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Attention: Mitch Long, Project Manager
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Subject: Gold Creek Hydrologic Assessment Memo

PROJECT BACKGROUND

The Kittitas Conservation Trust (KCT) has identified the lower 3 miles (mi) of Gold Creek above Keechelus Lake near Snoqualmie Pass as a candidate location for habitat restoration (Figure 1). The primary objectives of the Gold Creek Restoration Project (Project) are to restore perennial flow and improve instream habitat for threatened Gold Creek Bull Trout (*Salvelinus confluentus*). The hydrologic, hydraulic, and geomorphic conditions within the project reach will be assessed to better understand the causal mechanisms contributing to seasonal dewatering, and the associated impacts to Gold Creek Bull Trout. These findings will be used to develop conceptual designs that meet the primary objectives of the Project by restoring natural geomorphic processes.

Existing information relevant to the Project has been reviewed and compiled to guide the assessments and conceptual design development. This information has been synthesized to describe the existing knowledge base related to the Project, and to identify key data gaps that need to be resolved to meet the objectives of the Project (NSD 2013). This technical memo describes the current hydrologic conditions related to seasonal dewatering in Gold Creek.

PROJECT REACH

Gold Creek drains a 14.3 mi² (9,122 acre) watershed in the Cascade Mountain range, flowing for approximately 8 miles before entering Keechelus Lake near Interstate 90 (Figure 1) (Craig 1997, Wissmar & Craig 2004, USFS 1998). The drainage basin ranges from 2,507 to 6,933 feet (ft) above sea level with a total relief of 4,426 ft. Average annual precipitation is 87.6 inches (in) and mean temperatures ranging from 33 – 52 degrees Fahrenheit (Western Regional Climate Center 2013). The lower reach of Gold Creek (river mile (RM) 0 – 1.85) is a low-gradient (1%), braided channel flowing through a broad, alluvial valley of highly-permeable sand and gravel (USFS 1998, Collins 1997). The average bankfull width in this reach is 160 ft and valley width is 500 ft. The middle reach (RM 1.85 – 3.1) is more confined, with average bankfull and valley widths of 50 and 100 ft, respectively (Collins 1997). This reach averages a 3% gradient, and is composed of pool-riffle segments dominated by cobble and boulders (USFS 1998, Collins 1997). The upper reach (RM 3.1-7.1) is a high-gradient (5%) channel of step-pool segments underlain by boulders and bedrock (Collins 1997). The upper reach is moderately confined, with an average bankfull width of 40 ft and a mean valley width of 100 ft. Fish passage is impeded by a bedrock cascade segment and a waterfall at RM 5.3 and 7.1, respectively (Craig 1997, Collins 1997). Stream discharge measurements in lower Gold Creek range from 12.3 cfs in mid-August to 19.9 cfs in late September and a peak flow of 331 cfs was measured in mid-June (Thomas 2001). In recent years, channel dewatering in the lower and middle

reaches has been observed between mid-July and late September (Craig 1997, Mayo 2003). The dewatered segment has appeared to expand over time and directly impacts Bull Trout migration.

HYDROLOGIC ASSESSMENT METHODOLOGY

The current hydrologic conditions within the Project reach were assessed to describe the spatial and temporal character of ground and surface water gradients, and the timing and extents of dewatering in Gold Creek from July to October 2013. A network of monitoring locations was established to collect water surface elevations (wse) both for groundwater and surface water prior to, during, and following dewatering of the channel (Figure 2). These wse are used to establish flow gradients depicting direction and magnitude of water movement throughout the monitoring period. In addition to wse monitoring, the up and downstream extents of watered channel were recorded to demonstrate the spatial and temporal extent of channel dewatering.

MONITORING NETWORK

The layout of the monitoring network was setup to optimize data locations for determining hydraulic gradients across and down Gold Creek valley. The locations of groundwater and surface water monitoring were limited by access, and total number of locations limited by available budget. Groundwater wells were limited to the eastern floodplain of Gold Creek, as there is no ground access to the western floodplain for drilling equipment. Surface water stations were limited by landowner permission to below RM 0.52, and above RM 0.9.

The surface water stations were chosen to have one station upstream and one downstream of the dewatered reach extents, including one in Gold Creek Pond and Heli's Pond. The remaining surface water stations were located within the dewatered reach in deep pools, to maximize the period of record during the dewatering season. The groundwater wells were located to establish cross-valley gradients with the surface water stations, with a higher density of wells installed north of Gold Creek Pond.

Groundwater Wells

A total of 6 groundwater wells were included in the monitoring network (Figure 2). An existing well installed by the U.S. Bureau of Reclamation west of the Gold Creek Pond parking lot (GW 1) was utilized for this study. The remaining groundwater wells were installed on June 2nd, 2013 to a depth of 10 ft below ground. Cobble gravel substrate was observed at depth in all wells, with GW 7 the only well with a significant soil profile at the surface. Wells were constructed with 2 5-ft sections of 2-in PVC, with the lower section screened. Pressure transducers were installed in all groundwater wells to record wse (15-min increments) starting on June 3rd, 2013. An additional groundwater well on the western floodplain adjacent to SG 10 (Figure 2) was proposed to establish a control location outside of the potential influence of Gold Creek Pond. An attempt to hand-dig the well was made, however groundwater was not encountered at approximately 10' depth, and the hole was abandoned.

Surface Water Stations

10 surface water stations were installed within the project reach, with 8 stations in the creek and 2 located in Gold Creek and Heli's Ponds. The 8 stations in the creek include the downstream (SG 11) and upstream (SG 10) controls that are beyond the limit of seasonal dewatering, and 6 stations within the reach of the creek that dewater seasonally (Figure 2). All surface water stations were constructed with 2" PVC housing, capped on either end, and mounted onto a 7' T-Post embedded up to 4' into the channel alluvium. Staff plates were installed on some of the surface water stations to better facilitate periodic elevation measurements for calibration. Station locations in the creek were approximated prior to

installation, and installed in the field in the closest proximal deep pool in the channel. Locating stations in the deep pools increased the length of record, as they are the last portions of the channel to dewater. As the dewatering season progresses, some of the surface water stations were lowered into hand-dug pits to extend the length of record for the station. However, some of the stations were installed in locations where the water was of sufficient depth below the surface that they went dry at some point during the monitoring period.

Gold Creek (SG 2) and Heli's Ponds (SG 8) wse were collected and are used as a proxy for groundwater elevations where they occupy the valley bottom. Based on data collected through a dewatering season on Gold Creek Pond showing a minimal change in wse over time (Didricksen 2001), a staff plate was installed and elevations recorded in-lieu of a pressure transducer being installed.

FIELD OBSERVATIONS

Several field surveys were conducted by NSD and KCT staff during the monitoring period to record the up and downstream extents of watered channel in Gold Creek, locations of pools holding water in dewatered sections of the creek, and to collect measurements at the surface water stations for calibrating the pressure transducer data. These locations were collected with GPS and accompanying photos taken periodically. The up and downstream extents of watered channel are used to depict the spatial and temporal character of dewatering in Gold Creek

HYDROLOGIC ASSESSMENT RESULTS

The initiation of dewatering for the 2013 season was recorded on the SG 7 pressure transducer on July 24th, and first observed in the field on July 29th. The extent of dewatering continued to migrate up and downstream of SG 7, however several mid-summer rainfall events re-wetted sections of the channel for short periods. Pools within the dewatered sections of the creek ponded water longer than other sections of the channel, however most of the pools ultimately dried by late summer. Re-wetting of the entire channel (continuous flow through the project reach) was first observed in the field on October 2nd, however SG 7 re-wetted briefly on September 24th and is likely more representative of when the entire channel was again continuously flowing. The channel remained continuously flowing on October 4th, when all data was retrieved from the monitoring wells and surface water stations. All of the groundwater well and several of the surface water gage pressure transducers were left to continue collecting data.

Daily rainfall recorded at Olallie Meadows, WA (Figure 3) (NOAA SNOTEL station OMWW1) was used as a proxy for rainfall within the project reach for the duration of monitoring. The station is located on the southwestern side of Mount Catherine (on the southern side of Snoqualmie Pass across from Gold Creek valley) in the Cold Creek watershed at 3,700 ft elevation. The timing and magnitude of rainfall, and the resultant response in wse and wetted channel extent are examined for the duration of monitoring.

MONITORING NETWORK

The monitoring network consisting of 6 groundwater wells and 10 surface water stations collected data from June 3rd to October 4th 2013. Wse were recorded at all monitoring locations, however gaps in the data exist where wse dropped below the pressure transducer. 5 of the 10 surface water stations (SG 5 – 9), and 4 of the 6 groundwater stations (GW 3-5, GW 8) went dry for a portion of the monitoring period. For the purposes of interpretation, SG 2 and 8 (Gold Creek Pond and Heli's Pond, respectively) are assumed to represent groundwater wse.

Figure 4 shows recorded wse at all of the monitoring locations over the course of the study. Some surface water stations and groundwater wells have missing data, representing time when the wse fell below the

transducer at the location. The paired surface water and groundwater locations are shown in more detail in Figures 5-9. To better compare the temporal changes in wse between all of the surface water stations and groundwater wells, wse was scaled to start at 0-ft at the start of the monitoring period (Figure 10 and 11). Once scaled, the surface water stations (Figure 10) and groundwater wells (Figure 11) show that wse responds differently depending on the location along the creek. The relative change in wse demonstrates that some the stations respond similarly, with similar rates and magnitudes of change over the course of the monitoring season.

Upstream & Downstream Control Water Surface Stations

SG 10 was setup to capture the surface flow in Gold Creek upstream of the dewater reach. This station shows a gradual decline in wse to around August 5th (Figure 10), after which wse is relatively constant, short of a few brief rainfall events (August and early September) (Figure 3) triggering rapid increases in wse and gradual decline back to base flow. The relatively constant summer base flow at SG 10 suggests groundwater elevations adjacent to SG 10 are sufficient to maintain the creek wse during the dry summer months (Figure 10).

SG 11 is located downstream of the dewatered channel extent, and is below the confluence of the Gold Creek outlet channel. Outflow from Gold Creek Pond maintains perennial flow in the outlet channel, and is sufficient to keep Gold Creek flowing year-round downstream of the outlet confluence (Figure 10). There is no increase in wse at SG 11 in response to the few brief rainfall events during the dewatered season, until the event on September 24th. The relatively higher wse at SG 11 compared to SG 10 is attributed to the additional flow from the outlet channel.

Onset of Dewatering

Stations SG 4 and 11 have the lowest rate of declining wse, while wse at SG 7 declines most rapidly (Figure 10). Wse at SG 3, 5 and 10 all decline at a similar rate until July 15th, and wse at SG 6 and 9 decline at a similar rate until July 8th. SG 7 was the first surface water station to go dry (July 24th), followed by SG 9 (August 7th), SG 6 (August 18th), and SG 5 (August 23rd) (Figure 10). Wse at SG 4 begins to more rapidly decline on August 15th with SG 5, however the rate of decline is less and the station remained wetted through the dewatering season (Figure 10).

Groundwater wells GW1 and 7 have the lowest rate of declining wse (Figure 11), and GW 5 and SG 8 (Heli's Pond) decline the most rapidly. Groundwater wse decreases most rapidly at GW 5, followed by SG 8, GW 8, GW 4, and GW 3 (Figure 11). The locations of the most rapidly decreasing groundwater wells correspond to the locations of the surface water stations that dried. The timing of surface water stations drying directly correlates to the rate of wse decline in the groundwater wells. For example, SG 7 was the first station to go dry in the creek, and the closest groundwater well is GW 5 (well that dropped the fastest). The second station to go dry (SG 9) is closest to Heli's Pond (SG 8), which was the second fastest declining groundwater station. Interestingly, GW 8 was the third fastest declining groundwater well, indicating groundwater elevations on the eastern side of the valley drop faster than on the western side.

The wse at the groundwater station is higher at each of the paired surface water/groundwater locations, except at SG 6/GW 4 (Figure 7), during the onset of dewatering. This demonstrates that groundwater is supplying water to the creek as wse declines both in the ground and in the creek. At the 3 upstream paired stations (SG 9/SG 8) (Figure 5) (SG 7/GW 5) (Figure 6) (SG 6/GW 4) (Figure 7) the groundwater wse drops slower than in the creek until the surface water station goes dry. However, downstream at SG 5/GW3 (Figure 8), the groundwater wse drops more rapidly than at SG 5. The creek at SG 5 does not go dry until the groundwater wse approaches the wse in the creek. This suggests that there may be groundwater recharging the creek at SG 5 from the western side of the valley and there is a small tributary

on the west side in this area. The wse at SG 3 drops at a greater rate than the adjacent GW 7 until July 31st, after which the wse at SG 3 remains relatively constant while GW 7 continues to decline.

During Dewatering

The surface water stations that went dry have very distinct responses to the few brief rainfall events that occurred during August and early September (Figure 3). Wse at SG 9 rapidly increases concurrent with SG 10 (upstream control station) (Figure 10) and the precipitation events (Figure 3). Stations SG 4, 5 and 6 have a more gradual and delayed response (2-3 days) (Figure 10) to the same precipitation events. This suggests that continuous surface flow in response to these rainfall events travels downstream past SG 9, however the flow is very brief and the channel quickly goes dry. The more gradual and delayed response at the downstream stations (SG 4, 5 and 6) (Figure 10) is representative of groundwater recharge and not from surface flow. While they remained wetted for the duration of the study, SG 3 and 4 had similar groundwater recharge responses to the mid-summer rainfall (Figure 10). However the magnitude of the response is less than at the stations that went dry.

Groundwater wells GW 3, 4, 5, 8 and SG 8 (Heli's Pond) all went dry at some point during the monitoring period. GW 4, 5 and 8 all went dry August 15th, came back briefly following the rainfall event on September 5-6th, and again raised sufficiently to record wse following the September 22-23rd rainfall until the end of the study period. All of the groundwater wells except for GW 1 have a similar delayed response to the few brief mid-summer rainfall events (Figure 11) as SG 4, 5 and 6 (Figure 10).

Following the onset of dewatering in the creek, groundwater wse continues to decline at all of the paired stations (Figures 5-9). There are brief recharging events during the mid-summer rainfall events (Figure 3) that are sufficient to rewet the channel at SG 5 (Figure 8) and SG 6 (Figure 7) from rising groundwater. However at SG 6/GW 4 (Figure 7) the recharging groundwater attributed to rewetting the channel at SG 6 must be coming from the western side of the valley, as the wse at SG 6 remains higher than at GW 4.

Re-watering of Channel

Based on the monitoring data, the initiation of re-watering of the channel started during the rainfall event on September 22-23rd. The rapid rise and coincident timing with the rainfall event indicates that there was continuous surface flow in Gold Creek during this event, however it was short lived as SG 7 went dry 24 hours later (Figure 10). The much larger and prolonged rainfall event from September 27-29th was sufficient to re-water Gold Creek and maintain surface flow until data was retrieved on October 4th (Figure 10).

All of the groundwater wells that went dry during the monitoring period recharged sufficiently to again record wse following the rainfall event on September 22-23rd. The larger rainfall event a few days later raised wse in all of the wells even further, above their initial wse at the start of monitoring for all but SG 8. This rainfall event was also the only event eliciting a wse response in Gold Creek Pond (SG 2) over the course of this study.

FIELD OBSERVATIONS

The observed extents of wetted channel collected during several field surveys were used to map the spatial and temporal changes in the wetted channel (Figure 12 and 13). The first field observation of dewatering was on July 29th (Figure 12), which extended from RM 1.41 to RM 1.68 (1,425 ft of dewatered channel). The dewatered section of channel expanded upstream until it reached near RM 2 on August 19th, averaging near 100 ft/day, with a maximum of 170 ft/day between August 9th-13th (Table 1). The upstream extent of dewatering remained relatively constant (near RM 2) following August 19th, until the onset of re-watering of the channel on following the September 22-23rd rainfall event (Figure 3).

TABLE I – DEWATERED CHANNEL SUMMARY

DATE	MAX UPSTREAM EXTENT (RM)	MAX DOWNSTREAM EXTENT (RM)	MAX EXTENT MOVEMENT UPSTREAM (MI)	MAX EXTENT MOVEMENT DOWNSTREAM (MI)	RATE OF MOVEMENT UPSTREAM (FT/DAY)	RATE OF MOVEMENT DOWNSTREAM (FT/DAY)	TOTAL LENGTH OF DEWATER CHANNEL (MI)	TOTAL LENGTH OF DEWATERED CHANNEL (FT)
7/3/13	-	-	-	-	-	-	-	0.0
7/29/13	1.68	1.41	-	-	-	-	0.27	1425.6
8/1/13	1.73	1.40	0.05	0.01	88.0	17.6	0.33	1742.4
8/9/13	1.84	1.26	0.11	0.14	72.6	92.4	0.58	3062.4
8/13/13	1.97	1.23	0.13	0.03	171.6	39.6	0.65	3432.0
8/19/13	2.02	0.51	0.05	0.72	44.0	633.6	1.07	5649.6
8/22/13	2.02	0.51	0.00	0.00	0.0	0.0	1.15	6072.0
8/26/13	2.05	0.51	0.03	0.00	39.6	0.0	1.24	6547.2
8/29/13	2.00	0.50	-0.05	0.01	-88.0	17.6	1.18	6230.4
9/2/13	2.01	0.56	0.01	-0.06	13.2	-79.2	0.95	5016.0
9/11/13	2.02	1.09	0.01	-0.53	5.9	-310.9	0.93	4910.4
9/26/13	1.68	1.53	-0.34	-0.44	-119.7	-154.9	0.15	792.0
10/2/13	-	-	-	-	-	-	-	0.0

As the channel dewatered, the downstream extent of the dewatered section progressed downstream averaging 50 ft/day from July 29th to August 13th (Table 1). A new section of dewatered channel emerged between August 13th and 19th from RM 0.52 to 0.66, just upstream of the confluence with the Gold Creek outlet channel (Figure 13). This furthest downstream section of dewatering did re-water sometime between the August 29th and September 2nd field surveys.

The total length of dewatered channel increased at an average rate of 234 ft/day between July 29th and August 26th (Table 1) to a maximum of 1.24 mi (6,547 ft). Dewatering progressed upstream at twice the rate as downstream between July 29th and August 19th, after which the upstream extent of dewatering did not move significantly. The dewatered section of the channel progressed downstream at a rate of 128 ft/day from August 19th to 26th, where it reached a maximum length of 1.24 mi (6,547 ft) (Table 1). The total length of dewatered channel started to decrease following the rainfall event on August 28th – 30th (Figure 3). By the field survey on September 26th, after an additional 3 rainfall events, the dewater section of the channel decreased to 792 ft (Figure 14). The entire channel was first observed to be flowing continuously through the project reach on October 2nd.

HYDRAULIC ANALYSIS

The primary objective of NSD's hydraulic analysis was to estimate hydraulic parameters to characterize current riverine conditions, influence of Keechelus Lake levels, and assist in the design of proposed restoration actions within the project reach. A hydraulic model was created using the one-dimensional Army Corps of Engineers HEC-RAS v4.1.0 hydraulic model.

HYDROLOGY

NSD conducted a hydrologic analysis of Gold Creek to determine appropriate stream flow values for use as part of the hydraulic analysis. Flood events that are expected to be equaled or exceeded once on average during any 2-, 10-, 25-, and 100-year period (recurrence interval) have a special significance for river design projects. These events are commonly referred to as the 2-, 10-, 25-, and 100-year floods. Recurrence intervals represent a long term, average period between floods of a specific magnitude. However, it is important to note that autocorrelation within hydrologic records suggests that low-frequency, or rare floods, could occur at shorter intervals or even within the same year, rather than on a predictable cycle as may be suggested by average values. For habitat enhancement project design purposes, the primary recurrence intervals of interest are the 2- and 100-year flows due to their influence on habitat and geomorphic conditions.

Peak Flows

Due to a lack of stream data for Gold Creek, several approaches were taken to estimate discharges associated with the 2-, 10-, 25-, and 100-year floods. Regression equations developed by the US Geological Survey (Knowles and Sumioka 2001) were used to estimate flow magnitude and frequency. Because the Gold Creek watershed is on the boundary between regions 2 (Puget Sound lowlands) and 5 (Mid-Columbia), estimates were calculated using equations for each region. It was found that Region 2 results are more representative of conditions at Gold Creek, as the watershed has considerably higher average rainfall than other areas within region 5.

Salminen (1997) used the maximum annual average daily inflow to Keechelus Lake to calculate recurrence interval flows using a Log Pearson Type III distribution and following USGS Bulletin 17B procedures (USGS 1982). These data were scaled to the Gold Creek watershed and compared to those calculated using the regional regression equations. It was decided that the estimates from Salminen (1997) are likely more representative of flows in Gold Creek as they rely on flow data rather than regional averaging. The flows used for the hydraulic model are summarized in Table 1.

TABLE 1 – PEAK FLOWS

RECURRENCE INTERVAL (YEARS)	FLOW BASED ON SALMINEN (1997) (CFS)	FLOW BASED ON REGIONAL REGRESSION (CFS)
2	617	793
10	1213	1452
25	1567	1802
100	2158	2404

HYDRAULIC MODEL

The existing condition hydraulic analysis was completed to inform the understanding of current hydraulic and geomorphic processes with the project area and to compare results with proposed condition modeling,

completed in future phases, to evaluate the effects of proposed restoration elements. The existing hydraulic analysis was conducted for the 2-, 10-, 25-, and 100-year peak flow discharges. Model runs were performed in a steady state (discharge does not vary with time) and non-deformable bed (no adjustments for scour, sediment transport and deposition).

Model Topography

The HEC-RAS model utilizes a bare earth LiDAR terrain surface collected in 2012 for KCT (Watershed Sciences 2012). The data was acquired on July 25th, 2012, when flows in Gold Creek are estimated to be 73 cfs. This flow estimate is based on calculated total in-flow into Keechelus Lake (287.14 cfs) on July 25th, 2012, and scaled to the contributing watershed area of Gold Creek (25.5% of watershed draining to Keechelus Lake). Because the LiDAR is unable to penetrate through water, the flow (73 cfs) in the channel when the LiDAR was flown was subtracted from the simulation discharges (from Table 1) to account for the artificially high channel.

Cross Sections

The hydraulic model utilized 74 cross sections to represent channel conditions and to evaluate flood elevations and hydraulics on Gold Creek within the project reach. Cross section locations represent computational points within the hydraulic model where the water surface and other hydraulic parameters are determined. Cross sections were located to reflect changes in channel and floodplain geometry, slope, and to capture constriction associated with the Forest Service frontage road (Gold Creek Rd) at the downstream end of the project reach.

Within each hydraulic model cross section, HEC-RAS allows additional data to be input to better define how water is expected to flow within the model extents. The most commonly utilized cross section options are ineffective flow areas, levee points, and blocked obstructions. Ineffective flow areas are defined as areas that contain water, but are not actively conveying water in a downstream direction. Levee points confine flow within a certain area and do not allow water outside these areas until the levee elevation is overtopped. Blocked obstructions are utilized to block a discrete area from conveying flow within the cross section. For this project, ineffective flow areas and levee points were utilized to better represent expected flow conditions within the project reach.

Roughness

Hydraulic analyses require an assessment of the resistance (drag force) the ground surface and other physical features exert against movement of water. This drag force is commonly referred to as roughness. The most accepted method to assess roughness uses the Manning's n resistance factor (Chow, 1959). Common factors that affect roughness values include: channel sediment size, gradation, and shape; channel shape, channel meandering, both bank and floodplain vegetation, obstructions to flow, flow depth, and flow rate. Manning's n values for this project were set for different roughness types using recent aerial photographs and in accordance with standard hydraulic reference manuals (Chow, 1959; Barnes, 1967; Hicks and Mason, 1998). Model roughness values were assigned based on the location of the active channel. Within the unvegetated active channel a roughness value of 0.038 was used, and 0.06 used for vegetated floodplains adjacent to the active channel (typically dense willow stands). The overbank floodplain was assigned a roughness value of 0.1.

Boundary Conditions

All hydraulic models require the user to input a known boundary condition at the upstream and downstream extents to begin the computational routine. The upstream boundary condition for all model runs was set to the corresponding peak flow rate minus the flow rate at the time of LiDAR flight (73 cfs). Peak flow rates were reduced to account for channel area that is not accounted for in the LiDAR (i.e. the channel is artificially high). Reducing the model flows in this fashion will result in more accurate model results of the water surface elevations and flow inundation, a key project metric, within the model extents. However, depths and velocities in the lowest parts of the channel will be underestimated. The downstream boundary conditions for all model runs were set to the water surface elevation of Keechelus Lake at high pool (elev. 2520.96 ft NAVD88) and low pool (elev. 2428.96 ft NAVD88). A summary of the boundary conditions used for the flow scenarios run is shown in Table 2.

TABLE 2 – MODEL BOUNDARY CONDITIONS

RECURRENCE INTERVAL (YEARS)	PEAK DISCHARGE (CFS)	UPSTREAM BOUNDARY CONDITION : MODEL PEAK DISCHARGE (CFS)	DOWNSTREAM BOUNDARY CONDITION : KEECHELUS ELEVATION (FT)
2	617	544	2520.96 – full pool
			2428.96 – dead pool
10	1213	1140	2520.96 – full pool
			2428.96 – dead pool
25	1567	1494	2520.96 – full pool
			2428.96 – dead pool
100	2158	2085	2520.96 – full pool
			2428.96 – dead pool

HYDRAULIC ANALYSIS RESULTS

Results of the existing conditions hydraulic modeling were examined for this part of the project to evaluate the influence of Keechelus Reservoir at full pool on channel hydraulics upstream. Additional review of the model results characterizing overall hydraulic results and their implications on geomorphic processes at work within Gold Creek, will be included in a geomorphic assessment memo to be completed in a future phase of this project. Additionally, this existing conditions model will be used to evaluate proposed hydraulic conditions reflective of conceptual design alternatives.

Channel shear stress and velocity were examined in Gold Creek upstream of the Keechelus full pool elevation to evaluate the hydraulic influence of the reservoir on the creek. Figure 15 shows the channel shear along the existing creek relative to Keechelus full pool elevation and the channel profile. We see that the channel shear drops upstream of RM 0.5 as flow crosses a hump in the channel profile, then accelerates as flow travels downstream over the hump and to Keechelus Reservoir. This location where the channel shear drops is coincident with the separate downstream reach of channel that dewatered between August 13th and 19th (from RM 0.52 to 0.66). The preliminary findings do not suggest that Keechelus Reservoir at full pool is contributing to dewatering at this location, however a more thorough investigation into the processes that formed this hump (at RM 0.5) in the channel profile is discussed below, and will be investigated in greater detail in the geomorphic assessment phase of this project.

CONCLUSIONS

Based on the findings from the monitoring network data and field observations, a more detailed understanding of the spatial and temporal character of dewatering in the creek emerges, and how that character is influenced by historic disturbances.

Two separate and distinct reaches of Gold Creek dewatered during the summer 2013 field season. Dewatering of the upstream reach was first recorded at SG 7 on July 24th, and first observed in the field on July 29th between RM 1.41 and 1.68. Dewatering progressed in the upstream direction at twice the average rate as in the downstream direction, until it reach RM 2.05, after which it did not continue further upstream and remained near RM 2 until the onset of re-watering. The downstream extent of dewatering of this upstream reach progressed to RM 0.96. A second dewatered reach of the creek emerged between August 13th and 19th near the confluence with the outlet channel, reaching a maximum extent between RM 0.5 and 0.66. The upstream reach of dewatering expanded to 1.09 mi long, and persisted for approximately 70 days. In contrast, the downstream reach of dewatering reached a maximum of 0.16 mi long, lasting between 10 and 19 days. Due to the distinct character between these reaches of dewatering, each is summarized and discussed separately.

UPSTREAM DEWATERED REACH

Both the field observations and monitoring well data show dewatering in the upstream reach of Gold Creek initiates near RM 1.5, and progresses up and downstream to a maximum of 1.09 mi long. The rate of groundwater decline is also highest at RM 1.5, which decreases downstream toward Gold Creek Pond. Figure 15 shows wse contours prior to (left) and during dewatering (center), and following re-watering of the creek (right). The influence of Gold Creek Pond on groundwater gradients across the entire valley bottom is immediately apparent, as the northeastern corner of the pond extends up-valley relative to the northwestern corner (Figure 15). The orientation of the northern shoreline of Gold Creek Pond is east-west, which is 25° to the axis of the valley (roughly northeast – southwest trending). This orientation results in lower groundwater elevations on the eastern side of the valley relative to the western side. Prior to the excavation of Gold Creek Pond, groundwater gradients would be expected to have been generally parallel to the valley axis, with Keechelus Lake as the downstream baselevel control. Gold Creek Pond now provides baselevel control for groundwater elevations upstream of the pond, which remains relatively constant over time due the outlet channel. Groundwater was observed issuing from the northern bank of Gold Creek Pond throughout the monitoring period, between 1 and 2 ft above the pond wse (SG 2). This phenomenon indicates a steep gradient as groundwater approaches Gold Creek Pond from upstream, and that the pond significantly lowers groundwater elevations relative to what they would be without the pond, consistent with findings of Cheng (1994). Figure 15 shows that groundwater elevations immediately upstream of Gold Creek Pond remain relatively constant (see 2540' contour) over the dewatering period. Groundwater elevations upstream (more than 300 ft upstream) of Gold Creek Pond drop 2 ft by August 18th relative to July 6th, however wse in the creek remains relatively constant where it's wetted (see 2550 wse contour in Gold Creek at SG 4) (Figure 15). This indicates that there is additional groundwater flow supplementing wse in the creek at SG 4 and SG 3, keeping these locations wetted longer into the dewatering season. Given their location, groundwater flowing from the western floodplain and toward Gold Creek Pond must be sufficient to recharge Gold Creek here.

The influence of Gold Creek Pond on groundwater elevations and gradients, and how they evolve over the course of the dewatering season, are used to develop a conceptual understanding of valley-wide groundwater flow character. A conceptual profile of groundwater flow through the upstream dewatered reach, and how it drops during the onset of dewatering is shown in Figure 16. As stated earlier, Gold Creek Pond provides a constant baselevel control on groundwater elevations, creating a steep gradient as groundwater enters the pond from upstream. As groundwater elevations start to decrease, the magnitude of decline increases

upstream of Gold Creek Pond up to near RM 1.5 (Figure 16). We estimate groundwater elevations are drawn down the most near this location based on the rate at which GW 5 declined (Figure 4), and this is where dewatering of the creek was first observed (Figure 12). Upstream of RM 1.5 the rate of decline decreases until the upstream influence of Gold Creek Pond it reached (where groundwater decline is equal to that which occurred prior to Gold Creek Pond). We estimate that this location is somewhere just upstream of RM 2, where the creek remained flowing through the summer. The progression of dewatering extending up and downstream of RM 1.5 is consistent with this conceptual profile (Figure 16), and demonstrates the influence of Gold Creek Pond on groundwater elevations and gradients through the project reach.

The Darcy equation (1) can be used to evaluate flow along the conceptual groundwater flow profile (Figure 16) to better understand the broader valley-wide groundwater character. Groundwater flow (Q_w) immediately upstream of Gold Creek Pond (1) and near RM 1.5 (2) was compared to measure continuity between these locations. Immediately upstream of Gold Creek Pond (1), groundwater flow (Q_{w1}) experiences a relatively small amount of change. The hydraulic conductivity (K_1) and flow area (A_1) remains constant through time, and the hydraulic gradient (dz/dx_1) experiences a small decrease. Near RM 1.5 (2) the flow area (A_2) and hydraulic gradient (dz/dx_2) decreases considerably more than downstream. Thus, there must be less groundwater flow at RM 1.5 (Q_{w2}) during the onset of dewatering than immediately upstream of Gold Creek Pond (Q_{w1}). This condition reveals there must be additional groundwater contribution immediately upstream of Gold Creek Pond. We hypothesize that this groundwater is coming from the western side of the valley, and that creek intercepts this groundwater flow as it crosses near SG 4 and SG 3, keeping these locations wet longer into the dewatering season.

$$Q_w = A \, dz/dx \, K \quad (1)$$

where Q_w = groundwater discharge (m^3/s)

A = subsurface flow area (area across valley) (m^2)

K = hydraulic conductivity (m/s)

dz/dx = hydraulic gradient (m/m)

The Darcy equation (1) was used to examine the influence of channel width in accelerating dewatering of the creek through the project reach. Figure 17 shows a profile down Gold Creek with the 2012 and 1944 bank widths relative to the dewatered reaches of the creek. Both the upper and lower dewatered reaches correlate to locations along the creek that have experienced significant widening since 1944 (pre-development reference condition). Within the upper dewatered reach, the most significant widening has occurred near RM 1.5, the same location where dewatering was observed to originate. Channel widths here have increased 335 ft, representing a 4.6 fold increase in width compared to the 1944 width of 72 ft. The impact of this widening on dewatering is conceptually shown on Figure 18 using the Darcy equation. As Gold Creek flows through the confined reach above RM X, there is some discharge in the creek (Q_{s1}) that flows downstream into the unconfined valley reach, and low subsurface flow (Q_{w1}). At the upstream end of the unconfined valley reach, subsurface flow increases (Q_{w2}) as the alluvial valley bottom material provides a conductive reservoir for groundwater storage. To maintain continuity, surface flow (Q_{s2}) must decrease to increase subsurface flow (Q_{w2}), creating a losing reach with the area (A_2) contributing to loss related to the infiltration area of the creek. As the creek widens downstream, the infiltration area (A_3) increases as the width increases, further diminishing surface flow (Q_{s3}). Near RM 1.5 Gold Creek has widened to the point where infiltration area has increased to the point that there is little to no surface flow (Q_{s4}). Surface flow lost to subsurface flow is shown to flow away from the creek on the eastern side of the valley, and down gradient on the western side of the valley (Figure 18). Subsurface flow on the eastern side of the valley

continues down valley and recharges Gold Creek Pond, and subsurface flows on the western side of the valley remain on the western side until recharging the creek near RM 1. The presence of perched wetlands and input from a small tributary on the western valley floodplain would help to supplement subsurface flows during the summer months, as there is likely an aquitard (low infiltration material) underlying these features. These wetland features are absent on the eastern floodplain, however prior to Gold Creek Pond there were wetlands where the pond was constructed. These historic wetlands would have had a similar influence on subsurface flows (recharging during summer months) where the pond currently is, resulting in a dramatically different groundwater flow pattern where the creek currently dewater.

DOWNSTREAM DEWATERED REACH

The downstream dewatered reach of the creek emerged between August 13th and 19th near the confluence with the outlet channel, reaching a maximum extent between RM 0.5 and 0.66 and lasting between 10 and 19 days. As with the upper dewater reach, there is a significant widening of the creek centered where the lower dewater reach originates (Figure 17). The channel has widened 282 ft since 1944, representing a 3.3 fold increase in channel width. This widening would have a similar impact on surface flows as described above, with increased infiltration area leading to a reduction in surface flow.

The regulation of Keechelus Reservoir elevation extends to RM 0.47 on Gold Creek, at elevation 2520.96 ft (NAVD 88) (full pool). This elevation corresponds with the top of a hump in the channel profile (Figure 19), representing where sediment falls out of suspension during transport events when Keechelus Reservoir is at full pool (typically in the Spring). This wedge of sediment extends upstream to RM 0.5, creating a low slope portion of channel with reduced sediment transport capacity. Upstream of RM 0.5 there is a second hump in the profile that correlates to the downstream extent of dewatering, and where the creek has experienced significant widening.

A review of the historic air photos reveals several modifications and subsequent channel responses at and near this location (between RM 0.5 and 0.6). The earliest recorded modification at this location is an old stream crossing at RM 0.58 in the 1944 air photo. Additional road construction and floodplain clearing/disturbance related to the construction of Gold Creek Pond is evident in the 1970 air photo. This floodplain disturbance significantly widened the channel, and included the construction of a road along the eastern (left) bank. A portion of this bank was eroded by the 1985 air photo, including the old roadbed and into a stand of larger trees that were recruited into the channel (at RM 0.57). After the trees fell into the channel they formed a large logjam that appears to have aggraded the channel, creating part of the aggraded hump seen in the current channel profile. The channel width did not increase as a result of this aggradation, but rather contributed to a channel avulsion that occurred between 2006 and 2011. This channel avulsion relocated the channel toward the western side of the valley where it remains currently up against bedrock, and moved the confluence with the outlet channel downstream approximately 280 ft. Our understanding is that the avulsion lowered the creek bed on the upper end of the avulsion, and transported that material downstream where it aggraded the bed on the downstream end of the avulsion. The resultant impact of this avulsion is a channel that is further away from the outlet channel, which is at a higher elevation and provides recharging water.

Potential Contributors to Dewatering

Based on our findings, historic disturbances in Gold Creek Valley have contributed to the frequency and duration of dewatering of Gold Creek. It is likely that Gold Creek experienced dewatering events historically during drought conditions, however landscape alterations in the valley have exacerbated the problem. Data collected over the 2013 monitoring period (July through September 2013) demonstrates the modification to the valley-wide groundwater flow due to the construction of Gold Creek Pond (Figure 15), and how that modification contributes to dewatering in the upper dewatered reach. There is a general decrease in groundwater elevation up-gradient from the pond due to the width of the pond, and the outlet

channel maintaining a lower wse further upstream than would be without the pond. The orientation of the pond, extending up the eastern side of the valley relative to the western side, draws groundwater from Gold Creek toward the eastern side of the valley, further contributing to dewatering (Figure 18).

In addition to the construction of Gold Creek Pond there has been significant widening of the active channel since 1944. The channel widening increased the infiltration area of the creek, further contributing to dewatering extent and duration. The magnitude of this increased infiltration area on dewatering is highlighted as locations along the creek where widening has been the most significant correlates to origination points of dewatering in both the up and downstream dewatered reaches (Figure 17). Further investigation into the contribution of channel width on dewatering will be conducted and included in a geomorphic assessment of Gold Creek. This assessment will look at historic mechanisms contributing to widening (logging resulting in loss of bank strength from root cohesion, road crossings, etc.), and if local aggradation occurs within the over-widened reaches.

Several additional potential contributors to channel dewatering have been identified, including a buried drainage line, Heli's Pond, and reduced base flow resulting from climate change. Several manholes were found along Gold Creek Lane and Snowshoe Lane between GW 4 and the northeastern corner of Gold Creek Pond connected by an 8" drainage pipe. The drainage line is between 5.5 – 6.5 ft below ground, which is less than the monitoring wells adjacent to the pipe. Groundwater in the monitoring wells dropped below the elevation pipe, however if the pipe is fractured it would be capable of lowering groundwater elevations when they are higher than the pipe. While the outlet of this drainage line was not found, we assume that it empties into Gold Creek Pond somewhere near the northeastern corner of the pond. Water can be heard flowing through this drainage line during the summer months down-valley from GW 8 when the creek is dewatered, suggesting that some lowering of the groundwater table occurs closer to Gold Creek Pond. If fractured, this drainage line could contribute to dewatering by increasing the rate of groundwater decline until it drops below the pipe. Further investigation into the rational behind installation of the pipe is ongoing and could inform potential restoration actions. Additional information will be provided in the upcoming geomorphic assessment.

During the summer of 1996, Heli's Pond was excavated as a source of gravel for resurfacing roads and construction of a berm immediately downstream of the outlet channel from Heli's Pond near RM 1.8 (Bennett 2007). The pond was excavated in an abandoned channel resulting from an avulsion sometime between 1957 and 1970. Monitoring of water levels in Heli's Pond (SG 8) shows that the pond rises and falls with the adjacent groundwater, and the outlet channel only regulates levels when the pond is near full. The potential for Heli's Pond to contribute to dewatering would be through evaporation losses, and/or interception of a highly conductive subsurface unit (relic channel with higher K-value) at depth acting as a drain that more efficiently moves groundwater down-valley.

The role of climate change could influencing dewatering is beyond the scope of this investigation, however regional climate models show a significant decrease in base flows associated with lower Spring snowpack resulting from more winter precipitation falling as rain (Fountain et al. 2009, Nelman et al 2011, Lee and Hamlet 2011). Based on this understanding, restoration concept plans will be developed that incorporate a strategy for mitigating these impacts from climate change.

RECOMMENDATIONS

Our understanding of the mechanisms contributing to dewatering of Gold Creek, and the sources for these contributors have been synthesized to develop recommendations to reduce the frequency, extent, and duration of dewatering. Based on this understanding, restoration should focus on restoring the landscape back to the pre-development reference condition to the extent possible. Key elements considered for restoration include Gold Creek Pond, over widened channel reaches, drainage line, and Heli's Pond.

The valley-wide impact of Gold Creek Pond on groundwater elevations is evident from the monitoring data collected, and restoration of the land back to the historic wetland that existed prior to construction the pond would have the following benefits:

1. Increase groundwater elevations up valley from Gold Creek Pond
2. Reduce the lateral gradient of groundwater flow away from the creek due to the orientation of the pond
3. Support locally higher groundwater elevations where the pond is currently, and downstream as the restored wetland slowly recharges groundwater during the summer months

These benefits would decrease the frequency, extent, and duration of dewatering by increasing groundwater elevations across the valley, and restoring a more natural down-valley gradient. To maximize the benefits, we recommend filling the entire pond with fill and regrading the landscape adjacent to the pond to re-create a large floodplain wetland complex. An alternative to this action would be to selectively fill the northeastern corner of the pond where it extends further up-valley. This approach would reduce the lateral gradients (movement of groundwater from Gold Creek toward the eastern side of the valley) upstream of the pond, but would have less overall increase in groundwater elevations compared to filling the entire pond.

Restoration of the historic channel width along the entire length of Gold Creek would have the greatest benefit in reducing infiltration area and resultant loss of surface flow to groundwater flow. Given the length of channel impacted, targeted restoration of the most significantly over-widened reaches should be prioritized. Key to restoring a narrower channel is the creation of a hardened floodplain along the margins of the current channel to mimic the historic channel banks (greater strength than current banks). The hardened floodplain would be constructed by placing large timber in gravel bars and planting trees. Following completion of the geomorphic assessment, selective excavation could be recommended if instream aggradation associated with channel widening is found to have occurred.

As with the larger Gold Creek Pond, we recommend filling Heli's Pond and planting the area to restore this location back to forested floodplain. Filling of the pond would reduce dewatering in the creek by reducing infiltration and eliminating evaporation from the pond, and reducing any subsurface connection to highly conductive groundwater flow paths that are moving groundwater at an accelerated rate.

Our preliminary recommendation is to plug the subsurface drainage line with concrete to prevent it from draining groundwater adjacent to the upstream dewatered reach. Further investigation into the rationale behind the installation of this infrastructure could refine this recommendation. It is described that during heavy rains, flooding in the valley is from rising groundwater more than from overbank flooding (Bennett 2007). This condition may have been the driver for installation of the drainage line, and will need to be accounted for when considering plugging the pipe.

In addition to restoration of these larger landscape features, additional stable instream large wood is recommended to provide needed pool habitat along Gold Creek through the project reach. Additional pools along the project reach would provide needed holding habitat for juvenile Gold Creek Bull Trout as well as adults migrating upstream. Cover associated with these instream wood placements would also protect juveniles from avian predation. Existing accumulations of wood in the creek could be stabilized using a variety of approaches, including ballast (including logs, rock, cobble etc.) and vertical posts/piles. Additional new stable large wood structures are recommended as well to further increase pool frequency and thus connection with subsurface flow maintaining water longer into the season.

These recommendations are based on the existing literature and data collected during the 2013 monitoring period, and are subject to further refinement as additional information is obtained and analyses performed. However, we anticipate that our overall recommendation to restore the landscape back to the pre-

development reference condition to the extent possible will not change. The specifics of which features, locations, and potential restoration actions are anticipated to be developed further in future phases of this project.

LIMITATIONS

We have prepared this report for Kittitas Conservation Trust, their authorized agents and regulatory agencies responsible for the Gold Creek restoration project. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices for geomorphology and hydraulics in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

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

Sincerely,
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Attachments:

- Figure 1 – Project reach map
- Figure 2 – Monitoring network locations
- Figure 3 – Rainfall during monitoring period
- Figure 4 – Water surface elevations at all monitoring locations for the entire monitoring period
- Figure 5 – Water surface elevations at SG 8 and 9 for the entire monitoring period
- Figure 6 – Water surface elevations at SG 8 and GW 5 for the entire monitoring period
- Figure 7 – Water surface elevations at SG 6 and GW 4 for the entire monitoring period
- Figure 8 – Water surface elevations at SG 5, GW 3 and GW 8 for the entire monitoring period
- Figure 9 – Water surface elevations at SG 2, 3, and 4, and GW 7 for the entire monitoring period
- Figure 10 – Relative wse at all surface water stations for the entire monitoring period
- Figure 11 – Relative wse at all groundwater wells for the entire monitoring period
- Figure 12 – Extent of dewatered channel between July 29th and August 13th
- Figure 13 – Extent of dewatered channel between August 19th and August 29th
- Figure 14 – Extent of dewatered channel between September 2nd and September 26th
- Figure 15 – Existing condition hydraulics near Keechelus full pool
- Figure 16 – Water surface elevations prior to and during dewatering, and after dewatering
- Figure 17 – Conceptual profile of groundwater elevation through project reach
- Figure 18 – Profile with current and historic channel widths through the project reach
- Figure 19 – Valley-wide conceptual groundwater flow and infiltration loss
- Figure 20 – Profile with current and historic channel widths through the lower dewatered reach

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