A Brief on Conditions and Potential Approaches for Sediment and Stream Channel Management on Camas Creek near Ukiah, Oregon

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Summary

Over the past several decades sediment deposition within Camas Creek's channel through Ukiah, Oregon has gradually decreased its ability to pass stream discharge, sediment, and debris. This has also increased the potential for flooding and concern of local residents with property in danger of becoming inundated during a high flow event. In response, several residents have spoken to the Confederated Tribes of the Umatilla Indian Reservation's (CTUIR) North Fork John Day Habitat Enhancement Project about the issue. CTUIR began searching for relevant information and finding little readily available beyond climate data, completed a longitudinal profile with related cross-sections and collected sediment data from approximately 0.5 miles below to approximately 2.5 miles above Ukiah, Oregon. The data presented in this brief provides a first look at existing conditions with a review of likely causes and an outline of a potential approach to address the issues.

Given historical and current land management practices within the Camas Creek basin and Ukiah's location within the basin addressing relevant issues requires the consideration of across the basin including land use, geology, climate, hydrology, and geomorphology. In an attempt to minimize this analysis and future efforts the basin was split into the Secondary Area of Influence consisting of the basin above the broader valley around Ukiah and the Primary Area of Influence within the broad valley surrounding Ukiah. Additionally, the Secondary Area of Influence was further broken into four subbasins including Camas Creek above Hideway Creek, Hideway Creek, Cable Creek, and the Lower Secondary Area of Influence between the broader valley around Ukiah and Hideway Creek. These gross areas can be treated as individual units contributing sediment and discharge to Camas Creek transported through the Lower Secondary Area of Influence.

Generally speaking, within the Lower Secondary and Primary Areas of Influence Camas Creek appears to be unstable as a result of historical and current land management practices and unstable is not able to withstand more dramatic discharges or events. Stability in this sense defined as a channels ability to adjust to high flow events or disturbances without compromising its structural integrity. This differs from 'traditional' stability using structures which remain unphased during extremely large and potentially disruptive events. While these historical land management practices may have been undertaken to maximize production the long term effects are now apparent in the form of restricted and unconnected floodplains, weak or nonexistent riparian areas, and generally over widened and incised channels.

Historical quantitative data describing the Lower Secondary Area of Influence suggests the reach has been and remains a transport reach for both stream discharge and sediment. While the role of species such as beaver is not clear, data suggests Camas Creek historically maintained a moderately mobile and narrower single thread channel that annually inundated the floodplain. The channels inability to withstand high flow events, inconsistent sediments loads, and the like differs significantly then those of the past and has resulted in a loss of channel complexity, excessive streambank cutting, channel widening, and the movement of significant volumes of additional sediment into the Primary Area of Influence.

Geomorphically speaking, the Primary Area of Influence appears to be a depositional environment which is typically difficult to deal with and has been further complicated by stream channelization transporting sediment further downstream than what would have historically occurred. Collected data indicates Camas Creek appears to maintain little of its historic stability as the channel has widened and deepened significantly in several places resulting in severely eroded streambanks and channel down-cutting with sediment deposition occurring below. This is most noticeable immediately above, within, and below Ukiah. Here levees widen as one moves down stream influencing Camas

Creek's ability to transport sediment, resulting in deposition just above and below the Ukiah/Granite Road Bridge. In short, Camas Creek has lost much if not all of its ability to pass both extremely large and low summer streamflows effectively as a result of historical land management practices within the Primary AOI.

Within and adjacent to Ukiah, small efforts to address relevant issues do not appear feasible given a concentration of smaller properties and larger scale sediment mobilization and deposition issues. Effective treatments would at the very least require consideration of the Primary Area of Influence with acknowledgement of processes outside that area. Of primary importance to any effort would be a determination sediment source, an estimate of volume, and identifying when sediment becomes mobilized. From this and other information a plan can be developed and implemented capable of withstanding high flow events and their associated sediment and debris along with low summer flows while maintaining stability.

CTUIR recommends a committee be developed consisting of city representatives, local residents, and landowners with a second committee capable of providing technical expertise and guidance. Due to the scale of the problem one should not expect to identify and implement a viable solution entirely during 2012 or perhaps even 2013. Permitting, funding, and technical limitations would prohibit immediate action although they would allow or force the consideration of relevant issues.

Specific treatments have not been identified in either the Lower Secondary or Primary Areas of Influence in deference to the local community. Generally speaking, efforts to stabilize the Lower Secondary Area of Influence would likely reduce sediment delivery to the Primary Area of Influence in the short term although the long term effects upon the Primary Area of Influence may not be as significant. CTUIR would support small and inexpensive intermediate efforts within the Primary Area of Influence to reduce erosion in relatively stable areas above Ukiah. However, such efforts would not be able to address larger scale issues.

I would like to express my appreciation for local landowners who shared their thoughts, Delbert Jones for his help in collecting data, and Ed Farren, Scott O'Daniel, and Jim Webster for their review, comments, and advice during the development of this brief.

Introduction

Historical land use practices, infrastructure development, and watershed response to annual and stochastic events appear to have influenced Camas Creek's channel. This has or has likely resulted in altered channel morphology, reduced streamflow access to the floodplain (reduced floodplain connectivity), increased potential for altered stream flow regimes and altered sediment transport and deposition. Regardless of the cause, the existing conditions have created a certain amount of concern among residents of Ukiah, Oregon and the surrounding area leading some to ask if the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) could assist with improving channel conditions to reduce potential property damage from high flow events within Camas Creek. CTUIR does have an interest in helping with such effort; however, due to the scope of the problem and population density addressing channel conditions within and adjacent to Ukiah necessitates a community driven approach given what appears to be the scope of the problem. Consideration must therefore be given to a more holistic approach and detailed understanding of existing channel process and treatments; namely sediment transport, distribution, and deposition given past, present, and future land management practices.

Unfortunately, quantitative information regarding channel processes or morphology upon which to parse out the root cause of existing conditions or long term trends is not always readily available or may be discontinuous across time and space. However, readily accessible data such as Digital Elevation Maps, precipitation records, and aerial photos can be effectively used; for instance, accurate (if imprecise) estimates of sediment transport rates and their trends can be derived from assessments of slope, spatial dimension, runoff, and land use throughout the watershed (Wilcock, Pitlock, Cui, 2009). Qualitative information such as narratives or other historical records may not provide sufficient quantitative information to determine past physical processes although an accurate assessment of past relative trends may be possible to provide a useful assessment of past and future changes (Wilcock, Pitlock, Cui, 2009). Efforts to reconcile or supplement existing or ground truth existing data may be required before any accuracy can be assumed and to provide baseline information to quantify existing conditions and long term trends. Without a solid understanding of the processes or features underlying existing conditions efforts to address any issue will in all likelihood create additional instability in the stream channel or be themselves unstable and/or ineffective.

Stability in and of itself is a relatively simple concept in static conditions or when considering 'overbuilt' structures capable of remaining immobile during extremely large and potentially disruptive events. For instance, stable structures such as levees tight against the stream channel are widely used to simplify stream channels and alter their ability to effectively carry water, sediment, and debris. While a levied channel may be stable in that it restrains a variety of stream flows and passes sediment through a specific area for long periods of time they also create additional problems that may not be realized for several decades. Once over-topped, levees can trap water, sediment, and debris behind them and streamflows, sediment, and debris passed downstream may create problems both in the downstream and levied areas. An alternative use of levees to allow a channel to adjust to high flow events or disturbances without compromising its structural integrity or form (dynamic stability) would may be set-back levees Their placement back off the stream still contains higher flow events while allowing for long term processes such as natural sediment deposition and erosion or channel migrations to occur within. This creates a semi-natural setting where the channel maintains ability to react to annual or stochastic events as well as resulting channel, riparian, and floodplain modifications while reducing some of the longer term problems. Efforts by landowners and their cooperators have made some progress toward recreating a dynamically stable channel by improving upland stock watering opportunities, restricting access to in-stream and sensitive riparian/wetland areas, improving channel stability/complexity, and floodplain connectivity without affecting the landowner's ability to effectively manage their land.

Given the history of land management, resulting stream channel instability above, within, and below Ukiah, Oregon, geomorphic and hydrologic constraints, concentration of landowners, and permitting and funding constraints any attempt to improve or influence conditions within the broader valley about Ukiah will require a significant effort by multiple parties. That is, participation by landowners who will consider larger scale factors outside the broader valley about Ukiah will be required if an effective solution is to be identified and implemented. This brief is a first attempt to describe available and required information, historic and existing conditions, and propose a community driven organizational structure.

Area of Interest

For the purpose of this brief, the primary Area of Interest (AOI) (Figure I) covers approximately 950 acres and includes the area denoted around Ukiah, Oregon. This includes Camas Creek's existing and paleo-channels from approximately 0.5 miles below Ukiah to approximately 2.1 miles above. The Lower Secondary AOI includes those portions of the watershed above the primary AOI that transport stream flow and sediment downstream to the broader valley about Ukiah below confluence of Hideway and Camas Creeks and Cable and Camas Creeks with the larger Secondary AOI above those confluences. The relative scale of the primary and secondary AOI alone suggests the need for a deliberate and coordinated approach across property lines and may well require a willingness by landowners to modify existing management practices if an equitable solution is to be reached.

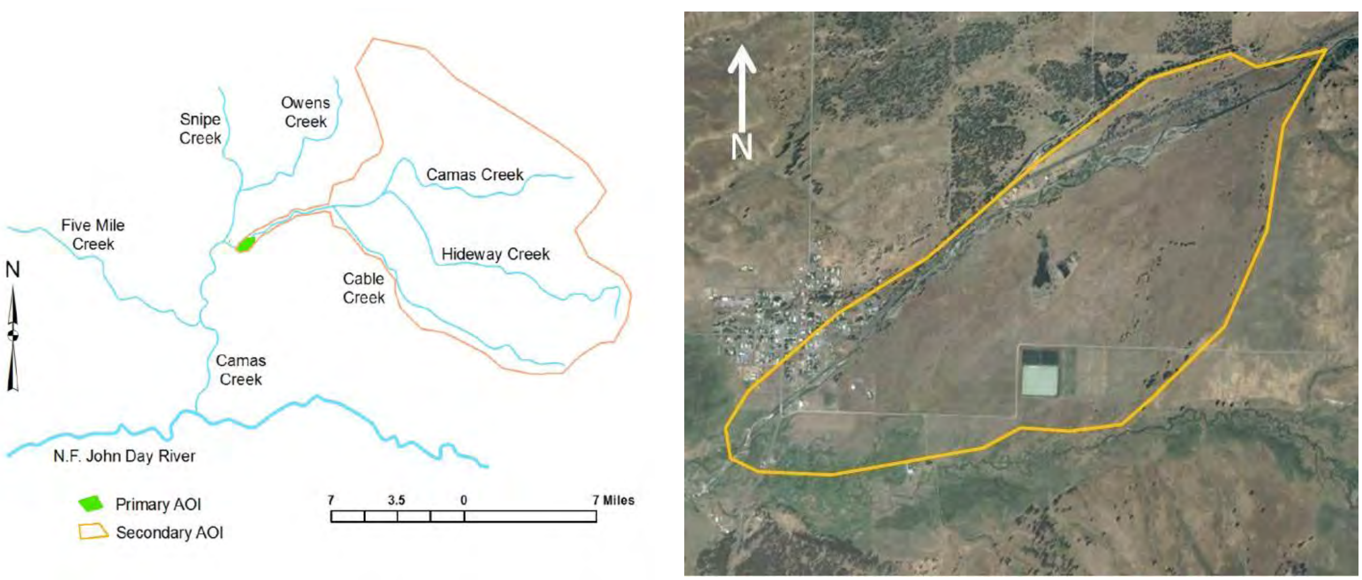


Figure I. Top, relative view of the primary and secondary AOI; Bottom, aerial photograph taken in 2005 of the primary AOI. Note the alluvial fan outlined in yellow and the levee most noticeable in the north east corner of the photograph.

Land Use

Several gross land management strategies can be readily identified as having influenced upon Camas Creek and while not an all-inclusive list many disturbances to Camas Creek's channel and riparian/floodplain can be attributed to these factors. Grazing within the Camas Creek basin beginning in the late 19th century was followed by logging in the early 20th century on private lands with eventual harvest on public lands. Historical and current grazing management practices have occurred throughout the basin and have influenced the stream and riparian areas ability to resist erosional forces, during regular and irregular stream flows. This primarily appears to be the result of decreased riparian vegetation fitness, bank cutting, and a loss of floodplain connectivity. While grazing practices have changed over time from unmanaged high pressure management for the entire grazing season to more managed summer grazing the effects of historic practices remain in some locations. In addition, management practices by some landowners also continue to directly influence floodplain, riparian, and in-stream conditions negatively. The presence and influence of wild game who have become accustomed to inhabiting areas for extended periods of time cannot be discounted. A loss of predators and their inherent role in moving wild game (Beschetta & Ripple 2012) have likely influenced elk distributions as well as the recovery of areas burned during the 1996 Tower Mountain Fire.

Infrastructure developments such as the construction of SR 244 have also influenced Camas Creek. Prior to 1960's the road along Camas Creek above Ukiah followed the northern scarp and did not significantly influence the stream floodplain connectivity or stream channel processes. Moving Hwy 244 down onto the floodplain reduced the active floodplain by more than half in some locations; straightening the channel and thereby increasing channel gradient, and concentrating stream energy into a smaller area. Levees within the broader valley around Ukiah were constructed to protect a mill, Ukiah, and ranches against the effects of high water events. They effectively reduce floodplain connectivity circumventing natural channel processes by concentrating stream energy within the channel. Sediments transported further downstream and deposited below what would have occurred naturally. To some extent this deposition was mitigated by annual dredging conducted by local residents with heavy equipment. This activity has not occurred recently due to environmental regulation and funding constraints, resulting in what may appear to be more dramatic deposition then in the past.

Geology

Although often ignored geology has a significant influence upon stream systems by imparting significant controls upon stream channel pattern and slope and sediment type and availability. The Camas Creek watershed consists of several formations created over the course of 360 million years or so (Ferns et al, 2001). The watershed's basement formations generally consist of Carney Butte Gabbronorite (~150 million years old (myo)), Elkhorn Ridge Agrillite (>215 myo), Phorphyritic Rhyolite (~24 myo), and Caldera filled Tuff of the Tower Mountain Caldera (~24 myo) with subvolcanic intrusions distributed in specific locations throughout the basin. These formations are overlain by Volcanoclastic deposits of Limber Jim Creek (~28 myo) and Grande Rhonde basalts (~15 myo). Numerous faults exist throughout the watershed trending primarily to the northwest the most noticeable of which reflect a drop of several hundred feet forming the Ukiah valley as well as the broad valley about Snipe Creek. Materials deposited on the fallen block include alluvial sediments underlain by sedimentary rock approximately 5 to 13 myo which helped form the broad meadows people are familiar with within the broader Ukiah Valley.

A series ridges and valleys from folded bedrock occur across the Camas Creek basin. Camas Creek roughly traces a valley trough (syncline) from Frazier Creek down to Ukiah and along Snipe and Lower Owens Creeks. Ridges (anticlines) also trace the divide north of the Ukiah Valley intersecting Camas Creek around Rancheria Creek. Due to the geologic processes geothermal springs are present in several locations providing recreational opportunities. Their influence upon Camas Creek is likely minimal simply due to their discharge relative to that of the rest of the basin.

The broader valley about Ukiah contains alluvial sediments deposited by stream flows less than 126,000 years ago surrounded by and above older (~ 11 to 5 million years ago) sedimentary rock. Two faults near Ukiah oriented east to west slipped and created the broad flat valley near Albee which was subsequently filled with alluvial sediments. A second fault south of Ukiah oriented northwest to southeast slipped to form the broad valley Ukiah resides in.

Differences between the Lower Secondary and Primary AOI are rather stark. The narrow canyon along SR 244 above the broader valley moved laterally within the existing canyon pulling rock from the walls when possible and reacting to short term depositional and erosional forces. Although a detailed investigation of sediment movement and characteristics has not been completed, unquantified empirical evidence suggests there may be a difference between sediments from Camas Creek above Hideway Creek (Upper Camas), Hideway Creek, and Cable Creek. Sediments from Camas Creek above Hideway Creek generally appear to consist largely of angular or less weathered basalt then those originating from Hideway or Cable Creeks. Sediments from Hideway Creek often appear to be smaller more rounded gravels and cobbles lighter in color then the larger and darker cobbles moving out of Cable Creek.

As with geologic formations, soils throughout the basin have largely been formed through volcanic action. Volcanic ash and pumice deposition along with the mechanical weathering of bedrock have contributed significantly to soil quality and quantity. Materials from Tower Mountain eruptions exposed in the higher elevations closer to the caldera form soils through mechanical weathering save where they were not covered by more recent volcanic activities. The most recent and significant volcanic activity contributing to soil quality and distribution in the basin was the eruption of Mt. Mazama 6,600 years ago. Wind and water have redistributed much of the material deposited that originally ranged from zero to two feet in depth (UNF, 1995). More recent volcanic eruptions of the Cascade Range have had comparatively little effect upon Camas Creeks Soils.

Climate

Climate including the spatial and temporal distribution of precipitation, form of precipitation, temperature cycles and range have a considerable influence upon vegetation and stream characteristics. For example, one would not directly compare Camas Creek with a tributary of the Hoh River on the Olympic peninsula which gets 12 to 14 feet of precipitation a year.

Temperatures within the North Fork John Day basin typically range between 10 and 90 degrees Fahrenheit throughout the year with annual precipitation ranging from more than 30” at the highest elevations around Tower Mountain to 17 inches in Ukiah. Precipitation falls primarily in the form of snow or Fall/Spring rains interrupted by dry summers. Data collected from the Arbuckle Mountain SNOTEL site (NRCS, 2012 - Figure II) supports trends for both air temperatures and precipitation data trends although the site lies at 5,800 feet in elevation as compared to Ukiah’s 3400 feet. Moderate temperatures are regulated by a continental climate with a marine influence which provides produces the most significant precipitation in the form of snow and rain during the late fall, winter, and early spring (Figure II) leaving summers hot and dry.

In Eastern Oregon as with many arid environments geology, soils, climate, and vegetation combine to create streams which are relatively quick to react to precipitation events. That is, they have what is called a ‘flashy’ character. Shallow soils and bedrock, significant differences in topographic features, aspect, and vegetative cover combine to create the conditions necessary to move large

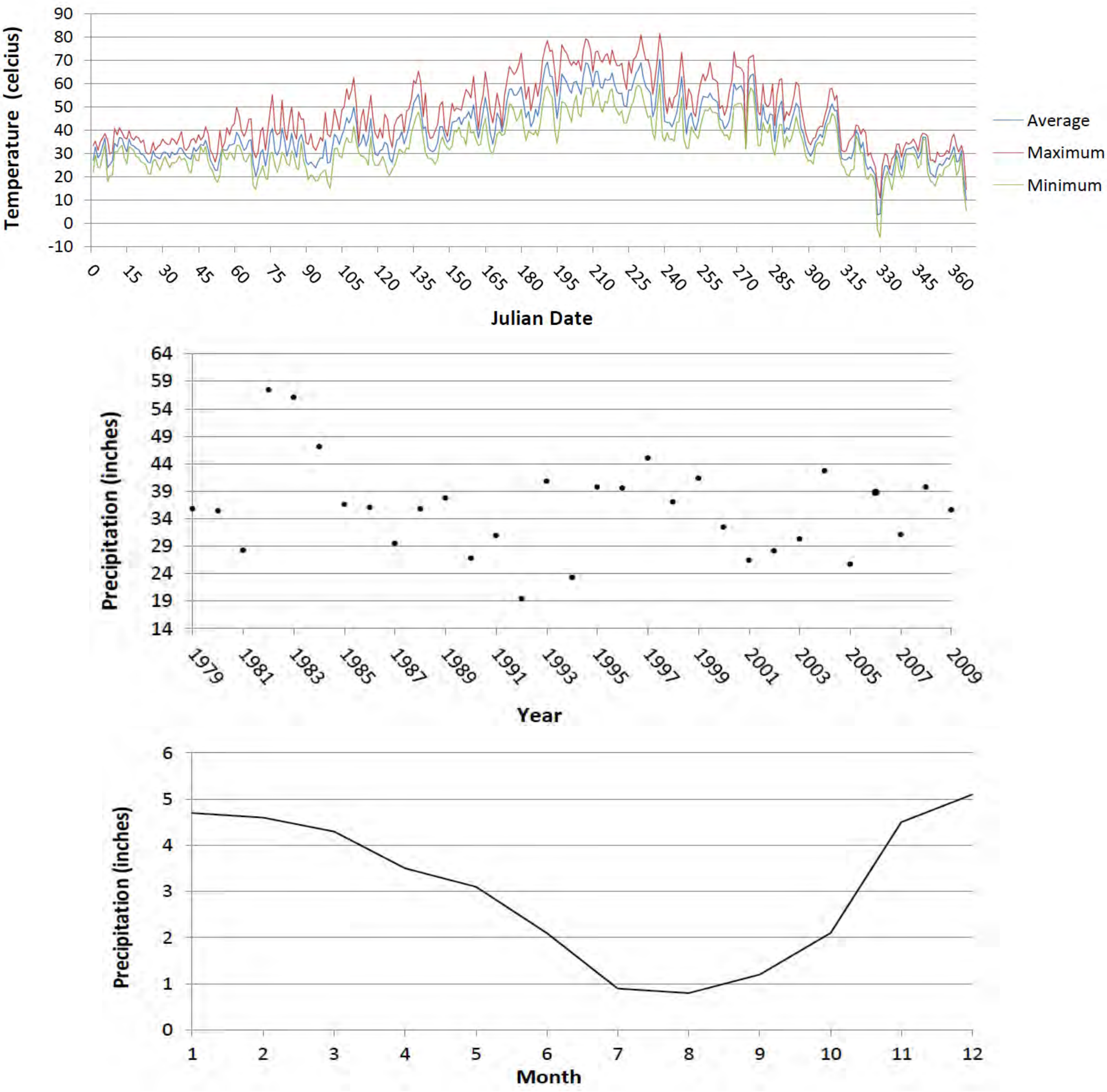


Figure II. Annual air temperatures (top), total annual precipitation (middle) and average monthly precipitation (bottom) from 1979 to 2009 in inches from the Arbuckle Mountain SNOTEL site (NRCS, 2012)

amounts of water. Summer flows leave much of the channel substrate dry and cold winter temperatures combined with low stream discharges leave many channels almost completely frozen throughout portions of the winter. During ice break-up additional channel scour by ice occurs in conjunction with precipitation events. Both streambank storage and shallow aquifer storage especially in the lower gradient meadows in broad valleys serve to buffer against late summer flows where they have not been compromised by land management practices. The loss of his storage can greatly influence terrestrial and aquatic vegetative productivity and habitat.

Hydrology

Figure III contains data collected at USGS Camas Creek Gauging Station 14942500 (between Hideway and Cable Creeks) draining 121 square miles indicating that from 1914 to 1991 average monthly streamflows peaked in April at 334 ft^3/sec while the lowest flows occurred during August averaging 5.2 ft^3/sec. Discharge data also indicates baseflow (when groundwater becomes the dominant source of in-stream flow) begins in June and ends in late September and average peak flows during the same period were less than 200 ft^3/sec though data from several years wasn't available and may have influenced peak values. When comparing daily stream discharge values to the average annual discharge the top four discharge years (1916, 1921, 1948, 1984) contained multiple months (typically February to May) with average discharges over 335 ft^3/sec. Several other years contained high discharge values though their duration may have only lasted a month or two and did not significantly influence yearly averages. The four years in which stream discharge peaked at over 1700 ft^3/sec did not coincide with the four highest average discharge years as one might expect. While events which have the potential to move sediments certainly occur annually, the longer duration (monthly) high volume discharges may not likely move sediments as effectively as the higher power 'pulses' visible in Figure III; however, at this time, the effectiveness or role of these pulses are unknown.

Ecovista (2003) estimated discharge for ungaged streams within the Camas Creek basin based upon methods identified in USGS (1993). Using the basin area, precipitation, and percent forest cover values from Ecovista (2003) peak estimated discharges were recalculated using regression equations in USGS 1993; calculated values are presented in Table I. Although Ecovista included the Lower Secondary and Primary AOI into the Camas/Wilkens Creek Subbasin, estimates for each parameter were made by comparing aerial photographs to those noted in EcoVista (2003). Estimated discharges support the idea that the 1964 stream flows on 30 January 1965 were equivalent to a 100 year event using the combined calculated discharge for Lane, Bowman, and Hideway Subbasins. When considering the 5 – 10 – 25 – 50 – 100 year reoccurrence intervals however, calculated values appear less convincing as the discharges over 1729 cfs (10 year reoccurrence) occur only three times outside the 1964 event appear in 1932, 1972, and 1991.

Excedeance probabilities identifying the 2, 5, 10, 25, 50, and 100 year flows (i.e. 1/2 - 1/5 – 1/10 – 1/25 – 1/50 – 1/100) in Figure IV represent the probability of a discharge occurring in a single year using data from USGS gauge #14042500 between 1 January 1960 and 31 December 1969. This commonly shaped stream discharge curve graphically shows power law behavior whereby the frequency of an event varies as a power of an attribute of that event such as the relationship between sediment load and discharge among others (Molnar et al 2001, Dodov and Foufoula-Georgiou, 2004). More pertinent to the discussion at this time is the difference between calculated values and gage discharges when Cable and Camas Creek basins are removed. Discharges calculated for the Flow Duration Curve range between 22% and 42% of calculated discharge values using regional equations validated actual and modeled flows for the areas above the gauge identifying lower standard errors for higher frequency events and higher for lower frequency events which was reasonable given the 68 year history of the gauge. Due to differences between the selected data from calculated discharges and those of USGS gage

#14042500 further discussion will utilize the calculated values. Regardless of their differences the curves general shape should not change dramatically although a vertical offset (shift along the discharge axis) may be required to reconcile the two.

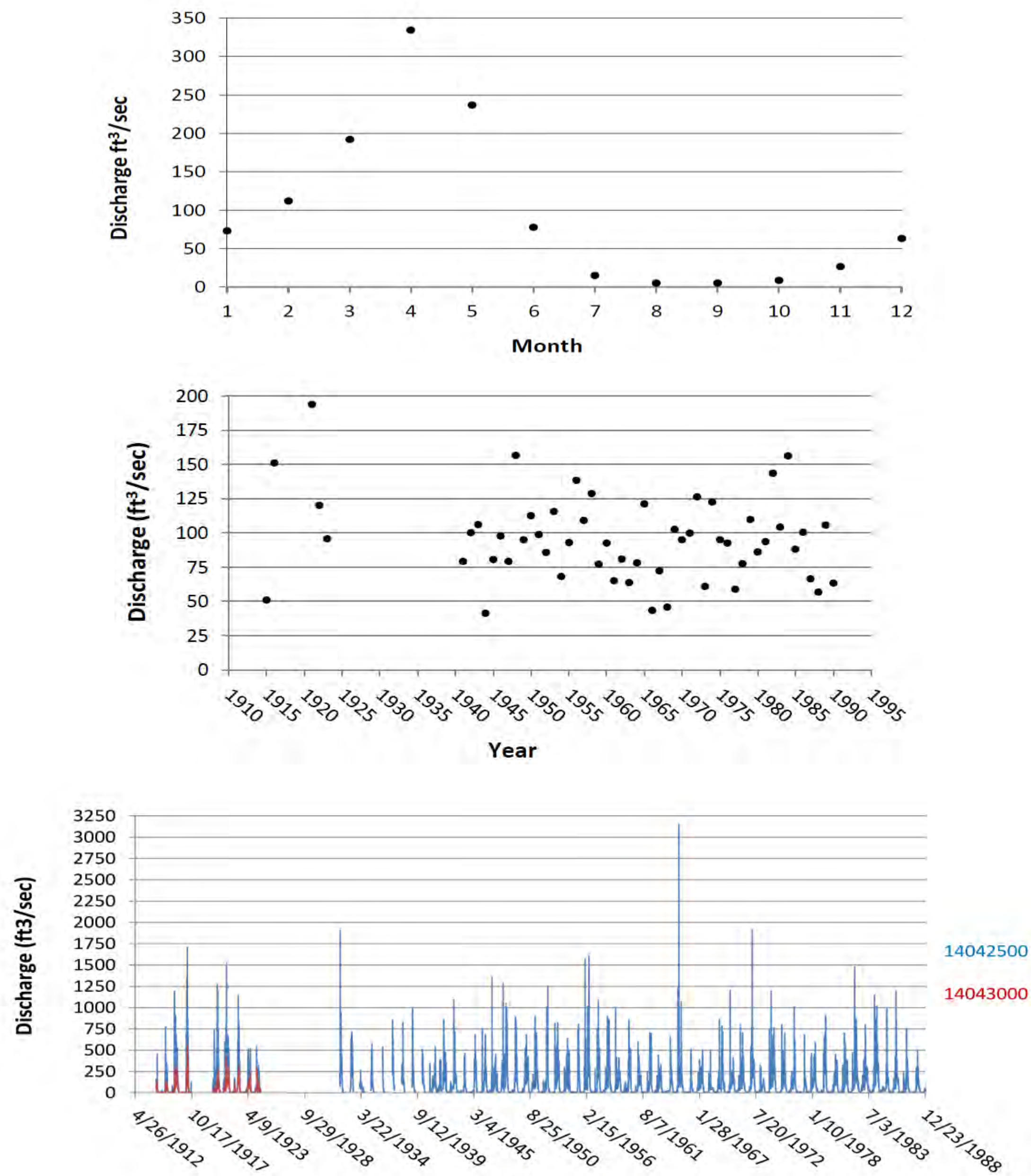


Figure III. Camas Creek discharge data collected (USGS gauge #14042500) and Cable Creek discharge data (USGS gauge #14043000) from 1914 to 1989 (USGS, 2012). The top chart reflects mean monthly discharges, the middle chart reflects annual peak discharges, and the bottom reflects annual discharges at both gauges.

Stream	2 Year Peak	5 Year Peak	10 year Peak	25 Year Peak	50 Year Peak	100 Year Peak
Lane Creek Area	205.8	342.2	406.5	504.4	588.0	682.1
Bowman Creek Area	456.6	694.9	860.1	1052.9	1244.9	1404.5
Hideway Creek Area	241.8	372.8	462.6	567.6	674.3	758.2
Cable Creek Area	282.6	434.8	539.4	661.6	760.7	883.8
Camas Creek Area	34.2	63.6	85.8	115.3	145.2	170.0
Total Discharge At Ukiah	1221.0	1908.3	2354.4	2901.8	3413.1	3898.6

Table I. Reoccurrence intervals and estimated peak discharges (cubic feet/second) by Subbasin within the Lower Secondary and Primary AOIs calculated using values from EcoVista, 2003 and regression equations from USGS, 1993.

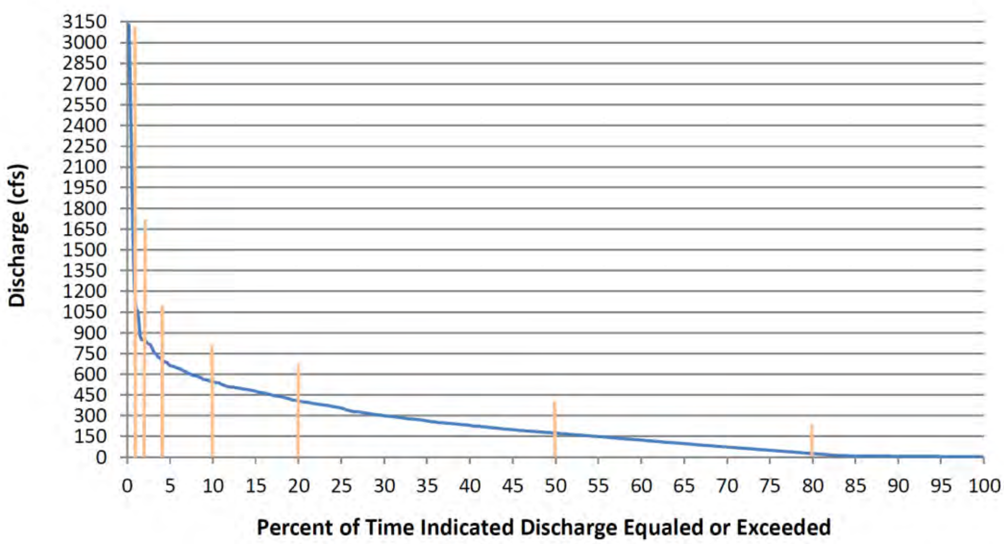


Figure IV. Flow Duration curve calculated using mean daily discharge data from USGS Gage #14042500 between 1 January 1960 and 31 December 1969. Orange lines reflect discharges coinciding with an exceedance probability of 0.8 (1.25 year discharge), 0.5 (2 year discharge), 0.2 (5 year discharge), 0.1 (10 year discharge), 0.04 (25 year discharge), 0.02 (50 year discharge), and 0.01 (100 year discharge) moving from the right to left.

Hyporheic and groundwater flows are also significant contributors to hydrologic processes. The hyporheic zone is the permeable sediments surrounding streams and rivers ere surface and subsurface waters mix may reach tens to hundreds of feet lateral to the channel following preferential flow paths formed by well sorted and buried sediments or fractured bedrock. This zone mixes and tempers inflows from surface or groundwater preserving water quality by combining warmer surface waters with cooler ground water in the summer and the inverse in the winter. In effect, the ground and bedrock act as heat sink cooling water temperatures in the summer and heating them in the winter as diurnal and seasonal temperature fluctuations are truncated with increasing depth below the ground. An example of this is a gravel bar where stream temperatures at the top can be two degrees above those at the lower end as water moving beneath or within the bar. This contrasts with to deeper ground water flows such as those entering Camas Creek below Ukiah which are significantly, although unqualified, are significantly cooler than surface water temperatures.

Geomorphology

Geomorphology brings together, climate, vegetation, hydrology, and geology and their influence upon past, present, and future landforms in the study of valley and mountain forms to understand features such as floodplain form (width, slope, and tributary arrangement) and channel form (width, slope, width/depth ratios) due in part to their dynamic nature which reflects a number of different competing and interrelated processes. A triumvirate consisting of the stream channel, riparian zone, and alluvial aquifer comprise the primary components of stream structure (Poole and Berman, 2001).

A generalized model of geomorphic influence upon stream character lies north of Ukiah along Snipe Creek. A steep headwater canyon containing a narrow high gradient channel with little sinuosity gives way to the broad fault-bounded valley containing a low gradient floodplain and more sinuous channel isolated from another broad valley containing a low gradient floodplain and sinuous stream channel by a narrow high gradient bedrock controlled valley. Within the broader valley's streambank erosion and channel downcutting has created an inset floodplain (Figure V) which occurs naturally and in response to certain land management practices including where animals have free access to the stream channel.

Figure V. Picture of Owens Creek and an inset floodplain just above SR 244. The cross-section was collected at the cutbank on Owen creeks left bank and perpendicular to the stream channel at that point. The inset floodplain stretches from approximately 2 meters to approximately 42 meters.

A more detailed model begins to reflect the complications of localized features in the broader scale. High elevation headwater areas support channels with less stream energy due to lower stream flows within tightly confined and high gradient valleys although high elevation meadows may reflect conditions further down in the watershed. Stream channels generally consist of cascades whereby stream energy is dissipated through flows continuously tumbling over and around individual large clasts or step pools where energy dissipates through drops into small pools. Cascades are created by a combination of bedrock and boulder to fist-sized material distributed laterally across the channel occurring at intervals less than one channel width apart (Montgomery and Buffington, 1997). Step pools consist of material similar to that of cascades though their gradients are typically slightly lower, channel spanning clusters occur at one too four channel widths apart (Grant et al., 1990), and hold smaller material within the intermediate pools. These channel forms are indicative of sediment supply limited streams where smaller material has been washed through the reach if it exists at all and mechanical weathering (i.e. heat, cold, abrasion, ice, and pressure) of bedrock does not produce much in the way of small material. Sediment movement downstream is minimal due to the relative material size with respect to available stream power.

Channel type and materials within middle elevation areas reflect more advanced mechanical, biological, and chemical weathering, available sediment supplies, and other physical, chemical, and biological factors. Stream gradients have decreased from those above and sediments have become smaller as they are worn from movement downstream and valleys become wider in response to greater stream power and migrating channels. Local soils may be deeper, vegetation more abundant, and ambient temperatures warmer than upstream leading to a greater influence of chemical and biological weathering. Soils are likely deeper and shallow hyporheic cycles and/or groundwater aquifers may become more abundant or relevant.

Channel structure may consist of lower gradient plane-bed channels lacking distinct pools and bars rather than the step pools noted above or at lower gradients, or pool and riffle sequences. Montogomery and Buffington (1997) identify plane bed channels as occurring at gradients below those of step pools and exist in much of Camas Creek below Hideway Creek. Inconsistent glide, riffle, and run habitats form a featureless bed due to a lack of discrete bars and high width to depth ratios and low sinuosity. The substrate may contain bedrock through sand sized material although it typically consists of sand to small boulder sized material. While streamflows are more robust than those above due to a greater drainage area, an over-widened channel and a lack of flow convergence may not develop strong pool-to-riffle morphology though localized scour may create smaller isolated pools within the larger channel.

Channels containing pool riffle sequences typically occur at a spacing of five to seven channel widths apart unless significant amounts of wood are present. These channel types exist in relatively unconfined valleys with narrower channels at gradients below those of plane-bed channels and sediments of sand to fist sized material. As with plane bed channels the substrate displays a variety of sorting and packing reflecting localized stream energy. Stream meanders, obstructions, or sediment transport and deposition form and reinforce localized flow convergence which helps to create and maintain pool riffle sequences. Sediments are sorted and maintained within specific portions of habitats often by annual events scouring a feature only to rebuild it the same year. In essence, many 'stable' features are actually dynamically stable over longer periods of time.

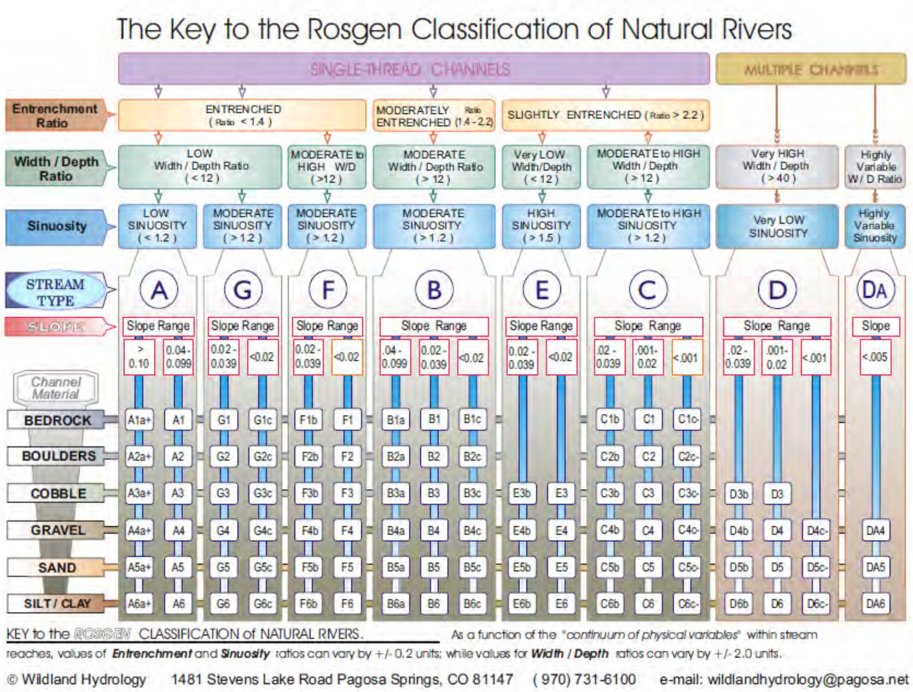
Even lower elevation areas reflect advanced mechanical weathering, available sediment supplies, and other physical, chemical, and biological factors than those of middle elevation areas. Stream gradients have decreased even further than those above, sediments have become smaller as they are weathered during downstream movement, valleys become even wider than those at higher elevations, soils deeper, vegetation more abundant, and ambient temperatures warmer leading to a greater influence of biological weathering. Deeper soils and sediment deposits have over time increased the potential for deeper and more complex hyporheic cycles and/or groundwater aquifers. Dune-ripple channels (Montgomery and Buffington, 1997) occurring in such low elevation areas is most commonly associated with sand-bed channels. They and gravel bedded stream in extreme cases depend upon the removal and replacement of dunes and riffles to consume stream energy.

Classification systems such as Montgomery and Buffington, 1997 and Rosgen, 1996 have been developed to identify the combination of factors and their influence upon channel geometry while standardizing a classification hierarchy. The extent of these investigations and their results are beyond the scope of this brief; however, these methodologies reconcile stream processes within broader scope of geologic and geomorphic constrains across broad spatial scales. Thus the factors which influence a particular type of channel in Oregon can be described and compared with another in North Carolina. The Rosgen Classification System combines sediment size, channel slope, sinuosity (stream length/valley length), width to depth ratio (channel width/depth), and entrenchment ratio (flood prone width/channel width).

For instance, C3 channels are dominated by cobble sized material with a slope of 0.1% - 2.0%, sinuosity (stream length/valley length) greater than 1.5, a width to depth ratio greater than 12, and anentrenchment ratio (flood prone area width/bankfull width) greater than 2.2. Sediment size distributions noted in Figure VI and shown in Table II tell of sediments that may exist within a single channel type and grading across channel types. Ranges defined for these parameters allow for multiple factors influencing the channel while remaining dynamically stable. In fact, healthy stream channels and robust riparian and floodplains are able to resist extremely high flow events with minimal or no disturbance; although one weakness may easily create instability in others given the appropriate conditions causing an entire reach to unzip during a single event.

As an example of how one disturbance can create a cascade of others consider a straightened channel where sediment input to a specific channel reach is nonexistent or passed through without influencing the stream power. Straightening a channel typically decreases channel sinuosity thereby increasing the channel slope (rise/run) and in effect stream power (Equation I) and by default water velocity (Equation II). Below a size dependent threshold channel sediments and in-stream structure are stable; however, as stream power and in effect water velocity increases within a particular channel velocities may exceed a critical value (Equation III) and place enough force (shear stress) upon an object to mobilize it and typically others in turn. A complete description of bedload movement is beyond the scope of this brief although the term sheer stress may be familiar to some. Higher velocity flows are generally able to mobilize larger material although local factors such as sediment size (uniform or non-uniform), sediment distributions across the channel, channel cross-section and slope, flow depth and uniform or non-uniform flow rates, among others, influence sediment mobilization. For example, if a head-cut forms (vertical erosion/drop in channel substrate elevation) a channels hydraulic radius (cross-sectional area/wetted perimeter) may remain relatively stable with stream energy consumed by substrate erosion, altering channel slope until equilibrium with the channel immediately above and below is attained. Given enough time and stream energy channel form may morph from a Rosgen Type 'C' channel to a 'G' channel to a 'F' channel back into an inset 'C' channel. Unfortunately, incised channels typically increase near-bank shear stress and may result in channel widening. A wider channel without an increase in depth elevates the hydraulic radius decreasing stream velocities and ability to transport larger sediments. This often occurs in the presence of bedrock or very large sediments such as below Hideway Creek or where stratified sediments occur such as in many locations within the Lower Secondary and Primary AOI.

Ignoring sediment, as in this example is typically not possible given its influence upon channel processes. Quantifying changes in terrestrial features such as vegetation, floodplain connectivity, in-stream structure, and channel form are relatively easy given information and techniques readily available. Valley and channel slope, channel dimensions, hydrologic parameters, and land use can often be quantified using aerial photography or direct surveys. However, identifying and quantifying sediment movement and relating it to stream discharge or most any factor can be difficult due to specific transitory parameters needed to initiate and maintain mobility. This is largely due to sediment-transport's strong dependence upon grain size where homogenous materials are more mobile than heterogeneous sediments where smaller material hides between larger and 'lock in' one another;



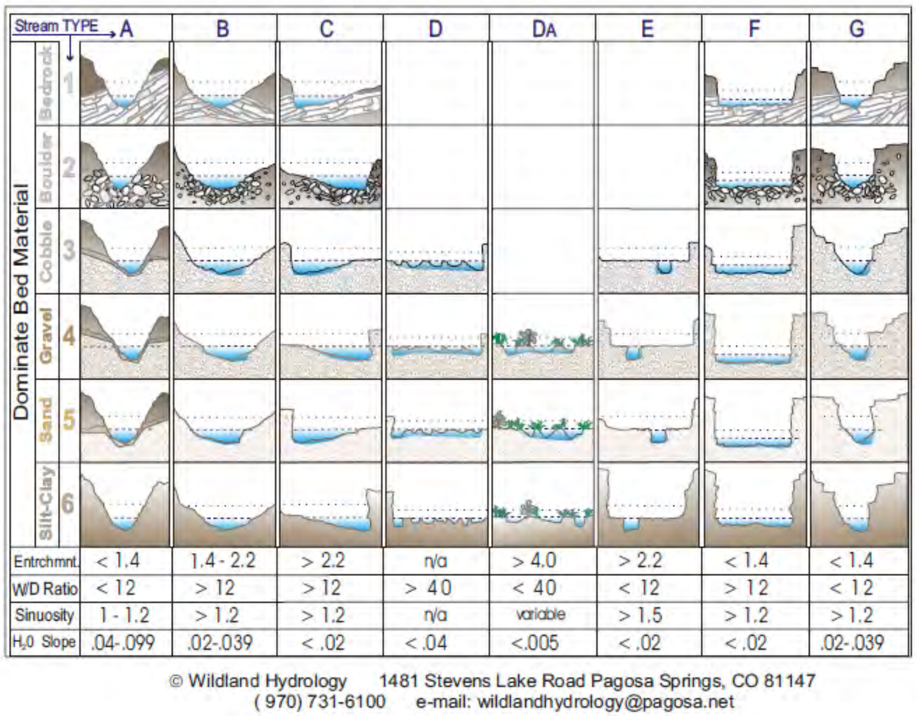


Figure VI. Stream classifications developed by Dave Rosgen (Rosgen 1996).

Sediment Class	Size Range (Inches)
Silt/Clay	< 0.024
Sand	0.024 – 0.079
Gravel	0.079 – 2.5
Cobble	2.6 – 6.0
Rubble	6.0 - 10.1
Boulder	10.0 – 80.0
Bedrock	>80.0

Table II. Sediment size distribution in inches.

$$\omega = \gamma Q S$$

Equation I. Stream Power (ω) per unit area is the product of waters specific weight (γ), stream discharge (Q), and slope (S) (Ritter, Kochel, Miller, 2002).

$$v = \left(\frac{1.49}{n}\right) * R^{2/3} * S^{1/2}$$

Equation II. The "Manning' equation describing stream velocities as they relate to channel roughness (n), hydraulic radius (R), and slope (S). The manning coefficient is a dimensionless number ~0.045 for Camas Creek between Hideway and Cable Creeks.

$$Vc = Ku * y_1^{1/6} * D_{50}^{1/3}$$

Equation III. Critical velocity (V_c) where by sediments smaller than 50% of the total sediment size distribution will be mobilized as it related to a constant of 11.17 (K_u, English units), average flow depth in the main channel or overbank areas (y_1), and streambed particle size (D_{50}).

streambed topography creating non-uniform shear stress across the channel; unsteady stream flows over time and velocities created by rising and falling stream stage; individual basin attributes including geology, soils, biota, wood recruitment, and the like; non-linear relationships between discharge and sediment load whereby sediment load may not remain constant for a given discharge. Additionally, sediment transport into a reach without commensurate transport out or sediments transported out of areach brings into question channels morphology and in effect longer term stability. That is, can the reach be supply- or sediment-limited (excess stream energy) or is the stream underpowered for a given sediment load and unable to transport available sediments. Incipient motion (Wilcock, Pitlick, Cui, 2009) problems are concerned with the flows at which sediment transportation begins. As such, a designer's primary consideration may be channel dimensions capable of passing sediments under a specific flow frequency regime or mobilizing a portion of the sediments within a reach given particular flow regime. Conversely, transport rates become an issue when considering a streams sediment budget, capacity to respond to significant sediment inputs, and the potential for channel aggradation erosion within a reach. Confusing the two can create even larger problems than currently exist. If for instance flows are able to pass high volumes of sediment though the sediment is not available stream bank cutting or head cuts may occur. Conversely, flows may not be capable of moving sediments if the sediment source or channel dimensions have changed leading to sediment aggradation.

A number of investigators including but not limited to Bayani et. al., (2004), Buffington et. al., (1992), Parker and Klingman (1982), Wiberg and Smith (1987), and Bathhurst (1987) have worked to develop an understanding of sediment movement; however, and as previously noted, the physical mechanisms underlying descriptive formulas are nonlinear and errors entered into a model do not typically produce equivalent errors in the product (Wilcock, Pitlick, Cui, 2009). Equations I, II, III represent the most basic relationships and oftentimes do not reflect or explain relationships outside of well constrained laboratories. Relationships developed in natural settings are not as plentiful and although more useful, careful consideration of the problem, processes, and land management practices are required.

These considerations have shifted some conversation from a model viewing sediment transport as continuous throughout the system to one considering size specific movement. In streams where the highly connected streams a particle has the potential to be transported throughout a system which can be further described through continuity or the balance of material entering and leaving a system (Hooke, 2003). Fine sediments in suspension or moved along the streambed may pass through a system while larger materials such as boulders, rubble, or even cobble forming extremely stable gravel bars may not move without the help of very high flows or through mechanical weathering. In the second case continuity becomes more important within more localized areas. For instance, in-stream sediment migration may occur from one gravel bar to another or a gravel bar to the general stream bank given local controls such as bedrock, debris jams, or gravel bars in part or whole created by the immobile material.

Hooke (2003) identified five classes of sediment connectivity considering the variable and temporal nature of connectivity (Table III). The classification requires that both sediment size and temporal scale are identified and are designed for contemporary surveys of channel connectivity. In this classification Hooke (2003) identifies unconnected systems as utilizing local sediment sources almost independent of one another where the influence of one upon another requires large time scales or large flow events. A lack of connectivity may be due to a streams insufficient transport ability and sediment size whereby downstream migration only occurs if another sediment source is introduced. Partially connected systems contain little course sediment transport between individual reaches except during large flow events. Most channels likely display a degree of partial connectivity although the coarsest sediments are occasionally transported unlike unconnected systems. Conversely, connected systems

Connectivity	Description
Unconnected	Local stores/sinks with incompetent reaches between.
Partially Connected	Transfer only during extreme flow events.
Connected	Course sediment transport during 'normal' flow events.
Potentially Connected	Competent to transport but supply limited.
Disconnected	Formally connected but transport is now obstructed.

Table III. Competency classifications modified from Hooke, 2003.

contain easily and frequently transported course sediments through the system during 2 and 5 year events. Sediments temporarily stored are easily remobilized with channel variation and to some extent may transport rates may not be consistent or constant. Potentially connected systems maintain the ability to move the largest sediments if they were present. That is, the systems are supply limited and the classification could easily be changed by the presence of adequately sized sediments. The final category identifies disconnected systems as having barriers to connectivity precluding sediment movement downstream. Dams are a prime example of this.

To understand the effect of sediment Reid and Dunne (1996), among others considered weathering, sediment sources, sinks, and erosion throughout a watershed and what has evolved into the development of sediment budgets to account for sediment sources and disbursement within and through a basin. With adequate resources and time sediment budgets may be created within a single system or within subbasins of larger systems to understand their influence upon the larger system, or quantify the properties of the larger system. Much of the requisite data may be garnered through previously secured aerial imagery, sediment data, or topographic surveys, or morphometric channel data. Often the most accurate estimate of transport rate and trends in transport rates can be described using slope, dimension, runoff, and land use within a watershed (Wilcock, Pitliclk Cui 2009). Many applications only require an order of magnitude estimate or the relative importance of process rates (Reid and Dunne (1996) to be effective.

Data Collection

As previously noted a combination of data sources were used in this effort which included literature searches, aerial photography, and data collection. Where data was physically collected cross-sections reflect gross changes in channel morphology or specific features such as confined and unconfined channels in both the Lower Secondary and Primary AOI. Data collection utilized a laser level, stadia rod, and tape measure in the Lower Secondary AOI. A survey grade Global Positioning System (Trimble R8) was used in the primary AOI resulting in a longitudinal profile and cross-sections (Figure VII) shown Appendix I. Pebble counts were made using methods described by Leopold and Dunne (1971) where expanding flows occurred and by Reid and Dunne (1996) within well-defined channels. The method described in Reid and Dunne measured surface sediments in a 1x1 meter area with sediments beneath sieved to a depth of 0.25 feet. To reduce costs sediments were sampled in association with cross-sections and only where obvious changes in sediment size or distribution were noted or expected to occur.

Analysis of the data utilized equations noted in this paper and WinXSPRO developed by the United States Forest Service (USFS). Calculations using an assumed Manning's 'n' and slope based upon survey data were comparable and easily within the same order of magnitude. Further efforts to address any of these issues would require a more comprehensive survey and calculations.

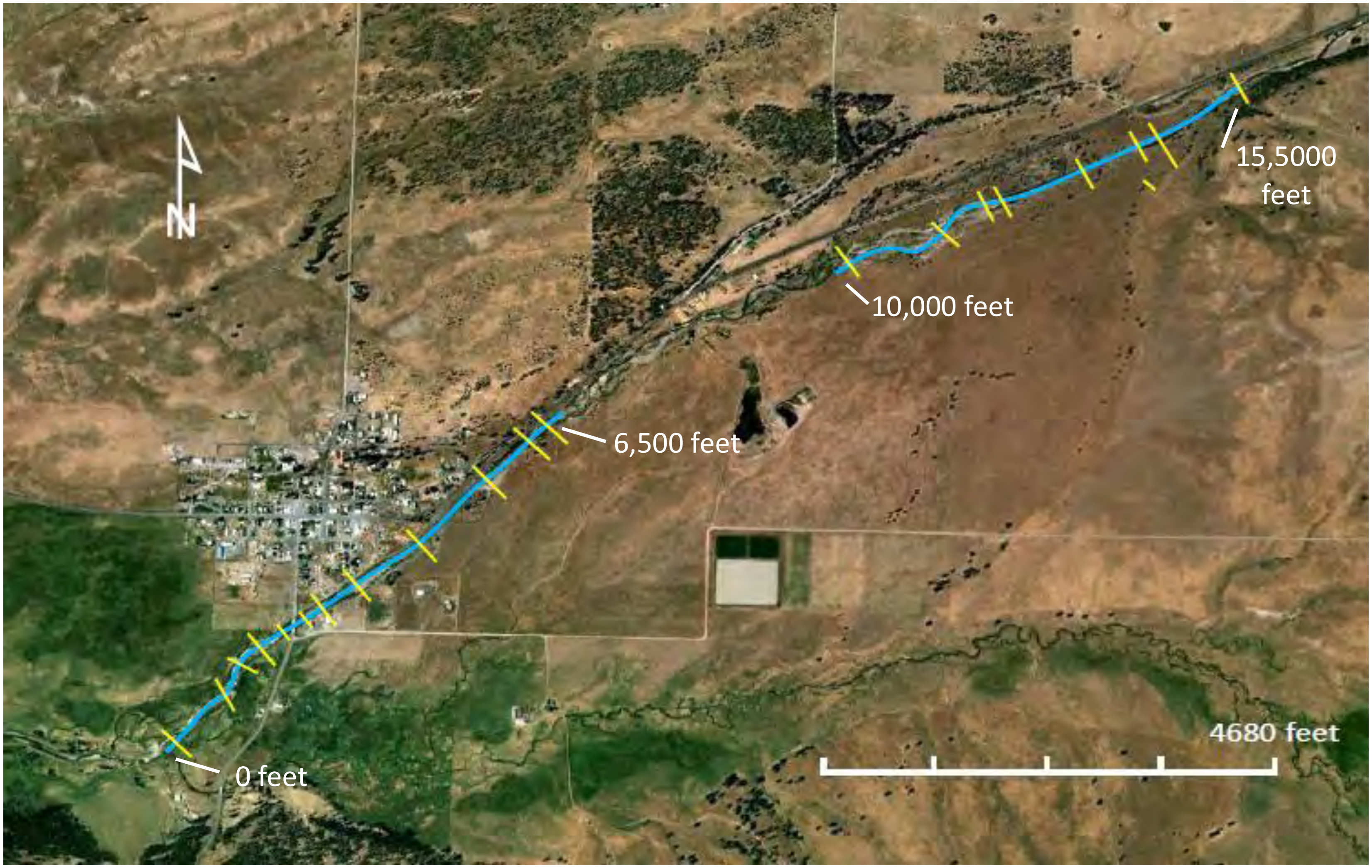


Figure VII. Data collected using a Global Positioning System in September 2011. Numbering begins at the upstream end of the area (upper right) at XS 1 and ending at XS 23 with XS 4 lying south of XS 3. The lower group begins at XS 10 with XS 14 and 16 (not shown) located between cross-sections 13 and 15 and 15 and 16.

Discussion

Although the consideration of individual factors constitutes an interesting theoretical or logical approach to understanding their interrelationships on the ground is where the fun really begins. Large scale contributors such as climate compounded by land management practices in the headwaters bear some influence upon the Lower Secondary AOI and Primary AOI; as do influencing factors within the lower elevation areas. However, a detailed consideration of all factors across the watershed would likely be an unwieldy process and inefficiently contribute to the overall effort given funding and labor constraints. Thus, for the purpose of this brief, the watershed will be further split into four subbasins including Upper Camas Creek (above the confluence of Hideway and Camas Creeks), Hideway Creek, Cable Creek, and Camas Creek below Hideway Creek. These divisions may be somewhat arbitrary at this point considering the limited amount of data available; however they do provide a convenient way to discuss the basin. With the exception of Camas Creek below Hideway Creek all subbasins drain Tower Mountain and/or the Blue Mountain crest north of Camas Creek and contribute significantly to Camas Creek's streamflows and sediment/debris load. Camas Creek below Hideway Creek contributes little to overall flow and sediment/debris load as Owens Creek drains the Blue Mountains north of Camas Creek and Pine Creek drains much of the Lower Secondary AOI to the south.

A primary influence upon Camas Creek's watershed is that of climate where spatial and temporal distributions reflect distinct characteristics of elevation and aspect among others. Due to their proximity to the Pacific Coast and position within the Columbia River Basin, the Blue Mountains suffer a strong maritime influence providing moisture to the basin where snow generally begins to accrue in late October peaking in December/January and leaving by early June except the highest elevations or northerly aspects. This snow-dominated system is highly reactive to warming and cooling trends between storms which serve to increase the liquid-water content of the snowpack and in effect snowpack density as the snow settles. The liquid-water content of the snow pack often referred to as the snow/water equivalence (SWE) increases during warming periods until liquid water leaves the snowpack reflecting the influence of ambient air temperatures, precipitation, and various thermal inputs. This also provides a convenient way to show climactic influence upon the Camas Creek basin without specialized equipment that isn't typically deployed. Figure VII grossly represents the influence of air temperatures, elevation, thermal inputs, and their influence upon Camas Creeks discharge during 1989. Data from the USDA SNOTEL sites (NRCS, 2012) represent conditions at the County Line SNOTEL site (4,830 feet in elevation) below Lucky Strike (4,970 feet in elevation) to the northwest along the northern Blue Mountain crest with Arbuckle Mountain (5,770 feet in elevation) further west along the crest. In this example increasing air temperatures, and thermal inputs over the course of six months roughly coincide with increasing and/or decreasing SWE as the snowpack melts. Although these sites are not ideally suited to identify specific attributes of Camas Creek's behavior as Arbuckle Mountain is drained by Five Mile Creek and its elevation is less than that of Tower Mountain though it will be treated as a surrogate and the other two sites do not contribute directly to Camas Creek. However, their differences in elevation should provide a reasonable characterization of Camas Creek's response to climactic patterns. Temperature and snow water equivalent data were exaggerated and an offset included to better visualize their influence upon stream flow cycles.

Air temperatures collected at the SNOTEL sites during 1989 and stream discharge at USGS Gauge #14042500 are displayed in Figure VIII along with SWE. Air temperature fluctuations roughly coincided with stream discharge and changes in SWE in all locations from 1-15 March, temperatures at Arbuckle Mountain ranged between 2 and 49 degrees Fahrenheit with average temperatures ranging between 11 and 40 degrees Fahrenheit. This coincided with a significant drop in SWE at the County Line

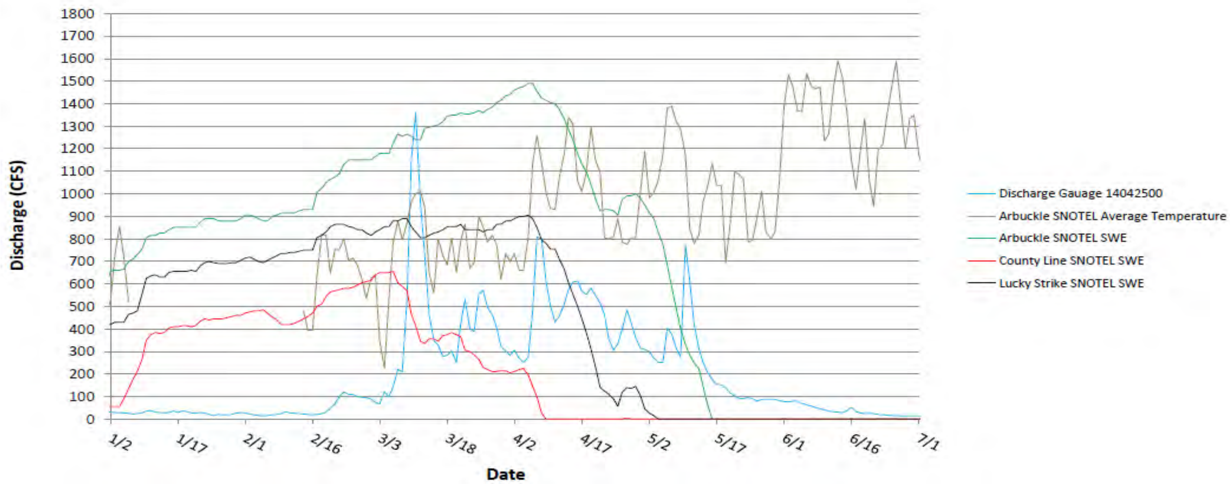


Figure VIII. Discharge data from USGS Stream Gage #14042500 and air temperature and snow water equivalent data from Arbuckle Mountain and County Line SNOTEL sites. Temperature and snow water equivalent data have been exaggerated and an offset included to better portray inter-relationships; thus, the graph displays only relative qualitative relationships.

site (12.3” to 7.1”) while the Lucky Strike site SWE rose slightly to 17.8” inches and fell back to 16.5” where it began, and the Arbuckle Mountain site rose from 23” to 26”. Stream discharge increased significantly from just over 200 cfs to 1,360 cfs and when combined with increases in SWE suggests a rain on snow event occurred. Other warmer periods also resulted in decreased SWE, melting snowpack, and higher stream discharge progressively from lower to higher elevations and from early April through mid-May. These relationships should be expected to occur over time with different peaks and valleys in response to annual weather patterns.

The longer term influence of precipitation patterns and spring runoff is a bit more complicated though their influence upon the stream channel and aquatic and terrestrial habitat may not be. Efforts by Ecovista (2003) concluded that while stream discharge equaling 1,050 (bank full event) would occur every two years, a large event exceeding 3,840 cfs would only occur every 68 years at USGS gage #14042500. Their efforts could not identify changes in peak flow frequency and magnitude or annual runoff totals. However, spring runoff contributions between 1968 and 1978 increased on average over other decades examined; likely a result of an accordant increase in annual spring rains. This supports a review of available data within a brief overlapping period (1979–1991 of stream discharge and Arbuckle Mountain SNOTEL data that the total annual precipitation trend line slope (zero would indicate no loss or gain) of -0.21 while the mean annual discharge maintains a slope of -3.7 and annual peak discharge maintain a slope of 35.8. In other words if only this data is considered total annual precipitation has decreased less than that of mean annual discharge while peak flows increased considerably. Such disparity could only occur if peak flows are responding to ‘rain on snow’ or similar events that would remove a greater amount of water in a brief period of time. If considering a broader period of time the slope of mean annual discharge (-0.3) and that of annual peak discharges (1.1) the curve becomes smoother as signal noise decreases.

Generally speaking, the basins upper elevations have been primarily influenced by common forest management (logging, road construction, altered fire regimes) and grazing while lower elevation areas have been more heavily influenced by grazing practices and infrastructure development and protection. While these practices directly influence physical attributes of the watershed, perhaps more importantly, they influence the watersheds ability to react to broader scale forces such as climate and precipitation.

With the advent of the Oregon Forest Practices Act in 1971 and other documents such as Total Maximum Daily Loads (ODEQ, 2012) and multiple use planning practices, terrestrial and aquatic conditions now receive more comprehensive management than what would have been rendered historically. Nonetheless, several factors remain true: road development and maintenance contribute sedimentation during storm events or spring runoff especially where road densities are high or equipment compacts forest soil and reduced water infiltration into soils or water intercepted by road cuts results in more overland flow or flow in roadside ditches increasing flow energy and the potential for erosion while reducing residence time within the soil profile and/or aquifer. Regulating access to roads may reduce their sediment contribution to streams their effect can still be noted upon terrestrial and aquatic species. Restoration efforts can decrease the influence of roads depending upon the degree of restoration although efforts may be impractical give funding technical constraints. Inappropriately sized culverts contribute to downstream scour by focusing stream flow energy and roadbed stability if culverts become plugged. An example of this is the Bruin Creek culvert a tributary of Desolation Creek where considerable portion of the road prism (approximately 25 feet in height) washed into Bruin Creek after the culvert became unstable and plugged with debris in 2011. A more pertinent example of the influence of roads are high road densities in excess of 4 miles per square mile within the Camas Creek basin which have been identified as a primary limiting factor within the Camas Creek Assessment Area with Bowmman, Hideway, and Lane Creeks being the most likely to exhibit in-stream effects (Ecovista, 2003).

By the 1950's more modern fire management had successfully extinguished all fires of moderate to low intensity. The loss of more frequent low intensity fires and selective logging practices increased moist forest types by 47% between 1937 and 1996 (USDA 1, 1997) on the Umatilla National Forest. This contributed to a shift in vegetation type from open Ponderosa Pine stands at lower elevations trending to mixed fir and eventually sub-alpine fir at higher elevations to densely packed mixed fir stands across many elevations. Sixty years after fire suppression began in earnest the only Ponderosa Pine stands left were those the loggers had missed with the balance consisting of crowded firs (Langston, 1995). Increased tree densities, more litter, and less frequent fires significantly increased fuel loading setting up conditions appropriate for high intensity fires such as portions of the 1996 Tower Fire. Approximately 45% of the area consumed by the Tower Fire burned with enough intensity to kill all vegetation (USDA 1, 1997). High to moderate intensity burns over 42% of the burn area left some riparian areas without sufficient vegetation to cool stream water three years later and removed in-stream woody structure (Tower Recovery Projects Final EIS, 2001). The remaining 58% largely burned without enough intensity to significantly reduce fuel loads (USDA 2, 2001).

A shift from open pine stands to denser more moist forest types has also likely influenced precipitation available for vegetative growth and streamflows. Species with more open canopies and growth patterns such as Ponderosa pine generally intercept less sunlight thereby improving conditions for grasses and forbs while increasing precipitations infiltration into soils during cold periods. Within maritime climates the tree canopy typically maintains a variety of reactions to snow events due in part to SWE while a change in the forest canopy may influence the snowpack's energy balance. Storck et al (2002) found that approximately 60% of snowfall during a single event of less than 1.9" was intercepted by tree canopies northwest of Crater Lake and 70% of that left the canopy as melt water drip and mass release to the ground below when conditions were conducive to snowmelt. The remaining 30% or ~0.5" was lost to the atmosphere through evaporation or sublimation when temperatures were below freezing. While Douglas fir, Ponderosa pine, and Lodgepole pine all intercepted similar amounts of snow, accumulations below dense stands was generally less and melted quicker than accumulations within harvested stands (15% of the original number of trees remaining) or small clearings. This is somewhat different than precipitation in the form of rain where the canopy must become completely saturated before dripping occurs and as such the ground below or in the shadow of a large tree may not become wet except during larger or longer term events. Additionally, warmer air temperatures allow for increased evaporation thus relieving the soil profile of valuable moisture.

The combined influences of forest management and climate are more relevant to the Upper Camas, Hidweay, and Cable Creek subbasins. They each cover approximately 90, 30, and 38 square miles respectively with forest cover of approximately 73, 77, and 79 percent and mean annual precipitation of approximately 27.1”, 28.4”, and 27.8” respectively. Although the classification for this brief splits Camas Creeks somewhat differently, estimates by Ecovista (2003) of peak discharge based upon USGS methods (1993) for each subbasin suggests the Upper Camas area produces the greatest discharge followed by Hideway Creek and then Cable Creek. Considering that forest coverage and precipitation were similar for all, Upper Camas Creek benefited from a larger basin area while Hideway Creek benefited from greater precipitation.

The lower secondary and primary AOI suffer similar influences from climate as those areas above trough to a lesser degree in response to decreased precipitation and more open vegetation types. The most marked difference is a shift to a more dominant grazing management scheme and the geomorphic setting as it relates to channel processes, riparian health and floodplain connectivity.

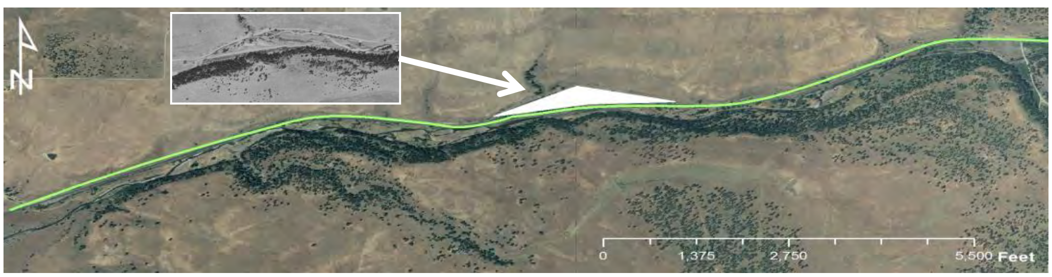
The collected data cannot reflect all changes in both the secondary and primary AOI although generalized inferences to changes along Camas Creek and its tributaries since the late 1900s can be made. Generally speaking, there appears to have been a loss of effective floodplain area and connectivity throughout much of the Camas Creek watershed. This statement reflects the findings and recommendations included in documents such as the North Fork John Day Subbasin Plan (CBMRCDA, 2005), Mid-Columbia Steelhead Recovery Plan (NMFS, 2008), and the Oregon Department of Environmental Qualities 303(d) list (ODEQ, 2012) and observations by CTUIR personnel.

Floodplain

Terrestrial areas outside the stream channel play and riparian areas an important role in buffering against high flow events and maintaining water quality while providing valuable resources for both domestic and wild creatures. As such, direct or indirect modifications can have important implications upon channel morphology and processes and water quality. Moving SR 244 onto the floodplain from the northern valley scarp and several levees within the lower secondary AOI provides such an example. The roadbed and levees have reduced Camas Creek’s available floodplain and in effect its ability to distribute stream energy across the floodplain during high flow events thereby concentrating stream energy within the channel. Areas identified in Figure IX represent a loss of approximately 123 acres of floodplain below Hideway Creek due to meander cutoffs by SR 244.

While the area of a floodplain alone consumes a portion of stream energy, water depth, obstacles on the floodplain (floodplain roughness), and multiple flow paths across the floodplain also diffuse stream energy. A connected floodplain distributes water, sediments, and debris more readily access the floodplain with existing vegetation and deposited features capturing debris creating more complex flow paths. A well connected floodplain also increases discharge residence time and improves the channel and riparian areas ability withstand erosive forces by distributing sediments over a broader area and decreasing the streams energy slope and in turn the opportunity for large scale or dramatic stream channel evulsions. Extending the duration of floodplain flooding increases the opportunity for groundwater aquifer and hyporheic recharge and providing higher quality late summer streamflows.

$Q = A * V$ Equation IV. Stream Discharge (Q) the product of cross-sectional area (A) and velocity (V).



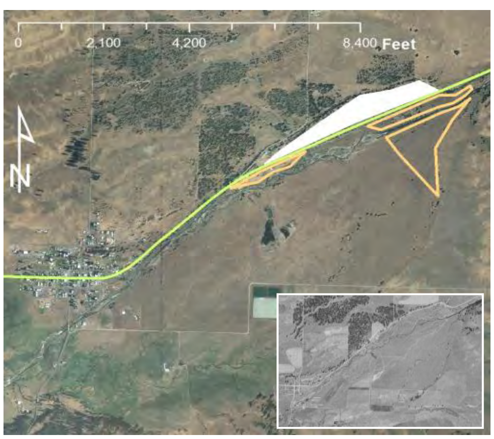


Figure IX. The loss of available floodplain due to rerouting SR244 (white areas) and levee construction (orange outline). Insets show pre construction aerial photos from 1956 (middle reach) and 1946 (lower reach); background photo was taken in 2006.

Top – From Hideway Creek to Cable Creek where ~10 acres is now isolated from Camas Creek.

Middle – From Cable Creek to the broader valley about Ukiah where ~13 acres is isolated from Camas Creek.

Bottom - Ukiah Valley where ~100 acres are isolated from Camas Creek.

Cross-sectional data collected below the confluence of Hideway and Camas Creeks indicates the stream channel has changed considerably over time while metrics such as bankfull and wetted width are difficult to determine in paleo-channels due to vegetative regrowth and trampling by animals comparisons can be made. Rough calculations using Equation 2 and Equation 4 suggest the paleo-channels base flow depth would have been approximately 4” higher than the original channel and 12’ narrower at cross-section 1 (Figure X). Paleo-channels would have effectively concentrated baseflows while allowing much greater floodplan access with approximately two feet between the water surface and top of the streambank (freeboard) as opposed to the existing channels approximate four feet of freeboard on the same northern bank. The left bank of the existing channel lies approximately 10 feet from the toe of the southern valley wall prohibiting significant flows to the south while its trapezoidal shape also passes flows more efficiently than the paleo-channels more complex shape which includes an inset floodplain resulting from previous erosional events.

Cross-section 9 (Figure X) which lies several hundred yards downstream from cross-section 1 maintains a similar shape as the first although in this location the adjacent southern valley wall contains bedrock outcrops that prelude the presence of a floodplain. Adjacent paleo-channels are markedly different than the existing channel with a bank to bank average width of 52 feet as opposed to 92 feet for the existing channel. Without any indicators of a bankfull discharge we are unable to definitively define a flow depth; however, paleo-channels maintained a channel depth of approximately two feet as opposed to approximately 5.5 feet in the existing channel with cross-sectional areas of 80 and 359 respectively. Given cross-sectional area alone the paleo-channel would have allowed significantly greater floodplain connectivity then currently exists. The change in stream gradient and channel form and substrate is most likely due to a bridge abutment at the lower end of the property at which point Camas Creek formed a head cut which worked its way upstream ending at the bedrock contact previously noted. This resulted in an average channel depth of 4.5 feet over 6 cross-sections between the road abutment and bedrock contact A quick calculation several years ago on the reaches lower end that shares a profile similar to Cross-section 9 suggesting that would take a 10 - 25 year event or greater to access the floodplain.

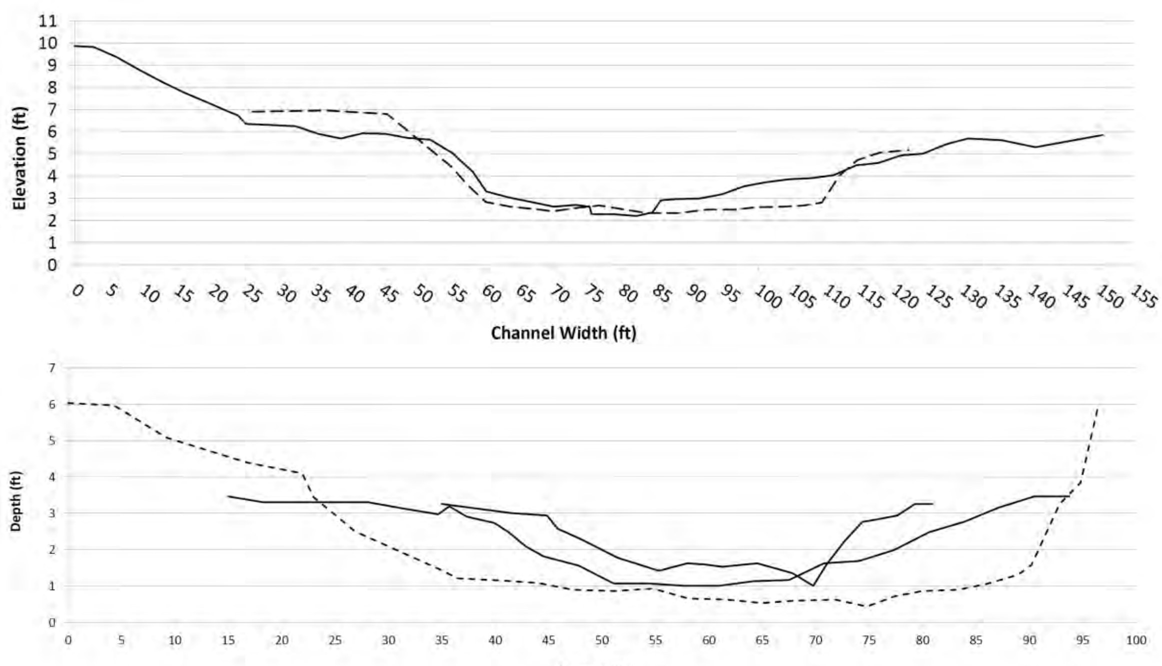


Figure X. Data for Cross-section 1 (top) and Cross-section 9 (bottom) collected below the confluence of Hideway and Camas Creeks. Paleo-channels are represented by a solid line while existing channels of September of 2011 are represented by a dashed line.

At face value, cross-sections one and nine appear to represent the paleo-channel as far down as Cable Creek although local conditions may have selectively influenced stream behavior. Several small drainages direct run off to Camas Creek between Hideway and Cable Creeks although their contributions only occur from late winter to mid spring. The additional discharge from Cable Creek would increase the size of Camas Creek's channel due to both discharge and sediment/debris input and elevated the importance of floodplain connectivity to diffuse stream energy and buffer against the streams flashy nature although there is no reason to expect historic floodplain connectivity would have changed significantly until Camas Creek entered the broader valley around Ukiah and as such, cross-sections one and nine likely represent Camas Creek's channel throughout most of the lower secondary AOI.

Within the broader valley the situation is markedly different due to the change in stream gradient and resulting alluvial fan. With sediments and debris annually deposited upon alluvial fans and fluctuating water levels floodplain and riparian vegetation are typically less abundant; however, low gradient alluvial fans may support robust vegetative growth in some instances. Available historic photographs do not suggest robust vegetation ever existed although the period of record may be inadequate. Descriptions of historic grazing practices suggest that viable vegetation may have been removed from along Camas Creek prior to the first aerial photographs (Langston, 1996). Streamflow and sediments historically distributed across the alluvial fan and in multiple channels are now passed further downstream through levees that at one time stretched from the old mill site above Ukiah to approximately 0.5 miles below Ukiah. Thus, past land management and flood control efforts have created a single straight channel up to ten feet deep in two locations at the valleys eastern end and just above Ukiah as opposed to multiple tortuous paleo-channels. The original alluvial fan is being recreated where levees have failed or end. Deposition within and aside an active channel due to a decrease in stream gradient and stream energy from expanding flows block stream channels which in turn avulse laterally across the alluvial fan increasing channel and floodplain complexity and connectivity at once. As the size of individual channels decrease their number will increase to maintain capacity further distributing sediment/debris across the floodplain. Smaller and more sinuous paleo-channels were identified using aerial photographs primarily on the upper third of the alluvial fan along with multiple sites with thin soils and exposed alluvial material indicating significant historic sediment deposition and floodplain connectivity. Aerial photographs from 1939 (Figure XI) do show a highly mobile single tread channel entering the broader valley about Ukiah; however, at this time we cannot be sure how much the channel had been influenced by land management practices and it possible that channel incision had occurred to some degree which caused abandonment of smaller more tortuous channels.

Channel incision begins above cross-section 1 although floodplain connectivity would still occur during higher flow events. Adjacent to the old mill site and though cross-section 2 (Figure XII) Camas Creek has incised up to 10 feet in depth and a width of 105 feet in a well-defined single thread channel. This contrasts the variability of sampled paleo-channels with depths ranging between two to three feet with significantly less width save the more complex channel to the south. Levees at cross-section 5 (Figure XII) effectively constrain flows within a 109 foot wide channel ten feet in depth that would be approximately two to six feet above the adjacent floodplain if the levee were overtopped. Conversely, cross-section 7 (Figure XII) begins to reflect the character of paleo-channels as streamflows begin to expand across the floodplain where the levee ends. This has resulted in four channels separated by gravel bars and debris; distributed across approximately 450 feet laterally for 1,700 feet before being forced back into a single channel by levees.

The lower set of cross-sections mirror conditions above although local limiting factors are slightly different. Cross-sections adjacent to Ukiah (Figure XIII) show significant natural and man-made channel disturbance beginning above cross-section 10 where Camas Creek has been restricted laterally by offset levees and channel incision for 1,200 feet. In 2011 cross-section 10 maintained a depth of ten feet and width of 105 feet while at their narrowest point approximately 220 feet below cross-section 12 levees are 100 feet apart with an easily defined active channel 33 feet width approximately eight to ten feet in depth. Well-established willows grow on either side of the channel and although some scour has occurred within the willows, sediment deposition or excessive scour are not evident. The well-defined trapezoidal channel and a lack of deposited sediments and debris strongly suggest converging flows pass all mobilized material downstream. The degree to which substrate and streambank erosion occurs at this location has not been identified. This portion of the channel differs from that at cross-sections 15 and 17 in that levees at cross-section 15 are 176 feet apart and 135 feet at cross-section 17; in both cases, significant deposition has occurred with little to no evidence of erosion. Although cross-section 15 contains a relatively well-defined baseflow channel 6.5 feet in depth and a width of 30 feet a second high flow channel to the south becomes active during high flows. The channels are separated by a well-developed gravel bar that has maintained is position and shape long enough to begin growing vegetation on top. Cross-section 17 contains a small channel against the southern levee less than half the width of those above, south of a relatively level area of worked gravels, and south of vegetation abused by high flows and passing sediment and debris. Just downstream of cross-section 17 the Ukiah Granite Road bridge constrains Camas Creek within the 140 foot wide abutments and at cross-section 20 (Figure XIII) 300 feet downstream levees are nonexistent or ineffective as deposited sediment have recreated a cross-section similar to that of cross-section 7 above. Cross-sections 15, 17, and 20 strongly suggest sediment and debris passed through the narrower portions of the levees above are deposited to a greater degree as one moves downstream beginning between cross-sections 13 and 15. The wider channel does not appear to provide sufficient energy to pass or mobilize sediments during higher discharge events. The degree to which this has or has not occurred over time and in response to specific high flow events was not determined. Oral historical accounts suggest that features placed during the late 1960's channelization effort were ineffective at forcing the channel to pass sediment and debris.

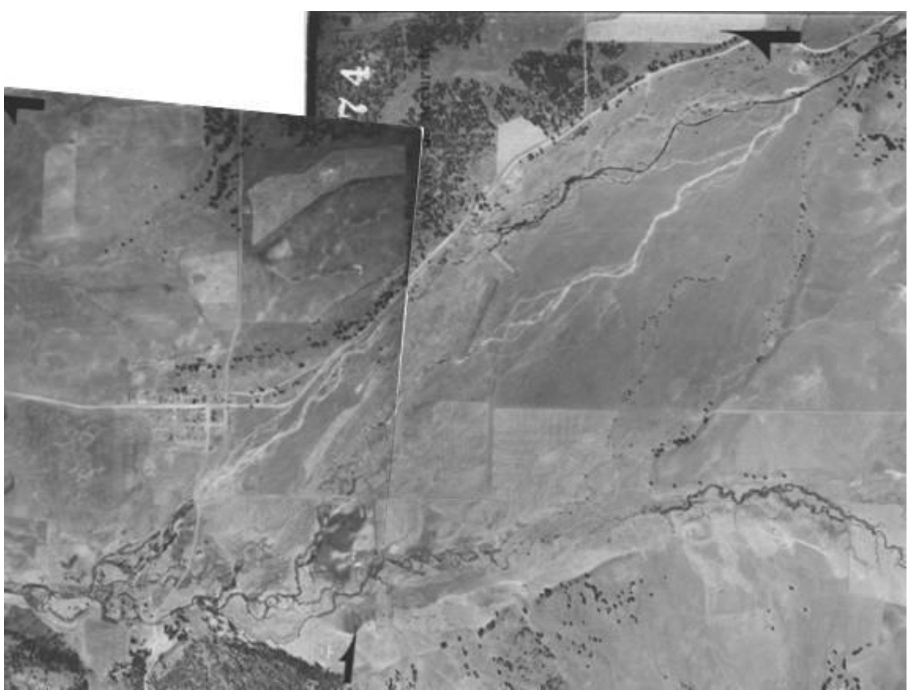


Figure XI. Historic channels of Camas Creek within the broader valley around Ukiah compiled from aerial photographs taken in 1939. The existing levee below the old mill site roughly follows the northern wet channel.

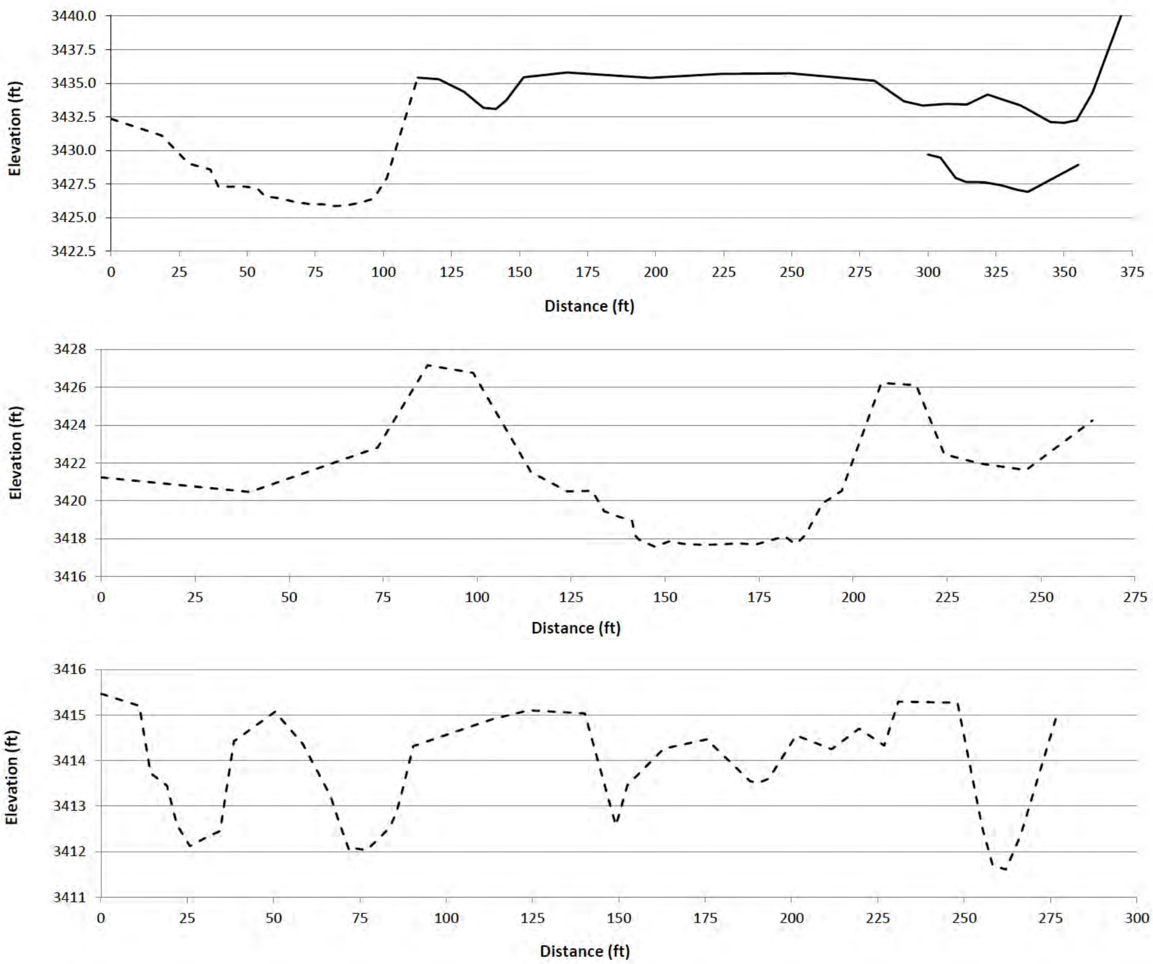


Figure XII. Cross-section data from XS 2, XS 5, and XS 7 (top to bottom respectively) collected in the upper primary AOI. Cross-section 4 lies in the lower right portion of the top graph. Paleo-channels sampled in September 2011 are represented by a solid line while existing channels are represented by a dashed line.

Calculated peak discharge rates to suggest Camas Creeks ability to pass a 100 year flow event (calculated at 3,899 cfs) within the Primary AOI's existing channel is only possible at cross-sections 5 and 10 (4,172 cfs and 4,433 cfs respectively) using data from pebble counts and estimated slopes Calculated values for cross-section 2 at the six foot bank height (2006 cfs) indicate the channel has the ability to pass discharges between a five and ten year event while calculated values for cross-section 15 (1,761 cfs) lie somewhere between a two to five year event. Conversely, paleo-channels are only able to pass 332 cfs 226 cfs at cross-section 2 and 4 respectively within the sampled channels which are comparable to the smaller channels at cross-sections 7 and 20 using actual and assumed values for slope, substrate size, and roughness. Given these numbers floodplain connectivity has clearly been restricted beyond historical levels by levees and channel modifications through land management practices

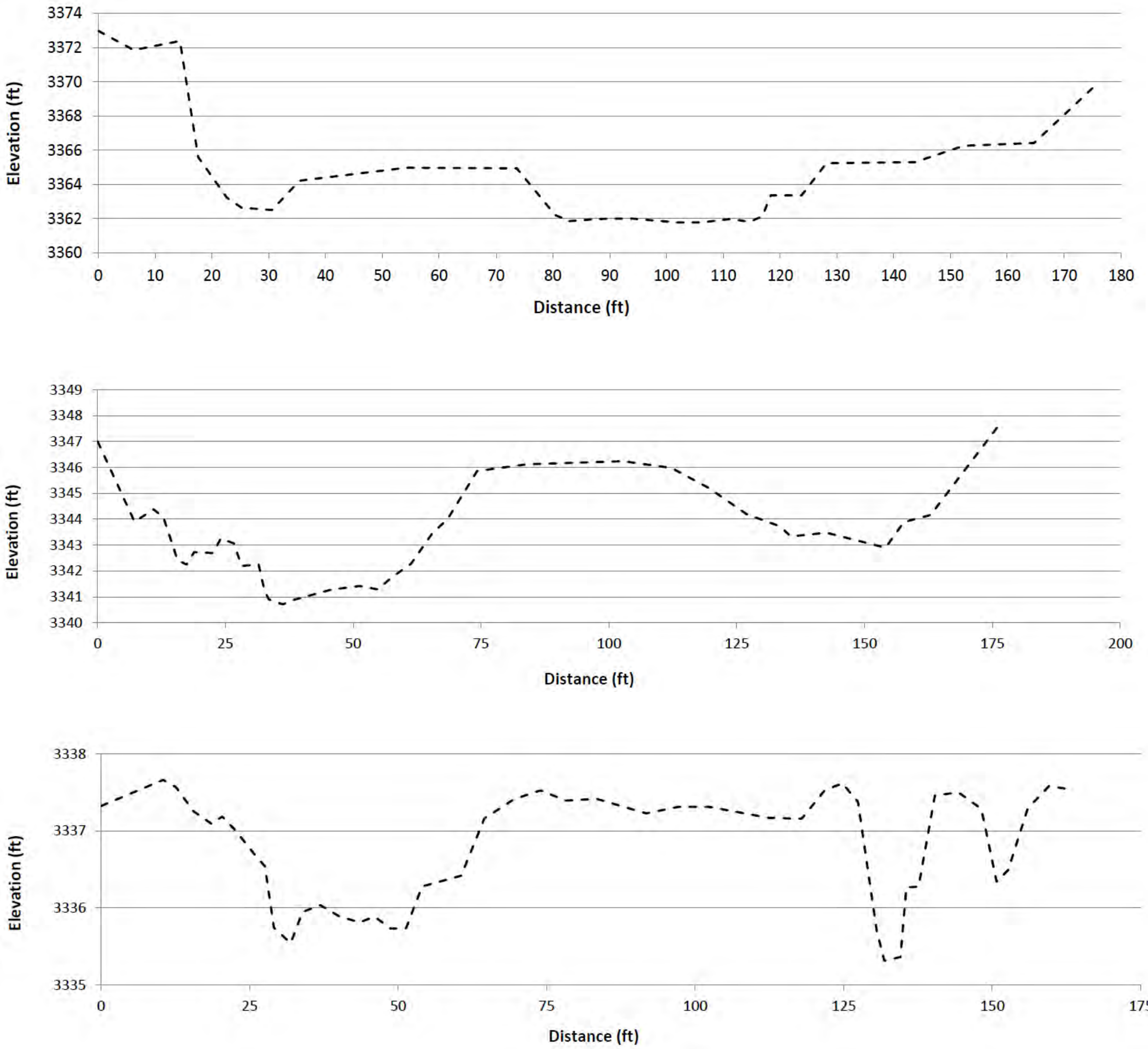


Figure XIII. Cross-section data collected in the primary AOI XS 10, XS15, and XS 20 (top to bottom respectively). Cross-section 4 lies in the lower right portion of the top graph. Paleo-channels sampled in September 2011 are represented by a solid line while existing channels are represented by a dashed line.

Riparian

Areas adjacent to the stream channel and directly influenced by the stream derived moisture called the riparian area has several functions: stabilizing streambanks, providing materials and leaf litter for in-stream structure and primary production, and protecting water quality. Since the riparian areas role in both streambank stability and in-stream structure are strongly related to existing conditions they will be discussed later; however, the riparian areas relation to water quality and the adjoining floodplain areas shall be addressed.

Camas Creek has been listed on the Department of Environmental Qualities 303(d) list (ODEQ, 2012) for temperature impaired streams with water temperatures exceeding 13 degrees Celsius based upon a seven day average maximum temperatures. While multiple factors influence stream temperatures the primary determinates are climactic factors, riparian, vegetation, stream channel morphology, and hyporheic connectivity. Climactic drivers such as solar radiation, air temperatures, and wind directly influence vegetative shade, stream channel size, and healthy hyporheic connectivity serve to buffer against heat flux from or into the channel. Stream channel width and aspect and local topography influence biological characteristics such as vegetation type, height, density, and spatial distributions creating and maintaining buffers against climactic drivers immediate to and away from the stream channel. These buffers serve to store heat within a system and integrate various discharges and temperatures over time (Poole and Berman, 2001). For instance, a narrower stream channel restricts heat flux from the stream through a smaller surface area while aspect and local topography may decrease a channels exposure to solar radiation and winds. The most obvious influence of vegetation is the physical attenuation of solar radiation in conjunction with slower wind speeds limiting convective and evaporative heat exchange. The loss of a buffer zone created by riparian vegetation allows for greater daily maximum temperatures and/or lower minimum temperatures which may become additive over time. That is, if daytime temperatures are artificially increased and nighttime temperatures are unable to compensate and average stream temperatures may increase over the course of time and become lethal for aquatic species. Unfortunately, many of Camas Creek's riparian areas appear to have been or are currently degraded with various degrees of recovery. This is in part due to localized head cuts isolating vegetation from either the stream channel or flows beneath the ground surface. Additionally, if subsurface flows are compromised advective heat transfers to or from the ground will become less pronounced. Without their buffering affect stream temperatures may then increase during the summer or decrease during the winter.

The sun's location directly overhead during the summer is mitigated in the Lower Secondary AOI in part by riparian and floodplain vegetation and quite often by the channels proximity to the southern valley wall. During the winter the southern valley wall in the Lower Secondary AOI completely shades most of the channel allowing for significant icing within the stream channel. The extent to which this occurs in the primary AOI cannot be determined without access to the area.

Although data could not be located to identify or contrast thermal inputs into Camas Creek within the Primary AOI existing channel characteristics and riparian vegetation suggest the riparian and floodplains vegetative influence upon the primary AOI is less pronounced than that of the narrower canyon above. Channel orientation does not change significantly from the Lower Secondary AOI reach, and topography does little to prevent direct thermal inputs. Woody vegetation in the form of pine trees occur in portions of the broader valley around Ukiah largely on the north side and off of Camas Creek with willows along much of the middle and lower portions of the Primary AOI. The upper portions of this reach maintain a similar channel to that mentioned in the Floodplain section due to severe channel incision and/or the presence of levees. Below the levees Camas Creek regains some of its natural dynamic stability and although willows are numerous vegetative cover is not significant. This may be due to natural recovery which has not yet reached a climax association.

Although specific information related to the role of beaver in both the Lower Secondary AOI and Primary AOI has not been located mention of healthy beaver populations were known to exist in the Blue Mountains before being largely trapped out in the early 1800's (Langston, 1996). In addition to slowing and distributing streamflows across a valley floor through dam construction their influence upon hyporheic flows and local groundwater levels would have improved vegetative growth within the riparian area and across the floodplain and lower water temperatures through healthy hyporheic flows. Woody vegetation populations would likely have been much more robust then what currently exists even in the face of predation by beaver. Less desirable species remaining after willows and the like were culled may have created a canopy capable of bolstering the boundary layer above and about Camas Creek thereby decreasing heat flux into and from the stream.

Channel

As previously noted, Camas Creek follows a syncline or U-shaped fold from Frazier Creek to Ukiah (ODGMI, 2001). This likely influenced Camas Creek's character, discharge, and sediment contributions resulting in a Rosgen "Type IV' valley limiting Camas Creek's ability to shift laterally between River Mile 26.5 to 15 to 300-400 feet in many locations below Hideway Creek. Although levees and SR 244 have reduced the effective floodplain in several locations, grossly calculated sinuosity for both paleo and existing channels came out to 1.06 which is similar to that of a Rosgen "Type A" channel. However, Channel form (slope, entrenchment, width/depth ratio, defined meandering channel, weak pool/riffle habitat, and point bar formation) are more indicative of a Rosgen "Type C" channel tending toward a Rosgen "Type F" channel in some locations. Previously noted paleo-channels below Hideway Creek suggest Camas Creek may have historically contained greater sinuosity though it would also be reasonable to conclude this was a local reaction to input from Hideway Creek. Additional work on a larger reach may or may not prove this to be the case.

Paleo-channels suggest Camas Creek historically maintained a moderately mobile single thread Rosgen "C" type channel with high connectivity to the floodplain as the previously noted peak discharge rates indicate. Calculated paleo-channel entrenchment values > 7.0 were much larger than the existing channel's values of 1.2 and 1.4 for cross-sections 1 and 9 respectively. Although the floodplain could become inundated under higher flow events with the existing channel, incision and widening has reduced the opportunity for this to occur.

In several locations immediately below Hideway Creek, thin soils and exposed cobbles outside or on the fringes of paleo-channels suggests these areas were worked during annual spring runoff events. Although a detailed sediment analysis has not been completed for either the existing or paleo-channel several observations can be made given channel geometry and estimated discharge rates. At this time stream energy is largely concentrated within the existing channel beyond a 5 year event with quick calculations suggesting the channel may pass a 10 to 25 year event in some locations before accessing the floodplain; thus significantly increasing stream power locally within the channel. Paleo-channels indicate this power would have been greatly distributed across the floodplain and with a healthy riparian area would have been better able to withstand erosive forces. Due to what was in all likelihood much more complex channels filled with wood, debris, and beaver dams, sediment loads would have likely been smaller with a more protracted spring runoff and less stream energy. Sediments may have contained rubble sized material although it is less likely this sized material was mobilized annually as it appears to be now. We can determine though that the Lower Secondary AOI is and has always been a transport reach for sediments and debris to a certain extent due to a relatively narrow canyon, channel slope, and sediment size. Although evidence of sediment deposition does exist adjacent to paleo-channels they lay on the periphery outside of the thalwag in deposits one would associate with transitory gravels and not permanently stored to a significant degree within the stream channel or on the floodplain.

Although sediment movement and distribution within the Paleo-channels can only be inferred, distributions within the existing channel area are more readily identified at this time. Above Hideway Creek Camas Creek appears to contain greater amounts of larger more angular sediments than below Hideway Creek, with higher proportions of well weathered gravel sized material below. Below a bedrock contact approximately 2,700 feet downstream from Hideway Creek channel substrate size increases (Figure XIV) to contain greater proportions of cobble sized material. Visual estimates of sediment indicate smaller sediments are more prevalent below Cable Creek although we have not been able to confirm that. Smaller sediments often indicative of excessive streambank erosion have been noted along lower Hideway Creek and constitute a significant portion of Camas Creek's substrate below Hideway

Creek. Smaller sediments are often entrained as excessive stream energy (high near bank shear stress) removes unconsolidated material from streambanks for which grazing management practices are at least partially responsible on lower Hideway Creek; however, geology may be a more dominant factor. Further upstream outside of grazing units along cycling trails sediments appear somewhat similar to those below. While attempts to address streambank cutting on Hideway Creek would be useful the basins geomorphology may not allow for an excessive reduction in fine sediments originating from that basin. At this point there does not appear to be significant differences in geology between Hideway and Cable Creeks save what appears to be a greater proportion of Grande Rhonde Basalts about Cable Creek.

Below the bedrock contact in Camas Creek and adjacent to exposed bedrock on the southern valley wall boulder-sized materials create localized habitat and influence channel characteristics. The influence of bedrock does not continue outside this area and above, alongside, and below the bedrock the channel substrate is armored. That is, the substrate is vertically stratified with well sorted larger cobble sized material atop smaller well mixed material. Smaller sediments that appear to originate from Hideway Creek are 'hidden' between the larger substrate materials through this reach to some extent with greater proportions existing above the bedrock contact. The plain bed armored character of the existing substrate strongly suggests that sediments are mobilized during bankfull events as stream flows increase, shear stress builds to where armored sediments are mobilized in mass exposing finer sediments below. Smaller sediments are then mobilized and the armor reestablishes itself as flows decrease.

In an effort to get a rudimentary handle on sediment migration without a more intensive bedload study painted cobble and rubble sized rocks protecting data loggers were placed in the channel where hyporheic flows were suspected to exist. The locations were associated with local geomorphic features of interest such as above and below bedrock and in riffles. The following year we were unable to locate any painted rocks suggesting that bedload movement occurs throughout much of the reach and sediments can travel significant distances.

Sediment mobility has contributed to existing channel conditions in conjunction with land management practices, resulting in a loss of riparian habitat and in-stream structure; excessive streambank cutting alters the basic channel shape and in effect its ability to pass discharge. As with most of Camas Creek within the Lower Secondary AOI, channels have become wider without significant increases in either depth or flow save where flow constriction temporarily increases stream power creating minimal scour. Relatively low channel slope at an estimated 1-2 percent and sinuosity do not provide adequate power to excavate pools without stable in-stream structure. Smaller debris pushed to the margins of the channel and larger stable material is unable to provide local controls upon in-stream habitat and channel gradient. Weak gravel bars within the existing channel are unable to maintain deposits in many instances and therefore sediment may still be passed downstream. Thus, concentrated stream energy stream energy is primarily consumed by passing sediments and streambank cutting as opposed to distributing this energy across the floodplain as occurred with paleo-channels.

Another effect of the simpler channel which now exists is a loss of hyporheic complexity and contributions to Camas Creek and the surrounding riparian and floodplain areas. Hyporheic flows rely upon a three dimensional structure consisting of consistency or diversity of substrate material, feature amplitude, alluvial depth, and water elevation relative to a feature. A series of transitional environments and pressures are formed above structures driving water movement through, around, or under the structure with greater depth. The local head pressures combined with alluvial depth, sediment consistency, and geologic constraints create and maintain transient or permanent hyporheic flows on a variety of scales. The most basic example is water movement beneath a gravel bar driven by

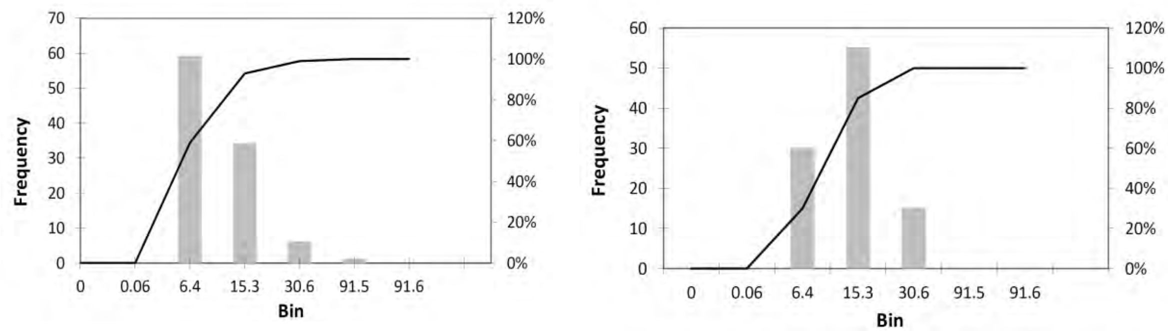


Figure XIV. Sediment data from cross-section 1 (left) and 9 (right) collected below the confluence of Hideway and Camas Creeks. Cross-section 1 lies approximately 1,000 feet below the confluence of Camas and Hideway Creeks and cross-section 9 approximately 3,500 below the confluence.

streamflows backed up at the top of the riffle with its downstream end at lower elevation. Additional complexity may range from water movement across a meander due to channel sinuosity or extremely porous alluvial material and the presence of a partially buried paleo-channel.

Given sufficient head pressures and/or alluvial sediment consistency and depth circulating flows may travel hundreds of feet until a geologic feature or sufficient ground water intrusions force them to the surface. Regardless of groundwater's influence upon deeper hyporheic flows diurnal temperature cycles are attenuated (buffered) with greater residence time and depth as heat is lost to the surrounding material; given hundreds of yards the diurnal cycles may be completely removed diverting the daily mean temperature from that of the surface water (Poole et.at. 2008). In effect, heat is 'stored' during the summer when surface water temperatures are elevated relative to ground temperatures and 'lost' to flows during the winter when the inverse is true. Surface water temperatures are therefore moderated to a limited extent by the location and volume of these deeper cycles; the presence of geologic knick points and alluvial material's hydraulic conductivity being two of the primary constraints.

Unlike deeper hyporheic cycles medium and shallow flows are less reactive to ground temperatures often due to the sheer volume of water and short residence time. The cumulative effect to both short and long term cycles is extremely important with respect to water quality and aquatic biota. Multiple gravel bars or meander bends slightly attenuating diurnal fluctuations may allow aquatic species to survive temporarily elevated temperatures and/or increase primary productivity. Baxter and Hauer (2000) identified Bull trout spawning activity at the valley-segment, reach, and pool-riffle scales correlating with Bull trout spawning activity; others such as Geist (2000) have attempted to identify the relationship between hyporheic flows and spawning activity to varying levels of success.

In an attempt to gain some understanding of hyporheic flows within the Lower Secondary AOI data loggers were placed in 2.5" PVC tubing, capped, and buried within the substrate open end down below the confluence of Hideway and Camas Creeks. Data loggers collected temperatures at one hour intervals (Figure XV) between 13 August 2008 and 1 October 2008 at three locations over a 0.8 mile reach.

Data collected from the three locations were not conclusive due at least in part to the methods coarseness. The most upper and lower data sets suggest there was little hyproheic influence in areas consisting of long plane bed riffles; however, the middle location does suggest the appearance of flows entering the stream channel likely in response to a bedrock outcrop across much of the channel. The bedrock's upstream extent is not easily discernible although it can be identified up to approximately 1,400 feet downstream of the known contact. Like much of the Camas Creek within and below this reach, a mix of rubble and cobble sized substrate overly a heavily impacted sand, gravel, and cobble mix, the depth of which is currently unknown. Flows along the bedrock interface likely occur and may have an influence upon water quality.

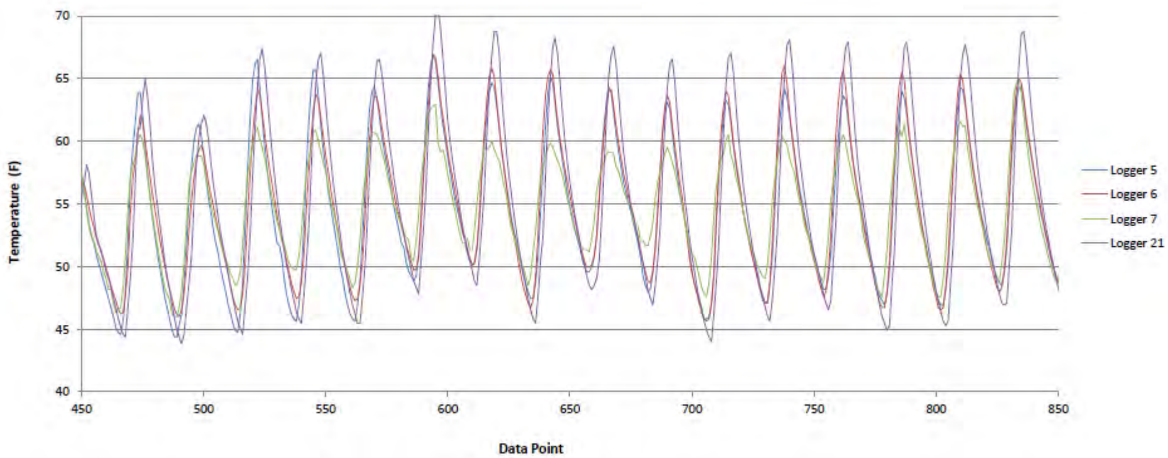


Figure XV. A sample of temperature data collected below the confluence of Hideway and Camas Creeks from 13 August 2008 through 1 October 2008 at one hour intervals. Data loggers 5, 6, 7 reflect subsurface substrate temperatures while logger 21 represents surface water temperatures

Data logger 5 was positioned several feet above the bedrock contact with logger 6 approximately 30 feet above near the top of a riffle above logger #5 and logger 7 approximately 30 feet above logger 6 near the bottom of a riffle. Similar to Arrigoni et al 2008, data do not show a change in the mean diurnal fluctuations although the signal is dampened with no apparent phase shift. Logger #5 maintained the greatest diurnal fluctuations followed by logger 6 and Logger 7. That is the data show a buffered characteristic between Logger #7 and #21 with a similar although to a lesser degree signal at loggers 5 and 6. This dampening can most likely be attributed to upwelling hyporheic or groundwater flows associated with the bedrock contact just below logger #5. However, similar mean temperatures without a significant phase shift and heavy icing during the winter suggest these hyporheic flows are most likely associated with short duration and/or low volume hyporheic cycles. While Argonni et al 2008 we were unable to identify a change in mean summer diel temperature cycles associated with 100-500 meter long cycles our effort was either not extensive enough to make a similar determination. Either they do not exist or our effort was not extensive enough. Additionally Argonni investigated a larger river with more off- and spring-channel habitat. In-stream habitat where these data loggers were placed consists of weak riffle run sequences unlike the balance of the stream channel containing continuous plane-bed riffle habitat.

Regardless of the actual processes in play the data does indicate some complexity in the form of riffle/run sequences with associated hyporheic cycles remain although the presence of shallow bedrock may be the dominant factor. While hyporheic flows do appear to exist throughout the Lower Secondary AOI their complexity and role in water quality has no doubt decreased as a result of active or passive channel modifications. Due to the valleys width and the presence of shallow bedrock deeper moderating hyporheic flows may not exist in the lower secondary AOI; however, paleo-channels, wet areas, and springs suggest significant complexity exists within and below the floodplain that could be reactivated with some effort. Reactivation could positively alter water quality the floodplains buffering capacity if the incised channel is restored.

Data from the broader valley about Ukiah primarily consists of the cross-sections and longitudinal profile previously noted, pebble counts at select locations, and aerial photographs. As such, the ability to speak comprehensively about this reach is somewhat limited. Once entering the broader valley about Ukiah Camas Creek has, as previously noted, formed a low gradient alluvial fan in response to a change in channel gradient. This altered the character of Camas Creek and introduces another set of constraining factors and potential problems which have been compounded by the construction of levees. Topographical maps suggest both overland and subsurface flows historically followed the alluvial fans gradient to the southwest after entering the broad valley in multiple surface channels and flowpaths within the alluvial fan. Flows also moved vertically and horizontally through the alluvial fan resurfacing near Pine Creek and below Ukiah. Levees now route Camas Creek in a more western route then many of the Paleo-channels which disallow or restrict floodplain connectivity and effectively contains stream energy within a smaller area and reduces channel sinuosity. While this may be an effective way to transport streamflows without disturbing adjacent areas they may not be constructed with consideration of additional factors such as sediment loading and migration, channel behavior with respect to stochastic events, and changes in stream characteristics respond to land management practices or natural catastrophic events such as fire. The existing and past levees and previous efforts to constrain Camas Creek appear to have been constructed or completed with limited consideration for anything more than passing water. That said, attempts to identify the details of previous efforts have not proven fruitful and as such relevant information may have been missed.

Beyond what was noted while discussing floodplain connectivity above where Camas Creek enters the broader valley about Ukiah, the channel incised approximately six feet along the right bank although it does contain an island and secondary channel to the south. This quickly increases to a depth of ten feet at the old mill site continuing to the end of levees just above cross- section 7. Aerial photographs taken in 1939 (Figure XI) show a single thread channel within the narrow valley splitting into multiple or at least shifting channels between cross-sections 2 and 3. The single thread channel may have previously been influenced by land management practices as an older channel to the south once departed from its current course further upstream. A split in Camas Creek's channel shown in the 1939 photo occurs between cross-sections 2 and 3 and may be responsible for the lower right bank elevation in cross-section 2, although farther off the channel the floodplain elevations on both sides are similar. Regardless, the existing channel with a depth of six or nine feet depending on the streambank and 112 foot width at a six foot depth is considerably greater than the two to three foot depth and 30 to 90 foot width of the paleo-channels.

Cross-sections show a repeating pattern of down cutting and over widening in response to local controlling factors above confining levees with sediment deposition below as stream flows spread out and depositing sediments (Figures XII & XIII). As previously noted smaller sediments are often associated with streambank erosion and with significant erosion within the existing channel due to increased near bank shear stress from flowing waters compounded by an increasingly incised channel one would expect to see differential sediment sorting in a downstream direction.

Pebble counts at cross-section 1 and cross-section 2 (Figure XVI) are similar save a slightly lower percentage of gravel sized sediments at cross-section 1 most likely due to a decrease in shear stress upon the channel substrate. Given a deep narrow channel and a wide shallow channel turbulence created by the substrate will be greater in the shallower channel resulting in a general decrease in water depth, widening of the channel, and decreased shear stress such as at riffles. Higher levels of shear stress occur in narrower portions of the channel such as where in-stream structure constricts the thalwag creating local scour deepening the channel. Thus, a difference in pebble counts can be explained through established relationships influencing local conditions as broader relatively homogenous setting. Unlike the Lower Secondary AOI above, concentrated discharges have eroded previously deposited sediments vertically and laterally without structures creating and maintaining scour; this is likely due to extensive amounts of highly mobile sediments previously deposited on the alluvial fan transported from areas upstream. Sediments were historically deposited laterally across the alluvial fan as sediments and debris blocked flowing channels, shifting discharge laterally across the fan and creating a new channel. Due to the alluvial fans low gradient (approximately 1%) and flashy precipitation dominated nature channels across the fan would not have been as instable as higher gradient more 'traditional' alluvial fans one sees in desert environments. As such, individual channels are not always discernible when standing away from the feature although paleo-channels are visible on aerial photographs within the upper third of the fan suggesting they were reactive to sediment and debris deposition during high discharge events. Water spreading across the alluvial fan funneled into channels further downstream or subsided into the fan itself. Single thread channels smaller than the existing channel are clearly visible and were sampled although their age relative to smaller channels is unknown at this time and pebble counts were not conducted as they have long been covered with grass. It isn't unreasonable however, that a single primary channel with associated smaller channels could have existed in tandem with multiple smaller channels.

Cross-section 5 clearly reflects the presence of a levee both in form (Figure XI) and in sediment distribution (Figure XVI). The plain bed channel within most of the upper levees between cross-sections 3 and 6 consists of roughly equal portions gravel and cobble sampled at cross-section 5 due to the channels over widened trapezoidal shape. Although cross-section 5 represents the sediments within the levee there is a transition from greater proportions of cobble sized material at the upper end and a transition back to courser material at the lower end not visible in the data. Pebble counts for cross-section 7 (Figure XVI) do not show this transition as well as cross-section 6 (Appendix II), as the cross-section collected material across what would be the active channel during high flow events. As such, smaller sediments more prevalent on dry gravel bars during data collection were overrepresented as compared to larger material in the primary flow channels. Below cross-section 7 where the channel becomes more convoluted and discrete pool, riffle, run habitats become more prevalent sediment size increases as smaller materials are passed through; cross-section 8 (Figure XVI) shows this distribution well.

Sediments at cross-section 10 through 17 contained greater proportions of gravel sized material hiding between larger sediments indicative of excessive streambank erosion occurring through the upper portions of this reach. Subsurface sediments through the Primary AOI were relatively consistent in both size and proportion and did not appear to reflect spatial differences or trends. As such, we are unable to describe anything of note at this time. Sediment samples at cross-section 20 show equal proportions of gravel and cobble sized material where here again gravel is hidden between larger material. In this location as with cross-section 17 channel larger material was present in well-defined channels in the broader channel adjacent to what are exposed gravel bars during baseflow.

The relationship between cross-sectional area and wetted perimeter, otherwise known as hydrologic radius, differs between existing and paleo-channels. Calculated values (Table IV) for channel full events show that unconstrained paleo-channels values were three times less than that of the existing channel overall. In other words, the existing channels are three times more efficient at passing discharge then paleo-channels. This does come at a price though, as improved efficiency translates into increased stream energy in less sinuous, more trapezoidal, and smoother channels and in effect greater

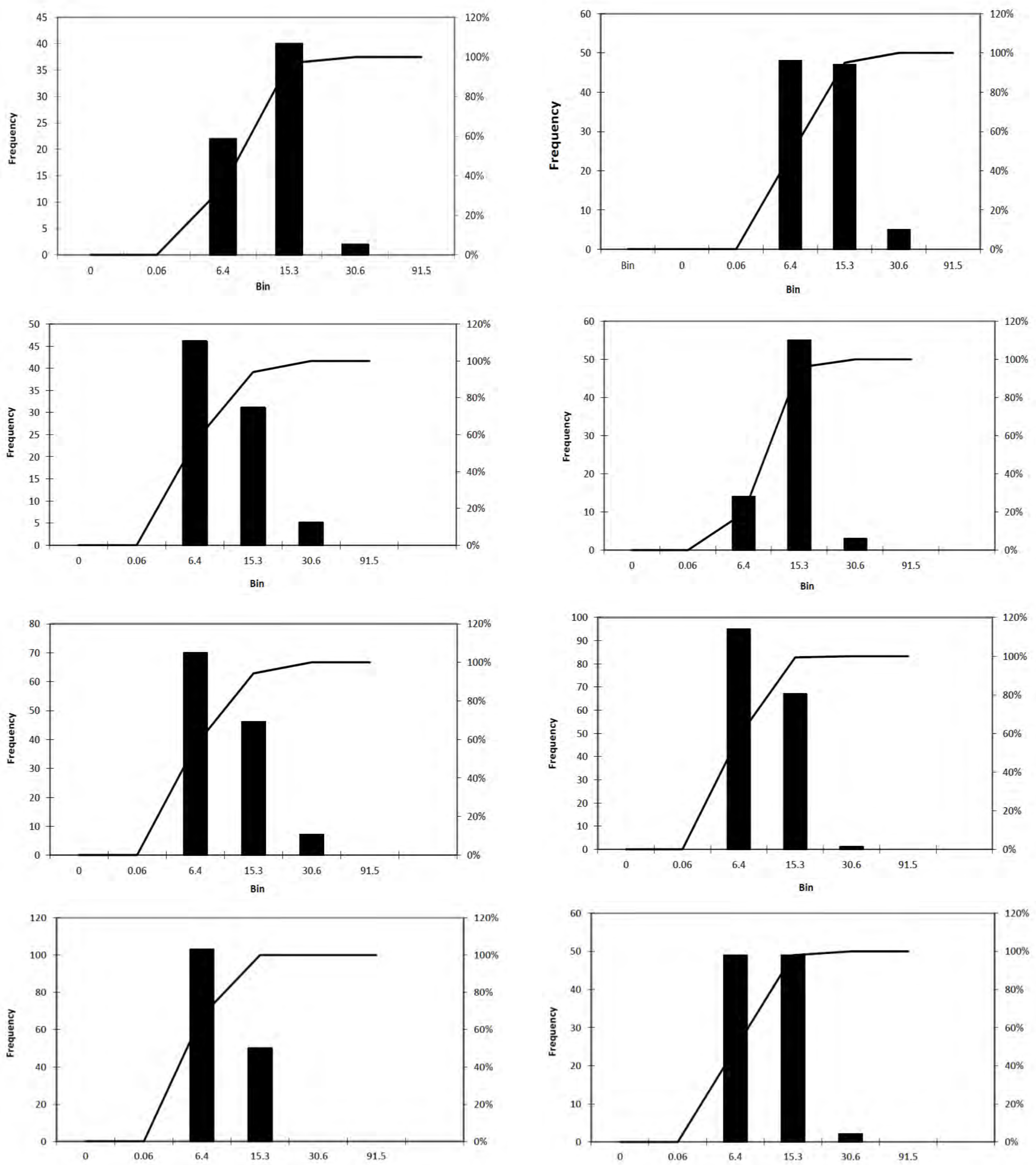


Figure XVI. Pebble count data from cross-sections 2, 5, 7, 8, 10, 15, 17, and 20 (left to right and top to bottom within the broader Ukiah Valley sampled during September of 2011.

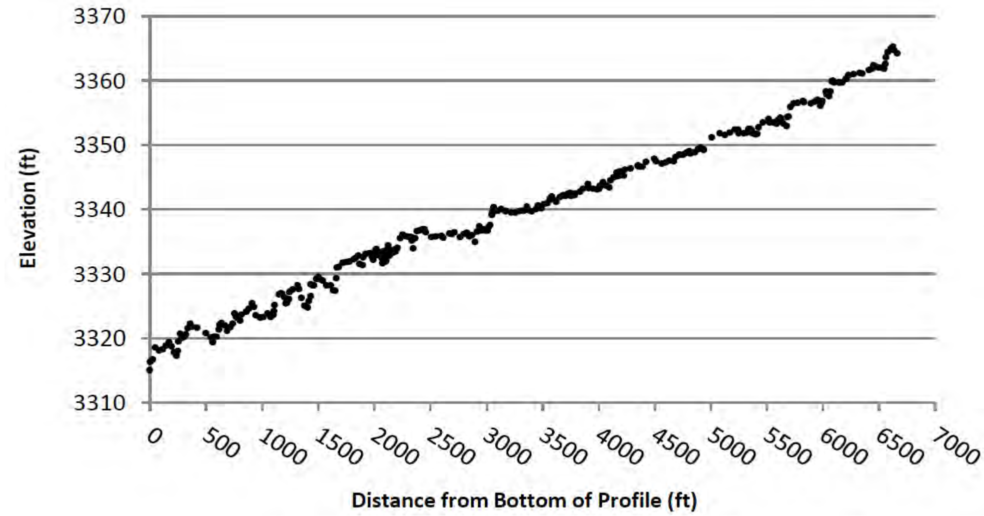
shear stress upon the channel substrate. Without additional factors available to consume extra energy such as increased sediment load Camas Creek has expanded its channel creating a positive feedback loop especially where local instability exists (i.e., cross-sections 10).

Cross-Section	XS area	XS Width	XS Perimeter	Hydraulic Radius
2 existing	461.29	112.46	114.15	4.04
2 paleo	145.36	82.65	83.4	1.74
4 paleo	99.2	55.36	56.46	1.76
5 existing	730.81	108.5	112.38	6.5
7 existing	65.19	39.29	40.38	1.66
10 existing	877.52	160	165.56	5.3
15 existing	517.53	173.85	177.17	2.92
17 existing	266.94	130.00	132.29	20.2
20 existing	71.14	73.25	73.82	0.96

Table IV. Results from WinXSPRO calculations for selected cross-sections. Note that at cross-sections a single channel for cross-sections 7 and 20 were selected to represent the primary conduit across the channel. In both these locations a single defined channel did not exist.

Although the sampled cross-sections within the broader valley about Ukiah were not located at regular intervals, Appendix I show a fairly regular decrease in elevation throughout the upper cross-sections. Local conditions do create specific controlling factors creating departures from this trend. For instance, cross-sections 6 and 7 located directly below the upper levee lie within 130 feet of one another and due to spreading flows and deposited sediments and diffuse channels do not show significant differences in elevation. Cross-sections 6-9 display a diffuse character one may expect to see in response to excessive sediment load and diffuse stream power to mobilize the material. The lower group displays similar behavior with respect to a gradual stepping down of cross-sections 10, 11, 12, 13, and 15, smaller changes in elevation between cross-sections 15, 16, 17, 18, 19, 20, and 21, and larger changes in the last four cross-sections. In both the lower and upper (Figure XVII) profiles those reaches within the leveed areas between points 3,300 and 5,400 in the lower profile and 12,300 and 13,970 in the upper profile display an even 'well behaved' character. That is, the existing levees help minimize turbulence by concentrating stream energy with a uniform shape throughout. Their consistent armored plain-bed character with greater proportions of gravel also suggests shear stress is generally minimized.

This relationship does breakdown within the lower profile below point 3,300 at cross-section 17 as the levees widen from 94 feet at cross-section 13 (point 4,498) to 176 feet at cross-section 15 (point 3509) to 142 feet at cross-section 19 (point 2,550). This combined with increased vegetation growth and sediment deposition which decreases channel roughness, flow velocities, and shear stress resulting in sediment deposition at the channel margins and filling inward. Cross-section 15 does contain a rather large gravel bar forcing much of Camas Creeks the thalwag into a single channel 74 feet within the larger 176 feet channel width. By cross-section 17 however, sediment deposition has begun to significantly influence channel characteristics by confining the thalwag to a well-defined channel 30 feet in width along the southern levee which is partially filled with vegetation. Since specifications or design plans for the channelized reach through Ukiah constructed in the late 1960's could not be located we cannot identify the original channel depth. However, given the gradually increasing levee width and resulting decrease in flow depth sediment deposition and the current conditions are not surprising. Additionally, the bridge below cross-section 17 lies at what appears to be an interface between the wetter areas



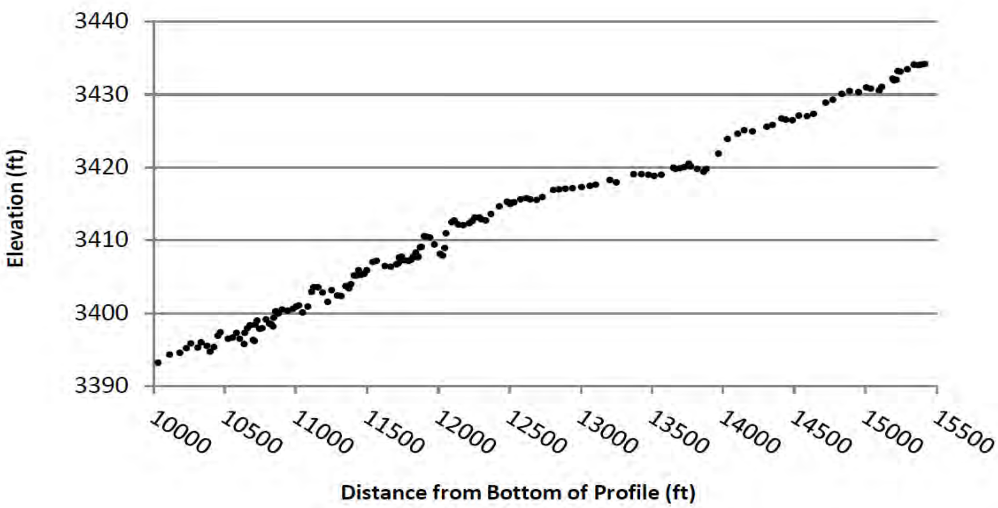


Figure XVII. Longitudinal profiles collected in September of 2011 within the broad valley about Ukiah beginning approximately 0.5 miles below Ukiah (point number 0) and ending approximately 2.5 miles above (point number 15,395) .

adjacent to Camas Creek and the dryer alluvial fan above as viewed on aerial photographs. Although we did not collect topographic data for this area and our cross-sections were limited to the areas between the levees this change in vegetation suggests that percolating flows working through the alluvial fan are resurfacing at this point. If this is the case, it could indicate a break in gradient of the stream channel and possibly an extension of the alluvial fans sediments are deposited resulting in a decreased slope propagating sediment deposition. The longitudinal profile shows changes in elevation between cross-sections 15 – 21 are less than those above and below; decreasing approximately six feet over 1,500 feet of stream length (0.004 slope) with even less drop between cross-sections 17 – 20. Below the Ukiah-Granite Road Bridge levees are either buried or nonexistent with multiple channels and well worked sediments that appear to be increasing in elevation. In place of channel design specifications from the

1960's construction plans for the bridge itself were located identifying a final channel grade approximately 8 feet below the girders able to pass a 50 year event (3,720 cfs) in 1983 although at this time approximately four feet of clearance on the upstream side in the thalwag allow for a quickly calculated 960 cfs to pass unhindered. We cannot speak to the bridge constricting flows passing underneath although the possibility exists during high flow events.

Although sediment deposition adjacent to and below the bridge may be the result of or at least partially the result of sediments migrating from the Lower Secondary AOI or higher and local channel down cutting provides an alternative explanation. Concave longitudinal profiles such as that between points 2,500 and 6,500 are indicative reaches experiencing vertical erosion are typically followed by depositional (convex) sections of stream channel. Cross-section 10 lies at point 6413 below the upper end of the convex profile and a three foot drop in substrate elevation over 100 feet of thalwag where Camas Creek is attempting to reestablish a meander bend adjacent to SR 244. Additionally, a weak levee on the south side of Camas Creek and an active beaver dam on the south side of Camas Creek constrain flows in addition to robust levees approximately 200 feet downstream on the channels northern streambank. These combined factors serve to focus high flow events that expand laterally approximately 175 feet, 1,700 feet above cross-section 10. Assuming a natural channel equal to that of cross-section 4, cross-section 10 has expanded 8.9 times over proposed historic levels resulting in a loss of approximately 800 ft^3 of streambank and substrate along 100 feet of channel. The convex channel pattern terminates near point 3,300 (Figure XVII) with a small stutter below followed by significant deposition at and below cross-section 15.

The upper longitudinal profile suggests that similar forces are at work between points 12,500 and 15,250 (Figure XVII) roughly coinciding with cross-sections 1 and 6. Streamflows constrained by levees entering the broader valley create a four foot drop over 250 feet of channel length beyond which substrate elevations smooth out with minor differences in elevation reflecting the presence of weak riffle/run sequences. Although levees only exist adjacent to the old mill site, aerial photographs from 1939 depict a single thread channel with what appears to be multiple channels within. While the photograph collected on 8 August 39 would have captured Camas Creek close to its lowest baseflow and may give the appearance of multiple channels, other features also further suggest the channel has been influenced by land management practices. Regardless of the past management practices a comparison of cross-sectional area assuming the historic channel was equal to that of cross-section 4 indicates the existing channel is 4.6 times larger at the shallower left bank, resulting in an estimated 36,229 ft^3 loss of channel bank and substrate in a 100-foot reach. Cross-section 3 (point 13,974) lies within a drop in substrate elevation previously noted which has likely formed in response to material deposited in the southern portion of the channel by a weak meander directing flows into the northern streambank. Additional cross-sections above and below cross-section 3 that could further describe what is occurring were not collected. This gravel bar also appears to strip Camas Creek of at least a portion of the larger sediments. The channel adjacent to point 12,292 maintains a slightly shallower gradient then those above and below save the lower end which is influenced by the levees termination. This decrease in channel gradient is due to deposited material at the levees lower end backing up sediments upstream; that is the formation of a head cut that has migrated upstream. With the end of stable levees at cross-section 6 Camas Creek splits into multiple channels lying at or near ground surface as with paleo-channels represented in cross-section 2. Tortuous channels contain distinct pool riffle run sequences absent or weakly developed within the levee and channelized reaches.

Within the primary AOI the hyporheic zone appears to have been more complex historically than those reaches above due to the local geomorphic constraints and groundwater aquifer characteristics. Topographical maps suggest both overland and subsurface flows would have followed the alluvial fans gradient to the southwest after entering the broad valley in multiple surface channels and within the alluvial fan exiting around both Pine and Camas Creeks.

Aerial photographs (Figure XI) supported by verbal accounts suggest Camas Creek annually lost surface water flows within the alluvial fan above Ukiah. This is a common trait of these features as deposited sediments are typically unconsolidated or weakly so and therefore contains relatively high porosity. During spring runoff streamflows typically overwhelm the substrates ability to pass water vertically to the groundwater aquifer allowing flows to pass across the entire feature. However, as groundwater aquifer levels fall a channel may dry up if the channel is directly connected to a groundwater aquifer if the channel lies above and not directly connected to an aquifer. Of these two possibilities the first is mostly likely responsible for a dry channel through Ukiah during the summer months. Although there may be several potential 'fixes' for this they appear problematic. Efforts to improve in-stream flows during this period would require a substantial increase in stream flows originating from an upstream source which does not appear feasible. Addressing sediment issues may positively influence channel form, elevation, and connection to the groundwater aquifer; however, if the final channel form is not dynamically stable and appropriate for the given constraints and function of the alluvial fan on which it resides the effort will prove a failure.

Conclusion

Considering previous land management practices, existing conditions and data, and what appears to be the primary concerns of landowners this is at best a complicated issue requiring cooperation of the community at large to address. Investigations thus far point to a stream channel lacking any of its historic fundamental dynamic stability in both the Lower Secondary and Primary AOI. Conditions within the Lower Secondary AOI are directly influenced by SR 244 in specific locations which constrain potential efforts and the channels character limits its ability significantly reduce long term sediment downstream. This does not suggest benefits associated with channel and riparian modifications within the lower secondary AOI are unimportant or unworthy of consideration. For instance, narrowing the baseflow width to depth ratio would allow the storage of a considerable amount of sediment in the short term while improving in-channel complexity, reducing streambank erosion, strengthening hyporheic exchange, and bolstering vegetative health and streamside shade would all improve larger scale issues.

Streambank erosion, lower floodplain connectivity, riparian health and compromised hyporheic processes have most certainly contributed to existing conditions within the Primary AOI. Increased near bank shear stress alone caused by lower floodplain connectivity and less robust riparian vegetation have likely contributed to channel erosion and deposition; especially in an alluvial fan. With certainty, any effort to address issues within the primary AOI needs to consider influencing factors within the secondary AOI although it appears at this time that sediment issues within and adjacent to Ukiah are strongly related to channel instability from levee construction, management, and maintenance within that reach. Given that the Primary AOI lies within an alluvial fan which is notoriously difficult to deal with, simple channel modifications or treatments at a single location (small site) will not likely be successful without addressing channel instability and sediment mobility throughout the larger reach. For instance, assuming the Ukiah/Granite Road Bridge is not likely to be relocated anytime soon efforts below the bridge, while possible, would need to consider the actions influence the channel above the bridge and the potential for instability. Evidence does support localized natural changes in channel morphology as a result of a reaction to a forcing factor below Ukiah. CTUIR removed 1,100 feet of levee in 2006 and installed structures to create and maintain scour on the outside of a meander bend. Since then the reach has been adjusting by laterally shifting the confluence of Camas and Pine Creeks, scour pools associated with the structures have been maintained, sediment deposition has increased the elevation of a gravel bar, and runs are becoming riffles as paleo-channels are being reactivated. This is not dissimilar to what may be occurring within the sampled reach in and above Ukiah.

Site specific sediment mobilization and deposition forces one to consider if the root problem is related to incipient motion or sediment transport rate. Sediment mobilization or point at which they become immobile is of vital importance when maximizing channel form. The loss off appropriate flows due to a changing streambed or channel form and sediment load may also be an issue. Sediments have been largely removed within the Lower Secondary AOI save those transported through while the Primary AOI contains significant sediment reserves which are being mobilized by stream power concentrated within the incised channel. While incipient motion is an issue with respect to the streams ability to mobilize sediments there may well be a transport issue in that the stream was able to pass sediments with additional energy removing sediments from the streambank. Sediment mobilization or lack thereof may be due to several factors such as channel form and/or stream gradients, valley slope or quite simply sediment size. At this point, an educated guess is the most one can provide, and while the solution may be as simple as removing a bridge supporting evidence appears lacking.

Recommendations

Regardless of the final selection a stepwise or linear protocol leading to a final solution should be identified from the onset to prevent perpetual investigation or undefined objectives that often lead to inaction. Inclusion of a diverse group of local landowners and government entities and interested parties such as technical experts into a cohesive group could provide the support necessary to investigate, design, and implement a viable solution to the issue. For instance, local landowners have knowledge of past land management practices and their results, technical knowledge, and the City of Ukiah has the ability to complete grant applications and secure funding from multiple sources. CTUIR also has the ability to provide limited funding and technical expertise and would be willing to help secure the requisite consultants or educational institutions to fully understand and address the issues. Additional parties such as the North Fork John Day Watershed Council may also have a desire to contribute to any undertaking. Perhaps the most useful effort at this point beyond an initial coordination meeting and developing a chain of command would be the formation of a **Council** and a separate **Technical Team**.

> **Council or lead group** should be responsible task management, acting as a sounding board for concerns and desires, coordinating investigations and implementation, and selecting an appropriate practice or developing a consensus. The council should likely include representatives from the City of Ukiah, local landowners, citizens of the Ukiah Valley, and should include people familiar with public policy and legal issues among others. Additional efforts outside of the immediate Ukiah valley may need to be included if issues are to be addressed in those areas.
>
> **Technical Team** should be formed to provide comment and advise the Council with regard to technical issues. This would include comment regarding data collection and methods used during analysis, the viability of proposed actions, and providing implementation oversight. The team would support the Council and not contain a membership mirroring that of the Council.

Although there are many unanswered questions several key factors require consideration to structure the approach and determine if the primary issue is related to incipient motion or transport rate. These include;

Sediment budget - Although sediments originating throughout the basin may influence the Lower Secondary and Primary AOI, a detailed assessment would be expensive and inefficient given the primary concerns. As such a sediment budget similar to that described in Reid and Dunne (1996), considering the three gross subbasins including Camas Creek and its tributaries above Hideway Creek, Hideway Creek, and Cable Creek would simplify the effort. Factors such as vegetation, soils, and geology should provide for a relatively accurate sediment budget.

Bedload Study - Although a comprehensive bedload study is both labor and time intensive there does not appear to be any sound data related to sediment movement and timing available. As such, a study of bedload movement would provide information regarding sediment migration timing and volume.

Site Survey - A comprehensive topographic and/or detailed cross-sectional and longitudinal profiles to include pebble counts and a full suite of morphometric data as a bare minimum. Details related to existing and paleo-channels and any other relevant factors should be considered.

Realizing local residents and property owners have a vested interest in protecting their property and would like to see something done sooner than later, the nuances of permitting alone preclude quick actions. Permit applications require a well thought out design often resulting from an analysis of the historic and current conditions which takes a concerted effort when multiple parties are involved. Based upon previous experience, unless a programmatic biological opinion (programmatic) or similar document can be used this process can take one to two years alone to secure permits from Oregon Department of State Lands, Oregon State Historical Society, the U.S. Army Corps of Engineers, National Oceanic and Atmospheric Agency, and U.S. Fish and Wildlife Service among others. While smaller efforts designed to provide a temporary fix may pass be cleared under a programmatic document in-stream work can only occur between 15 July and 15 August without additional approvals. The schedule below would in all likelihood need to be modified depending upon intermediate and final decisions; however, this seems to be a reasonable first guess.

2012/13 - Establish a council or lead group and technical group to begin accepting input and directing future efforts.
2013/14 - Collect necessary data and secure design if possible.
2014/15 - Permitting and if possible implement.
2015/16 - Implementation
2016 and beyond - monitoring.

At this time, potential treatments for existing and future conditions have not been detailed due to a lack of specific input from the local community. However, dredging which has been mentioned several times by local residents only appears to be a short term fix when tied to a more comprehensive strategy addressing long term channel stability issues. Funding for long term periodic dredging would need to be developed by the City of Ukiah and/or the local community as funding through CTUIR will not be available. However, relatively inexpensive features in more stable portions of Camas Creek's channel above Ukiah could be supported by CTUIR and may prove beneficial in reducing short term erosion without compromising any long term solution the community identifies. Small structures in specific locations would not likely in and of themselves be capable of addressing the larger issues. Any path forward needs to be identified and addressed by the local community at large with assistance from others.

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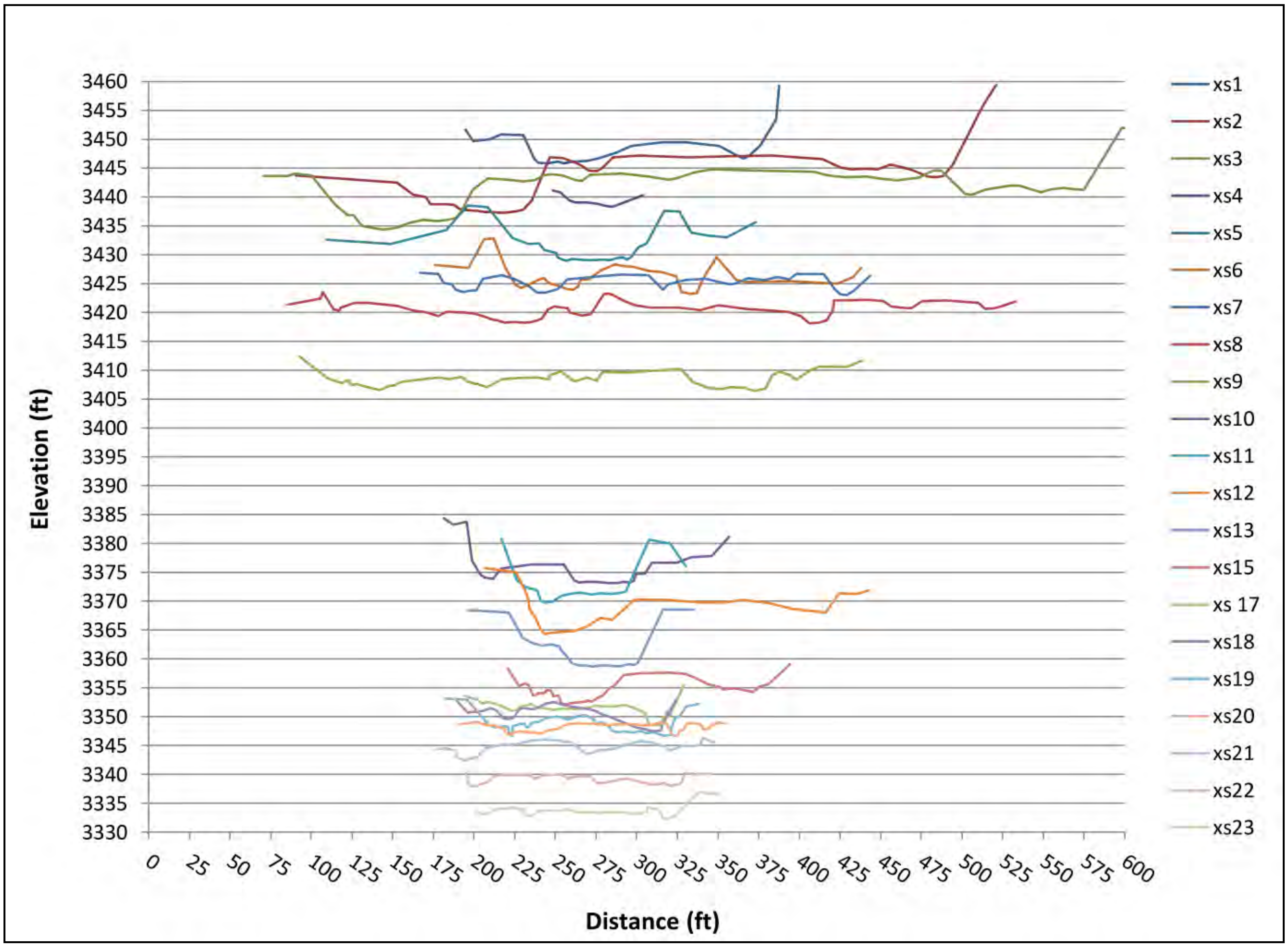
Appendix I



Elevation (ft)
3460
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Pictures of Cross-sections 2, 5, 7, 8, 10, 17, 20 from top to bottom.