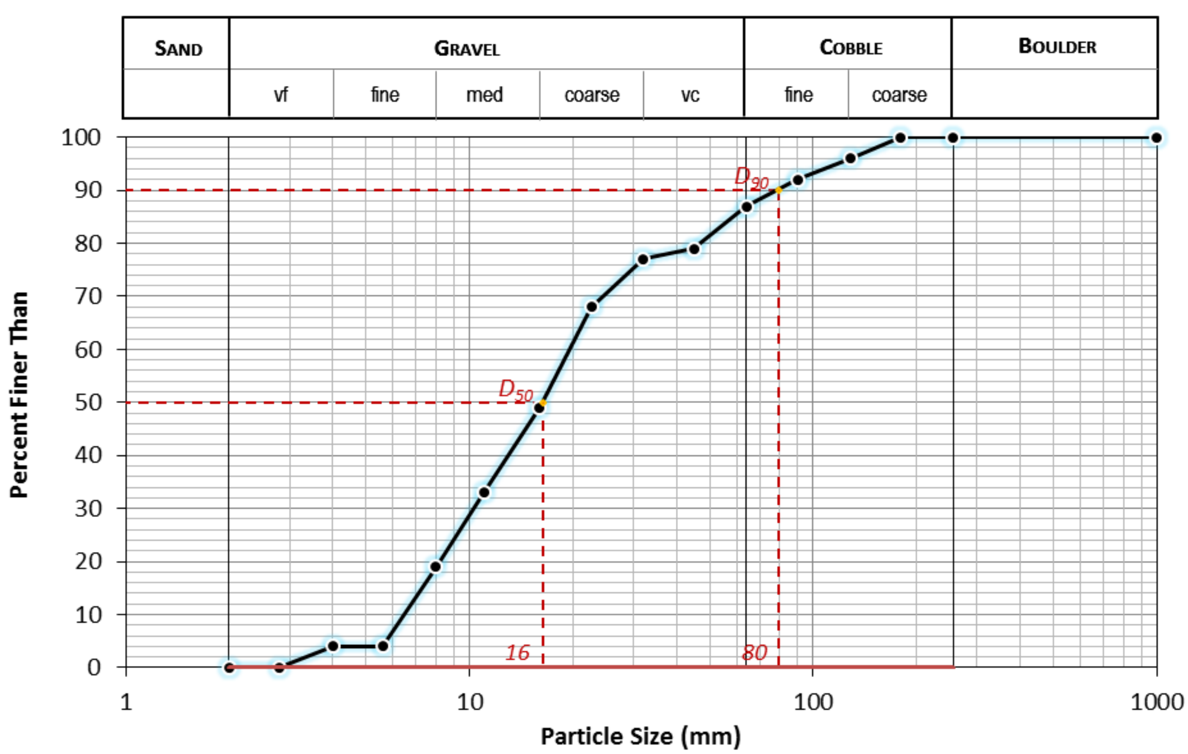


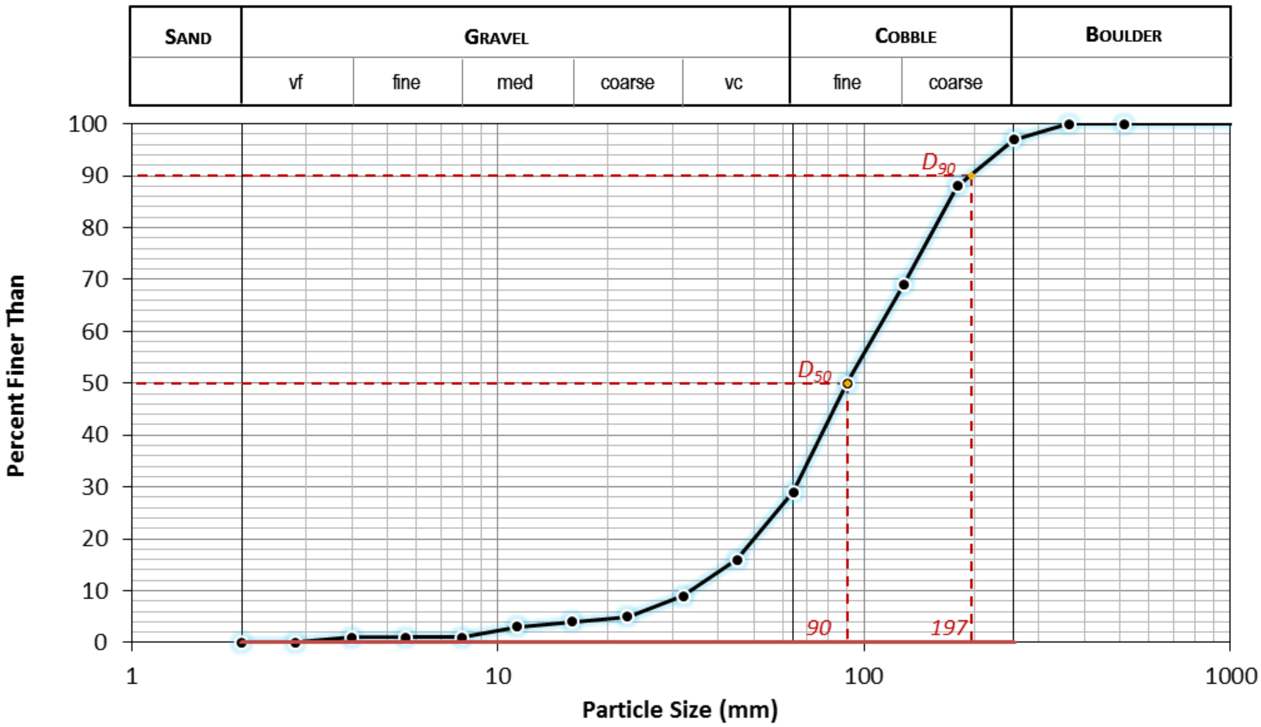
Upper Hidaway Creek – Surface sample



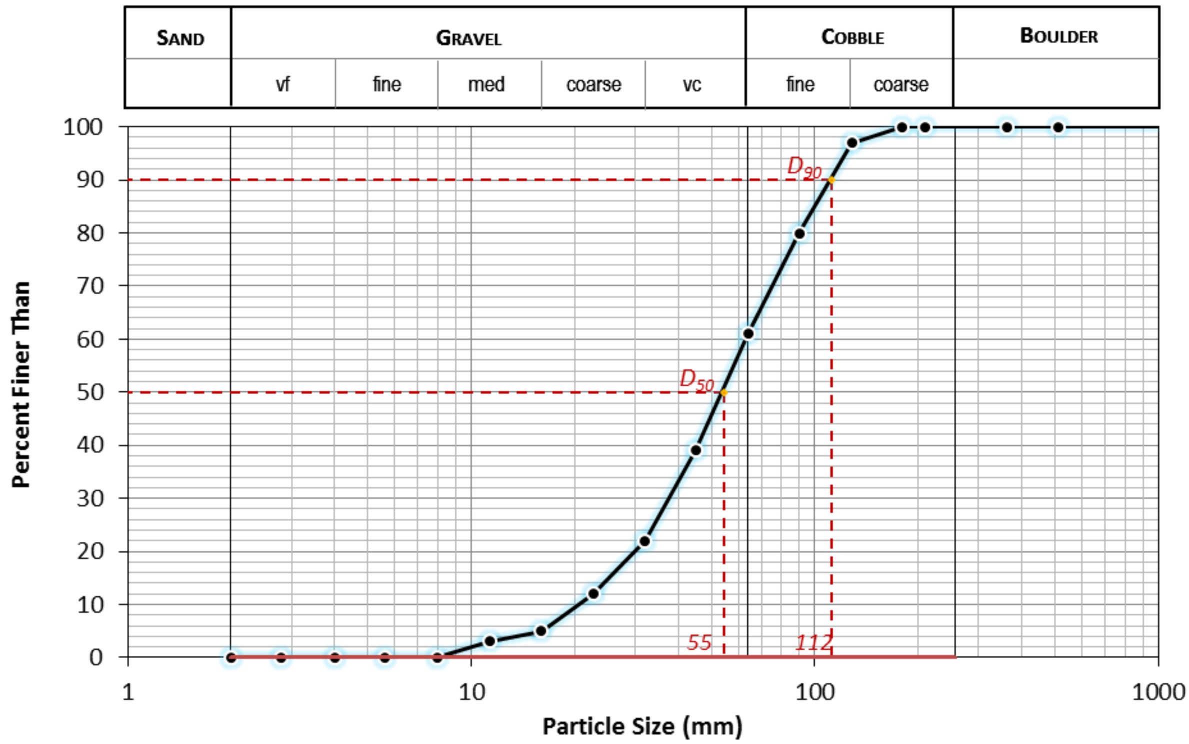
Camas Creek RM 15.2 – Surface sample



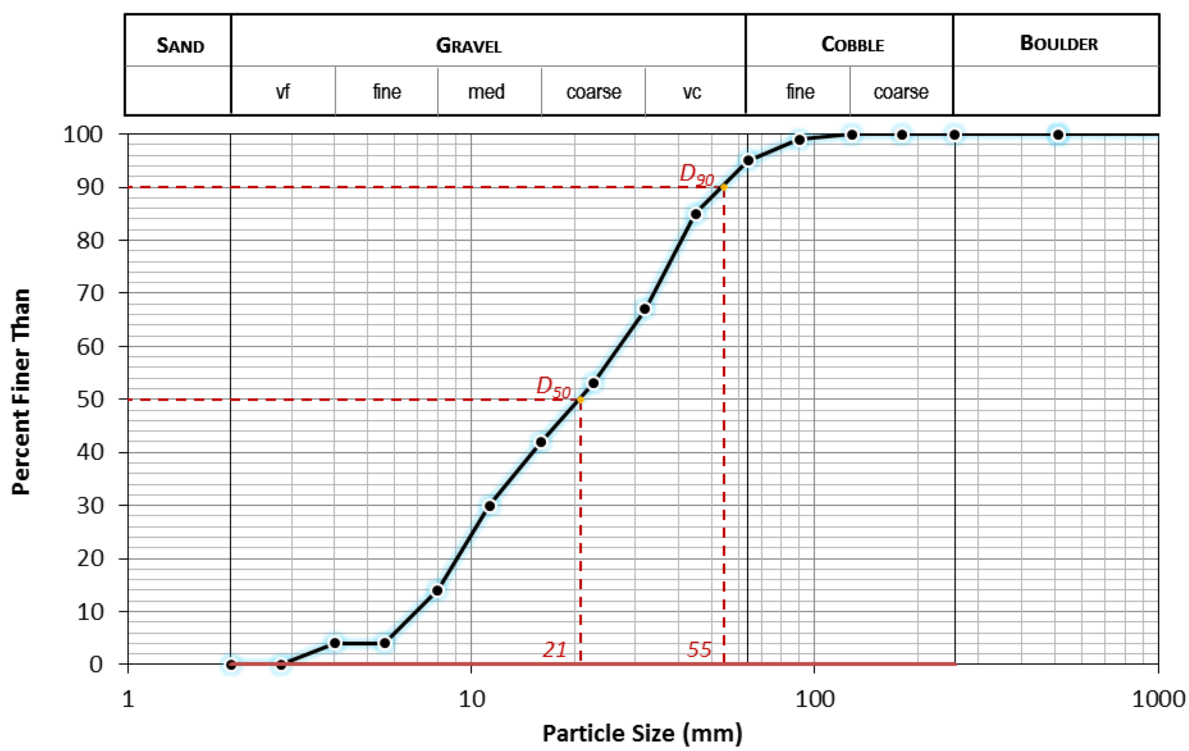
Camas Creek RM 15.2 – Subsurface sample



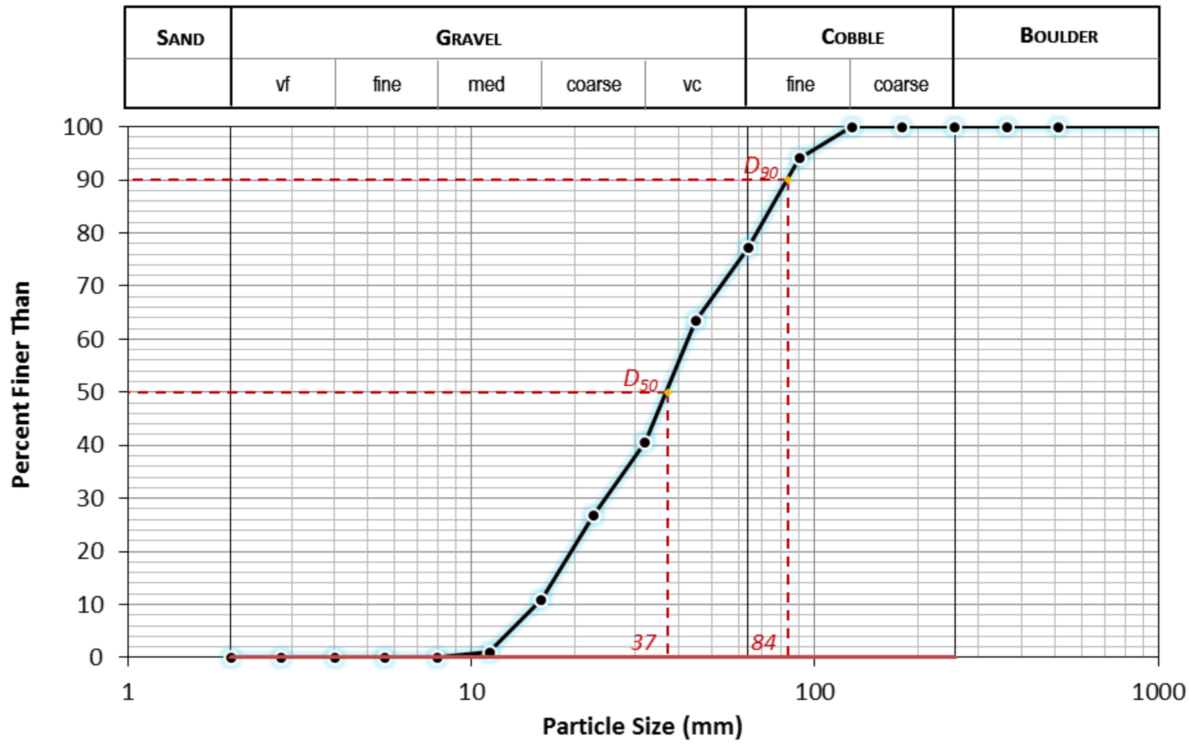
Camas Creek RM 14.6 – Surface sample



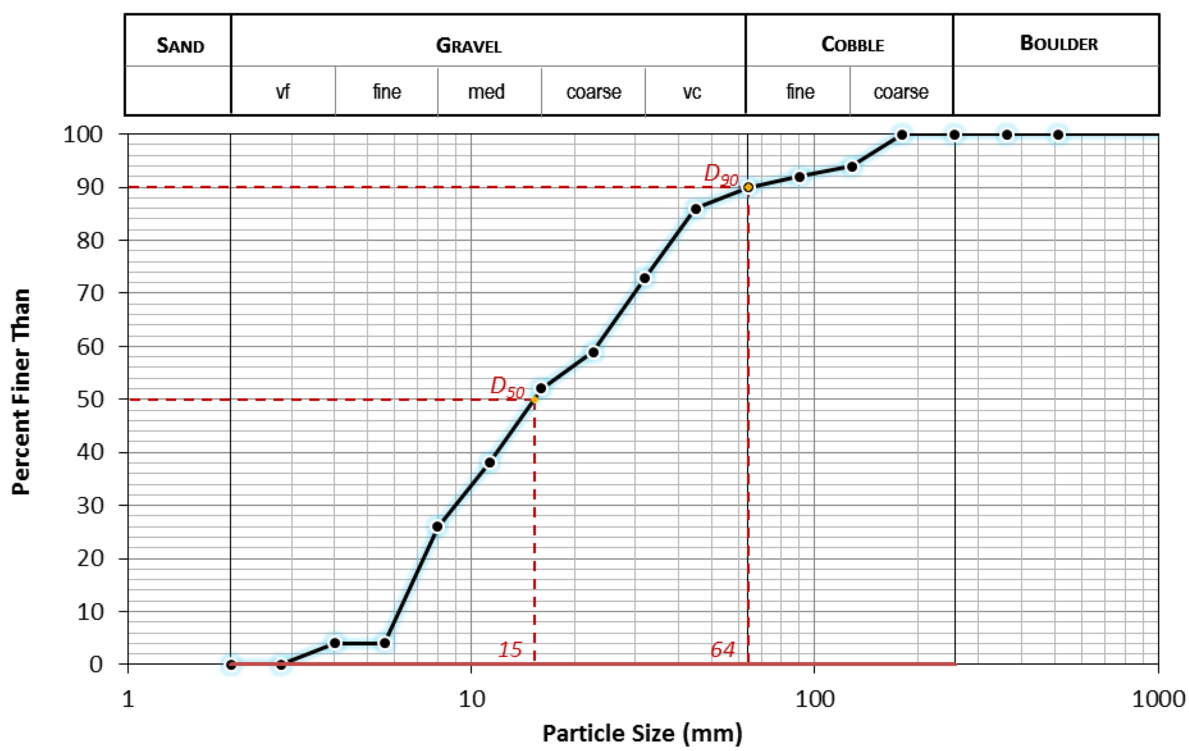
Camas Creek RM 14.38 – Surface sample



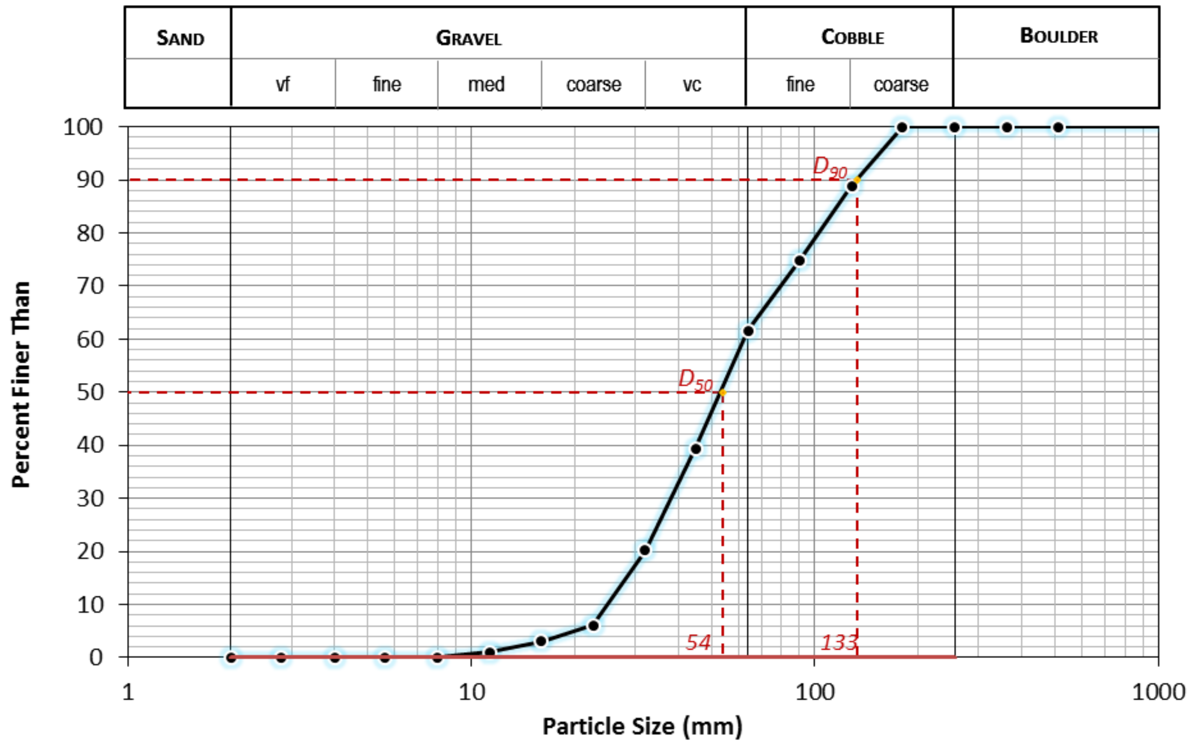
Camas Creek RM 14.38 – Subsurface sample



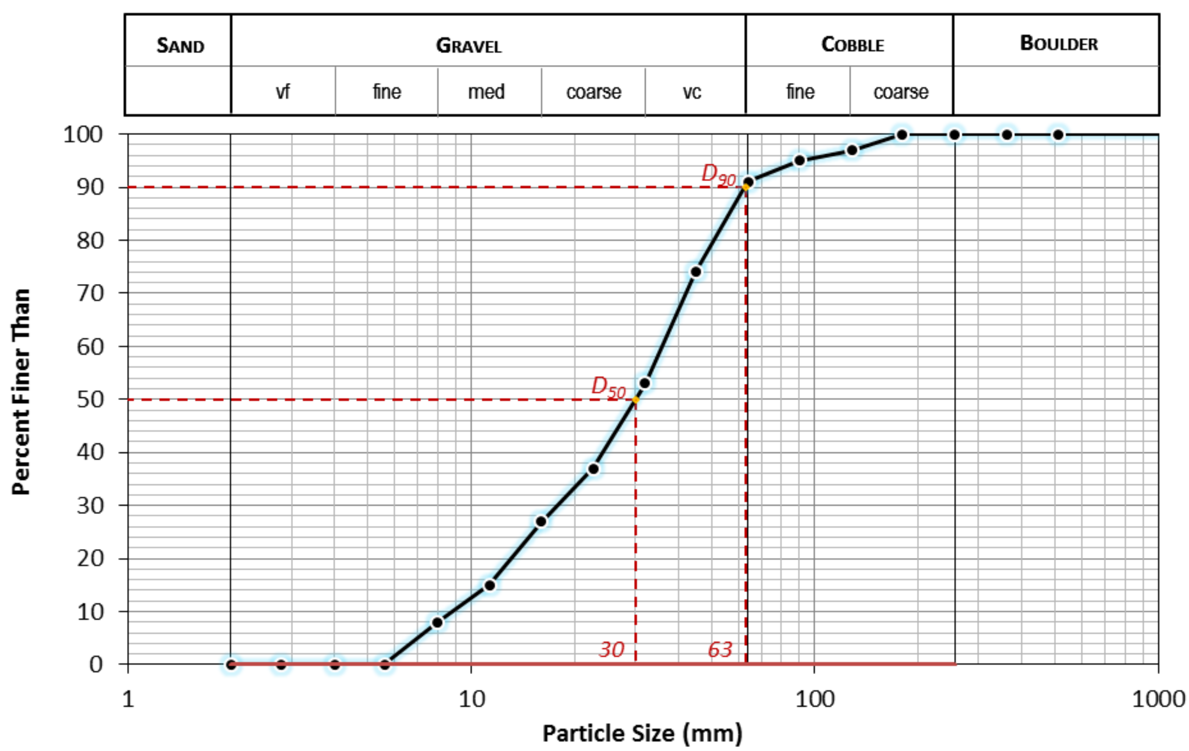
Camas Creek RM 14.3 – Left High Flow Channel – Surface sample



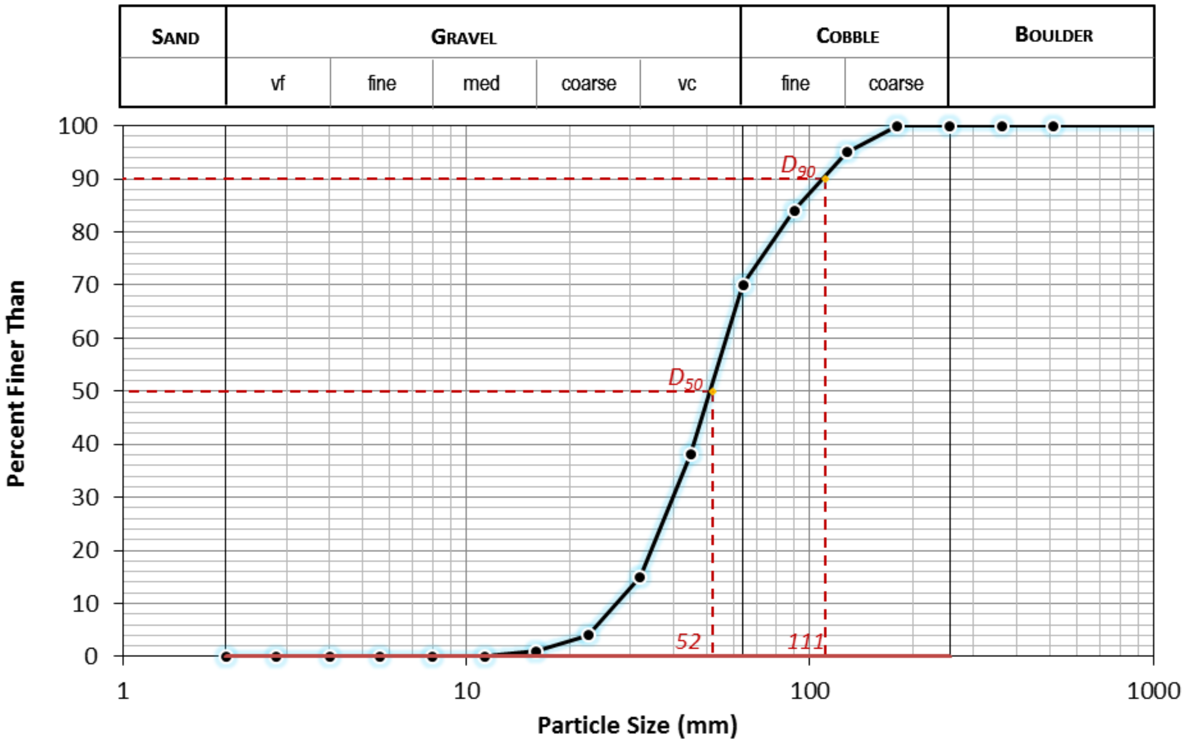
Camas Creek RM 14.3 – Left High Flow Channel – Subsurface sample



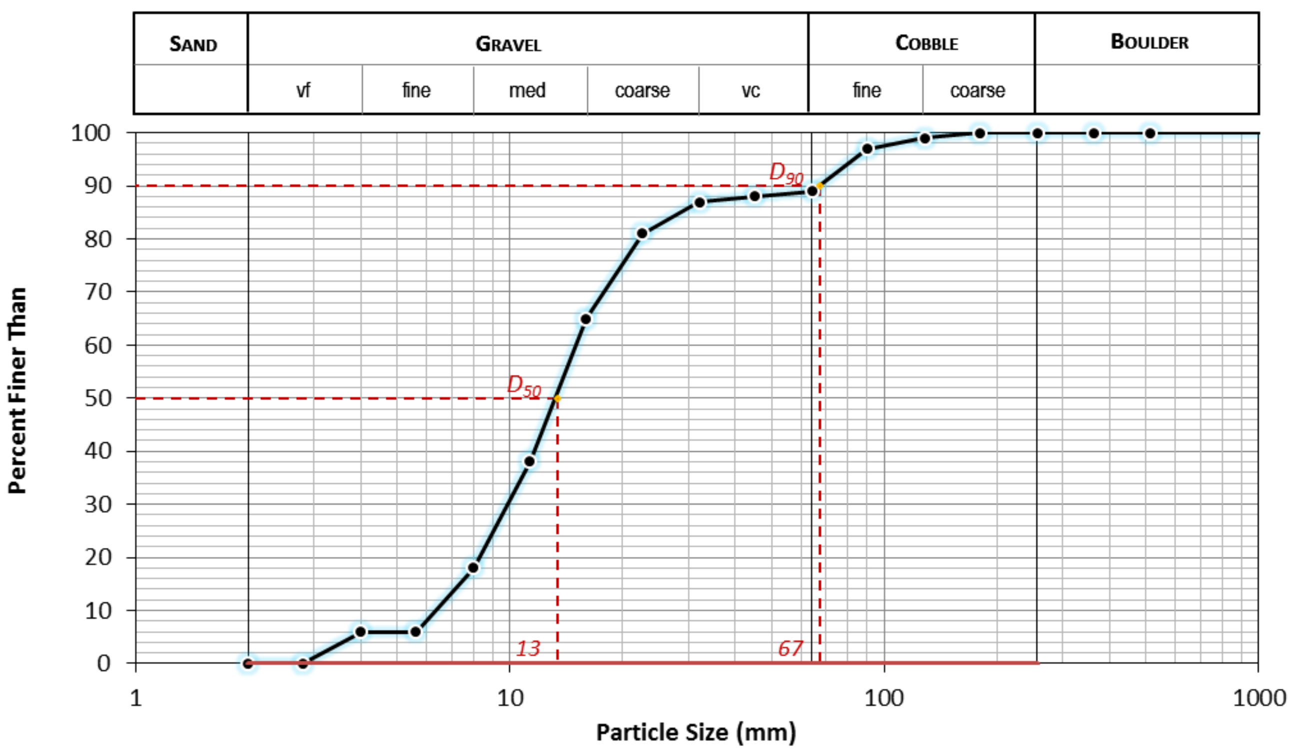
Camas Creek RM 14.3 – Mainstem Surface sample



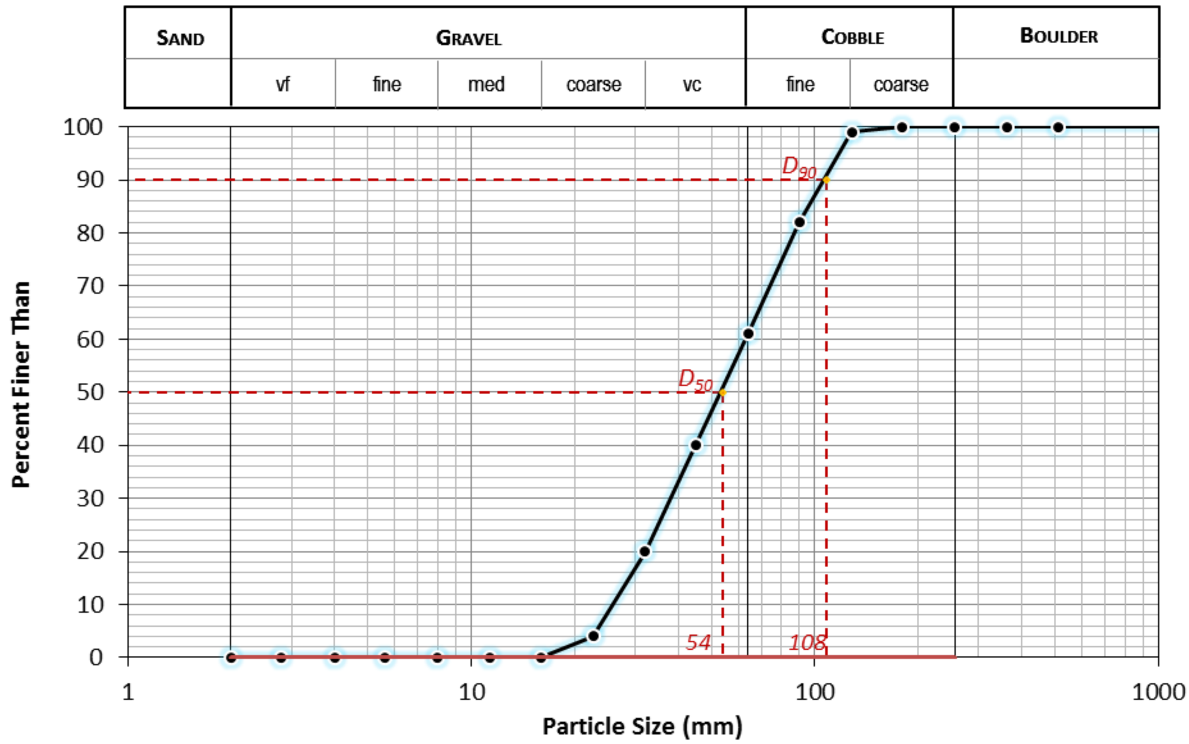
Camas Creek RM 14.3 – Mainstem Subsurface sample



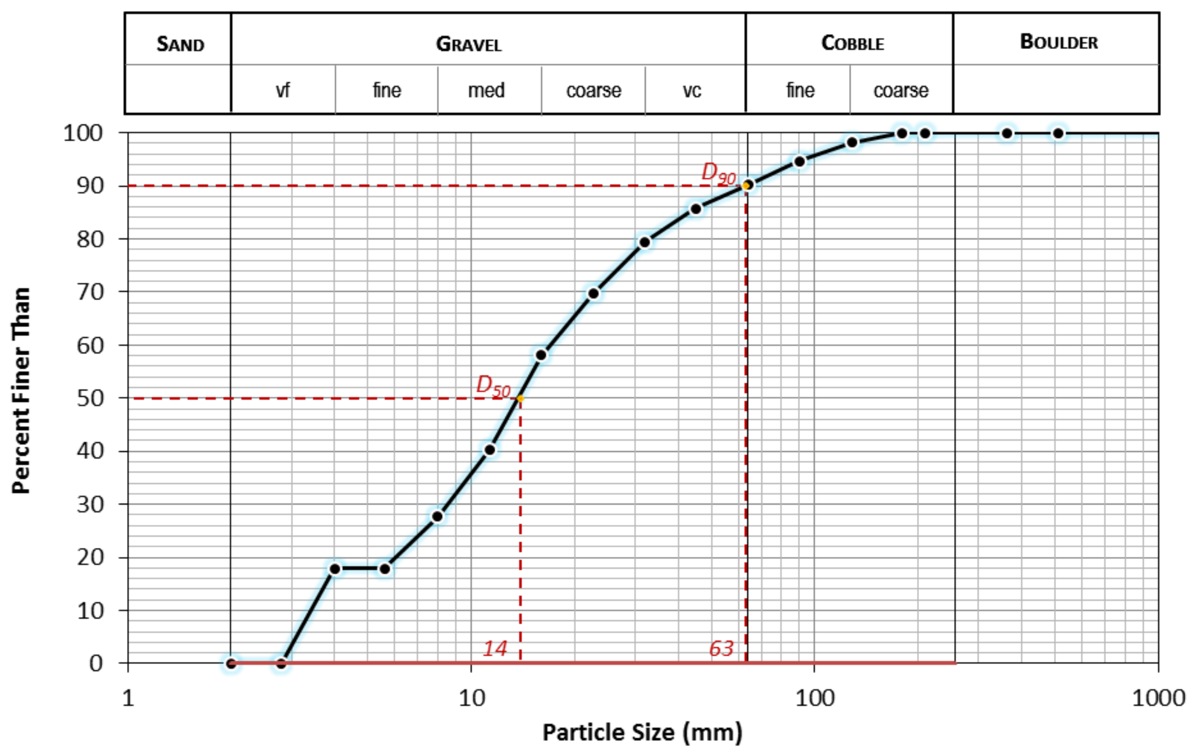
Camas Creek RM 12.75 – Surface sample



Camas Creek RM 12.75 – Subsurface sample



Camas Creek RM 12.51 – Surface sample



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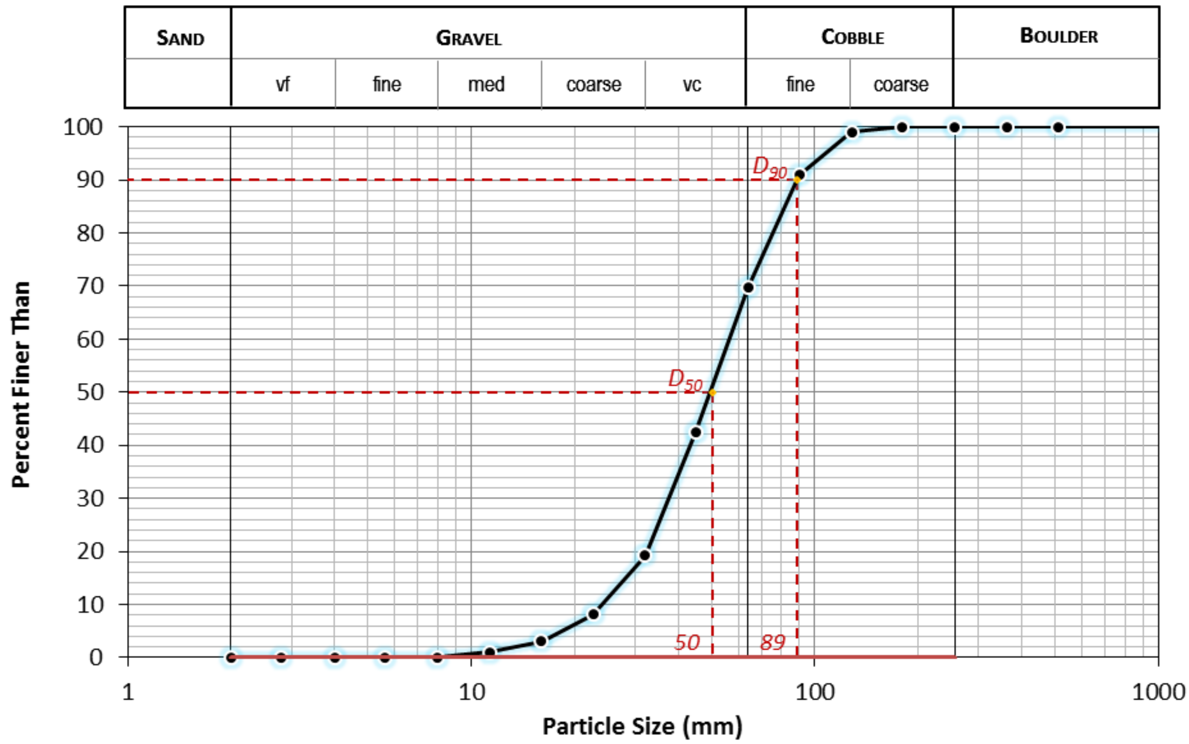
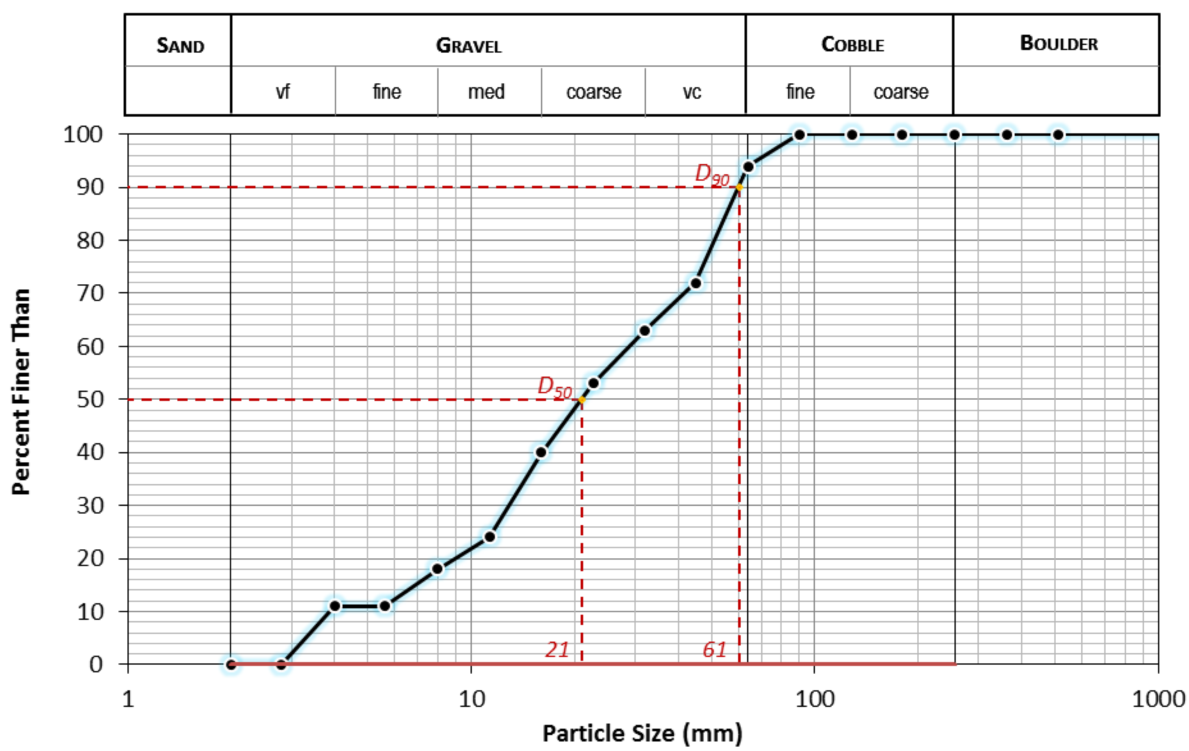


Camas Creek RM 12.5 – Surface sample



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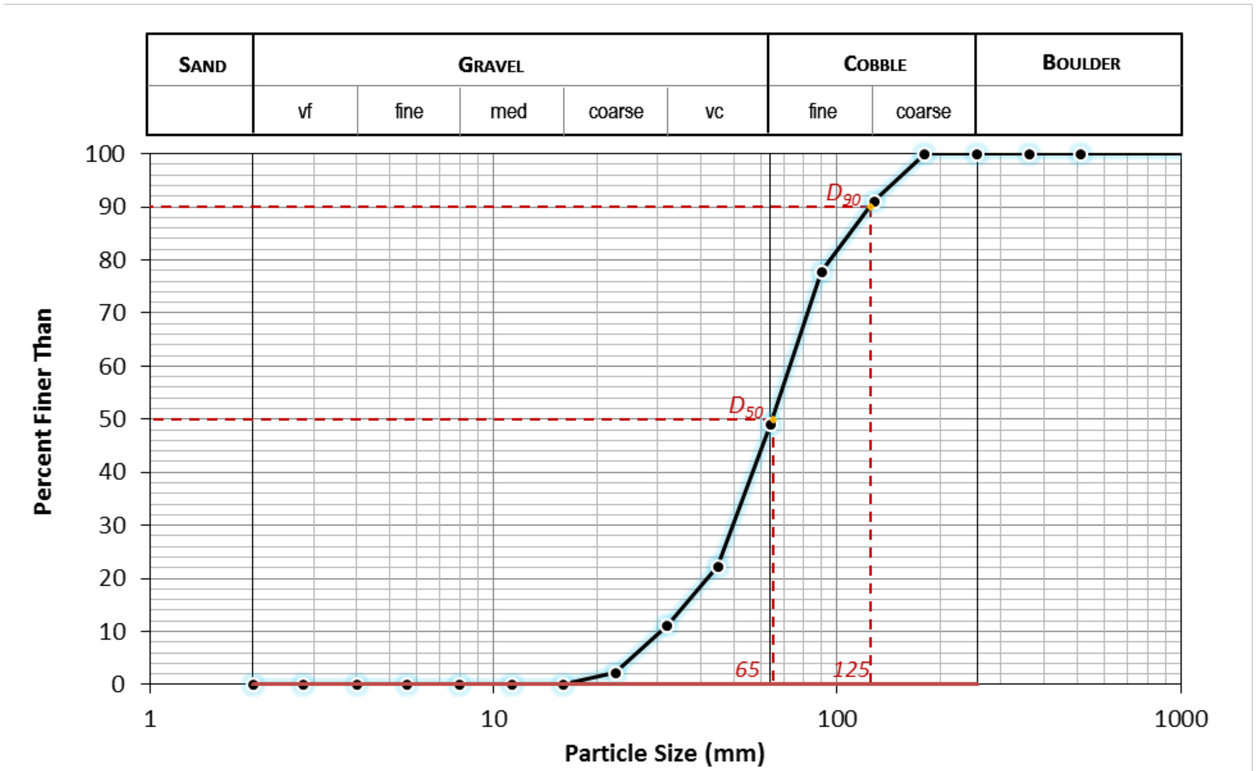
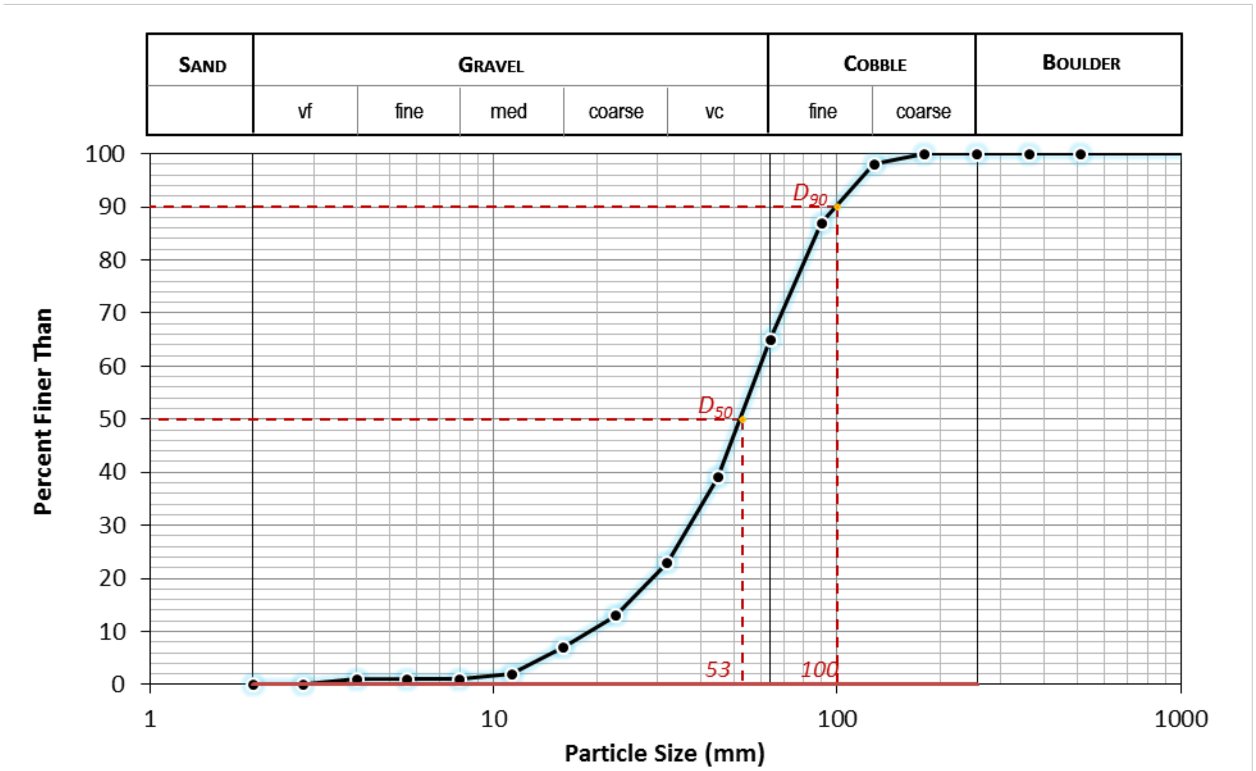
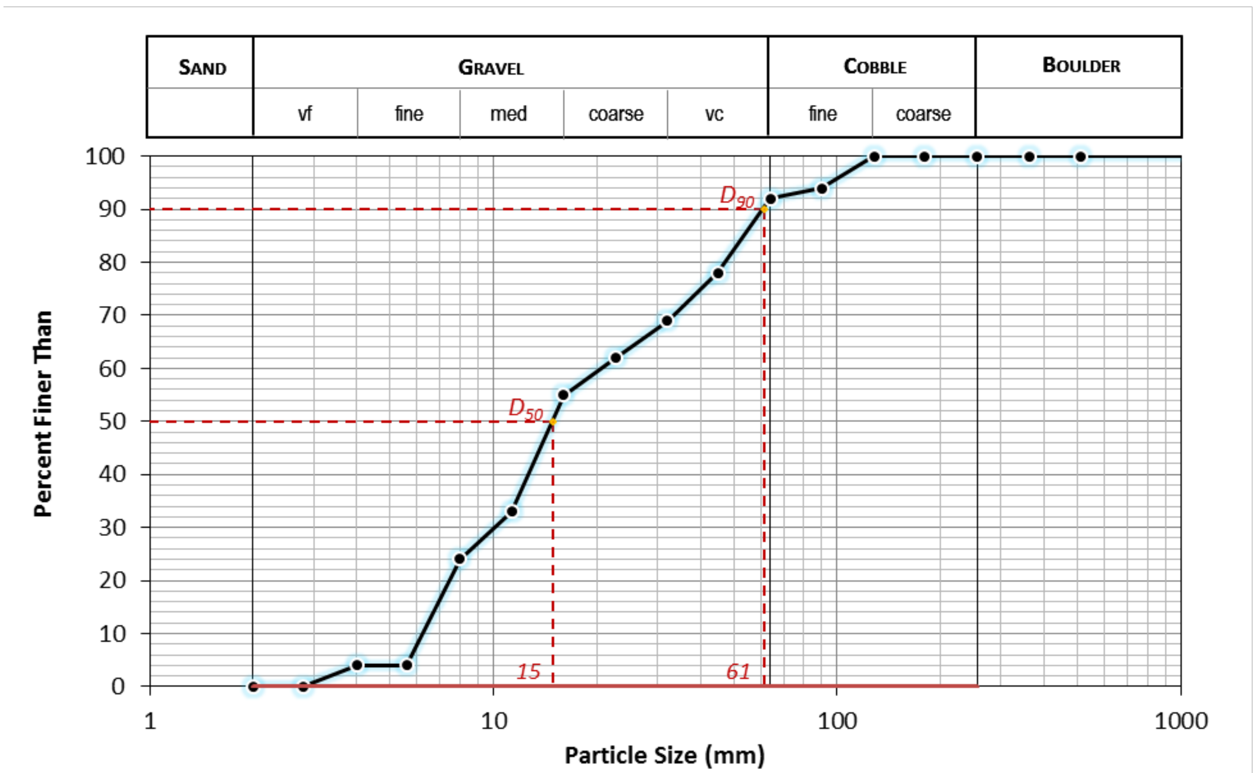


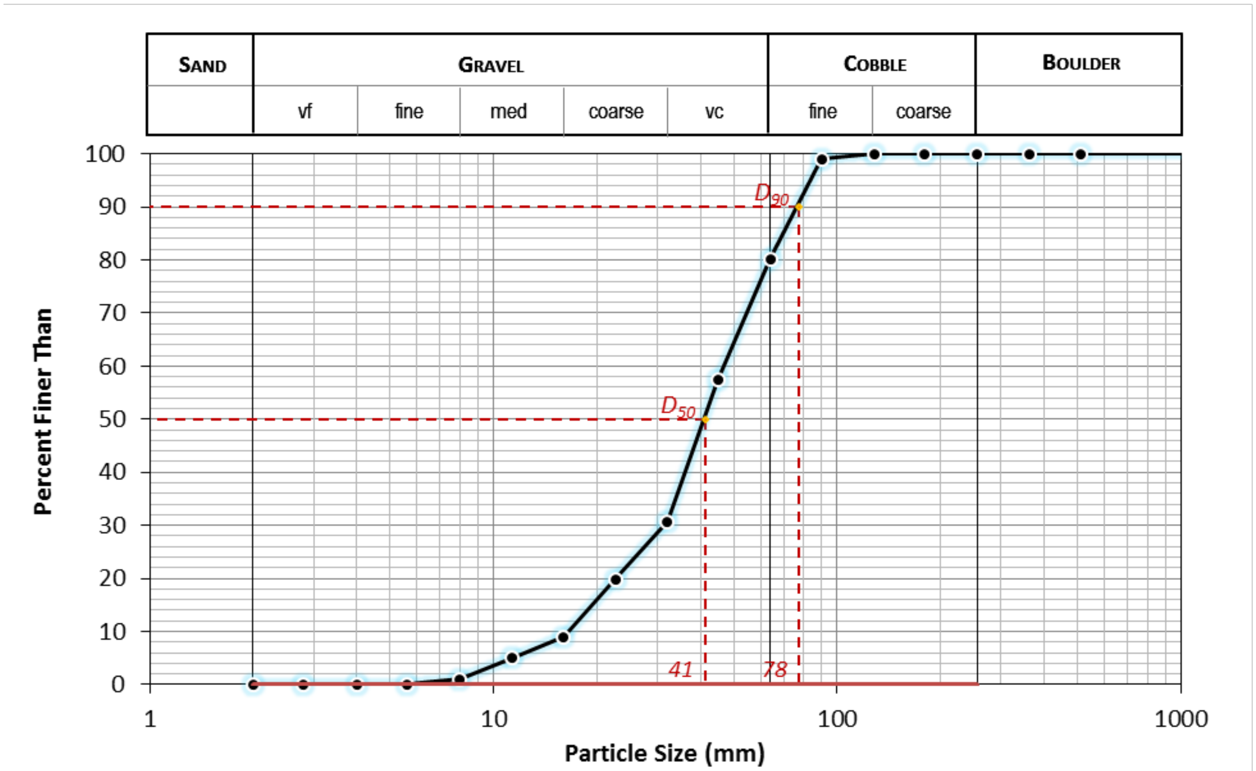
Camas Creek RM 12.45 – Surface sample



Camas Creek RM 12.2 – Surface sample



Camas Creek RM 12.2 – Subsurface sample



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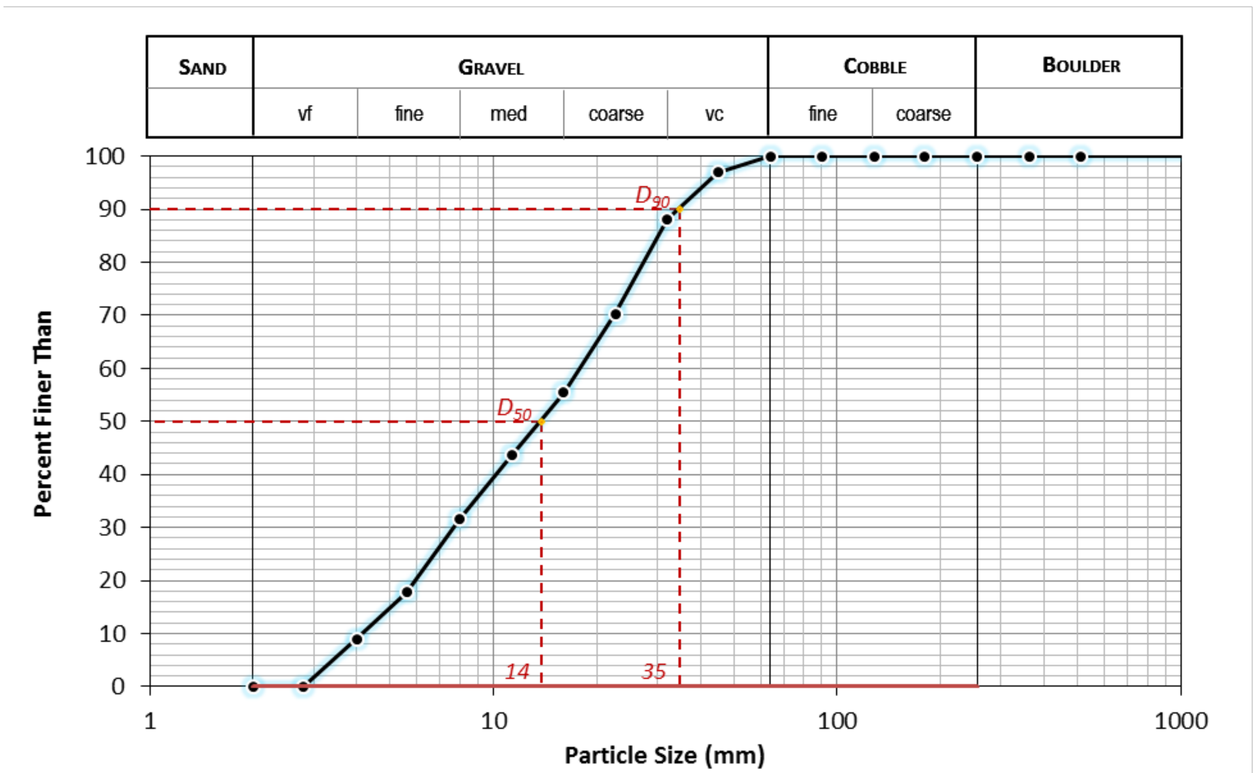

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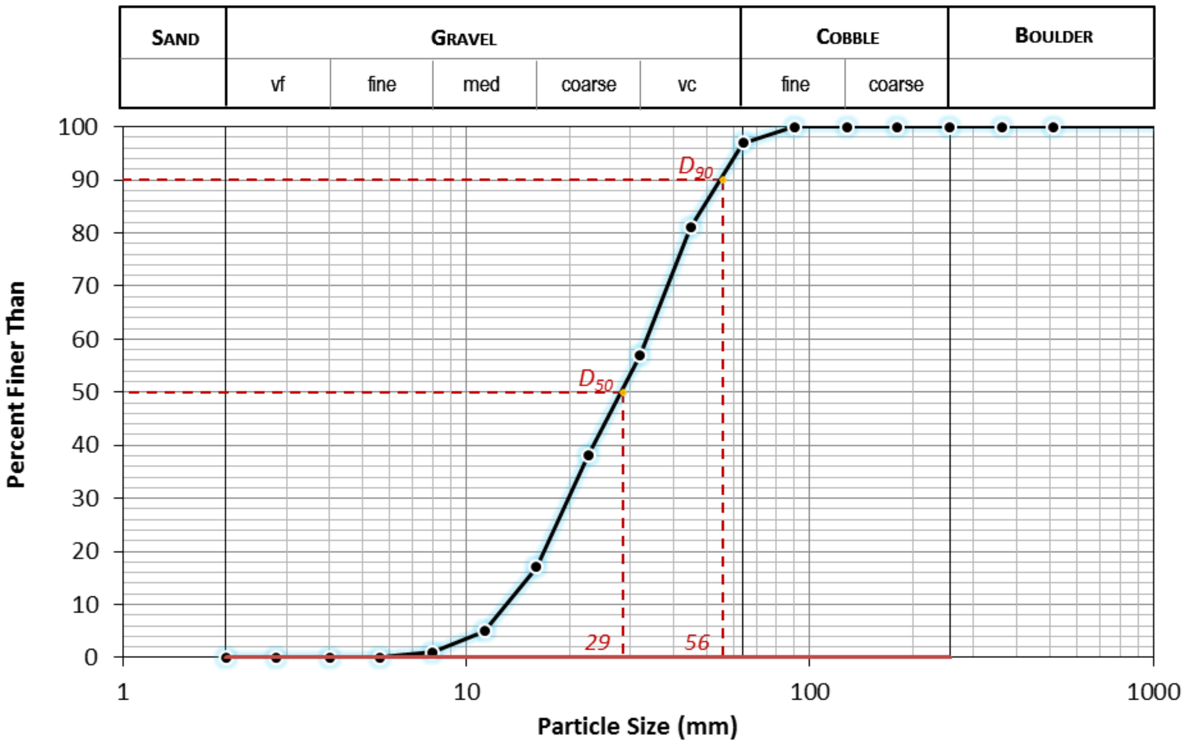

Camas Creek RM 11.95 – Surface sample

Camas Creek, Oregon Restoration Opportunities

March 2016

Prepared for:
Confederated Tribes of the Umatilla Indian Reservation
46411 Timine Way
Pendleton, Oregon 97801
541-276-3447

Natural Systems Design

1900 N. Northlake Way, Suite 211
Seattle, WA 98103

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LIST MAPS

1. INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) have contracted Natural Systems Design (NSD) to assess potential actions for restoration of watershed- and site-scale geomorphic, hydrologic, and hydraulic processes contributing to habitat conditions within Camas Creek, a tributary to the North Fork John Day River (NFJD) in Oregon. In January 2016 NSD completed a Geomorphic Assessment of Camas Creek as the first step in identifying restoration opportunities within the framework of stakeholder concerns related to existing infrastructure and property (flood risk), channel forming processes, hydrology, water quality, and aquatic habitat degradation related to the support of listed anadromous species. The Geomorphic Assessment (NSD 2016) characterized historic conditions, anthropogenic disturbances, and their link to the current conditions within the watershed. Findings from the Geomorphic Assessment and this analysis of Restoration Opportunities have been prepared to provide baseline information and to guide community members and resource managers in developing a strategic approach to holistically improving conditions in the Camas Creek watershed. Potential actions are based upon findings of the Geomorphic Assessment (NSD 2016), which identified impaired geomorphic, hydrologic, and hydraulic processes within the Camas Creek study area that have contributed to ongoing sediment accumulation in Ukiah and habitat degradation throughout Camas Creek and its tributaries. The restoration actions presented are not being mandated by this assessment, by NSD, or CTUIR.

1.1 Study Area

The Camas Creek watershed drains 408 square miles of northeastern Oregon, spanning a vertical relief of 4,070 ft from its headwaters in the Blue Mountains (6,770 ft) to its confluence with the NFJD River at river mile (RM) 57 (2,700 ft) (Map 1). The Camas watershed is approximately 50 miles south of Pendleton and 50 miles west of La Grande, and is largely within Umatilla County, with headwaters extending into Union and Morrow Counties. Nearly 52 percent (214 square miles) of the Camas watershed is within the Umatilla and Wallowa-Whitman National Forests, which are managed for multiple uses, including timber harvest, grazing, wildlife habitat, and recreation (USFS 2015). Approximately 69 percent of the watershed is forested, with remaining areas predominantly arid shrub and grasslands and some agriculture.

The study area for this assessment of Restoration Opportunities includes the Camas watershed above RM 11, approximately 1 mile downstream of Ukiah, Oregon. The study area has been divided into Primary and Secondary Areas of Interest (AOI).

- The Primary AOI focuses on the mainstem Camas Creek from the confluence with Cable Creek at RM 17.8, downstream to RM 11.
- The Secondary AOI includes the mainstem Camas Creek above the confluence with Cable Creek, and the major tributaries to Camas Creek including Pine, Cable, Mud, Hidaway, Lane, Bear Wallow, Rancheria, and Frazier Creeks.

1.2 Overview of Geomorphic Assessment Findings

The historic condition of Camas Creek was an anabranched channel with a healthy, forested riparian corridor that maintained wood supply to the creek, provided shade, and increased bank stability. Beaver augmented instream wood in the channel and floodplains, increasing water storage and reducing celerity of flow peaks, while buffering summer water temperatures. Instream wood provided deep pools intercepting cool groundwater, while providing cover for rearing juvenile salmonids. Side channels and off-channel wetlands once found along the creek provided ample rearing opportunities as well as refugia during high flow events.

Natural disturbances were common in the watershed historically, and played a role in the creation and maintenance of habitat. Wildfires, beaver, floods, and landslides all would have altered the creek in varying ways. These disturbances would have created a dynamic equilibrium, where rapid alterations to the system would be gradually diffused along the creek, and slowly recovered back to something close to the pre-disturbance condition. These natural disturbances are distinct from anthropogenic, or human-induced disturbances in that the human changes to the creek made in response to the disturbance (i.e. levee creation) do not allow the creek to recover back to the pre-disturbance condition. In addition, the response of the creek to disturbances along the channel has had negative consequences downstream. The current condition of Camas creek is one that is attempting to recover from historic anthropogenic disturbances where the opportunity exists, and remaining in a degraded state where there is no opportunity.

Historic anthropogenic disturbances included beaver trapping, homesteading, logging, grazing, channelization, levees, roads (and associated culverts & bridges), and diversions. These disturbances have altered the natural geomorphic processes (i.e. channel migration, a multi-thread channel form, and floodplain connectivity), resulting in degraded instream and floodplain conditions. The location and degree to which these disturbances are altering processes varies across the watershed. In general, the upper watershed and tributaries have been most impacted from beaver removal, logging, and road building. The lower watershed and mainstem Camas Creek through Ukiah, Oregon have been most impacted from grazing, channelization, levees, road construction, and diversions.

In the upper watershed and tributaries to Camas Creek, historic logging and fire suppression replaced the historic ponderosa pine forest with more shade tolerant and less fire resistant species. This change in forest composition combined with high fuel loads resulted in a more fire prone forest community, exacerbating the devastation following the Tower Fire of 1996. This stand-replacing fire destabilized steep slopes within the burned area, contributing excess sediment from Cable Creek. This sediment was largely retained within the creek, diffusing downstream at a slow enough rate as not to dramatically alter the channel downstream of Ukiah. In the adjacent Hidaway Creek, logging and road construction in the watershed in the 1960s initiated a pulse of sediment downstream that entered Camas Creek and continued downstream to Ukiah. Over time the rate of sediment delivery to Camas Creek has diminished.

The removal of beaver throughout the watershed has altered groundwater-surface water exchange, and has resulted in a loss of backwatered areas that would have supported vast wetland complexes. In the upper watershed these impacts have resulted in water flowing at a faster rate during spring runoff and during storm events, which results in increased peak flows and reduced water storage. This reduction in shallow groundwater storage and recharge has likely reduced summer low flow and resulted in greater duration and area of channel dewatering in the Ukiah area. In the lower watershed, loss of beaver has virtually eliminated the wetland complexes once found along Camas Creek and across the Ukiah alluvial fan.

In mainstem Camas Creek and the lower watershed including through Ukiah, natural processes are absent due to channelization, levees, and road construction. Channelization and levee construction occurred during construction of the Brown and Hoxie Mill site in Ukiah in the early 1940s and at a large scale in response to the flood of record in 1965, resulting in a straight, single thread channel through Ukiah to the Camas Street bridge. This dramatic change from an anabranched to a single thread channel planform initiated an immediate channel response, with meanders developing within the new levees following their construction. This process lead to the rapid erosion of the levees from the migrating creek, delivering high sediment loads to the creek downstream from the eroded levees and floodplain. As the levees continued to erode over time, the sediment delivered downstream was deposited in the creek as it flows through Ukiah. An expansion of the creek through town (widening of the levees) has resulted in a loss of transport capacity and a deposition of sediment in the creek. In addition to this accumulated sediment, the Camas Street Bridge creates a local backwater during large floods that induces additional aggradation up to 350 ft upstream of the bridge. The accumulation of sediment due to the levees and bridge has essentially buried the channel through town, exacerbating channel dewatering in the summer months. Upstream of Ukiah, where the levees have eroded, the channel has regained its anabranch planform, habitat elements such as large wood, pools, and even beaver are starting to appear.

Major findings:

- Historic anthropogenic disturbances have altered Camas Creek and its tributaries in a way that has degraded natural processes and in turn habitat conditions.
- Historic anthropogenic disturbances have altered the movement of water and sediment through the watershed in ways that have contributed to degraded habitat conditions.
- Flood control measures taken after the 1965 flood of record, including construction of levees and channel straightening, have degraded habitat conditions and resulted in a river in dis-equilibrium.
- Channel adjustments (levee erosion) due to straightening have resulted in high sediment loads entering the creek.
    - This excess sediment has deposited in the channel through Ukiah due to the levees being further apart and the channel being wider, resulting in increased flood risk to Ukiah.
    - Camas St Bridge confines flow during larger floods, contributing to increased flood risk to Ukiah upstream of the bridge from backwatering and sedimentation.

1.3 Salmonid Distribution, Use, and Review of Ecological Concerns

The John Day River basin supports some of the last remaining wild populations of summer steelhead (*Oncorhynchus mykiss*) and spring Chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River Basin with no hatchery supplementation. Despite significant recovery efforts, these populations remain depressed compared to historic levels. Currently, Camas Creek supports several fish populations that are found in the John Day River basin; these include (USFWS 2002, NPCC 2005, NMFS 2009, ODFW 2013, 2014, Bare et al. 2014):

- Middle Columbia Summer Steelhead (*Oncorhynchus mykiss*) (ESA-Listed)
    - Includes spawning and rearing habitat.
- Spring Chinook Salmon (*Oncorhynchus tshawytscha*)
    - Includes spawning and rearing habitat.
- Bull trout (*Salvelinus confluentus*) (ESA - listed)

The lack of pools, large wood, the predominant riffle habitat, lack of summer flow, and poor riparian quality described in the Geomorphic Assessment (NSD 2016) all correlate to the primary ecological concerns for steelhead and Chinook salmon within Camas Creek as documented in the Camas Creek Watershed Assessment (Ecovista 2003). The Watershed Assessment documented the following primary causal mechanisms:

- Habitat simplification (lack of pools and large wood),
    - Riparian timber harvest and roads.
- High stream temperatures,
    - Riparian timber harvest and roads, lack of canopy cover.

- Flow variation,
  - Sub-watershed timber harvest, riparian roads and high road density, cutbank and ditch erosion, soil compaction, soil and water detention and storage capacity, and bedrock storage capacity.
- Sediment.
  - Sub-watershed timber harvest, riparian roads and high road density, surface erosion, slumps and slides, subsoil erosion, cutbank and ditch erosion.

These ecological concerns have been folded directly into the goals and objectives listed in section 2 below.

The Watershed Assessment also ranked the subwatersheds which contribute the greatest to limiting steelhead and Chinook salmon production or survival based on the four primary ecological concerns (i.e. temperature, flow, sediment, habitat simplification). These subwatersheds from highest to lowest that are within the area of interest are:

- Bowman Creek
- Cable Creek
- Camas/Wilkins Creek
- Upper Owens Creek
- Hidaway Creek
- Lane Creek
- Lower Camas Creek

1.4 Public Partnership

The implementation of these Restoration Opportunities relies on the willing cooperation of public landowners, private landowners, and the people of the Camas Creek basin. It also requires the support of federal, state, local, and tribal governments. It is the goal of this assessment to engage the public as an active partner in implementing and sustaining the restorative actions described in this document. No project that occurs on public or private land will be forwarded to a subsequent phase of design or funding without landowner consent. Projects that have support of the landowner will include all landowner concerns (such as erosion and flood control protection and recreation uses) and will be incorporated as explicit criteria to guide project designs.

A public meeting was held in Ukiah in September 2015 to review the initial findings of the Geomorphic Assessment, identify stakeholder concerns, and to discuss potential actions with the local stakeholders. CTUIR and their partners plan on holding additional public meetings in Ukiah to review the actions and concepts presented in this document, solicit feedback, and proceed with future funding and design phases as allowable.

2. GOALS AND OBJECTIVES

The goals and objectives for the Camas Creek study area are derived from the findings of the Geomorphic Assessment (NSD 2016), the Camas Watershed Assessment (Ecovista 2003), and the five Touchstones of the CTUIR River Vision (Jones et al. 2008). The Camas Creek watershed supports ESA listed Mid-Columbia summer steelhead and bull trout, spring Chinook salmon, along with endemic cool water fishes (ODFW 2014). The CTUIR recognizes the importance of to First Foods in preserving tribal culture, also in protecting and restoring the natural processes that enable sustainable harvest of these food resources in perpetuity (Jones et al. 2008). The Camas watershed's natural ability to provide these cultural resources has been greatly impacted by beaver eradication, timber harvest, grazing, land use and development of the floodplain, channelization and flood control structures, and fire suppression. Restoring Camas Creek and its tributaries and distributary channels will improve natural processes through the five Touchstones identified in the CTUIR River Vision, which include hydrology, geomorphology, native riparian vegetation, native aquatic biota, and the connections between these factors (Jones et al. 2008). In turn, access to First Foods will be improved, and land managers and landowners will benefit from restored natural processes that contribute to productivity and ecosystem health in the long-term.

2.1 Goals

The goal of this assessment of Restoration Opportunities is to: Identify feasible restoration actions that address the causal mechanisms that have impaired watershed function and natural riverine processes. These actions are intended to:

- Improve instream habitats related to the ecological concerns for aquatic species,
- Provide resiliency to long-term climate change scenarios, and
- Protect or enhance human property and interests.

2.2 Objectives

The specific objectives of the Restoration Opportunities have been separated based upon their location within the Primary AOI (mainstem Camas Creek), or Secondary AOI (Watershed-Scale).

2.2.1 Primary Area of Interest (Mainstem Camas Creek).

The objectives within the Primary AOI are the following:

- Reduce channel confinement through the setback, removal, or relocation of impediments to channel migration to restore floodplain capacity and natural sediment transport regimes.
- Promote anabranching channel planform through the setback, removal, or relocation of impediments to channel migration.
- Improve summer base flow depth to reduce channel dewatering and juvenile salmonid stranding.
- Improve instream pool and large woody material quantity and frequency to increase juvenile salmonid refuge and rearing capacity.
- Increase riparian health to improve stream shading to lower high summer water temperatures and to increase large wood recruitment potential.
- Promote natural flow regimes to re-establish a dynamic equilibrium in which complex habitat is created and maintained through natural disturbances and channel response.

2.2.2 Secondary Area of Interest (Watershed-Scale)

The objectives within the Secondary AOI are the following:

- Increase water and sediment storage capacity in the second, third, and fourth-order tributaries and select fifth order streams to improve low-flow water supply and decrease high-flow peak magnitude.
- Improve road network and identify potential opportunities for road decommissioning within riparian corridors to decrease sediment inputs into tributary streams, promote recovery of riparian conditions, and reduce rapid runoff from storm events.
- Reduce forest stand density in recently burned areas to improve snowpack through reduced canopy interception and subsequent evaporation losses, promote the growth of larger, fire tolerant tree species, and decrease the potential for future high-intensity fires.

3. RESTORATION OPPORTUNITY DESCRIPTIONS

The development of strategies for the restoration of geomorphic, hydrologic, and habitat forming processes, and functions within the Camas Creek watershed are based on the assessment of watershed and reach-scale processes and indicators presented in the Geomorphic Assessment (NSD 2016) and the goals and objectives presented above. Collectively, the recommended strategies aim to improve physical and biological processes, which in turn will foster resilience to future disturbance in the watershed (including changes driven by natural variability and human impacts). Such resilience will ensure the recovery and continued productivity of listed salmonids in the watershed.

Recommended strategies were developed to guide both direct and indirect actions, long-term and short-term restoration actions in the watershed. Direct actions include activities such as removing, moving, or improving structural controls adversely impacting the river (e.g., levee setbacks, road realignment), building in-stream structures that emulate natural conditions (e.g., grade control, habitat features), and the construction of livestock or elk fencing to re-establish and protect riparian vegetation. Indirect actions include delineating or establishing channel migration or river corridors, or recommendation of conservation easements that facilitate natural recovery of habitat and sediment transport mechanisms. Indirect actions also include the recommendation for future management plans or public education programs to improve land use practices (e.g. road decommissioning plan).

The long-term objective is to restore the dynamic floodplain and stream channel interaction necessary to support a sustainable and resilient stream, floodplain, and riparian ecosystem. The core long-term recommendation is establishing a viable stream corridor that encompasses a restored floodplain, the channel migration zone, and a riparian corridor through the Primary AOI. Ensuring there is land adjacent to the stream where the channel is allowed to migrate over time and riparian forests are enabled to mature is a crucial part of the overall management strategy to protect and restore salmonid habitat in the Camas Creek watershed. The benefits of establishing the corridor are not limited to the ecosystem, but would greatly reduce or eliminate flood hazards in Ukiah, reducing risks associated with winter ice floes, and increased forage production within adjacent floodplains.

Following the goals and objectives discussed above, potential restorative opportunities have been spatially separated into watershed-scale (Secondary AOI) and mainstem Camas Creek (Primary AOI) actions. Figure 1 shows a flow chart of the opportunities relative to each other across the Camas Creek watershed. The opportunities have been crafted to both stand-alone and, in many cases, be implemented together in time and across the watershed. Chapter 4 below further discusses the potential to combine and sequence opportunities to achieve a greater restoration of natural physical and biological processes than if implemented as stand-alone actions.

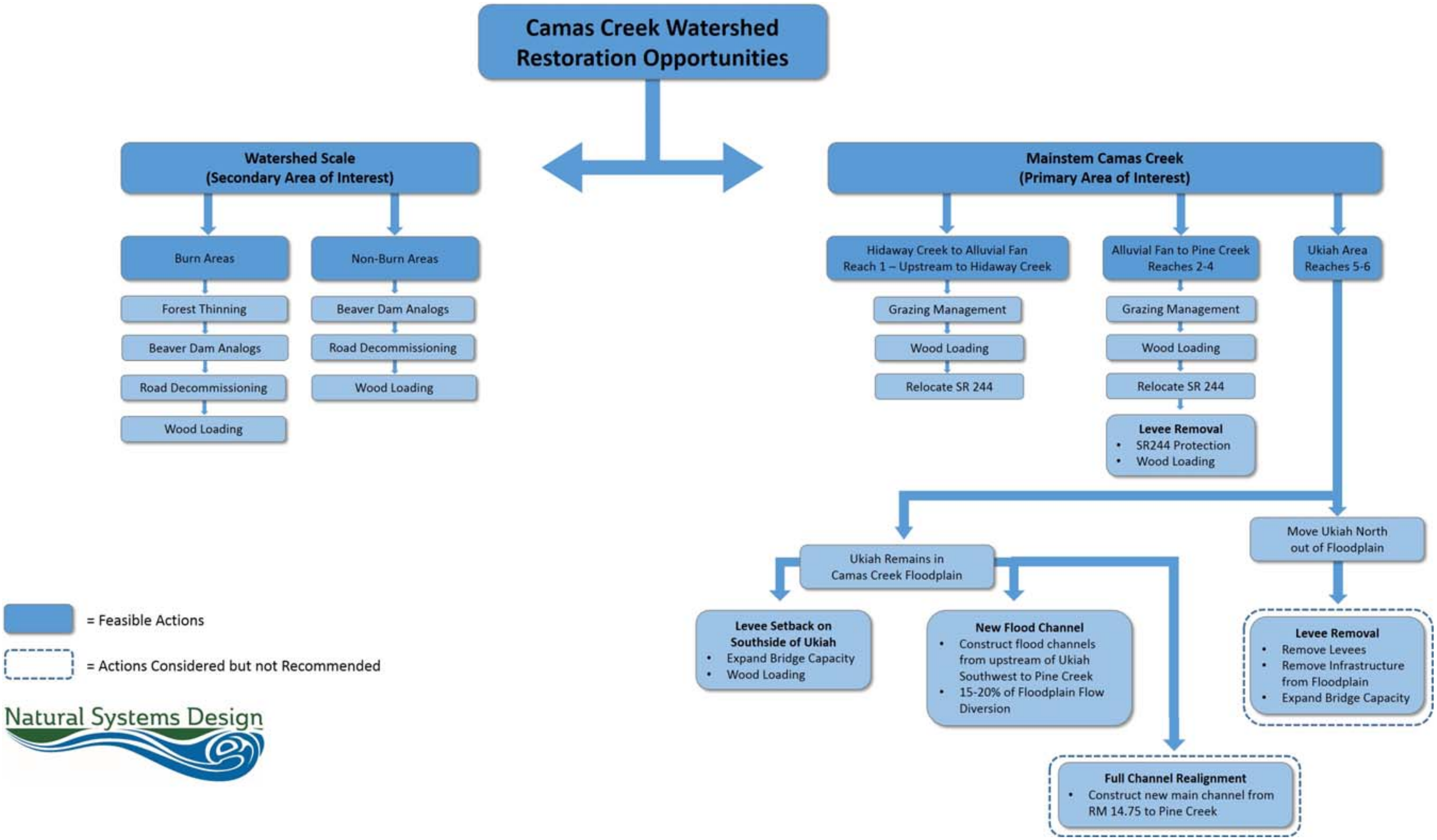

Figure 1. Flow Chart of Potential Restoration Actions

The sections below describe each of the restoration opportunities in detail. Each description includes:

- Scale and location of the restoration action,
- The impaired process and causal mechanism that the action is addressing and the benefits to geomorphic, hydrologic, and aquatic habitat processes,
- Social and construction feasibility.
- The time scale of the benefits, and the overall resiliency to expected climate change.

3.1 Watershed-Scale (Secondary AOI) Restoration Opportunities

The primary impaired processes and causal mechanisms within the upper watershed (Secondary AOI) are as follows (NSD 2016):

- Timber harvest, along with a change in fire regime and resulting in high fuel loading.
- Reduced instream wood loading.
- Beaver removal and road construction resulting in increased sediment production and decreased sediment retention, and higher peak flows and lower summer low flows.

The actions below have been segmented spatially into the recently burned areas and the non-burned areas as shown in Map 2. The burned areas have regenerated into forests with high stem densities resulting in higher fuels loads and few large diameter trees. Thinning of these areas will provide the source material for the construction of beaver dam analogs in both burned and non-burned areas.

3.1.1 Prescribed Thinning and Wood Loading/Beaver Dam Analogs

Two separate but related actions are proposed that link the recovery of burned areas and increased water and sediment retention in the upper Camas watershed:

- The thinning of high-density forest stands, and
- Installation of beaver dam analogs.

Both actions are described here and are interrelated in that the wood material that is removed by thinning can then be used to construct beaver dam analogs. While these actions are interrelated, they also can be approached as stand-alone actions.

As described in the Geomorphic Assessment (NSD 2016), fire suppression throughout the watershed and particularly within the UNF and WWNF over the past century has dramatically reduced the frequency of low and moderate severity fires (Boula et al. 1995). This practice has increased fuel loading and altered the stem density and dominant species (more shade tolerant trees) within coniferous forests of the Camas basin, thereby increasing fire severity while reducing the abundance of fire tolerant species such as ponderosa pine and western larch. Forest stem density in areas recovering from logging or wildfires (DBH < 6 inches) is up to 100 times higher than in patches of mature forest (Figure 2, 12 – 30+ inch DBH). Without thinning of high stem density areas and reduction in fuel loading, it is likely that a future wildfire in the upper watershed will be similar in intensity and extent to the Tower Fire.

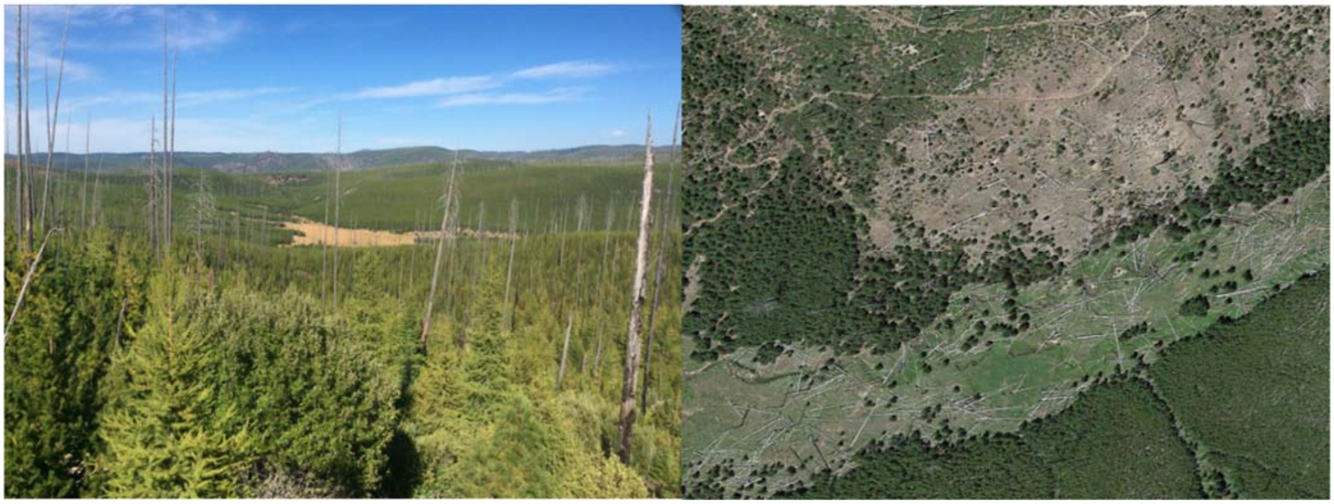

Figure 2. Standing snags in young, regenerating forest with stem density of approximately 8,000 - 13,000 stems/acre (left) and large wood delivered to valley bottom (right).

The prescribed thinning will target the recently burned areas as shown in Figure 2 and Map 2. Any thinning actions in these locations will need to be closely coordinated with the US Forest Service to identify target stem densities and the highest priority thinning locations. Wood material harvested from this thinning will be used in the construction of simulated beaver dams.

Trapping of beaver for pelts virtually eradicated the species from the Camas basin, likely contributing to the historic loss of wetlands and moist meadow habitat in the watershed (Boula et al. 1995, Ogle et al. 2010). The removal of beavers and their dams has reduced functions related to the trapping of sediment and organics, reduction of flow velocity, floodplain engagement, groundwater recharge, and the regulation of runoff and thermal regimes (Naiman et al. 1988, Pollock et al. 2007).

The construction of simulated beaver dams or beaver dam analogs has been used in the west to address channel incision, reduce stream power, increase floodplain engagement, and restore riparian vegetation (e.g. Pollock et al. 2014). Based on current research, beavers typically build dams in perennial stream channels with slopes of less than 6%, an unconfined valley, and a bankfull stream power of less than 2000 watts per meter (Pollock et al. 2014). Upper Cable and Hidaway Creeks and their tributaries are prime examples for such conditions. In the Camas Creek watershed the construction of beaver dam analogs would target 2^{nd}, 3^{rd}, and select 4^{th} order stream channels and portions of Cable Creek that fall well within these geomorphic and hydraulic parameters (Figure 3).

Figure 3. Typical channel types where beaver dam analog construction would occur.

Map 2 shows the locations of the proposed beaver dam analog construction as well as priority areas for this treatment based on proximity to thinning areas, water storage potential (e.g. density of 2^{nd} – 4^{th} order streams), potential for increased sediment yields due to historic fire impacts, and importance to steelhead, bull trout, and chinook survival and production. Priority areas for thinning which were severely burned by the Tower Fire of 1996 include:

- Upper Cable Creek
- Hidaway Creek

In addition to close proximity to the thinning areas, both the Cable and Hidaway Creek subbasins have a high potential for water and sediment storage based on the density of stream networks. Hidaway Creek also provides critical bull trout habitat (ODFW 2014). The Lane Creek subbasin also has a high density of 2^{nd} – 4^{th} order streams and provides habitat for steelhead, as such, it is also recommended as a high priority area for beaver dam analogs.

Second priority areas which support critical habitat for steelhead, have 2nd – 4th order streams suitable for beaver dam analogs, but are not priorities for stand thinning include:

- Bear Wallow Creek
- Bowman Creek
- Frazier Creek

The construction of simulated beaver dams would involve the installation of bundled woody material that has been harvested from prescribed thinning areas. Thinned material could be bundled to a diameter of 4 ft using biodegradable (manila) rope at two to three locations along the bundle length (Figure 4). Typical bundle lengths would be equal to the mean height of stands targeted for thinning, which typically range from 10 - 20 ft. Implementation of different bundle lengths should be consistent with the variability of stream channel widths and geomorphic features. Single bundles or bundles placed end to end can be installed within the channel, anchored to existing riparian vegetation (Figure 4) or using simple, small diameter batter (angled) posts.

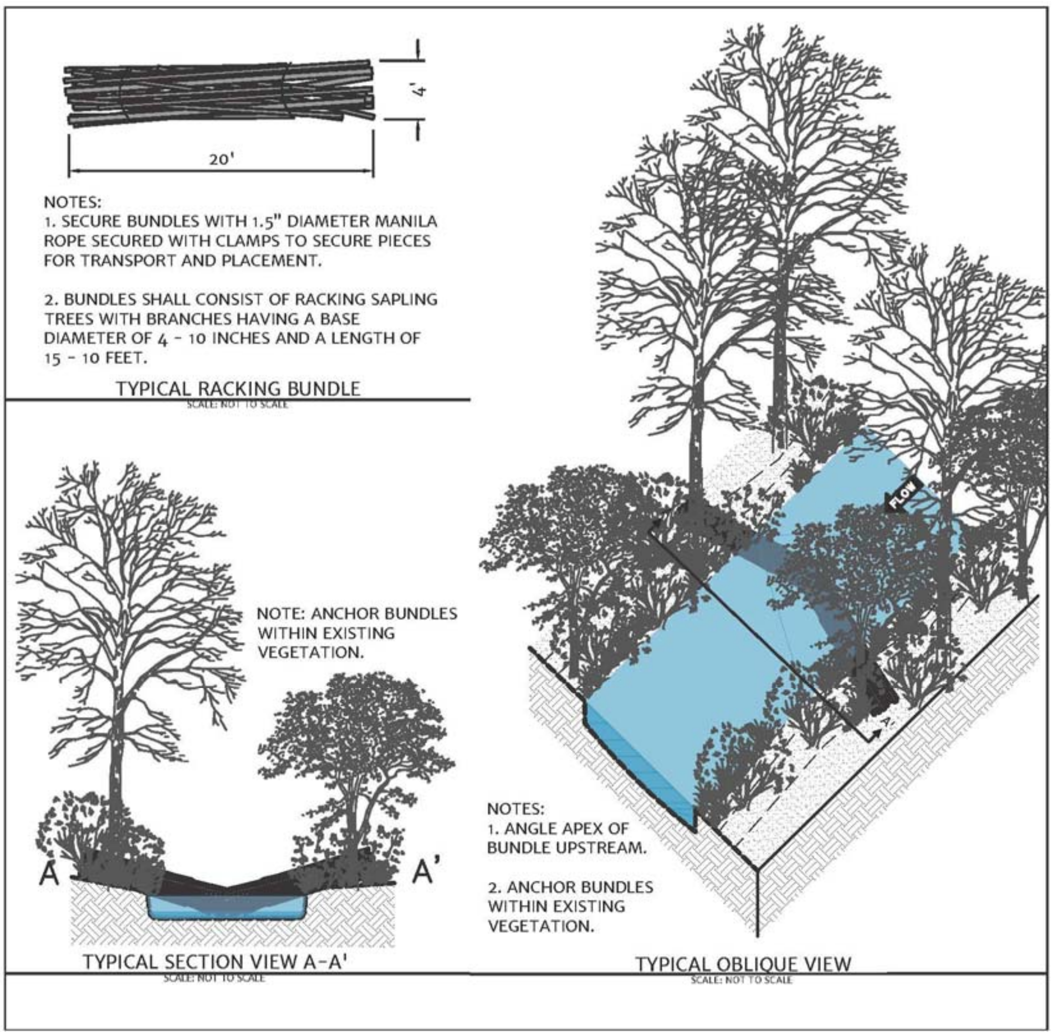

Figure 4. Typical racking bundle comprised of 10 - 20 ft poles <10 inch diameter. Bundles are bound to a diameter of 4 ft using 1.5 inch manila rope and clamps at two locations. Shown is a typical installation of two wood bundles placed end to end and anchored within existing vegetation to create a low-lying beaver dam analog.

Water and sediment storage potential of bundle placements will be contingent on the relief and valley bottom width of the channel segments in which these treatments are applied. Similar to a reservoir or artificial basin, storage volume is positively linked to valley width and bundle spacing (area of potential storage) and negatively correlated with valley slope (Figure 5). Thus, low-relief (< 4 % slope) systems with wider valley bottoms will have greater storage potential per bundle placement versus steeper channels with naturally confined valleys where storage potential is low.

Optimal bundle spacing (inducing backwater to the next upstream bundle placement) is thus variable by channel width and gradient. For a 4 ft diameter bundle, a 2 percent channel, and a floodplain width of 100 ft, each beaver dam analog could potentially store 1 acre-foot of water, with beaver dams spaced along the length of the channel every 200 ft (26.4 acre-feet per mile of channel). A similar channel with a floodplain or valley bottom width of just 50 ft could store up to 0.5 acre feet of water every 200 ft, or 13.2 acre-feet per mile of channel.

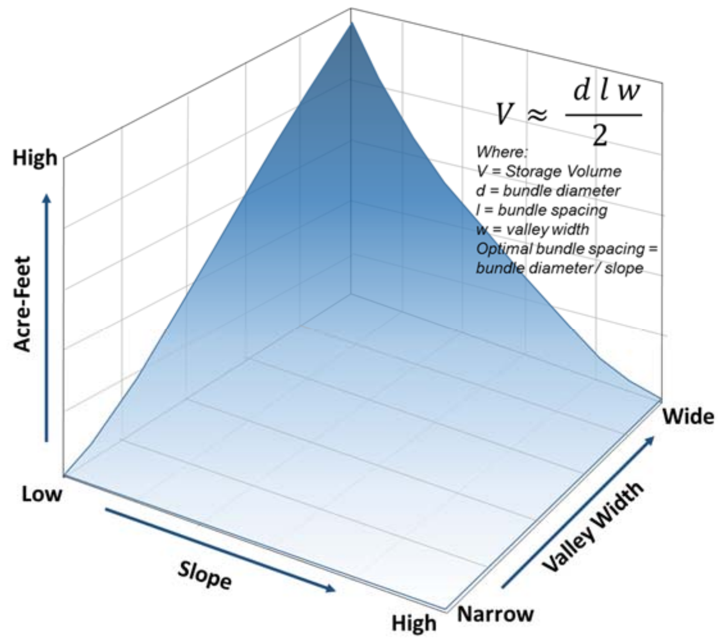

Figure 5. Relationship between channel slope, valley width, and storage potential (acre-feet of water) using channel or valley-spanning beaver dam analogues.

Field measurements and review of remotely sensed data indicates floodplain widths range from 0 – 180 ft and gradient ranges from 1 – 4 percent in Hidaway, Frazier, and Cable Creeks and 2nd – 4th order streams, which suggests there is ample channel length in the Camas watershed in which these restoration activities could be implemented, greatly increasing both water and sediment storage

Figure 6. Naturally occurring debris bundles in the upper Camas watershed. In addition to channel-spanning beaver dam analogs, bundles can be placed in portions of the channel to improve hydraulic complexity and habitat formation.

capacity while improving aquatic and riparian habitat. Wood bundles can also be placed laterally or perpendicular to flow in portions of the channel to deflect flow away from eroding banks, increase channel sinuosity and flow splits, and to encourage pool formation (Figure 6).

Objectives Addressed

- Reduce stem density/fuel loading in recently burned areas to increase snowpack retention by lowering canopy interception and decrease the potential for future high-intensity fires.
- Increase water and sediment storage capacity in second, third, and fourth-order tributary streams and their associated floodplains to increase peak flow retention and groundwater recharge to improve low-flow conditions.
- Increase frequency and extent of wetlands and riparian forest.
- Increase instream wood loading and pool formation to improve juvenile salmonid rearing and refuge habitats.

Feasibility

The need for forest thinning and the close proximity between thinning locations and streams suitable for application of beaver dam analogs increases the construction feasibility of this action. Bundle/dam installation locations should be initially located through ground reconnaissance, with locations flagged and recorded in GPS for future construction. The number of bundles at each installation site will be determined by the field reconnaissance and flagging can be used to designate bundle location and orientation.

The existing high density road network allows for ground-based access to both harvest sites and beaver dam placement areas. The bundles can also be placed via helicopter or through high-line logging in areas that do not have existing ground access. In locations where bundles cannot be anchored through racking within existing woody vegetation, battered piles should be driven on downstream sides to prevent mobilization during runoff events. A similar approach should be implemented in larger 3^{rd} and 4^{th} order streams to ensure the stability of bundle placements. These locations will require ground-based equipment access, and thus should be applied in locations where there are existing access roads.

The use of a helicopter to place the bundles is likely the most efficient and cost-effective approach to the placement of bundles in roadless areas. The following guidelines should be implemented when planning the use of a helicopter to install the bundles:

- Helicopter "turns" (the distance between pick up and drop off of bundles) should be limited to 2 miles to reduce flight times and increase placement efficiency.
- Existing roads and logging landings should be used to stage bundles for pick up by the helicopter.
- A Vertol helicopter can lift approximately 8,000 lbs. which likely restricts the lift capacity to a single bundle per turn.
- Depending on flight distance a helicopter can likely place between 6 – 8 bundles per hour.

Costs associated with the action include time and equipment for thinning and bundling work, the reconnaissance of bundle placement sites, and the helicopter mobilization and operation costs.

Long-term function of the beaver dam analog strategy will be best achieved with the re-establishment and retention of a viable and healthy beaver population. This will create a regenerative and self-sustaining process of beaver dam construction and repair and will reduce the reliance on human intervention. This will likely require the reduction in removal and trapping of beavers in the Camas basin, the introduction of new animals, and the regeneration of riparian forests as food sources.

Resiliency to Climate Change

The functions of beavers and beaver dam impoundments may be even more important given the latest projections from recent climate change modeling. These models predict a 16% decline in maximum snow-water equivalent values for the Camas Creek watershed by the 2040's (Hamlet et al. 2013). This research also predicts a 20% increase in peak flow magnitude, and a 13% decrease in mean summer baseflows over this same period, which would exacerbate summer dewatering within the Camas alluvial fan (Hamlet et al. 2013, NSD 2016). The construction of beaver dam analogs and their ability to recharge groundwater to support summer baseflows and to impound water during storm events will provide watershed resiliency to predicted changes in the seasonal pattern of runoff. Any future application of this treatment should quantify the proposed storage and relate the impoundment potential to changes in summer baseflow and high flow.

Timeline for Implementation and Resulting Benefits

An action team should be developed consisting of local land managers and project sponsors to identify specific thinning opportunities and to develop the specific construction and access plans necessary to install the beaver dam analogs. This planning can be completed in the near-term with project implementation within 1 – 3 years. This action is a short-term opportunity. Once completed, benefits associated with instream habitat complexity would be immediate (1-3 year timeline), while benefits associated with basin hydrology and riparian habitat would progress over a long-term timeline (3+ years).

3.1.2 Road Decommissioning

Forest roads provide important access throughout the Camas watershed for recreation, hunting, and timber harvest. However, forest road density in the watershed frequently exceeds 4 miles per square mile as described in the Geomorphic Assessment (Map 3, NSD 2016), and the construction of forest roads for logging and recreation has likely increased delivery of fine sediments to tributaries in the Camas watershed. Roads also tend to concentrate flows into roadside ditches due to reduced infiltration rates by compacting and sometimes surfacing, increasing flashy runoff and inputs to tributary channels. Roads located within 150-feet of creek channels are considered to provide the highest risk to riparian function and high road densities are likely impacting the hydrologic regime and fine sediment delivery to tributaries in the study area (Ecovista 2003). According to the Camas Creek Assessment (Ecovista 2003), the subwatersheds that are most likely to be impacted from roads are the upper Camas (Bowman and Bear Wallow Creeks), lower Hidaway, and the Cable Creek subwatersheds (Map 3).

While the decommissioning of forest roads can provide immediate benefits to stream conditions, the selection of these roads needs to be carefully balanced with the need for continued recreational, harvest, and fire management access. The decommissioning of roads should concentrate efforts in the following locations:

- Upper Camas
- Hidaway Creek
- Cable Creek

Map 3 shows the areas of highest road density. Within these areas, decommissioning should focus on roads within 150-feet of the creek channel, areas exhibiting mass wasting, and areas with road densities greater than 4 miles per square mile. Decommissioning of roads and road segments would result in the permanent closing, stabilization, and hydrologic disconnection of the road prism to eliminate the need for future maintenance and to restore aquatic and terrestrial habitats. This would include a variety of treatments including removal of culverts and fill at stream crossings, construction of new waterbars and dips, outsloping of road surfaces, recontouring or blocking of road entrances, scarification of the road prism and ditches, placement of cleared brush on the road surface, and seeding or revegetation of select sites.

A road decommissioning plan could be developed with the USFS and local users to identify key access arterials that need to be retained, and subsequent improvements to those arterials that would address possible erosion issues. Special consideration should be given to maintaining a working road network to support the management of forest health, recreation, fire management and emergency response, commercial timber management, and range access. A decommissioning plan should also identify creek crossings with undersized culverts or fish passage barriers for repair or full removal to address any issues with blockage or potential for culvert failure.

Objectives Addressed

- Reduce road density within riparian corridors to reduce sediment inputs into tributary streams, improve riparian conditions, and reduce rapid runoff from storm events to decrease peak flow event magnitudes on the mainstem Camas Creek.

Feasibility

Once a road is selected for retirement the construction steps are relatively straight forward. Road decommissioning typically requires ground-based equipment to remove drainage devices, rip road surfaces, create barriers to vehicle traffic, and revegetate. Road selection and decommissioning methods should be closely coordinated with local USFS staff and regulations. Based on the density of roads and the scale of potential road decommissioning in the Camas watershed, USFS funding for decommissioning may not be adequate or available.

Resiliency to Climate Change

Reducing overland flow along compacted road surfaces during storm events will help to mitigate the projected increases in peak flow magnitude and reductions in summer baseflows under future climate scenarios. Road reduction will reduce the rapid overland runoff thereby decreasing peak flow magnitudes downstream from the upper watershed. In addition, roads recolonized by forest will also intercept rainfall and help to retain snowpack later in the spring and early summer months by providing shade, and groundwater recharge will increase through infiltration to subsurface soils and groundwater storage areas.

Timeline for Implementation and Resulting Benefits

The road decommissioning plan can be initiated with the local stakeholders (land managers, recreational interests, and project sponsors) in the near-term with a goal for identifying and acquiring funding to decommission priority roads within 1 – 3 years. This opportunity could also be combined with the forest thinning and beaver dam analogue treatment, which will require ground access for equipment in some treatment areas. Access routes could then be decommissioned following thinning and restoration activities. This action is a short-term opportunity to initiate but based on the availability of funding it will likely require 3 – 20 years to complete. Once completed, benefits associated with basin hydrology would progress over a long-term timeline (3+ years).

3.2 Mainstem Camas Creek (Primary AOI)

The primary impaired processes and causal mechanisms within the mainstem Camas Creek (Primary AOI) are as follows (NSD 2016):

- Channel confinement resulting in a change from anabranching to single thread channel, channel incision, altered sediment mobilization and deposition processes, loss of groundwater storage and hyporheic exchange, and a reduction in floodplain connectivity and overall flow capacity.
- Riparian vegetation removal and ungulate grazing resulting in very poor woody riparian vegetation, a reduction in LWM recruitment potential, and a lack of stream shading.
- Poor instream complexity (pools, cover, secondary flow channels) resulting from lack of wood recruitment due to human actions (removal, confinement).

The actions below have been spatially segmented into areas upstream of the Camas alluvial fan (upstream of RM 14.75/Reach 1), and downstream of the alluvial fan (downstream of RM 14.75/Reaches 2 – 6) as shown in Map 4. Reaches 1-5 all have areas of channel confinement, riparian degradation, and poor instream habitat; however Reaches 4 and 5 contain the primary areas of human infrastructure and habitation (Ukiah). Landowners and land managers should also identify opportunity areas in the Secondary AOI such as Cable Creek and Hidaway Creek where these restoration actions could be implemented should funding become available.

3.2.1 Grazing Management

Riparian health from Cable Creek to Ukiah is primarily poor to very poor in condition (NSD 2016, Ecovista 2003). Historically, the riparian corridor was likely characterized by robust populations of willow, alder, hawthorne, cottonwood, fir, aspen, and ponderosa pine (Thorson et al. 2003). Timber harvest and subsequent grazing by cattle and elk has reduced riparian health throughout the Primary AOI and in portions of the Secondary AOI, including Cable Creek. Recovery of a functioning riparian zone is essential to addressing limiting factors associated with the lack of wood and pool formation, forming and maintaining an anabranching channel form, improving bank stability and reducing sediment input, and lowering high summer water temperatures (NSD 2016). Figure 7 shows typical riparian conditions within the Primary AOI.

Two actions are essential to the restoration of the riparian corridor in the Primary AOI:

- Reducing grazing pressure on woody species from cattle and elk;
- Increasing flow interaction with the adjacent floodplain (discussed below).

Map 5 shows the proposed area of grazing management associated with the Primary AOI. Within this area a number of actions can be implemented to reduce and eliminate the heavy browse of woody species, these include:

- Establish off-channel watering or specific "water gaps" and stream crossings to limit herbivore access to the creek, limit bank trampling, and reduce grazing pressure near the stream channel. Off-channel water development for stock should be developed prior to any riparian exclusions.
- Development of a "rest/rotation" plan for the riparian corridor that focuses on reducing grazing pressure during the growing season, and specifies the timing, duration, and frequency of grazing (Wyman et al. 2006).

Figure 7. Cattle grazing along the right bank of Camas Creek (left). Grazing, historical vegetation removal, and an incised channel has resulted in very limited riparian growth (right).

Additional considerations must also be given to the overall distribution of livestock, stocking rates, utilization levels and patterns, and fencing/pasture design all with the goal of maintaining the economic feasibility and practicality of the management strategy while targeting the recovery of woody species (Leonard et al. 1997). Land owners and managers should work together to identify areas where existing pastures could be subdivided and old fences refurbished to improve upland forage use. The key to the successful implementation of a riparian area management program will be the understanding, input, and cooperation of the livestock managers within the area. This will likely involve public workshops where local managers can identify critical needs in balance with the goal of improving riparian health.

The presence of deer and elk in the watershed and their typical reliance on browse in riparian areas indicates that these ungulates contribute significantly to the depression of woody species along Camas Creek and in portions of Cable Creek. Along with a cattle grazing management plan, the restriction of deer and elk within the Primary AOI and other heavily browsed riparian areas should also be implemented where appropriate. Local landowners should work with managers to identify browsing and overwintering locations commonly used by ungulate populations. The deer and elk fencing plan should mirror or support any cattle fencing plan, however deer and elk fencing should be a minimum of 6-feet tall with a 16-inch gap at the bottom to allow smaller animals to pass (VerCauteren et al. 2007). Since these fences are typically more expensive than the traditional 4-strand barb wire and post fence used on cattle ranges, exclusion fencing should concentrate on areas of critical regrowth. The exclusion zones can then be rotated through a monitoring program that assesses riparian response and health. Oregon Department of Fish and Wildlife and USFS should also be engaged in these conversations to ensure that hunting access is maintained for the management and regulation of natural ungulate populations.

Objectives Addressed

- Restore riparian areas to a proper functioning condition which allows the riparian zone to stabilize stream banks, dissipate flood energy, filter and trap sediments, develop long-term, and improve wildlife habitat and stream cover (Prichard et al 1998).

Feasibility

Given private land ownership throughout much of the Primary AOI, the development of a grazing plan will require coordination between local landowners, CTUIR, and public land managers within USFS, ODFW, Umatilla County, and the City of Ukiah. Initial costs will include the construction of exclusion fencing, however annual maintenance will also need to be accounted for, along with identifying the parties responsible for management of the grazing plan.

Resiliency to Climate Change

The establishment of a robust riparian floodplain within the primary AOI will provide stream shading and floodplain roughness which will help to reduce summer water temperatures and slow and dissipate the energy of increased flood flows upstream of Ukiah.

Timeline for Implementation and Resulting Benefits

The grazing management plan can be initiated with the local stakeholders in the near-term and a pilot fencing project should be implemented within 1 – 3 years. This pilot project should attempt to coincide with the pilot wood loading project (described below) to achieve greater biological benefits associated with floodplain flooding and woody riparian vegetation restoration. This pilot project could show the local community the scale of the proposed project elements and build a trust between the stakeholders moving forward into other actions. This action is a short-term opportunity. Once completed benefits associated with improvements with increased woody and forested floodplain conditions would likely occur over a long-term timeline as the riparian corridor becomes established (3+ years).

3.2.2 Large Woody Material Loading

Figure 8. Typical conditions in mainstem Camas Creek at RM 15.7.

The role of large wood in streams and the benefits associated with pool formation, channel processes, fish habitat, and the routing of sediment and water has been well documented (Abbe and Montgomery 1996, Abbe and Montgomery 2003, Collins et al. 2012, Montgomery et al. 1995). Stable accumulations or key pieces of large woody material (LWM) act as hard points in the floodplain that create backwater, promote sediment deposition and pool formation, and in some areas allow the development of forested islands that provide a future source of LWM to the channel, maintaining an anabranched channel planform in the long-term. The lack of a robust riparian community has resulted in reduced channel shading and higher stream temperatures, a lack of large wood recruitment and a similar reduction in pool formation (Ecovista 2003). LWM also supports hyporheic flow recharge which is important for influencing water temperatures and in supporting salmonid redd health. The lack of pools, large wood, the predominant riffle/plane bed habitat, and poor riparian quality identified during the field survey in 2015 all correlate to the primary limiting factors for steelhead and Chinook salmon as documented in the Camas Creek Watershed Assessment (Ecovista 2003). Along with the lack of instream wood and pool complexity, the Camas Creek channel has experienced incision from channel confinement from RM 15 (the upstream extent of the alluvial fan) downstream to RM 12.6 (just upstream of the Camas Street Bridge). Figure 8 shows typical conditions near RM 15.7 in Reach 1.

Based on Oregon Watershed Enhancement Board (OWEB) criteria and the 2015 field data, large wood loading and pool frequency are both below "desirable" conditions (WPN 1999). Large wood loading ranged from 0 key pieces/mi to 10.1 pieces/mi, which is below the OWEB criteria for a "desirable" condition (> 48 key pieces/mi) (WPN 1999). Further, OWEB defines a key piece as being >24 inches in diameter and 32 ft in length, and very few pieces or standing trees of this size were located during the field assessment (WPN 1999). Pool frequency ranged from 0 pools/mi to 1.6 pools/mi in reaches through or above Ukiah within the primary AOI, which is well below the OWEB criteria for a "desirable" condition (~ 15 pools/mi).

Wood loading targets typically use reference reaches of "natural and unmanaged" forests (e.g. Fox and Bolton 2007). Since the Camas watershed has been highly modified through timber harvest, there are no applicable reference reach conditions for determining wood loading targets within the watershed itself. In developing a target for wood loading on Camas Creek we used the best available scientific literature as follows:

- OWEB puts the "desirable" wood loading at >48 key pieces/mile (WPN 1999).
- Fox and Bolton (2007) indicate that for "douglas-fir-ponderosa pine" forests in unmanaged basins a recommended loading (75^{th} percentile of their dataset) of 400 to 500 pieces and 32 key pieces/mile.

<u>Given these recommendations, the proposed wood loading for Camas Creek is 32 - 48 key pieces per mile, with a resulting target of > 15 pools per mile.</u>

Increased wood loading can be accomplished through the installation of engineered log jams at strategic locations throughout the Primary AOI (Map 6). Wood loading should also be considered in select tributaries such as lower Cable and Hidaway Creeks, and in association with beaver dam analogs as proposed in the Secondary AOI. Engineered log jams in the Camas mainstem should be placed to maximize flow bifurcation, floodplain and secondary channel activation through the localized raising of water surface elevations, increase channel length, and promote an anabranching channel form. This, in turn, will force pool formation, provide overhead cover for aquatic species, recharge floodplain groundwater, create hydraulic complexity for sorting of spawning gravels, improve hyporheic flows supporting water quality and salmonid redd health, and improve riparian growth.

Map 7 shows a typical application of ELJs at RM 17 upstream of Ukiah. In this area two types of ELJs were applied to achieve multiple hydraulic, geomorphic, and habitat-related goals. The apex structures (Figure 9) were positioned to promote flow through existing secondary channels, raise local water surface elevations to improve floodplain flow depths and interaction with riparian vegetation, and to promote scour pool formation. The channel edge structures (Figure 10) were positioned to improve habitat and promote scour pool formation along the channel margins in both primary and secondary channels, and to provide some stability along SR 244. Through detailed engineering efforts these structures can be scaled and designed to fit site-specific bank geometries and flows as needed throughout the primary AOI.

The prioritization of areas for wood loading in the primary AOI should address the reaches with the fewest existing key pieces and pools per mile first, while also prioritizing areas that will provide the greatest increase in habitat formation, floodplain activation, and water storage. Based on the results of the Geomorphic Assessment (NSD 2016), priority locations currently lacking key sized large wood pieces and pools are reaches 2, 4, and 5, all of which are located within the Camas alluvial fan. This does not preclude actions within reaches 1 or 6 as both of these reaches are also well below target conditions for large wood and pool frequency and contain existing habitat areas that could be greatly improved through large wood additions.

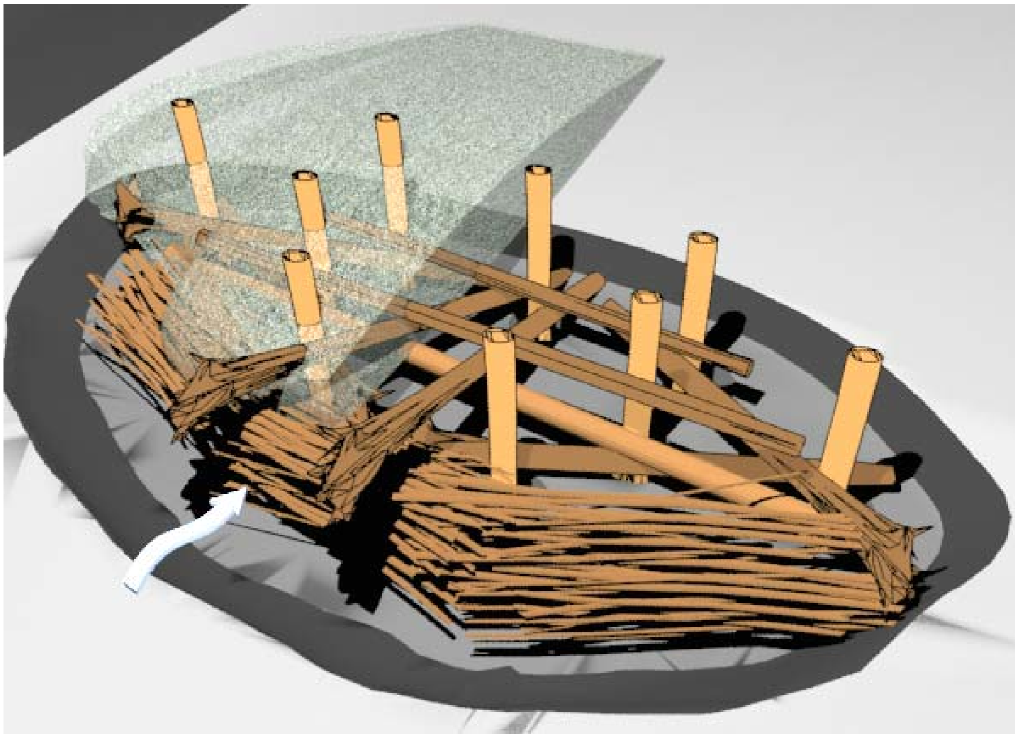

Figure 9. Typical apex style engineered log jam using piles, key sized pieces, and racking material embedded in channel to encourage bifurcation of flow and local increases in water surface elevations.

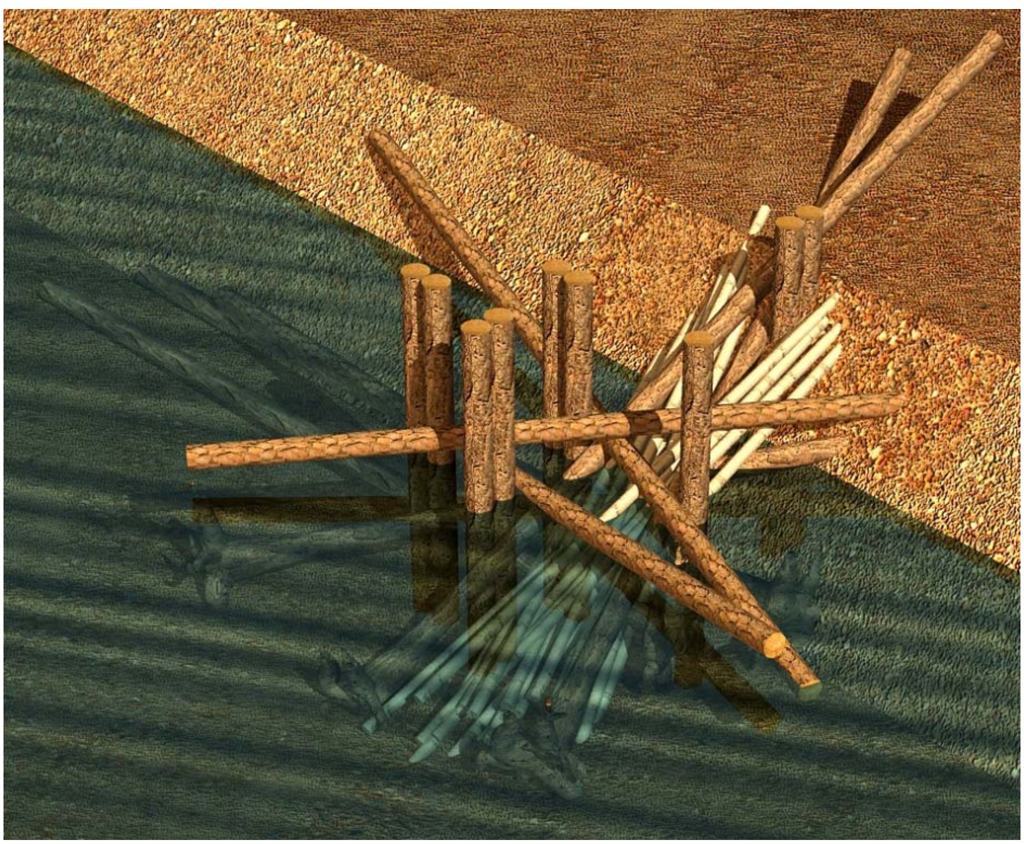

Figure 10. Typical channel edge style engineered log jam using driven piles, key sized pieces with intact rootwads, and racking material to create edge habitat, form pools, and deflect flow away from banks.

To determine the areas of the greatest potential for increases in floodplain activation due to the placement of wood structures we evaluated the effect of a future incremental increase in water surface elevation relative to the adjacent floodplain height. Maps 8 and 9 show the areas of greatest potential for floodplain activation due to increases in local water surface relative to a 2-year flow (1,400 cfs). Throughout reach 1 (Map 8, upstream of the Camas fan) the channel is confined by both the valley walls and SR 244, but as shown by the relative elevation mapping, the potential for increased floodplain engagement is good throughout this reach as much of the floodplain to the south of SR 244 is relatively low lying under existing conditions. This indicates that wood loading could provide an effective means for increasing secondary channel habitats and improving soil hydrology in support of riparian restoration efforts. Map 8 also indicates areas where increasing the water surface would not create additional habitat, such as the segments near RM 17.5 and 16.5, which are confined to the toe of the southern valley wall by levees and SR 244. These areas would require additional restoration actions (such as full or partial levee removal) to improve floodplain connectivity and off-channel habitat. Map 9 highlights the effect of levee confinement in reach 2 and through much of reaches 4 and 5, with little additional floodplain engagement under the 2 ft rise scenario. Much of the additional floodplain and off-channel activation would occur in areas that currently have low-lying, anabranched channels. These areas could be greatly improved with the addition of large wood and ELJs. Channel segments currently confined by levees or elevated roadways (SR 244, Camas Street, etc.) would require full or partial levee removal or road realignments to achieve additional floodplain engagement.

Boulder clusters can also be installed in addition to wood structures to provide flow velocity refuge for juvenile salmonids. Reach 1, which is somewhat confined by the valley walls and SR 244, already exhibits areas of bedrock outcropping and isolated boulder clusters and is the most appropriate reach for the future installation of boulders. The clusters (3 – 5 rocks, 3 - 4-feet in diameter) should be placed between ELJs within the main channel to provide velocity refuge.

In addition to natural process and biological benefits the construction of ELJs will create more in-channel structure to assist with breaking ice jams upstream of Ukiah. Camas Creek has a history of forming ice jams during the winter months with large floes forming during spring runoff (CTUIR, John Zakrajsek, personal communication 2016). The strategic placement of ELJs can work reduce the risk of large ice flows forming in a single location that can cause flooding and damage to infrastructure.

Objectives Addressed

- Increase local water surface elevation to improve hydraulic connectivity between the main channel and floodplain areas to increase water storage and floodplain recharge. This will provide greater flow capacity to reduce flood peaks and will improve groundwater recharge to increase low flows during summer months to reduce channel dewatering.
- Improve flow connectivity to secondary and off-channel habitats.
- Improve floodplain soil moisture to encourage riparian restoration efforts.
- Increase instream wood loading and pool formation to improve rearing and refuge habitats.
- Improve sorting and retention of spawning gravels through creation of backwater, hyporheic, and hydraulic complexity.

Feasibility

The primary AOI provides a high level of ELJ construction feasibility due to good construction access, low summer water levels during construction, and ample opportunity for effective treatments. The upper watershed also provides a local source of large wood which can be harvested and staged up to a year in advance of construction. The thinning efforts described above can be used to contribute larger key pieces as well as slash and racking material for the ELJs, however this will require coordination with the USFS.

All wood treatments should be completed with respect to decisions made concerning the relocation of segments of SR 244 and levee setback or removal efforts (see below). Once the treatment reaches are selected we recommend the use of the Bureau of Reclamation's Large Woody Material - Risk Based Design Guidelines (Reclamation 2014) to implement a risk-based design approach for the placement of individual and groups of wood structures. The approach applies information from the watershed, reach, and site-scales to determine the level of risk for public safety and property damage. The risk level determination then defines the minimal design criteria that should be used for ensuring stability of the proposed LWM structures. This is a transparent step-wise analysis approach that includes public survey and incorporation of landowner and stakeholder input to ensure a final design that is supported by local stakeholders while meeting project goals and objectives. Monitoring of ice jam formations should be completed prior to LWM and ELJ placements to ensure that these structures do not increase flood risk or damage to infrastructure by increasing ice jam formations.

Resiliency to Climate Change

The installation of large wood in the primary AOI helps to mitigate both the higher peak flow and lower summer flows as predicted by current climate change models (NSD 2016). The structures will increase the flood inundation of the adjacent floodplain, slowing and retaining flows, and reducing the magnitude of peak flow quantities through Ukiah. This floodplain recharge will also help to support low water levels during summer months which currently see dewatering of the channel in reaches 3 – 6.

Timeline for Implementation and Resulting Benefits

While the Primary AOI encompasses multiple private and public stakeholders we recommend that a pilot project located in one of the priority reaches and with a single or multiple willing landowners should be implemented in the short-term (1-3 years). This planning, design, and construction for engineered log jam projects typically takes 1 year to 18 months to complete given the level of design or landowner complexity. This pilot project could show the local community the scale of the proposed project elements and build a trust between the stakeholders moving forward into other actions. This action is a short-term opportunity. Once completed benefits associated with improvements to instream habitat would be immediate, with benefits to floodplain connectivity, channel form, and function likely occurring following a channel forming flow event (2-year flow) in a short-term timeline (1 – 3 years). Many ELJ structures have an intended design lifespan of 50 years, allowing natural processes of wood delivery and riparian forest regeneration to develop.

3.2.3 State Route 244 Relocation

The construction of State Route (SR) 244 to the north of Camas Creek has confined the active channel corridor, resulting in a single thread, high-velocity channel along much of the roadway. Within the Primary AOI, this constriction has also reduced floodplain capacity and eliminated the historical anabranching channel form while reducing the channel's natural capacity to maintain this planform (NSD 2016).

Channelization of Upper Camas Creek associated with expansion of SR 244 from Starkey to Ukiah occurred in the 1950s (Popek 1995). Prior to the construction of SR 244 in the Primary AOI, a county road ran parallel to Camas Creek east from Highway 395 along the valley toe, along what was likely an old railroad grade. Due to its location along the edge of the alluvial fan and floodplain upstream, this historical road alignment did not impede the natural course of Camas or confine the floodplain.

With the 1954 completion of SR 244, the floodplain was bifurcated in many places, including the alluvial fan from RM 13.6 – 14.7; in the unconfined valley bottom from RM 16.2 – 16.7, RM 17.4 – 17.7, RM 17.9 – 18.3, RM 18.5 – 18.9, RM 20.4 – 20.5, and RM 21.5 - 21.8; and in the upper watershed at 29.3. In many places, the SR 244 road alignment acts as a levee, and results in more than 85 acres of disconnected floodplain and potential off-channel habitat areas (Figure 11).

Figure 11. Typical floodplain infringement from SR 244 within the Primary AOI.

Map 10 shows the proposed areas of SR 244 relocation within the Primary AOI. The locations for relocation are proposed in order to maximize increases in floodplain capacity and future channel migration potential. Highway relocation includes construction of a new road prism at the toe of the northern valley wall/floodplain boundary, and the removal of all road fill and riprap protection from the current alignment. The three high priority locations are:

- RM 13.6 – 14.7
- RM 16.2 – 16.7
- RM 17.9 – 18.3

Secondary priority locations are:

- RM 18.4 – 19
- RM 20.3 – 20.5

Table 1. Proposed SR 244 relocation metrics.

LOCATION	LINEAR FEET OF HIGHWAY REMOVAL	LINEAR FEET OF HIGHWAY CONSTRUCTION	ACRES OF RECONNECTED FLOODPLAIN
RM 13.6 – 14.7	5,300	5,900	51
RM 16.2 – 16.7	2,800	3,100	17.6
RM 17.9 – 18.3	4,900	5,100	18.7
RM 18.4 – 19	2,200	2,300	4.9
RM 20.3 – 20.5	1,200	1,400	3.8

The improvement of floodplain capacity and channel migration potential provided by the SR 244 relocation at RM 13.6 – 14.7 would also benefit from the removal of relict levees that are currently failing and directly adjacent to the channel. The locations of these levees are shown in Map 10.

If highway relocation is not feasible then the installation of culverts or bridges in strategic locations may still provide increased floodplain capacity but would not provide a restoration of channel migration processes. In addition, these areas would only be hydrologically connected during seasonal peak flow events which limits their biological benefits.

Objectives Addressed

- Increase floodplain capacity to provide storage and attenuation of peak flows.
- Increase channel migration potential to allow an anabranching channel form to improve the formation of mainstem and secondary channel habitats.
- Increase width of channel corridor to allow riparian forest to regenerate.

Feasibility

The relocation of SR 244 will require support from multiple private landowners to allow the acquisition of a new highway right-of-way, construction of new highway alignments that meet Oregon Department of Transportation design and safety standards, and removal of abandoned highway segments. We recommend that a separate feasibility study should be conducted to bring both local and state stakeholders together to identify feasible relocation options and weigh those options against project construction costs and overall benefits. This study would then determine if highway relocation is a feasible treatment through the Primary AOI.

Resiliency to Climate Change

Highway relocation in the primary AOI helps to mitigate both the higher peak flow and lower summer flows as predicted by current climate change models (NSD 2016). The increase in floodplain capacity during peak flow events will allow for the greater retention of flood flows, thereby reducing the magnitude of peak flows through Ukiah. This floodplain recharge and the formation of multiple channel threads will also help to support low water levels during summer months which currently see dewatering of the channel in reaches 3 – 6.

Timeline for Implementation and Resulting Benefits

Due to the complexities associated with coordination and consensus of multiple private stakeholders and high costs, this action will likely require 3 – 20 years to coordinate, design, and implement and is therefore considered a long-term opportunity. Once completed, benefits associated with channel response and to channel form and function would likely occur over a long timeline (3 – 20 years).

3.2.4 Levee Setback in Ukiah, Oregon

Channelization and levee construction occurred at a large scale in response to the flood of record in 1965, resulting in a straight, single thread channel through Ukiah to the Camas Street Bridge. Much of the material used to create the levees was likely dredged from the creek channel. This dramatic change in channel planform initiated an immediate channel response, with meanders developing within the new levees following their construction. This process lead to the rapid erosion of the levees upstream of Ukiah from the migrating creek, delivering high sediment loads to the creek downstream from the eroded levees and floodplain. An expansion of the creek through town due to the wider alignment of the existing levees results in a loss of transport capacity and the deposition of sediment in the creek upstream of the Camas Street Bridge. This accumulated sediment has remained in-place due in part to the Camas Street Bridge, which confines flow, and the resulting aggradation of sediment has essentially buried the channel through town, exacerbating summer dewatering (NSD 2016).

The construction of levees to the north and south of Camas Creek through Ukiah has confined the active channel corridor, resulting in a single thread, high-velocity channel. This constriction has also reduced floodplain capacity and eliminated the historical anabranching channel form while reducing the channel's natural capacity to maintain this planform (NSD 2016). The lack of channel capacity through Ukiah results in overtopped levees on both left and right banks immediately upstream of the Camas Street bridge at a discharge of 1,400 – 2,000 cfs (between the 2 – 5-year flow event), inundating portions of Ukiah.

Dredging of the channel through Ukiah to increase flood capacity without associated levee setback would be an expensive and short term solution, requiring periodic additional dredging following larger flood events to clear newly deposited sediments. The configuration of the levees, with an increase in the width of the channel through Ukiah relative to upstream of town, creates hydraulic conditions through town that encourages the deposition of sediment. Additionally, the Camas Street bridge creates a local hydraulic obstruction that slows water during high flows, creating conditions for the accumulation of sediment. Figure 12 shows the aggradation that has taken place since the construction of the new bridge in 1983, exacerbating seasonal dewatering of the creek. The establishment of vegetation on these accumulated sediments suggests that the creek is in a state of disturbed equilibrium, where little to no additional sediment will accumulate during normal flooding events. Thus, any dredging of these accumulated sediments without levee setback would only create conditions for sediment to again deposit in the reach through Ukiah. In order to maintain flow capacity realized through dredging without levee setback, it would need to happen regularly and would likely still be insufficient to prevent the 100 yr flood from overtopping the levees through Ukiah.

Figure 12. Camas Creek aggradation at the Camas Street Bridge (Sep. 2015).

Levee setback through Ukiah assumes that all structures to the north of the creek channel will remain in place. The floodplain area south of the channel provides greater opportunity to establish an expanded channel migration corridor based on the proximity to the Camas Creek fan, and fewer dwellings and structures. As shown in Map 11, levee setback would require the removal of 2,400 linear feet of existing levee, and the construction of 2,500 linear feet of new levee. This would create a new active channel corridor with a mean floodplain width of 320 feet. This plan would also require the realignment of approximately 500 feet of Moxie Road as it approaches Camas Street to allow egress to the realigned levee.

Levee setback would begin as an extension from the existing levee near RM 12.95 and would align in a southwest direction to increase the floodplain area by 11.5 acres. A proposed levee alignment is shown on Map 11. This alignment can be adjusted to allow for the retention of existing structures to the south of the current channel, but the alignment that is shown would allow for the greatest benefit to both channel process and flood capacity.

With the expansion of the floodplain and channel corridor allowed by the levee setback there is a need for expansion of the existing Camas Street Bridge. A feasible solution is the construction of a second or expanded bridge deck to the south of the existing bridge. While it is desirable to remove all abutments and constrictions from the channel and floodplain, the resulting removal of the existing (functional) bridge and construction of a 350-ft. single span bridge may not be feasible or cost effective.

New channel construction through Ukiah following levee setback would target the creation of anabranching channel forms. This excavation would attempt to establish an equilibrium grade that is lower than the current channel elevation. Channel construction would also include the installation of ELJ structures to promote and maintain the anabranching channel form along with localized improvements for instream habitats.

Objectives Addressed

- Restore ability of the channel to form and support an anabranching channel, which in turn improves potential for perennial flows by reducing cross sectional channel area. This would directly address channel dewatering and the resulting fish passage barrier formed during summer low flows.
- Increase channel capacity to reduce flood risk.
- Allow channel migration to the south and away from human structures in Ukiah.
- Improve riparian floodplain habitats to increase stream shading, increase wood recruitment to address high summer water temperatures and the lack of instream wood and pool complexity for juvenile salmonids.

Feasibility

Levee setback through Ukiah will require a coordinated effort between local stakeholders and project proponents. The presence of multiple landowners, structures and dwellings, roads, and the need to expand the Camas Street Bridge, and the overall costs associated with the effort result in a difficult project to implement. We recommend that a stand-alone feasibility study should be performed prior to initiating any detailed design work for the levee setback action. This study should further evaluate flood risk through Ukiah, local stakeholder willingness to participate in the action, permitting constraints, and provide an assessment of bridge expansion options and overall project costs.

Resiliency to Climate Change

The increase in channel capacity and the resulting reduction in flood risk provides long-term resiliency to increases in peak flow quantities as predicted by the latest climate change models (NSD 2016).

Timeline for Implementation and Resulting Benefits

Due to the complexities associated with coordination and consensus required of multiple private stakeholders, and the likely high level of project cost this action will likely require 3 – 20 years to coordinate, design, and implement and is therefore considered a long-term opportunity. Once completed this project would provide immediate benefits related to the mitigation of flood risk in Ukiah. Channel response and benefits to channel form and function would likely occur over a longer timeline (3 – 20 years).

3.2.5 Levee Removal Upstream of Ukiah, Oregon

Historically, levees have confined Camas Creek from the Camas Street Bridge (RM 12.5) upstream through town to the head of the alluvial fan at RM 14.75. Since the mid-1960's the levees upstream of Ukiah have been breached in multiple locations, with these areas contributing an estimated 98,000 cubic yards of material to the channel (NSD 2016). Field reconnaissance in 2015 confirmed that the levees near RM 14.2 continue to erode (Figure 13), however the levees upstream of RM 14.4 show little indication of instability (Figure 13). The historic levee confinement has typically resulted in channel incision where, on average, the current channel is 6-8 feet below relic channels on the floodplain. The confinement has also led to the formation of a single-thread channel, and a reduced channel migration corridor. Currently the 2-year flow is contained within the levees where they remain intact in reaches 2, 4, and 5 (Figure 14, NSD 2016). Large swaths of low-lying floodplain to the north of the right bank levee in reach 2 are currently inactive even at higher flows.


Figure 13. Eroding levee along Camas Creek at RM 14.2 (left) and intact left bank levee at RM 14.4 (right).

Levee removal upstream of Ukiah will allow for the establishment of a new active channel corridor 100 – 1000 feet in width (average width of 750 ft.), increased floodplain activation, and the elimination of levee erosion and gravel mobilization (Map 12). Approximately 8 acres of additional floodplain area could be immediately reconnected with the removal of the right bank levee between RM 14.4 – 14.6. Removal of other levees would allow the channel to re-establish an active channel corridor and anabranched planform. This action can be implemented independently of other actions but the overall effectiveness will increase with the relocation of SR 244 from RM 13.6 – 14.7, and the installation of large woody material (LWM) within the stream channel.

The installation of LWM would initiate several beneficial processes in conjunction with the levee removal:

- Bed aggradation in the lee of structures and in backwater areas following channel forming flows; increased floodplain connectivity due to flow deflection and local increases in water surface elevations.
- Higher groundwater table and improved riparian growth potential.
- Anabranching channel planform within an active channel migration corridor.
- Increased hydraulic complexity encouraging pool formation, gravel sorting, and habitat development.

The levee sections proposed for removal shown on Map 12 were identified from ground reconnaissance and aerial mapping (where ground access was not available). A total of 4,800 linear feet of levee is available for removal. Of those sections the priority removal areas are (in order of greatest to least priority):

- RM 14.4 – 14.7. 3,400 linear feet of relict levee on the left and right banks confine the channel and isolate adjacent floodplains from inundation. No infrastructure immediately adjacent to the levee removal areas would be at risk. Figure 13 shows the left bank levee within this area. Levee removal in this location should also evaluate potential future channel migration risk along SR 244.
- RM 14.1 – 14.3. 600 linear feet of eroding levee on the left and right banks provide little flood protection and are continuing to contribute coarse-grained material into the stream channel. Levee removal in this location should also evaluate potential future channel migration risk along SR 244.
- RM 13.5 – 13.7. 800 linear feet of levee on left and right banks currently protect several buildings on private property. Levee removal in this location will require coordination with private landowners.

This action can be combined with the levee setback and enhancement of channel capacity described above, along with the construction of flood relief channels as discussed below.

Objectives Addressed

- Increase channel capacity to reduce flood risk and promote sediment deposition upstream of Ukiah.
- Restore ability of the channel to form and support an anabranching channel type which in turn improves potential for perennial flows.
- Allow future channel migration to the south across the fan and away from human structures in Ukiah.
- Improve riparian floodplain habitats to increase stream shading, increase wood recruitment to address high summer water temperatures and the lack of instream wood and pool complexity for juvenile salmonids.

Feasibility

The feasibility of these actions is good in relation to construction access and removal of the levees themselves. The upstream levee segments at RM 14.4 – 14.7 provide the greatest feasibility with regards to a lack of existing human infrastructure that could conflict with levee removal or with subsequent channel migration and floodplain inundation. The downstream segments at RM 13.5 – 13.7 are the least feasible due to the protection that the existing levees provide to human infrastructure. The majority of these actions would primarily be performed on private property and within the ODOT highway right-of-way. Coordination and cooperation from these stakeholders is essential to the implementation of this action.

Resiliency to Climate Change

Levee removal in the primary AOI helps to mitigate both the higher peak flow and lower summer flows as predicted by current climate change models (NSD 2016). The increase in floodplain capacity during peak flow events will allow for greater retention of flood flows, thereby reducing peak flow magnitude through Ukiah. Floodplain recharge will also help to support low water levels during summer months, which currently see dewatering of the channel in reaches 3 – 5.

Timeline for Implementation and Resulting Benefits

Due to high cost and the complexities associated with coordination and consensus required of multiple private stakeholders, this action will likely require 3 – 20 years to coordinate, design, and implement and is therefore considered a long-term opportunity. Once completed this project would provide immediate benefits related to the mitigation of flood risk in Ukiah. Channel response and benefits to channel form and function would likely occur over a longer timeline (3 – 20 years).

3.2.6 Construction of Flood Channels near Ukiah, Oregon

The flood channels are existing topographical depressions that run south of Ukiah from the existing channel across the alluvial fan to the southwest. Modeling of the existing hydraulic conditions during a 2-year flood event showed that these channels do not currently convey flood flows (Figure 14). This is largely due to the

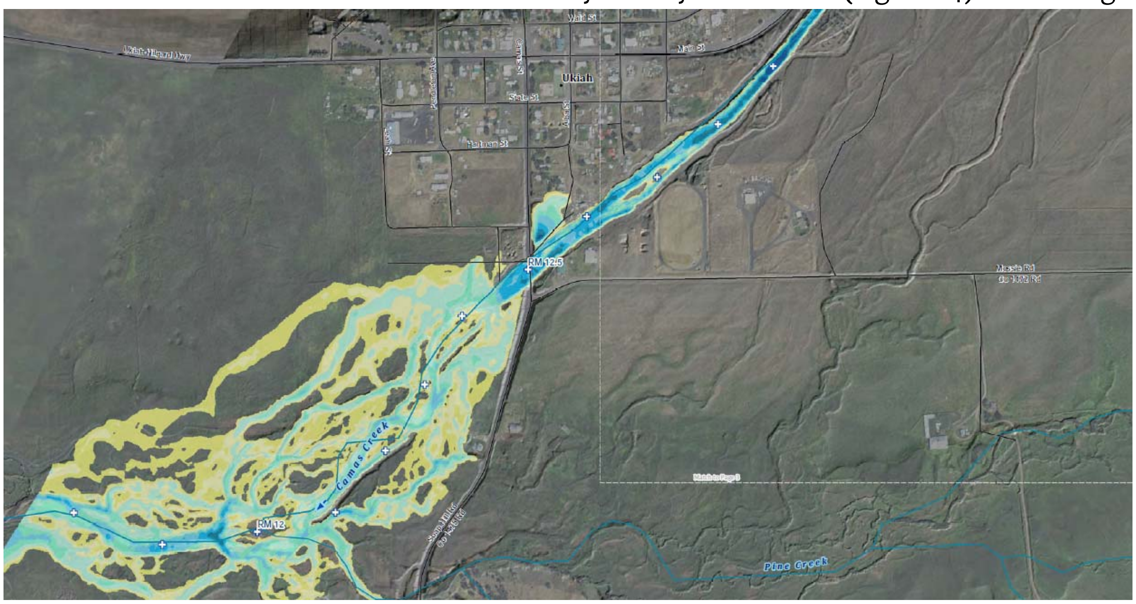

Figure 14. Existing Condition 2-Year Flow (1,400 cfs) Flow Depth near Ukiah, Oregon (NSD 2016).

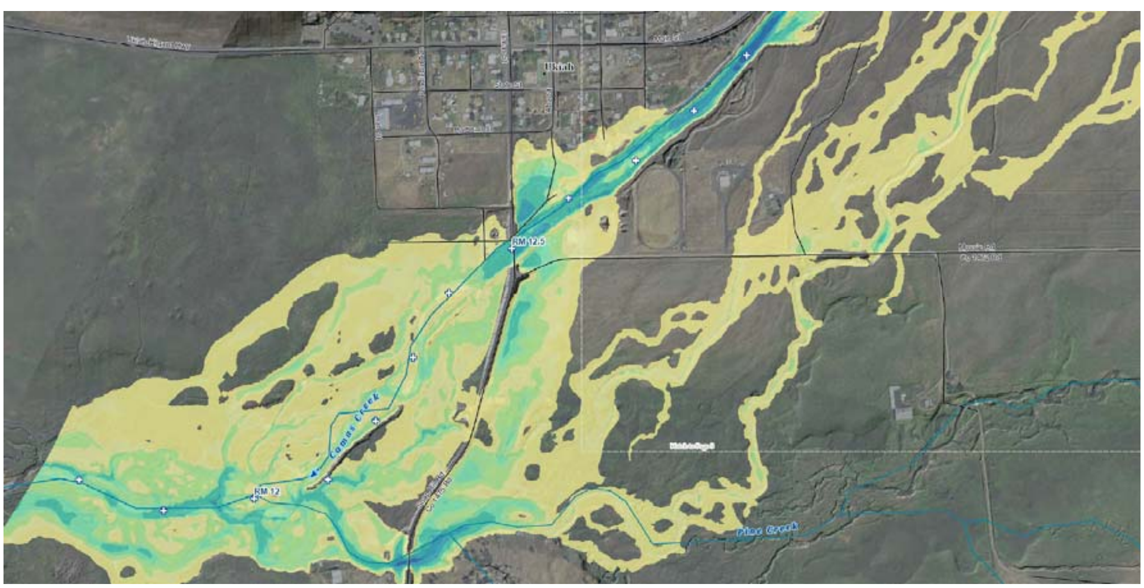

Figure 15. Existing Condition 100-Year Flow (4,900 cfs) Flow Depth near Ukiah, Oregon (NSD 2016).

incised nature of the channel and the existing levees. Modeling of the 100-year flow event shows that these channels are able to carry flood flows during extreme events (Figure 15).

This action proposes to increase the hydraulic connection to these existing flood channels to reduce the flood risk to Ukiah. This action would also require additional infrastructure within the flood channels to safely convey flows to Pine Creek without increasing risk to existing human infrastructure such as the sewage treatment ponds or nearby drain fields. The goal of the action would be to divert up to 10 – 15% of a peak flow event. This would provide some additional capacity during flood events which would reduce flood risk through Ukiah, but would provide little improvement to main channel geomorphic processes or habitat conditions unless implemented with levee removal and wood loading actions.

The current flood risk through Ukiah was evaluated as part of the Geomorphic Assessment (NSD 2016). Flood risk was also assessed by simulating an unsteady discharge, increasing flows from 1,000 cfs to 9,800 cfs (twice the 100-year flow) to determine the discharge at which banks, levees, and roadways are overtopped. The evaluation did not model a scenario of levee failure, thus the results of the modeling exercise only convey the risk of flooding while the existing levees remain intact.

At higher flood stages (100 year flow event), the upper alluvial fan becomes activated at several locations along the left bank near RM 14.6 and 14.1, with additional overbank flow near RM 13.25. Overbank flows span the alluvial fan to the southwest, entering Pine Creek before it rejoins Camas downstream of Ukiah, thus diverting flood flows away from the present mainstem channel of Camas and reducing the overall flood magnitude at Ukiah. The floodplain channels along the alluvial fan are not well connected at flows below the 100-year discharge (4,900 cfs) due to channel incision driven by levee confinement. Lowering or breaching of the levees, along with excavation of inlet channels and the installation of large wood structures at the existing flood channel inlets to aggradate gravels and raise local WSE would alleviate flood risk in Ukiah, directing portions of total flow across the fan and into Lower Pine Creek (NSD 2016).

Map 13 shows the locations of existing flood channels and the flow paths that could be enhanced to carry additional flood flows south across the Camas Creek alluvial fan. Increased activation of the existing flood channels upstream of Ukiah could reduce peak flows through Ukiah by 10 – 15%. This would reduce 100 year flow depths at the Camas Street bridge by only 0.5 ft. immediately following construction. Further reductions in flood depth could be achieved through the following steps:

- Installation of in-channel obstructions (wood) to increase channel aggredation, and raise local water surface elevations to improve flow connectivity between the main channel and the flood channels.
- Excavation of flood channel inlets and portions of the flood channels to improve connectivity and capacity to carry flood flows.
- Potential re-routing of flood channels away from private property and the existing impoundments and sewage treatment facilities within the alluvial fan.
- Installation of culverts within Mossie Road at several locations to improve channel capacity and to protect the road from flooding and erosion.
- Removal of existing, partially eroded levees upstream of river mile 14.
- Protection of existing homes and structures near the existing sports field and track.
- Evaluation of flood risk to the sewage treatment ponds.

Objectives Addressed

- Enhance flows into flood channels across the Camas Creek alluvial fan to reduce flood risk in Ukiah and to improve connectivity between the main channel and the floodplain across the fan.

- Provide flood capacity resiliency through the Ukiah area to allow for future increases in peak flows as modeled under current climate change scenarios for the Camas Creek watershed.

This action would only provide flow relief during large (100-yr) floods, but does not provide corresponding improvements to the current limiting habitat factors. A more effective means of providing greater flood capacity while additionally improving instream habitats is the implementation of setback levees through Ukiah as discussed above.

Feasibility

Implementation of a few or all of the flood channel connection options shown on Map 13 will require support from not only the private landowners effected by potential increased flood flows to the south of Ukiah, but from the greater Ukiah community as well. The proposed actions require the improvements to flood channel conveyance (i.e. channel excavation, culverts in Mossie Road), in-channel obstructions (i.e. large wood structures to deflect flows), and levee removal or breaching. While all of these actions have a relatively high construction feasibility, it will require extensive work with the local community and landowners to implement these actions.

If this action is pursued a detailed study and design will need to be undertaken which will include a full understanding of landowner and stakeholder participation and risks, and a full evaluation of project costs and benefits.

This opportunity will also require a restriction in future building to the south of Ukiah to prevent additional human structures from being in conflict with the desired channel flows and movement. This can be accomplished through city ordinance or policies that create a "no build" zone in relation to the future channel and floodplain areas.

Resiliency to Climate Change

Given the current climate change modeling that predicts a 20% increase in peak flows over the next 40 years, both the frequency and extent of inundation may be at risk of increasing through Ukiah (NSD 2016). The enhancement of flood channels across the Camas Creek fan helps to mitigate the higher peak flows. The increase in floodplain capacity during peak flow events will allow for greater retention of flood flows, thereby reducing the magnitude of peak flows through Ukiah.

Timeline for Implementation and Resulting Benefits

Due to high project costs and the complexities associated with coordination and consensus required of multiple private stakeholders, this action will likely require 3 – 20 years to coordinate, design, and implement and is therefore considered a long-term opportunity. Once completed this project would provide immediate benefits related to the mitigation of flood risk in Ukiah. Channel response and benefits to channel form and function would likely occur over a longer timeline (3 – 20 years).

3.3 Additional Opportunities Considered But Rejected

The development of this assessment of Restoration Opportunities examined several actions that were not ultimately proposed for implementation due to low feasibility. The following briefly describes two of these actions that were discussed with CTUIR staff in the field but ultimately rejected.

3.3.1 Full Channel Realignment to the South of Ukiah

The full realignment of Camas Creek to the south of Ukiah was considered as an alternative to the proposed construction of flood channels (discussed above). This action proposed a channel plug near RM 14.6 and the excavation of a new main channel south across the alluvial fan following an existing flood channel alignment. This action would provide flood risk relief to Ukiah and restore natural migration and floodplain processes to the channel itself.

The action was rejected as not feasible due to the potential construction cost associated with new channel excavation, installation of at least two new bridges at Mossie Rd. and Camas Rd, and the potential impacts to private property both from the new channel and flooding and through the loss of the flowing creek channel through Ukiah.

3.3.2 Full Levee Removal through Ukiah

Full levee removal through Ukiah would increase flood capacity and allow natural channel migration processes to develop to restore both habitat and hydraulic conditions through this reach. This action was rejected as it would require moving most of the human infrastructure south of SR 244 through Ukiah.

4. PRIORITIZATION AND SEQUENCING

The project prioritization framework was developed by applying a hierarchical implementation of restoration strategies (watershed scale process prioritization) adapted from Roni et al. (2002) and Beechie et al. (2008), which results in the logical sequencing of restoration actions based on their probability of "success, response time, and longevity." The logical approach is a very flexible ranking method that has been implemented throughout the Columbia River basin with success. This approach applies the following order to restoration actions:

1. Protect intact habitats.
2. Remove migration barriers to intact habitats.
3. Restore watershed processes (e.g. instream flows, sediment reduction, riparian areas).
4. Instream habitat enhancement.

Using this framework, opportunities were prioritized and sequenced based on the extent and durability of anticipated biological benefits, feasibility (social, construction, permitting, overall complexity), ability to meet project goals and objectives, and their short-term or long-term timeline for implementation and resulting benefits. This prioritization ranked actions separately between the Primary and Secondary Areas of Interest, as these actions can typically be implemented independently from each other. Preference in priority was given to actions that exhibited a high feasibility and/or provided immediate improvement of a targeted impaired process. Table 2 provides the "score sheet" for each of the actions along with their ranking and sequencing.

Within Table 2 the Action Ranking denotes the ranked order of the proposed action within either the Primary or Secondary AOI. The Prioritization and Sequencing rationale describes the reasoning behind the action ranking as well as opportunities for actions to be combined with one another to maximize benefits and gain cost efficiencies. By combining projects and sequencing complimentary actions, impacts to public uses can be reduced, permitting and funding can be streamlined, and disruption to the aquatic and terrestrial environments minimized.

Several of the actions encompass large areas (e.g. multiple stream miles or entire subbasins). Each of these actions typically contain prioritized action areas within them. Please refer to the action descriptions above for discussions of within-action prioritization or sequencing.

4.1 Protect Intact Habitats

Through the assessment of existing watershed conditions, few stream reaches within the Primary or Secondary AOI were identified as suitable for protection or preservation efforts without additional restoration. Most functioning stream channel is located within the upper watershed and is on USFS-managed lands where physical and biological processes are most stable and in turn where relatively functioning habitat exists. Since these areas are on public lands the need to implement protection or acquisition efforts is not necessary. Undeveloped areas in both the Primary and Secondary AOI outside the USFS-managed lands (e.g. floodplain downstream of Ukiah) should be maintained as open or forested to prevent further infringement of the floodplain and riparian corridor. CTUIR and other local stakeholders should identify opportunities for acquiring privately held lands or work with landowners to implement land preservations strategies. These issues are not addressed within the scope of the current restoration opportunities.

4.2 Remove Migration Barriers to Intact Habitats

The primary barrier to fish migration within the Primary and Secondary AOI is the seasonal dewatering of Camas Creek between RM 12 and 14. Several of the actions contribute will increase summer low flows through the recharge of wetlands and groundwater in the upper-watershed and Camas Creek floodplain. These actions are prioritized below. The assessment and implementation of the road decommissioning action should identify the priority barriers to fish migration within the upper watershed (Secondary AOI).

4.3 Restore Watershed Processes

Many of the proposed restoration actions are aimed at restoring natural watershed processes related to water and sediment storage, a channel in dynamic equilibrium, and the development of a healthy riparian corridor with ample wood supply, habitat complexity, and resiliency to natural disturbances and long-term changes. These processes have been impacted over time through road building, timber harvest, floodplain and channel modifications, beaver removal, and grazing. To the extent possible, efforts to restore in situ water and sediment storage in the upper watershed should be implemented to alleviate the impacts of logging and associated road building on runoff and sediment delivery to tributaries. Restoring healthy riparian and upland forests will aid in this effort. Actions that achieve these goals are prioritized accordingly in Table 2, with priority treatment areas discussed in the action descriptions in the preceding sections.

4.4 Instream Habitat Enhancement

Nearly all of the proposed actions would improve instream habitat through increased habitat availability and complexity. Specific instream actions include the placement of beaver dam analogs, ELJs, and boulder clusters. Forest thinning, levee removal, and grazing management are also proposed as potential actions, but are considered indirect actions with regard to instream habitat enhancement. Current instream habitat is limited by altered watershed and reach scale hydrology and sediment loading, limited riparian canopy, and large wood and pool frequency far below OWEB target levels (WPN 1999). Instream actions are prioritized in Table 2 below.

Table 2. Prioritization and Sequencing of Restoration Opportunities.

ACTION	ACTION RANKING	PRIMARY BENEFITS	TIME SCALE TO ACHIEVE BENEFITS	FEASIBILITY	PRIORITIZATION & SEQUENCING RATIONALE
SECONDARY AREA OF INTEREST (UPPER WATERSHED)					
Forest Thinning & Beaver Dam Analog Construction	1	Forest Health Peak and Low Flow Hydrology Attenuation Sediment Retention Instream Habitat Complexity Reduction in the Severity of Fires, and Frequency of Large Stand-Replacing Fires	Short-term	High	Provides immediate benefits to upper watershed forest health and hydrology and can be implemented independently from downstream (Primary AOI) actions. Opportunity exists for thinning efforts to produce woody material for use in the wood loading effort within the Primary and Secondary AOI. Addresses 2,3,4 of logical approach

ACTION	ACTION RANKING	PRIMARY BENEFITS	TIME SCALE TO ACHIEVE BENEFITS	FEASIBILITY	PRIORITIZATION & SEQUENCING RATIONALE
Road Decommissioning	2	Peak Flow Hydrology Attenuation Sediment Reduction Improvements to Riparian Condition	Long-Term	Moderate	Provides long-term benefits to reductions in sediment supply and alterations to basin hydrology. Can be implemented independent of other actions over time, or in association with thinning and beaver dam analog construction.
PRIMARY AREA OF INTEREST (MAINSTEM CAMAS CREEK BELOW CABLE CREEK)					
Grazing Management	1	Stream Temperature Future Wood Recruitment Bank Stability/Sediment Reduction Sediment and Water Storage	Long-Term	High	Provides long-term benefits addressing key instream water quality and habitat ecological concerns. Can be implemented in conjunction or independently of other Primary AOI actions.
Levee Setback Through Ukiah	2	Increase Floodplain Capacity and Channel Migration Corridor Peak and Low Flow Hydrology Attenuation Restore Anabranching Channel Form and Function Reduce Low Flow Passage Barrier	Long-Term	Low	Action should be implemented with instream LWM loading to initiate channel responses and floodplain activation following levee setback.
Large Woody Material Loading	3	Instream Complexity and Cover for Juvenile Salmonids Flow Bifurcation to Restore Anabranch Planform and Increased Floodplain Connection by Increasing Flow Elevations Over a Range of Discharges. Peak and Low Flow Hydrology Attenuation	Short-Term	High	Provides immediate instream habitat, and floodplain benefits. Implement in association with riparian restoration efforts and with efforts to reduce channel confinement.

ACTION	ACTION RANKING	PRIMARY BENEFITS	TIME SCALE TO ACHIEVE BENEFITS	FEASIBILITY	PRIORITIZATION & SEQUENCING RATIONALE
Removal of Levees Upstream of Ukiah	4	Increase Floodplain Capacity and Channel Migration Corridor Peak and Low Flow Hydrology Attenuation Restore Anabranching Channel Form and Function	Long-Term	Moderate	Action should be implemented with instream LWM loading to initiate channel responses and floodplain activation following levee removal.
SR 244 Relocation	5	Increase Floodplain Capacity and Channel Migration Corridor Peak and Low Flow Hydrology Attenuation Restore Anabranching Channel Form and Function	Long-Term	Moderate	Action should be implemented with instream LWM loading to initiate channel responses and floodplain flows following relocation of the highway prism.
Connection of Flood Channels	6	Increase Floodplain Capacity to Reduce Flood Risk in Ukiah during 100-Year Flood Events	Long-Term	Low	This action provides little benefit during flood events smaller than the 100-year flood. It should be implemented with instream LWM loading and levee setback actions through Ukiah to initiate channel responses and maximize instream geomorphic and habitat benefits not achieved with the implementation of this action alone

5. LIMITATIONS

We have prepared this report for the Confederated Tribe of the Umatilla Indian Reservation, their authorized agents and regulatory agencies responsible for the Camas Creek geomorphic assessment and restoration opportunities identification project. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices for geomorphology in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

We appreciate this opportunity to be of service to the CTUIR for this project and look forward to continuing to work with you. Please call if you have any questions regarding this report, or if you need additional information.

Sincerely,

Natural Systems Design, Inc.

John Soden, MS, PWS	Mike Ericsson, MS, PG	Tim Abbe, PhD, PEG, PHG
Senior Biologist	Project Geomorphologist	Principal Geomorphologist

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Maps

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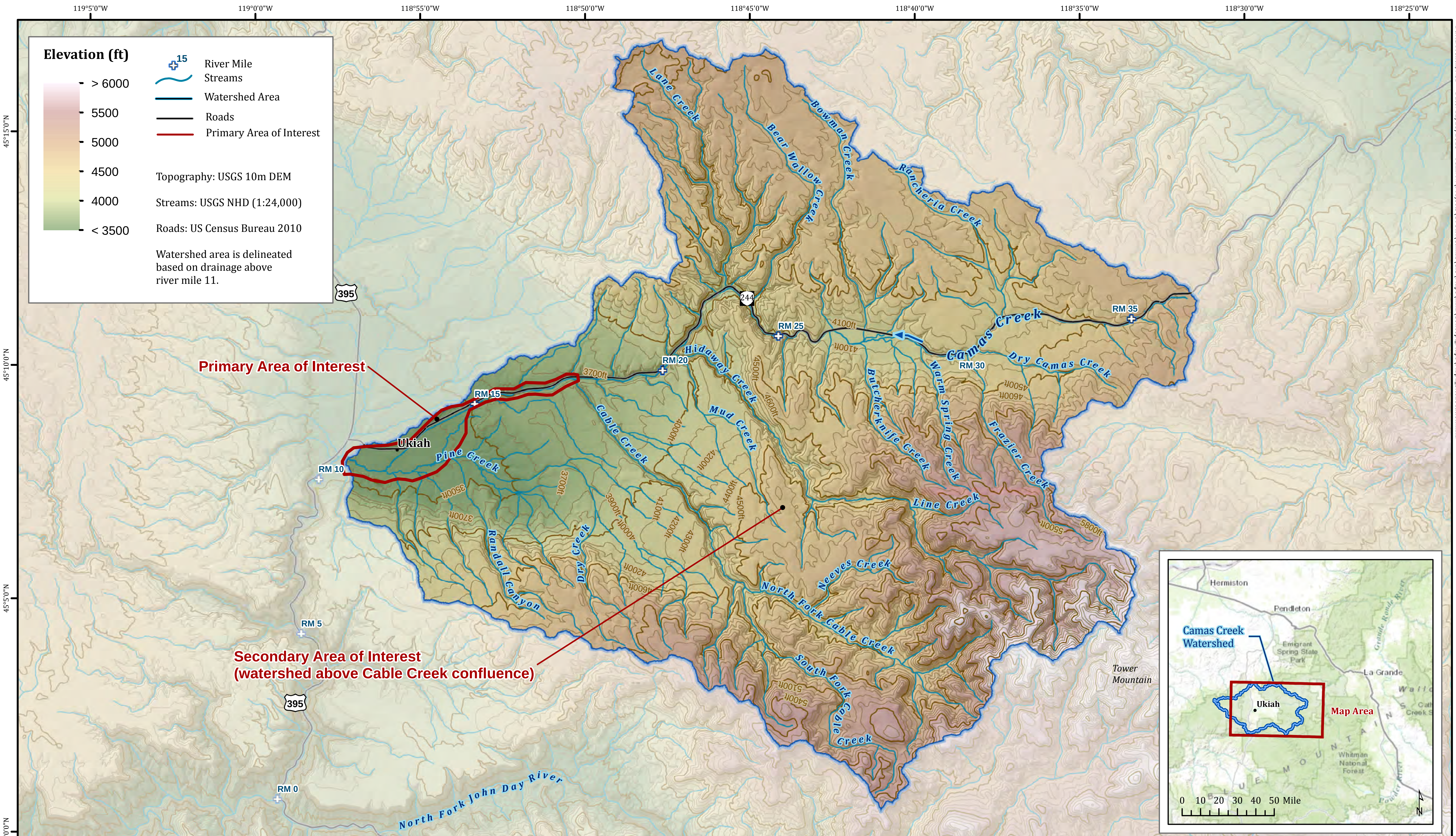
P.O. Box 15609, Seattle, WA 98105 T: (206) 834-0175



Camas Creek Geomorphic Assessment & Action Plan

Map 1 - Project Site Location and Study Area

Topographic data source: USGS 10 meter DEM

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Contour Interval = 100 ft

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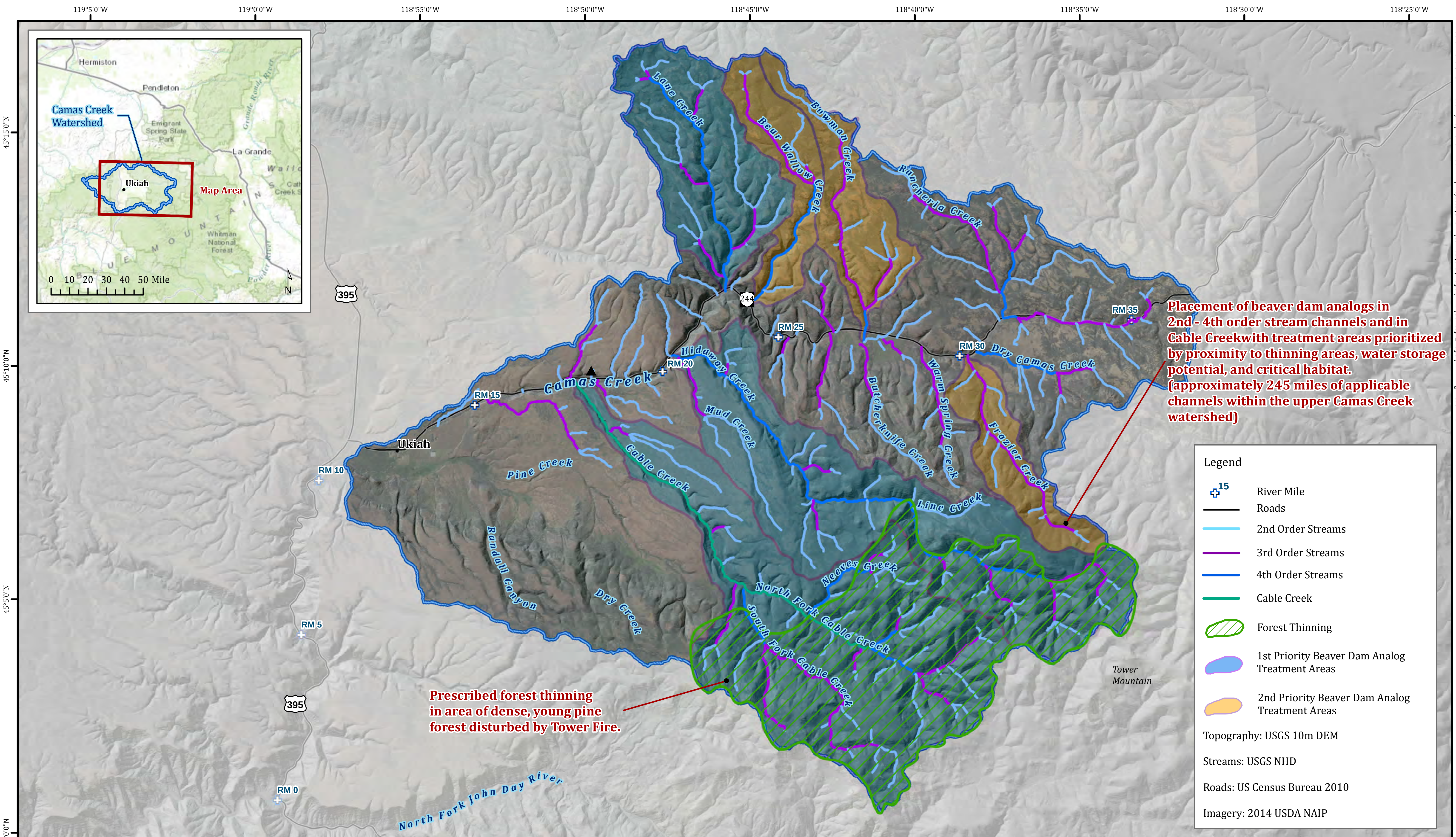


Camas Creek Geomorphic Assessment & Action Plan

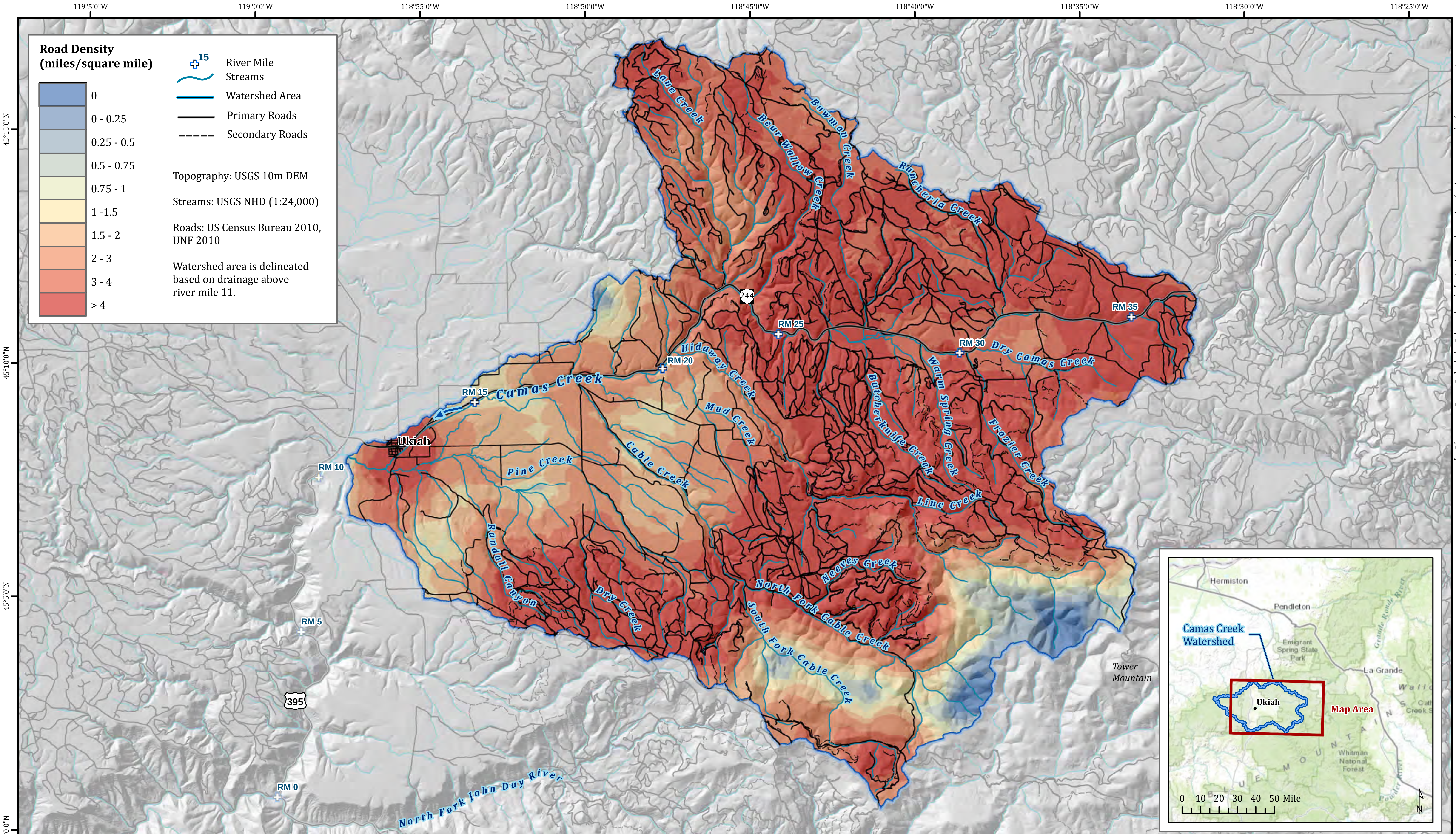
Map 2 - Forest Thinning Areas and Streams for Beaver Dam Analog Placements

N

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

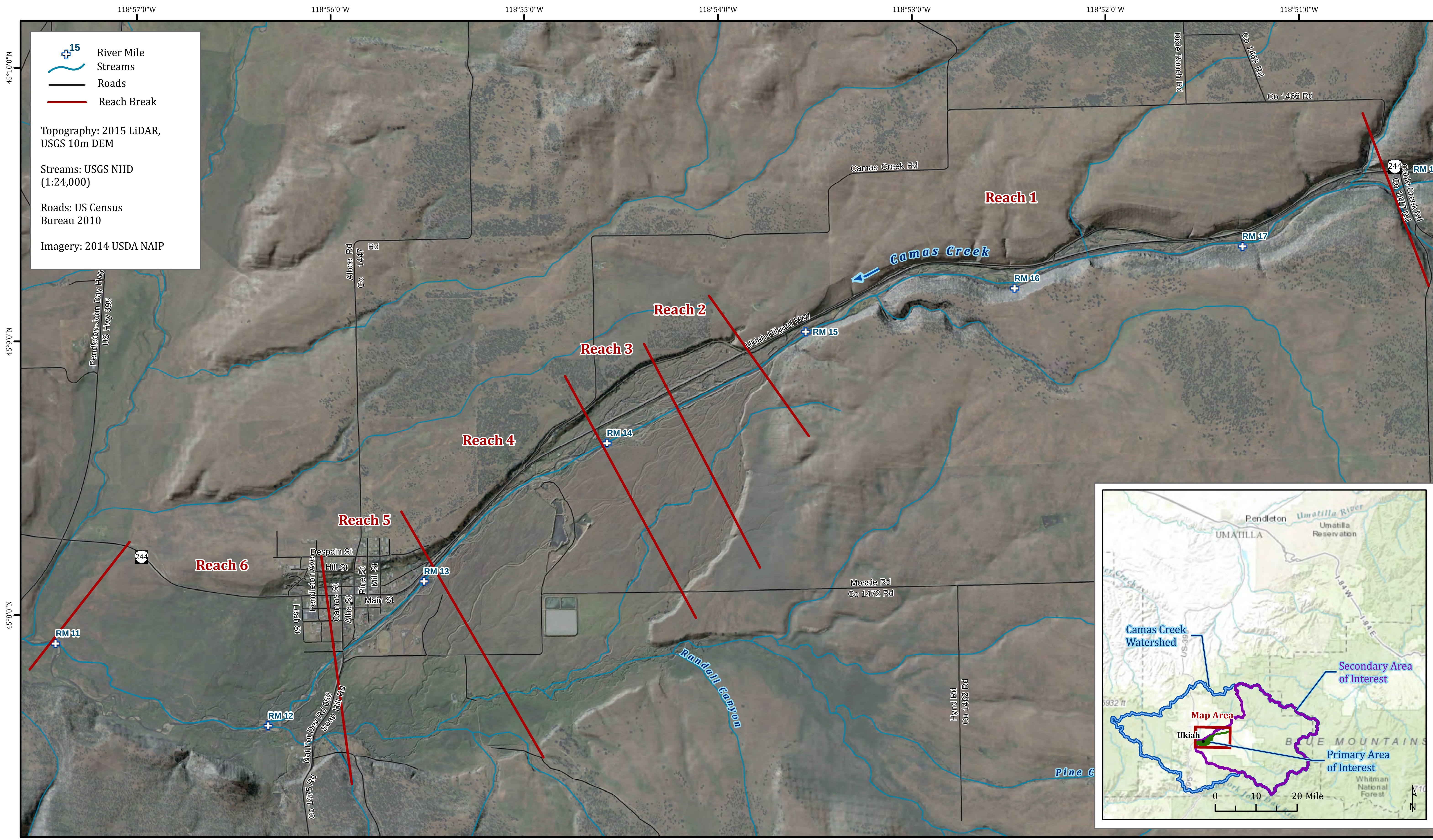
Map 3 - Road Density in the Camas Watershed

Road density is derived as the number of linear miles of motor vehicle roadway per square mile of drainage area.

0 1 2 3 4 5 Miles

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Map 4 - Geomorphic Sub-Reaches

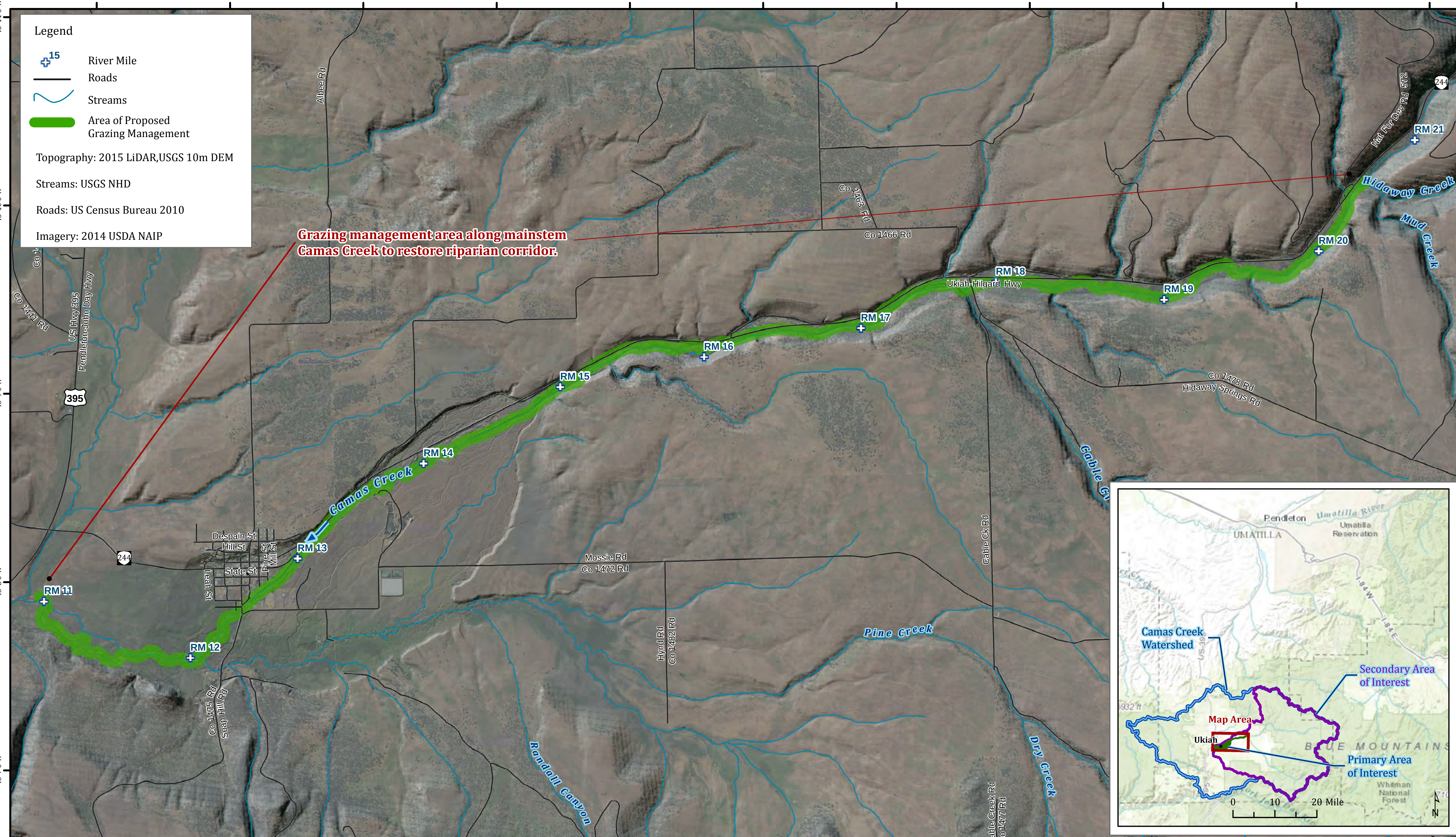
Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

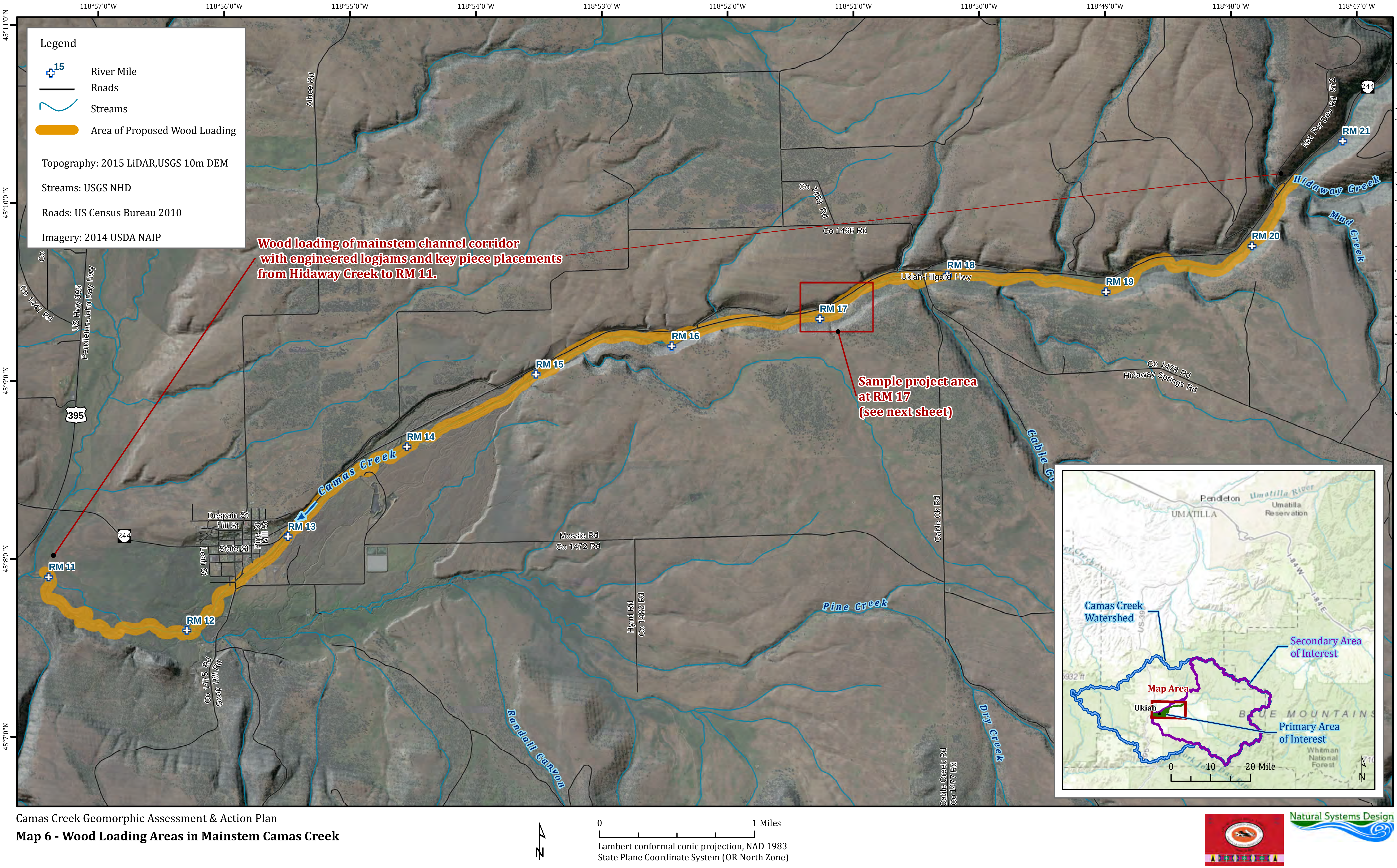
Map 6 - Wood Loading Areas in Mainstem Camas Creek

N

0 1 Miles

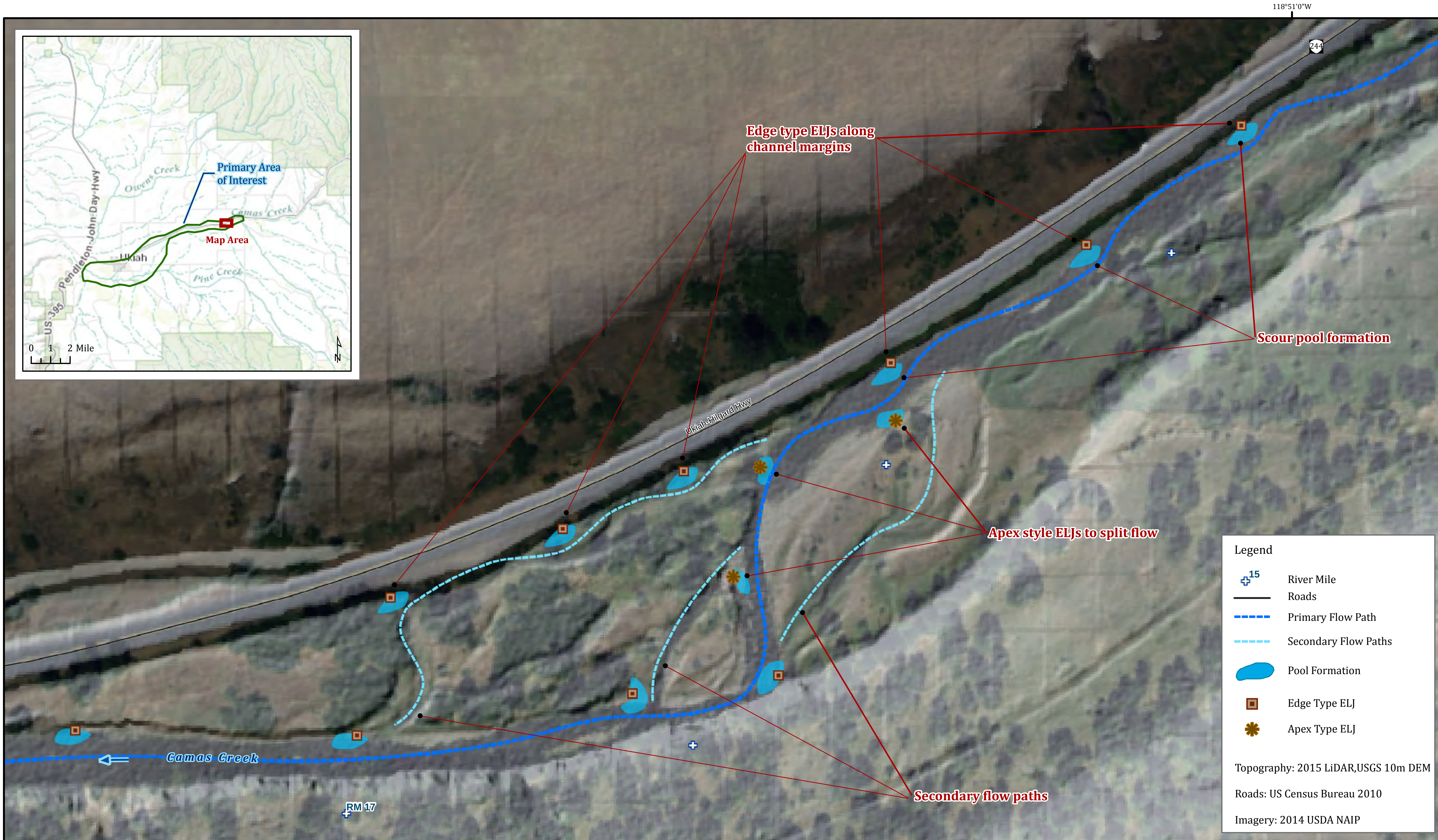
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Map 6 - Wood Loading Areas in Mainstem Camas Creek



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Camas Creek Geomorphic Assessment & Action Plan

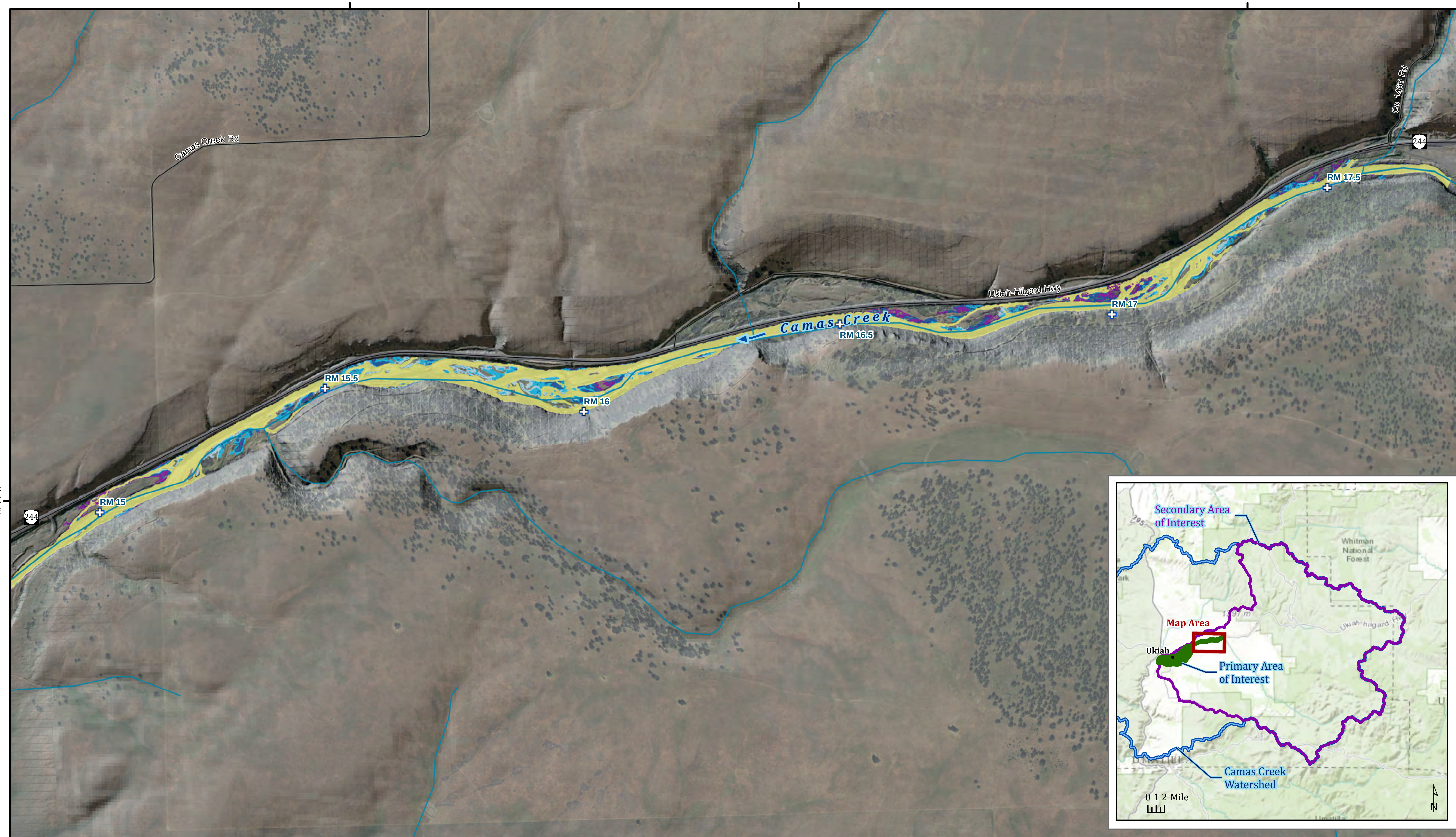
Map 7 - River Mile 17 Sample Wood Loading Project Area

N

0 100 200 300 400 500 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Map 8 - Incremental Rise in 2 year Water Surface, Reach 1

2 yr water surface simulated in Hydronia RiverFlow2D-Plus GPU using a discharge of 1400 cfs.

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Data sources: USGS NHD (1:24,000), US Census Bureau 2010, 2014 USDA NAIP.

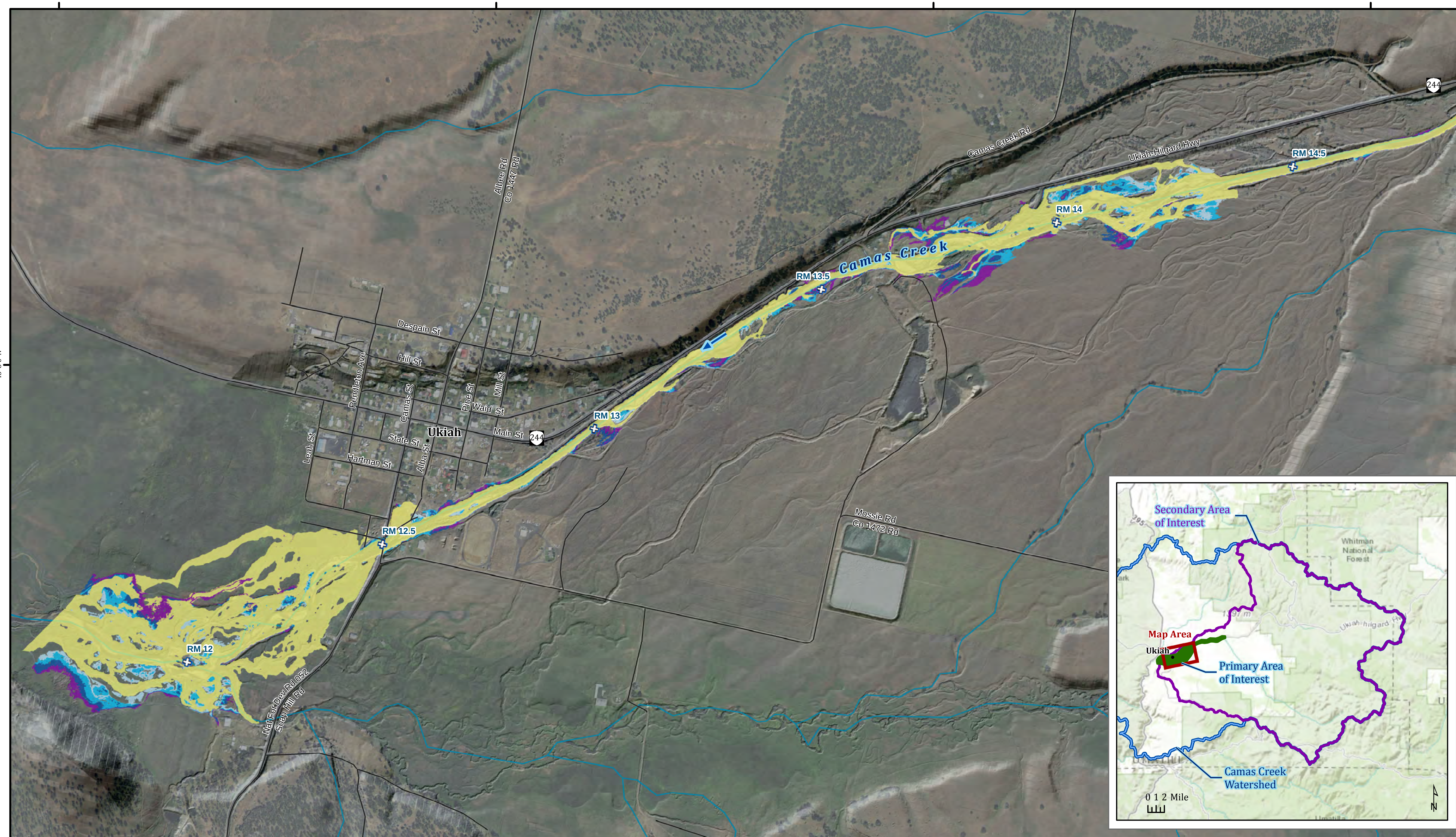
0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Height Above 2 yr WS (ft): 0, 0.5, 1, 1.5, 2

15 River Mile
Streams
Roads

Natural Systems Design



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Camas Creek Geomorphic Assessment & Action Plan

Map 9 - Incremental Rise in 2 year Water Surface, Reaches 2 - 6

2 yr water surface simulated in Hydronia RiverFlow2D-Plus GPU using a discharge of 1400 cfs.

Topographic data source: 2015 LiDAR DEM (Quantum Spatial) and USGS 10m DEM.
Data sources: USGS NHD (1:24,000), US Census Bureau 2010, 2014 USDA NAIP.

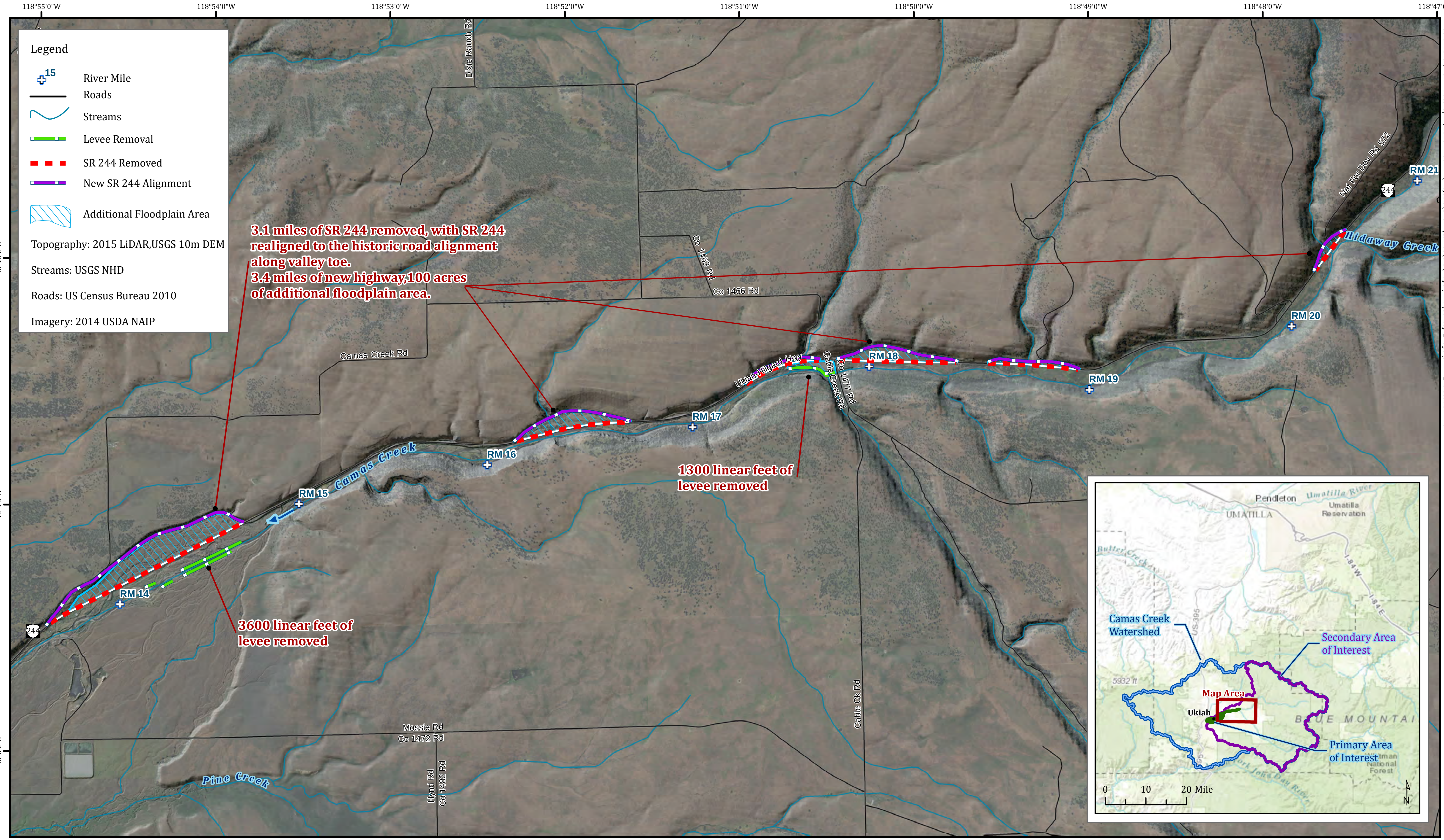
0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Height Above 2 yr WS (ft)
0 0.5 1 1.5 2

15 River Mile
Streams
Roads

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

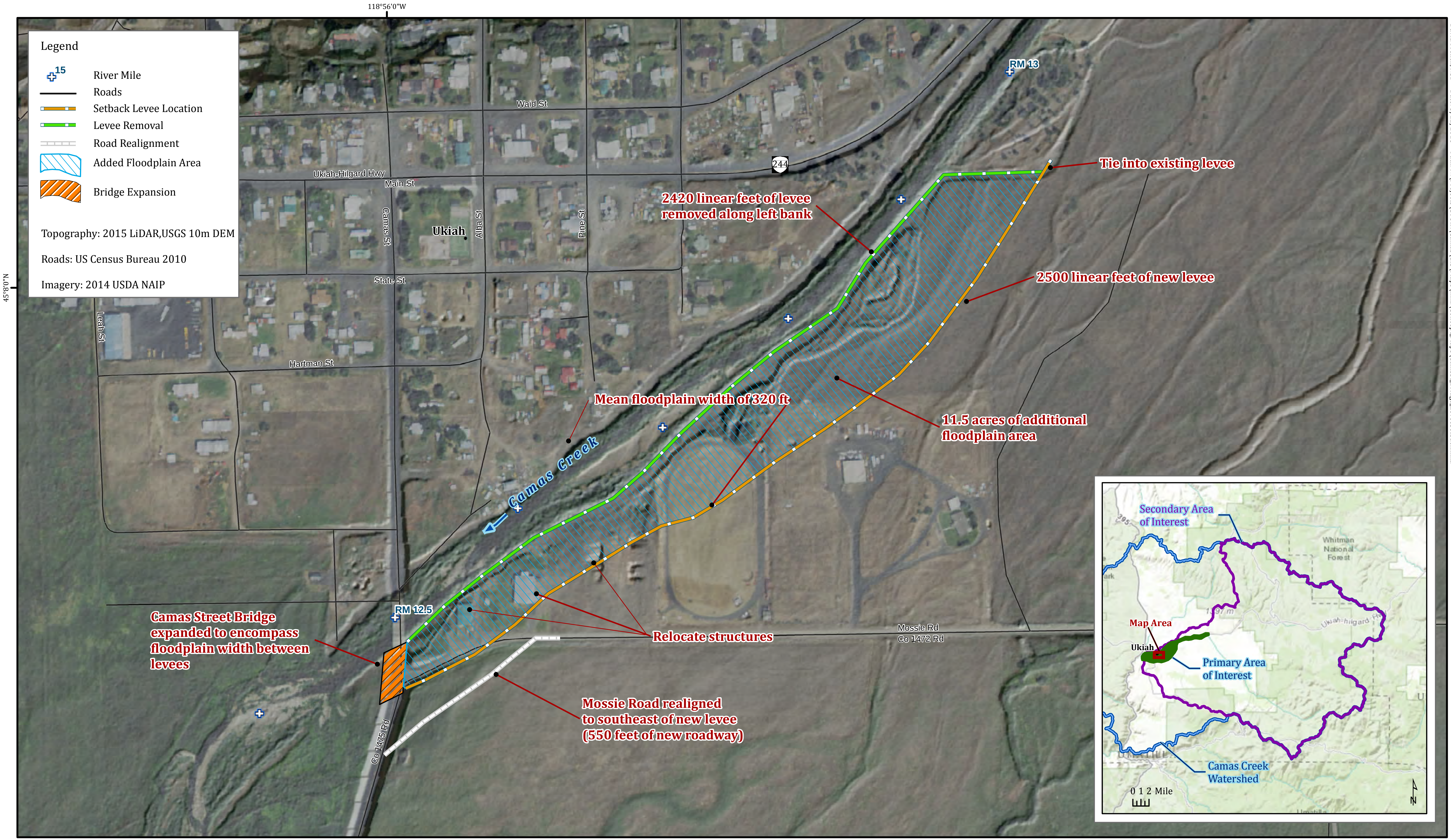
Map 10 - SR 244 Relocation

N

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



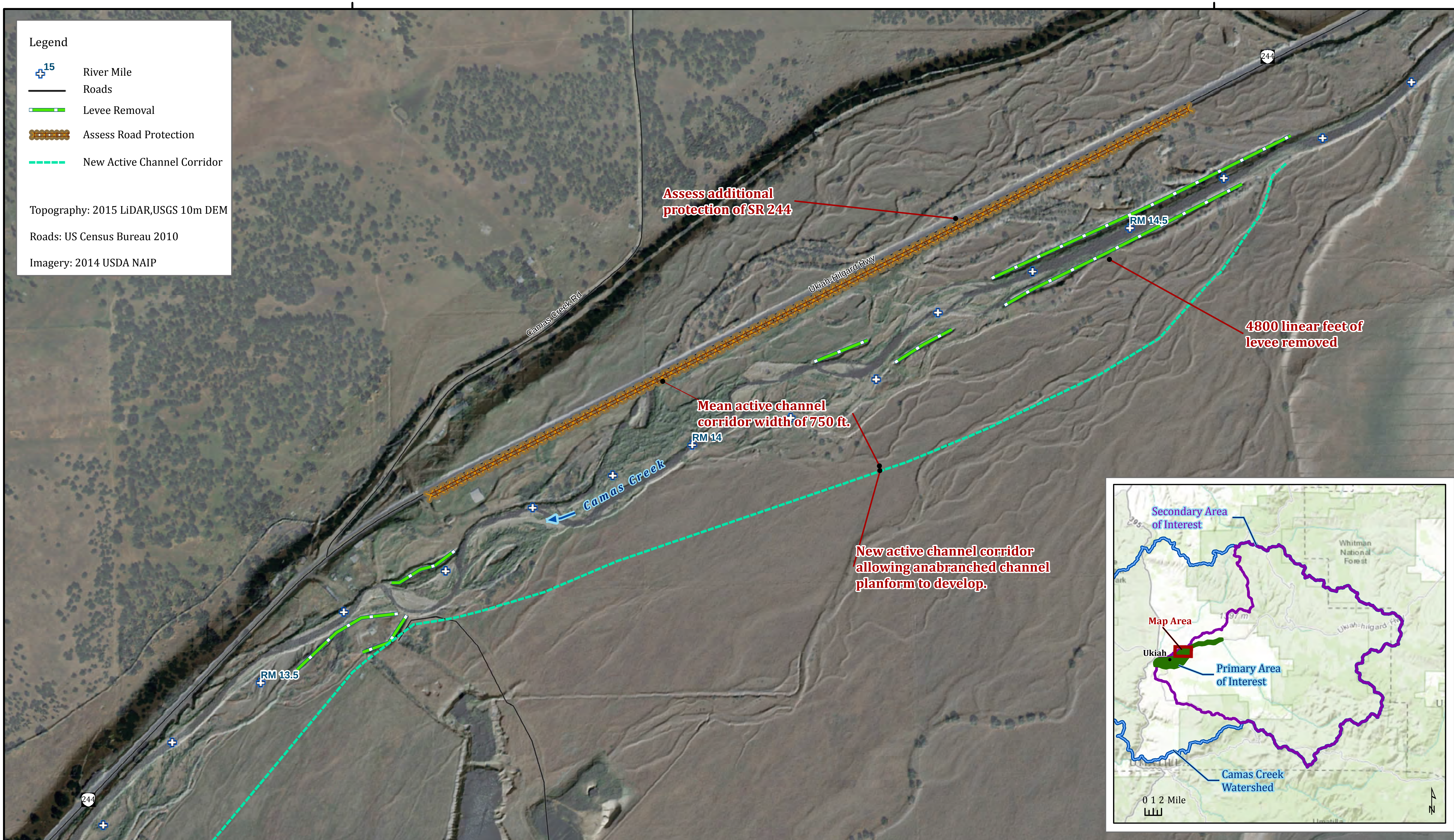
Camas Creek Geomorphic Assessment & Action Plan

Map 11 - Levee Setback through Ukiah

0 500 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



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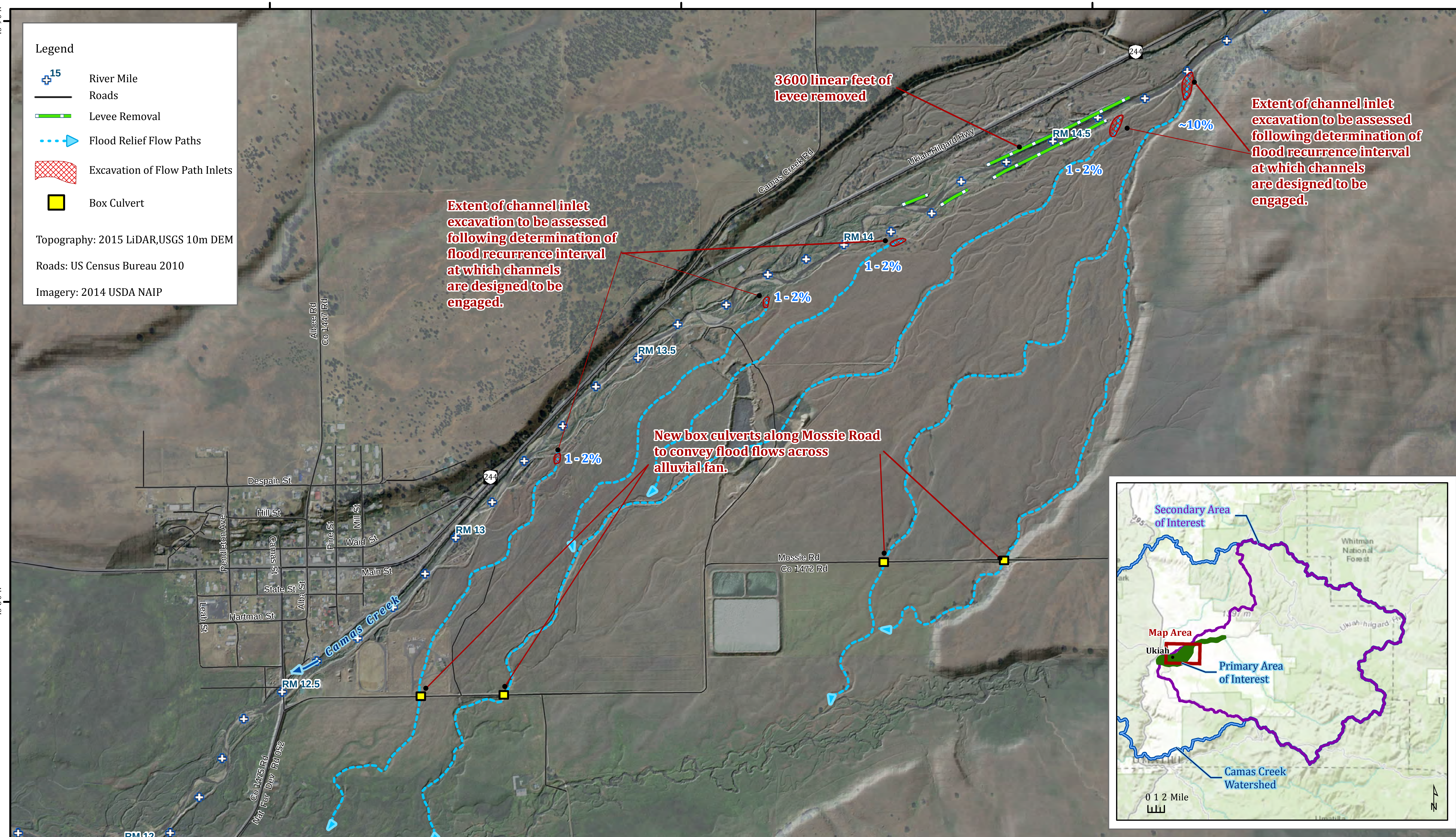
Camas Creek Geomorphic Assessment & Action Plan

Map 12 - Levee Removal Upstream of Ukiah

0 500 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design



Camas Creek Geomorphic Assessment & Action Plan

Map 13 - Alluvial Fan Flood Relief Paths

N

0 500 1,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (OR North Zone)

Natural Systems Design

David French, NSD Date: 3/22/2016 Path: N:\Projects\CTUIR\Camas\GIS\Maps\mxd\Concept_Maps\Fan_FloodChannel_Relief.mxd