Methow Thermal Refugia Restoration Assessment

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Project Background

The Methow River watershed has undergone significant anthropogenic alteration over the past century, which has contributed to the declines of native salmonids (Andonaegui 2000). Impacts from agricultural and urban development have acted to reduce instream flow, limit channel function, and reduce the extent of riparian vegetation (NPCC 2004; UCSRB 2007). As a result, stream temperature – a critical component of native fish habitat – has increased to levels detrimental to the ESA-listed salmonids, as evidenced by Washington State 303(d) listings for the Methow and Chewuch Rivers. Recent water temperature data collection (2013-2019) supports these listings and reveals that temperature impairment in the Methow subbasin is widespread (Crandall 2019).

Elevated stream temperatures can be stressful for the native salmonids of the Pacific Northwest that evolved within cold-water dominated streams (Beechie et al. 2013) and can negatively influence their productivity by limiting growth, elevating metabolic rates, increasing susceptibility to disease and predation, and creating thermal barriers to migration or reproduction (Berman and Quinn 1991; Schreck et al. 2010; Torgersen et al. 1999). Cold-water dependent salmonids may respond to elevated stream temperatures by seeking out cold-water refugia (Fullerton et al. 2018; Dzara et al. 2019), thus the presence of thermal refugia may allow species to persist in streams that otherwise pose a thermal threat to persistence. Sullivan et al. (2021) defined cold-water refugia as patches of cold-water relative to ambient temperatures ("cold-water patches") occupied by fish, and other aquatic organisms.

Compounding the effects of stream warming, the current and future impacts of climate change pose a significant threat to the long-term persistence of salmonid populations in the Columbia Basin (Beechie et al. 2013). Rising stream temperatures, along with other climate-change related impacts such as reduced snowpack, shifts in runoff timing, increased fire severity, and changes to fish community structure, will likely manifest as a persistent stressor to salmonid populations in the Upper Columbia, with potential outcomes including contractions and/or shifts in distribution, decreased productivity, and local extirpations (Reiman and Isaak 2010).

In the Upper Columbia, adult spring Chinook may be especially vulnerable to current and future elevated stream temperatures as they migrate into spawning tributaries during the warmest days of the year in July and August. Current conditions in the Methow River subbasin, and elsewhere in the Upper Columbia, may already pose a significant challenge for migrating adult spring Chinook as documented in recent estimates of 20-50% pre-spawn mortality upstream of Wells Dam (J. Cram and C. Snow, WDWF, unpublished data). While the precise mechanisms of pre-spawn mortality are not fully known, it is likely that elevated temperatures are a contributing factor.

During migration and on the spawning grounds, adult spring Chinook hold for periods of time to rest or await more favorable water temperatures before proceeding to spawn. During this time, they may benefit from holding within pockets of cold water. In the Yakama River, spring Chinook have been shown to seek out cold-water features, which may allow fish to maintain an internal temperature several degrees cooler than surrounding waters (Berman and Quinn 1991). Berman and Quinn also noted that both the availability and suitability of thermal refugia for holding spring Chinook may significantly influence their long-term persistence.

Thermal refugia can also provide important habitat for juvenile spring Chinook, as well as both adult and juvenile steelhead and bull trout. During summer, both juveniles and adults may be attracted to the cooler water located within the thermal feature and, conversely, in winter may be attracted to the relatively warmer water found within the same feature.

Thermal refugia can directly affect the distribution and productivity of Upper Columbia salmonids and will surely play a significant role in their future as the effects of climate change become more acute. Identifying, quantifying, and enhancing (where appropriate) existing thermal refugia are important steps in increasing current habitat quantity, quality, and productivity and enabling long-term persistence for ESA-listed species in the Methow. Additional information on the physical and biological aspects of thermal refugia can be found in Torgerson et al. (2012), Steel et al. (2017), and Sullivan et al. (2021).

Project Goals and Objectives

The project goal was to provide information on the locations and characteristics of cold-water patches (CWP) within the Methow River subbasin in order to inform the implementation of habitat restoration and land management actions to improve habitat quality and quantity in support of the recovery of ESA-listed fish species.

Project objectives included:

1. Review existing information on CWP from the Methow River subbasin, primarily the 2009 thermal infrared imagery dataset which identified the locations of numerous CWP in the Methow, Chewuch, and Twisp Rivers.
2. Conduct field surveys of identified CWP to verify their presence and describe their current characteristics.
3. Crosswalk CWP field information with the results of Upper Columbia Habitat Prioritization and the restoration project information contained within Reach Assessments within the study area.

4. Develop a catalogue of potential restoration and land management actions located in and around identified cold water patches.
5. Disseminate study results to local and regional restoration practitioners to facilitate integration into restoration project planning.

Methods

We used the results and data from the 2009 thermal infrared (TIR) aerial imagery (Watershed Sciences 2009) to identify the locations, sources (e.g., springs, alcoves, tributary inflows), and temperature characteristics of summertime CWP. TIR imagery covered the majority of the anadromous zone within the mainstem Methow, Chewuch, and Twisp Rivers (Figure 1).

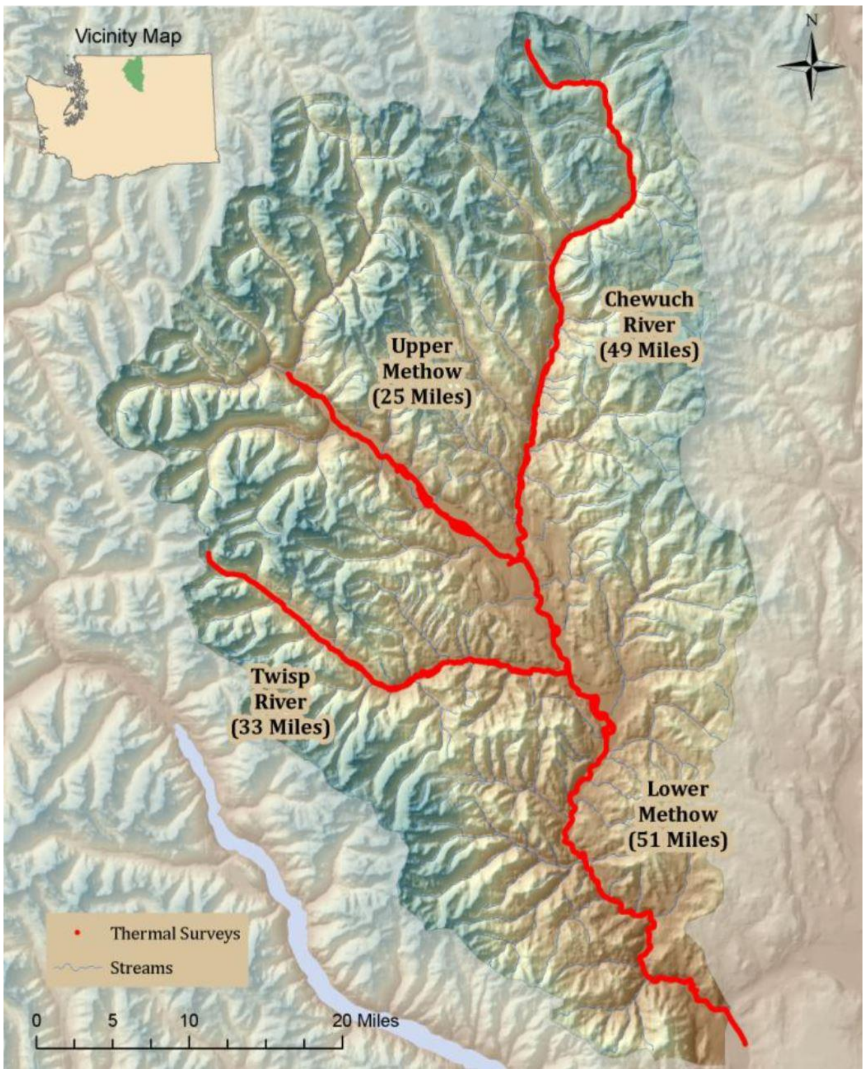

Figure 1. Thermal infrared imagery coverage, Methow River subbasin, 2009. Map from Watershed Sciences (2009).

We used a temperature differential of ≥2°C from surrounding waters to define CWP within the TIR dataset – a differential value that was based on information in Torgersen et al. (2012) and Sullivan et al. (2021). Most of these locations were specifically identified in the TIR report (Watershed Sciences 2009). If additional cold-water areas with 1.5 - <2°C differential existed in close proximity one of our sites, we made an effort to sample them. Additionally, several sites not identified through our summary of TIR data were opportunistically encountered in the field and were also included. Each CWP was assigned a unique identification number.

Field reconnaissance surveys of identified CWP were conducted during late July- early September in both 2021 and 2022. We initially planned to complete all field surveys in 2021, but area closures associated with the 2021 Cub Creek Fire prevented access into most sites in the Chewuch River. A small handful of sites in the Twisp and Methow Rivers were re-visited in 2022 to collect additional habitat data the result of a small modification to the site data collection protocol which occurred after those sites were visited in 2021. Due to specific needs for a separate habitat restoration effort (the 3R project downstream of Winthrop), several sites in the Methow -Thompson Assessment Unit were visited in February 2022 to examine winter conditions. These site visits are discussed, but we not included in the overall CWP analysis that focused only on summertime conditions. We did not expect to have the resources and time to visit every identified CWP through the TIR data, so we prioritized sites within the anadromous zone and reaches used by spring Chinook for spawning and early rearing. Hazardous field conditions caused by wildfire smoke curtailed field sampling in both years and because of this we were not able to sample the complete list of sites.

The goal of the CWP field reconnaissance surveys was to verify the continued existence and precise location of the CWP on the waterscape, as well as their physical characteristics. Using aerial imagery uploaded to a smartphone, or paper maps and a GPS, we navigated to the potential CWP site and used a calibrated hand-held rapid response thermometer (Cooper-Atkins, model 35200-K with a 5′ thermocouple, mounted on a broom stick) to probe for the presence cold water at that location. Prior to cold water probing, we determined the ambient temperature of the adjacent mainstem channel a short distance upstream of the CWP location. We used this mainstem temperature value to delineate the CWP location using the 2°C differential threshold. To align our findings with those from the Wenatchee River subbasin (Roumasset 2020), we used both 2 °C and 1 °C differentials to describe the CWP plume extent into the mainstem channel.

Once located, CWP were assessed for various characteristics that defined the location, source, area coverage, and plume of cold water entering the mainstem flow. Sites were sampled to coincide with warmer portions of the diel temperature cycle, so, with few exceptions, were sampled between 1300-1700 hours.

CWP sources were classified based primarily on the descriptions provided in Dugdale (2013) and included alcove, lateral seep, springbrook, tributary confluence, and wall seeps. In the field, and based on site and imagery information, it was not always evident exactly what class of CWP was present. Most commonly, alcoves could be difficult to differentiate from both lateral seeps and springbrooks. In general, we reserved the alcove designation for site that had some amount of off-channel habitat development (i.e., a defined channel) that was more extensive than a lateral seep, but less extensive than a springbrook. Springbrooks had both discernable channels and downstream discharge velocities, while alcoves were characterized by more stagnant flow. Surveys were conducted during low flow periods, so where present wetted high flow channels were generally classified as springbrooks (and not side channels) as they were more similar to that class during low flows. Additional hydraulic modeling could be used to more specifically define these types CWP. In any case, we used our best judgement to classify the CWP and regardless of the particular CWP class, site specific temperature and habitat information was collected in a similar fashion.

We also searched for the presence of fish in the CWP, as well as recording any site specific and/or noteworthy observations, and suggestions for potential CWP enhancement actions. In addition to date, time, latitude/longitude, patch identification number, and river kilometer a suite of information was collected to further defined the CWP in a fashion similar to what was compiled by Roumasset (2020) in the Upper Wenatchee River (Table 1). Photographs of each site were collected at the time of the site visit. All data were collected via the Esri ArcGIS Survey 123 smartphone app which worked well in practice for our purposes.

Table 1. Cold-water patch characteristics, Methow River subbasin, 2021-2022.

CWP Characteristic	Variable(s)
Source	alcove, lateral seep, springbrook, tributary confluence, wall seep, cold side channel
Bank	left, right, center
Mainstem channel unit	pool, glide, riffle, backwater, side channel
Dominant substrate	fines, sand, gravel, cobble, boulder, bedrock
Dominant cover	wood, rock, vegetation, depth
Temperature	mainstem, CWP (minimum and average), plume (minimum and average)
Spring channel area	length, average width and depth
Plume area	length, average width, maximum, minimum and average depth for both 2°C and 1°C plume areas

Data analysis consisted of sorting the CWP by stream, assessment unit, and reach, (https://www.ucsrb.org/science-resources/prioritization/) and summarizing the site information based on temperature profiles, CWP area, and plume area. We used site data, TIR imagery, aerial photos, LiDAR imagery (2018 or 2015 data based on location, available at https://lidarportal.dnr.wa.gov/), and site photographs to develop an individual summary for each CWP surveyed (Appendix A).

Due to a significant amount of environmental variation (e.g., year, location, time of day, air temperatures, mainstem temperature and discharge, snowpack, etc.) amongst survey events we did not make an attempt to develop a site-by-site comparison for CWP differential from mainstem. We also did not attempt to compare the degree of change for CWP differential between the 2009 TIR survey and our data collections because of the aforementioned variables, and also because the data collection methods between our surveys and the TIR differed significantly. The TIR data derive from the water surface temperatures while our probe-based surveys collected sub-surface temperatures which could be noticeably cooler than water surface temperatures. We did complete a cursory examination of absolute temperatures amongst sites and between surveys for the purposes of examining the relative contribution of sites and their persistence as a CWP relative to the mainstem.

Mainstem temperatures during sampling varied by stream, time of day, and date, as well as other factors such as stream discharge. We made no attempt to adjust or otherwise account for changes in mainstem temperatures during sampling, so reported differentials between mainstems and CWP should be viewed as a snapshot of conditions present at the time of sampling and not necessarily the absolute difference between the locations which could change based on the sample timing.

Discharge also varied throughout the study. Stream-specific discharges varied from a low of 49 c.f.s. in the Twisp River in 2021 to a high of 339 c.f.s. in the Methow River in 2021 (Table 2). Overall, the discharge regimes during all sampling events were indicative of low flow conditions.

Table 2. Sampling dates and stream discharge during CWP sampling, 2021-2022. Data from USGS gauges 12448500 (Methow), 12448000 (Chewuch), and 12448998 (Twisp).

Stream	2021 Dates	2021 Discharge	2022 Dates	2022 Discharge
Methow	7/28 – 9/14	176-339 c.f.s	9/12	253 c.f.s.
Chewuch	Not sampled	Not sampled	8/19 – 9/7	68-116 c.f.s.
Twisp	8/18 – 8/27	49-64 c.f.s.	9/6 - 912	50-56 c.f.s.

To provide context to our CWP restoration assessment, we cross walked CWP locations with Upper Columbia Prioritization results by both assessment unit (AU) and stream reach, and also included reach-based habitat limiting factors. We examined the various reach assessments for the Methow that covered the entire study area (USBR 2008, 2010, 2011; Yakama Nation 2010a, 2010b, 2015a, 2015b, CCFEG 2017, MSRF 2019) to identify any CWP proximate projects (both identified and completed) that were included in these assessments.

Results

CWP Distribution

Based on TIR data, 131 CWP sites possessing a ≥2°C colder water temperature differential were identified within the project area. Of these, we were able to visit 108 (82% of total) sites which were located primarily within spawning and rearing habitat for spring Chinook salmon (Figure 2). During the field surveys we encountered and sampled an additional 17 sites that were not included, or specifically identified as ≥2°C colder, in the TIR report for a total sample of 125 CWP.

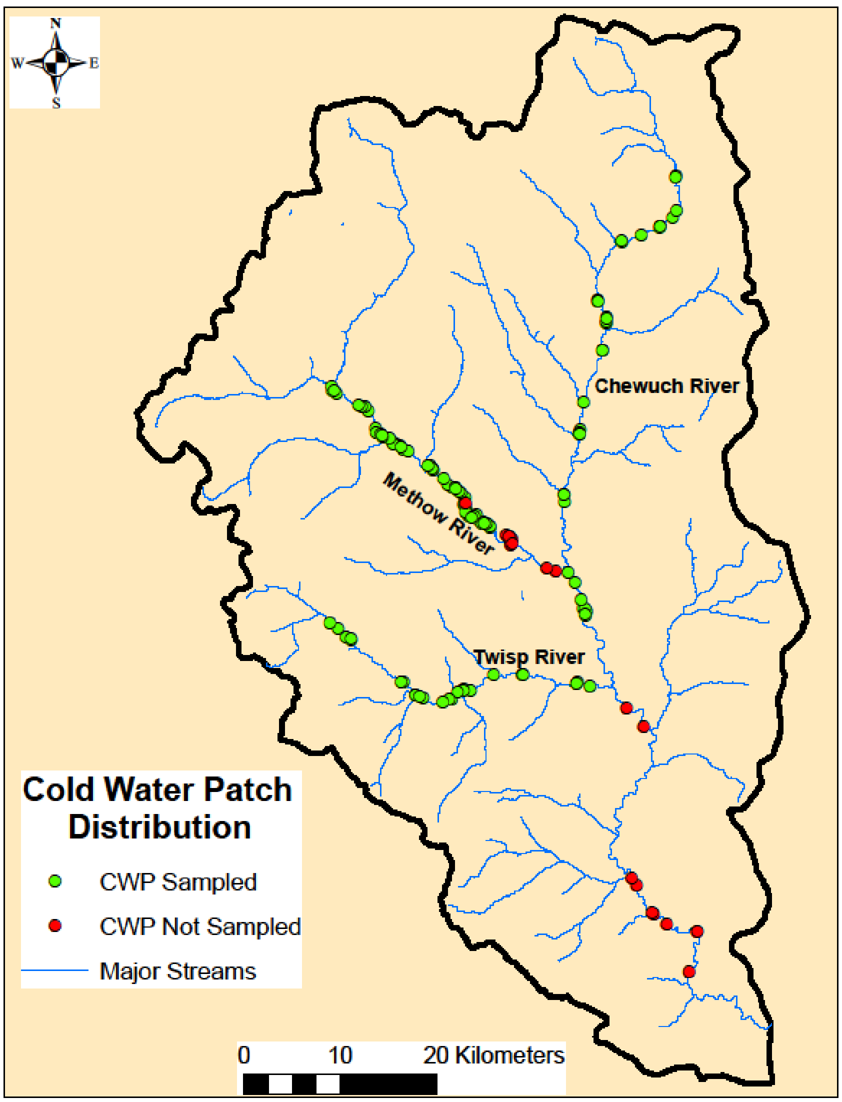

Figure 2 . Cold-water patch sites (sampled and not sampled), Methow River subbasin, 2021-2022.

Of the sites not sampled, all were located in the Methow River within the Methow – Fawn, Alder, and McFarland AUs. Hazardous field conditions resulting from wildfire smoke prevented sampling of these sites on the scheduled days and they were not able to be sampled later in the season. While we lack current data on these sites, we assume they still may possess CWP properties and so included them in the restoration summary.

Of the 108 TIR-based CWP visited, 102 were observed and located in close proximity to where they were indicated in the TIR data. Several sites, for example CWP #066 (lateral seep in Methow – Fawn AU), were located in a similar location, but had moved a short distance due to changes in the channel location which had migrated between 2009 and 2021-2022. Five CWP were not located due to a lack of a discernable flow (e.g., area was dry), thus the total number of CWP sampled in the field was 120. One additional site, CWP #165 (Falls Creek) was a tributary confluence with only a 0.5 °C differential and a minimum temperature of 18.6 °C, and it is not clear if this site is currently a functional CWP. Additional field measurements would help elucidate the status of this site over time. Overall, these results indicate a >94% persistence of CWP over the 12-13 years between the 2009 TIR and 2021-2022 field verification.

Ten TIR-based sites had temperature differential <2 °C in the field and thus did not strictly meet our CWP criteria. All of these were sampled in late August - September when mainstem temperatures had declined from summertime highs, thereby influencing the differential value which would have been higher if the site had been visited in during warmer portions of the year, thus we assume these sites still remain functional CWP during certain conditions.

In addition to the TIR-based CWP sites, we sampled an additional 17 sites during field surveys that we did not specifically identify from the TIR data. These sites included 7 lateral seeps, 7 alcoves, 2 springbrooks, and one tributary confluence (CWP #904, Eagle Creek, Twisp – Middle AU). Sites were spread across the survey area and located in the Methow – Fawn (n=5), Methow – Thompson (n=2), Methow – Rattlesnake (n=1), Twisp – Middle (n=4), Chewuch – Pearrygin (n=1) and Chewuch – Doe (n=4) AUs.

Of these sites, 11 had cold water signatures present in the TIR imagery, so it is possible that TIR results were misinterpreted during our initial analysis so these sites were not included in our site list, thus we do not consider these as "new" CWP sites that developed since 2009. Six sites, however, were not obviously present in the TIR imagery (CWP #902, 907, 913, 914, 916, and 917) and likely developed since 2009. All of these six sites were lateral seeps and alcoves.

A majority of the CWP sites (65/120 sites) were located in the Methow River, with 28 and 27 sites located in the Chewuch and Twisp Rivers, respectively (Figure 2, Table 3). In total, the survey covered 128.5 km of stream, spread across the three rivers including 44.2 km in the Methow, 46.1 km in the Chewuch, and 38.2 km in the Twisp.

Samples were located within ten assessment units in the Methow, Chewuch, and Twisp Rivers (Table 3). Sites were not equally distributed across AUs and over a third (45/120 sites) were located in the Methow – Fawn assessment unit which includes the Big Valley reach where numerous CWP are located. Three other AUs including Methow – Rattlesnake, Chewuch – Doe, and Twisp – Lower had more than ten CWP, while the remaining six AUs all had less than ten CWP each. Of the 23 TIR-base CWP that were not visited, four were located in the Chewuch – Headwaters AU and outside of the anadromous zone, ten were in the Methow – Fawn AU in lower Big Valley within and adjacent to the Heath Ponds complex, and the remaining nine sites located in the Methow – Alder (n=2) and Methow – McFarland (n=7) AUs.

Table 3. Cold water patch counts by assessment unit, Methow River subbasin, 2021-2022.

Assessment Unit	# CWP	# CWP Added	# CWP Not Located	Total CWP Sampled
Methow - Thompson	6	2	0	8
Methow - Fawn	40	5	0	45
Methow - Rattlesnake	14	1	3	12
Chewuch - Pearrygin	3	1	0	4
Chewuch - Doe	10	4	0	14
Chewuch - Thirtymile	9	0	0	9
Chewuch - Kay	2	0	1	1
Twisp - Lower	12	0	1	11
Twisp - Middle	9	4	0	13
Twisp - Upper	3	0	0	3
TOTAL	108	17	5	120

The 120 CWP visited, lateral seeps and springbrooks were the most common type, with 44 and 37 sites, respectively (Table 4). Alcoves were also relatively abundant with 27 sites. Eleven tributary confluences were sampled. Only one wall seep was visited (CWP #037 in Chewuch – Thirtymile) and while present, no cold-water information was collected as the CWP source was too far away from the mainstem and there was no observed surface water entering the mainstem.

Of the added CWP sites, alcoves (n=7) and lateral seeps (n=7) were the most abundant (14/17 sites) with only two springbrooks and one tributary confluence encountered (Eagle Creek, Twisp – Middle AU).

Table 4. Cold water patch type by assessment unit, Methow River subbasin, 2021-2022.

Assessment Unit	Alcove	Lateral Seep	Springbrook	Tributary	Wall Seep
Methow - Thompson	3	3	1	1	0
Methow - Fawn	8	22	14	1	0
Methow - Rattlesnake	3	6	2	1	0
Chewuch - Pearrygin	1	1	0	2	0
Chewuch - Doe	5	4	3	2	0
Chewuch - Thirtymile	2	2	3	1	1
Chewuch - Kay	1	0	0	0	0
Twisp - Lower	2	4	5	0	0
Twisp - Middle	2	1	7	3	0
Twisp - Upper	0	1	2	0	0
TOTAL	27	44	37	11	1

The Methow – Fawn AU had the highest number of lateral seeps, springbrooks, and alcoves compared to other AUs with 22, 14, and 8 of these classes each, respectively. No other AU had more than seven CWP of any one class with Twisp – Middle having seven springbrook CWP. Three tributary confluences were observed in the Twisp – Middle AU including Little Bridge Creek (CWP #163), Canyon Creek (CWP #162), and Eagle Creek (CWP #904).

CWP Temperature

Mainstem temperatures, used as a baseline to determine CWP presence as well as the temperature differential between the mainstem and CWP, varied between and within streams. Mainstem temperatures were generally warmest in the Chewuch River which had the highest maximum, minimum, and average temperature during the sampling (Table 5). Temperatures were also, in general, and not accounting for sampling time or date, warmest at the downstream (lower elevation) sites and coolest at the upstream (higher elevation) sites. Temperatures were also warmer later in the sampling period each day as is common for streams in the Upper Columbia region that experience diel warming.

Table 5. Minimum, maximum, and average mainstem temperatures at CWP sites for the Methow, Chewuch, and Twisp Rivers, 2021-2022.

Stream	Min Temp (°C)	Max Temp (°C)	Avg Temp (°C)
Methow	8.6	18.5	13.4
Chewuch	13.0	19.1	16.7
Twisp	10.1	17.0	13.7

Water temperatures varied across CWP classes with minimum temperatures ranging from 5.0 - 9.5 °C and maximum temperatures ranging from 11.7 - 18.6 °C (Table 6). The coldest CWP encountered was 5.0 °C at a lateral seep in the Chewuch – Thirtymile AU (CWP #137) and this site was 10.5 °C cooler than the adjacent mainstem at that time. The warmest CWP encountered was a tributary confluence (Falls Creek, CWP #165) in the Chewuch – Doe AU. This site did not express a ≥2 °C differential at the time of sampling as it was only 0.5 °C colder than the adjacent mainstem Chewuch River, thus was not meeting the definition of a CWP at the time of sampling.

Table 6. Minimum, maximum, and average CWP temperatures and maximum and average differentials by class, Methow River subbasin, 2021-2022.

CWP Source	CWP Min Temp (°C)	CWP Max Temp (°C)	CWP Avg Temp (°C)	Max CWP Differential (°C)	Avg CWP Differential (°C)
Alcove	5.8	14.6	9.2	12.0	5.4
Lateral Seep	5.0	14.1	9.7	10.5	4.0
Springbrook	6.4	11.7	9.0	11.7	4.9
Tributary	9.5	18.6	12.4	9.0	4.4

On average, springbrooks were the coldest CWP class, with an average temperature of 9°C, but both alcoves and lateral seeps were close to this value, with average temperatures of 9.2 °C and 9.7 °C, respectively. Tributary confluences were the warmest CWP class with average of 12.4 °C from the 11 tributaries that were sampled.

CWP Differential

In terms of CWP temperature differential from the mainstem, alcoves had the highest maximum differential with a value of 12 °C at CWP #031 in Chewuch – Doe AU (Table 6). Both lateral seeps and springbrooks also had large maximum differentials of >10 °C and the coldest tributary was 9 °C colder than the mainstem (Suspension Creek, CWP #002 in Methow – Fawn AU).

But overall, on average, all CWP classes were ≥4 - 5.4 °C colder than the adjacent mainstem temperatures with alcoves being the coldest followed by springbrooks, tributary confluences, and lateral seeps. The average differential of all CWP sampled was 4.6 °C colder which was 1.5 °C more (cold) than the average differential of the same sites based on TIR data which were 3.1 °C colder than mainstem in 2009.

Across assessment units, low and high minimum CWP temperatures both occurred in the Chewuch River and ranged from a low of 5.0 °C in the Chewuch – Thirtymile AU (CWP #137) to a high of 8.6 °C in the Chewuch – Pearrygin AU at CWP #090 (Table 7). Excluding the one CWP site in the Chewuch – Kay AU (CWP #114, alcove), the Chewuch AUs also had some of the highest maximum temperatures which ranged up to 18.6 °C in the Chewuch – Doe AU (CWP #165, Falls Creek). The Chewuch AUs also had the largest differentials, >10 °C in both the Chewuch – Doe and Chewuch – Thirtymile AUs, and an average differential range of between 3.9 – 5.9 °C. There was also cold water (6.4 - 7.8 °C) and high differentials (>6 - 9 °C) in both the Methow and Twisp River AUs.

Table 7. Minimum, maximum, and average CWP temperatures and maximum and average differentials by assessment unit, Methow River subbasin, 2021-2022.

Assessment Unit	CWP Min Temp (°C)	CWP Max Temp (°C)	CWP Avg Temp (°C)	Max Diff (°C)	Avg Diff (°C)
Methow - Thompson	7.8	13.4	10.3	7.5	2.7
Methow - Fawn	7.8	12.5	9.7	9	2.1
Methow - Rattlesnake	6.7	14.6	9.4	5	2.8
Chewuch - Pearrygin	8.6	14.5	11.3	7.7	3.9
Chewuch - Doe	6.6	18.6	10.5	12	5.6
Chewuch - Thirtymile	5.0	11.7	8.1	10.5	5.9
Chewuch - Kay	6.4	6.4	6.4	6.4	n/a
Twisp - Lower	7.4	11.7	9.4	6.7	3.8
Twisp - Middle	6.7	12.7	9.3	6.8	2.5
Twisp - Upper	6.4	9.5	7.5	6.7	3.7

CWP Plumes

Plumes of 1-2 °C colder water within the mainstem channel were present at a majority of the CWP sites sampled (87/120 sites, 72%). Several reasons were noted at the sites where no plume was detected in the field, including lack of CWP flow into the mainstem, swamping of CWP flow by mainstem flows, hence, temperature, or CWP flow into a dry mainstem channel. Data for some plumes were not collected in the field for a few reasons (see CWP site details, Appendix A), so the total number of plumes measured for both depth and area of at least the 1 °C plume was 78.

On average, plume depth across AUs ranged from a low of 5.8 cm in the Chewuch -Doe AU to a high of 21.6 cm in the Methow – Thompson AU (Table 8). Maximum plume depth never exceeded 100 cm and with only three sites (CWP #108, #150, #143) having depths >80 cm. The shallowest plumes were in the Chewuch – Doe AU while the deepest plumes were in the Methow – Thompson AU. Although not specifically measured, the average plume depths were shallow relative to the mainstem thalweg and adjacent waters in most locations (J. Crandall, personal observation).

Plume area varied widely across AUs from a low of 6.5 m^2 for the 2 °C area in the Twisp – Upper AU and a high of 407.5 m^2 in the Chewuch – Pearrygin AU (Table 8). Plume area of 1°C differential was always greater than the 2°C and exhibited over an 83-fold difference from the low (10.2 m^2 in Twisp -Lower AU) to the high (841 m^2 in the Chewuch – Pearrygin AU).

Table 8. CWP plume depths, areas, and volumes, Methow River subbasin, 2021-2022.

Assessment Unit	Avg Plume Depth (cm)	Area Plume 2C (m^2)	Area Plume 1C (m^2)	Plume Volume >1C (m^3)
Methow - Thompson	21.6	312	410.5	88.7
Methow - Fawn	10.7	28.7	77.1	8.2
Methow - Rattlesnake	16.7	71.7	75.4	12.6
Chewuch - Pearrygin	16.0	407.5	841.7	134.7
Chewuch - Doe	5.8	3.5	12.5	0.7
Chewuch - Thirtymile	17.8	12.8	28.6	5.1
Chewuch - Kay	n/a	n/a	n/a	n/a
Twisp - Lower	9.7	5.7	10.2	1.0
Twisp - Middle	13.8	18	283.4	39.1
Twisp - Upper	12.9	6.5	12.2	1.6
Average	12.6	57.7	135.6	17.5

Eightmile Creek (CWP #150) had the largest observed plume and our measurement was likely an underrepresentation of the extensive cold-water plume present at this site as it was so extensive which made accurate measurement in the field difficult.
Other notably large plumes were present at CWP #048 (lateral seep in the Methow – Thompson AU) and CWP #112 (a large, complex springbrook in the Middle - Twisp AU). The large plumes present at these sites strongly influence the large average plume areas of the AUs in which they occur.

Plume volume for the 1°C differential generally mirrored the trends observed with plume area especially for the AUs with the three largest plume areas (Table 8). The overall plume volume in some AUs were quite small and Chewuch -Doe had a plume volume of a scant 0.7 m^3, while the Twisp – Upper AU had a plume volume of only 1.6 m^3.

Due to the strong influence of the largest plumes on area and volume calculations, CWP plumes classified by area (Table 9). For both 2°C and 1°C plume areas, a large majority of plumes were <50 m^2 including 89% of 2°C plumes (61/68 2°C plumes) and 75% of 1°C plumes (59/78 1°C plumes). Thus, a large majority of plumes were small relative to the few larger plumes.

Table 9. Number CWP plumes by area size class, Methow River subbasin, 2021-2022.

CWP Plume Area (m^2)	# 2°C Plumes	# 1°C Plumes
<10	37	24
10-50	24	35
50-100	1	7
>100	6	12

CWP Repeat Visits

We completed repeat samples ten CWP sites across the two years of sampling with nine of ten sites in the Twisp - Lower AU and the remaining site in the Methow – Thompson AU. All sites functioned as CWP in each year sampled. In the Twisp – Lower AU, the minimum temperature of the CWP were relatively similar and did not exceed 0.6 °C across years (Table 10). Some Twisp – Lower sites were colder in 2012, some warmer. The one site in Methow – Thompson (CWP #075, springbrook) showed more variability and was 1.2 °C colder in 2021 compared to 2022.

Table 10. Minimum CWP temperatures of repeat sample sites, Methow River subbasin, 2021-2022.

CWP ID	Assessment Unit	Date	Min Temp (°C)	Differential (°C)
75	Methow Thompson	7/28/2021	10.5	1.2
		9/12/2022	11.7	
28	Twisp Lower	8/18/2021	12.3	0.6
		9/12/2022	11.7	
39	Twisp Lower	8/17/2021	8.8	0.1
		9/6/2022	8.7	
72	Twisp Lower	8/18/2021	7.5	0.6
		9/6/2022	8.1	
78	Twisp Lower	8/17/2021	10	0.5
		9/6/2022	10.5	
79	Twisp Lower	8/18/2021	8.6	0.4
		9/6/2022	9	
84	Twisp Lower	8/17/2021	10.1	0.5
		9/6/2022	9.6	
89	Twisp Lower	8/18/2021	7.9	0.3
		9/6/2022	7.6	
103	Twisp Lower	8/18/2021	7.2	0.2
		9/6/2022	7.4	
110	Twisp Lower	8/18/2021	9.2	0.2
		9/6/2022	9	

CWP Fish Observations

Fish were observed within 25 CWP during sampling (20.8%, 25/120 sites) including Chinook salmon, *O. mykiss*, and coho salmon. All fish were juvenile parr except for two adult spring Chinook that were observed in CWP #905 (Twisp – Middle AU) and #046 (Methow – Rattlesnake AU). Fish observations were limited to visual only, and we assume overall presence was likely higher than observed as fish were simply not detected.

Fish abundance ranged from 1 fish up to small schools of 20-35 individuals. The largest observation was a mixed school of 35 fish of both Chinook and coho salmon at CWP #143 (Methow – Thompson AU, alcove). Fish were observed in springbrooks (n=14), alcoves (n=8), and lateral seeps (n=3) within six of ten AUs (Methow – Thompson/Fawn/Rattlesnake, Twisp Lower/Middle, and Chewuch – Doe).

Discussion

Our investigation into CWP presence within the three major streams in the Methow River subbasin in 2021-2022 revealed a high degree of CWP persistence (>94%) over the more than a decade between the 2009 TIR data and our data collection efforts. Based on these results of location fidelity and cold-water persistence over time, it appears possible, if appropriate and feasible, to move forward with CWP enhancement and/or protection at the majority of CWP identified in the 2009 TIR data. Additional data collection at any proposed site to further verify the CWP and its extent is strongly advised prior to any restoration activities.

While our project focused on CWP during the warmest portions of the year in consideration of the cold-water benefits these habitats can provide ESA-salmonids, it is recognized that these same sites may provide thermal benefits (i.e., warmer water relative to ambient) to fish during other time of year including winter. An example of this was observed at the 3R restoration project site in the Methow – Thompson AU where long-term temperature monitoring at several CWP and the mainstem was able to document the thermal characteristics of the project site (Crandall 2021). Data indicate the CWP function as cold-water refugia, relative to the mainstem, in the summer (June – August) months then shift to warm-water refugia in the winter (November – March) months (Figure 3). Fish use of the three CWP within the 3R area is extensive and has been observed to occur year-round (J. Crandall, personal observation). Warm water habitats can be beneficial to salmonids and can significantly influence their productivity (Hahlbeck et at. 2021).

The CWP we investigated were discreet point sources, including tributary inputs, and do not necessarily reflect the thermal waterscape across larger scales within the Methow River subbasin. This is an important consideration for the development of CWP enhancement activities as our data are most applicable to CWP at the channel unit and microhabitat scale. Water flow and temperature dynamics across the entire subbasin setting, and within larger stream segments (e.g., gaining and losing reaches), can have strong influences on smaller scale features such as the CWP we verified (Torgerson et al. 2012).

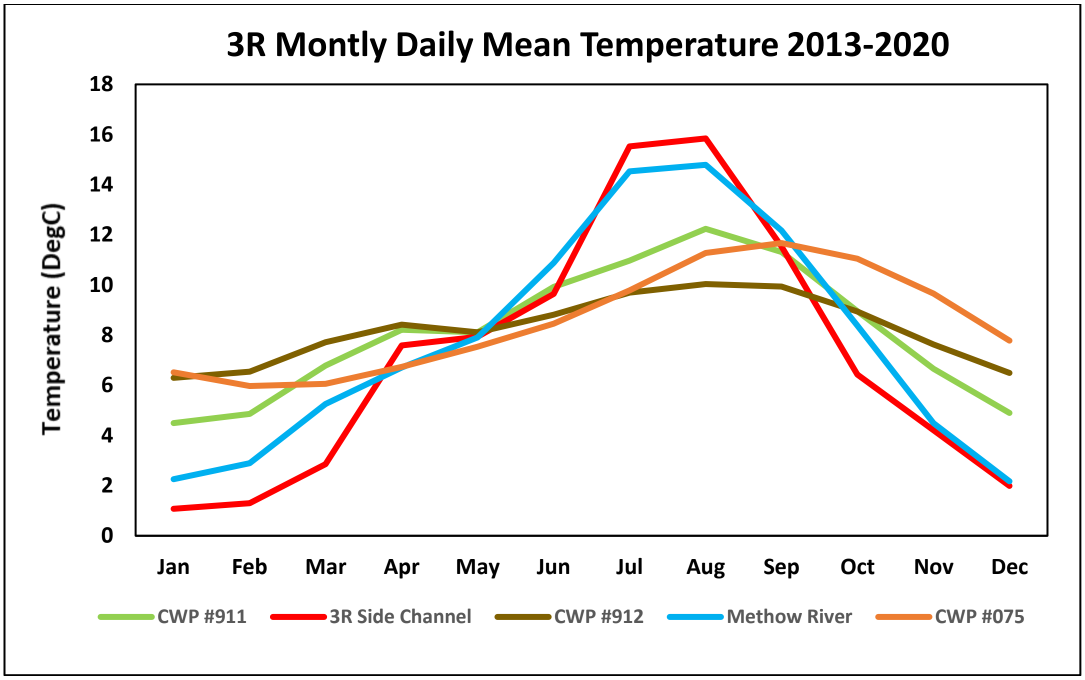

Figure 3. Monthly daily mean water temperatures, 3R project area, Methow River, 2013 – 2020.

Shifts within the larger scales, such as through climate change, landscape disturbances (e.g., wildfire, groundwater extraction), or shifts in stream channel geomorphology, are likely to influence CWP expression at smaller scales. Thermal heterogeneity across multiple scales is an important stream characteristic for cold-water dependent fish species (Fullerton et al. 2018), thus restoration planning will benefit from considering our results within the larger thermal profiles of the Methow River subbasin that were a component of the 2009 TIR data (Watershed Sciences 2009).

Our results indicate a high degree of CWP persistence over time in the Methow. Although long-term studies are limited, Dugdale et al. (2013) found much less CWP persistence, and high inter-annual variability, in two Canadian streams where only 40% of CWP were observed on multiple occasions over six TIR flights over a two-year period. 60% of CWP only observed on one of six occasions and, interestingly, only one CWP persisted over all six data collection events. It is likely that in many locations several factors, including stream discharge, and precipitation patterns, are correlated with CWP expression over time, thus changes in these variables also strongly influence CWP characteristics. We located six CWP that possibly developed since the 2009 TIR data collection, an indication of the transitory nature of at least some CWP in the Methow. Based on cursory field observations, it appears that many of these sites arose in relation to shifts mainstem channel bed position.

Only five sites were not located during the study, with most of these in a reach of the Methow River (Methow – Rattlesnake 02) that was largely dry (i.e., subsurface flow) during the sampling period. If stream discharge had been high during sampling, either during spring runoff or in another water year with higher baseflows, it is possible these CWP would have been present. Changes in stream channel morphology can also influence CWP expression, thus shifts in channel position in this unconfined reach may have been responsible for the lack of CWP expression at these locations. CWP #175 (Twisp – Lower AU) was dry for a different reason related to changes in irrigation infrastructure which curtailed ditch seepage into the site (C. Johnson, Methow Salmon Recovery Foundation, personal communication).

One other site, Falls Creek, a tributary to the Chewuch River (CWP #165, Chewuch – Doe AU) was only 0.5°C colder than the mainstem and did meet not our CWP criteria. The Falls Creek watershed was severely burned during the 2021 Cub Creek fire and has had several large runoff and debris flow events since that time. These disturbances are a likely reason for the observed change in water temperature in this creek. Additional monitoring is warranted to track the recovery of this stream and its potential return to a CWP.

Repeat sampling at a few locations, mostly in the Twisp River, revealed that these CWP had similar minimum temperatures across two sampling years with most sites expressing <0.5°C difference across years. While the repeat sampling was not extensive, it does reveal that for at least some sites, CWP temperatures may not shift dramatically over short time spans a likely reflection of the groundwater and/or hyporheic inputs that support them.

For all sites, average minimum CWP temperatures in 2021-2022 were slightly colder compared to the 2009 TIR data and generally within 1.5 °C of them. The sampling methods of these two data collection efforts were significantly different, so they are not directly comparable, and we assume our field methods were more suited to capturing the true microhabitats present within the CWP and able to measure sub-surface and substrate temperatures where cold-water flow was observed originating at many CWP. TIR-based results stem from water surface temperatures so may have missed or underestimated the coldest temperatures within a CWP.

With a few exceptions, the CWP measured in 2021-2022 were cold relative the waters in the adjacent mainstem reaches. Average temperatures for all CWP classes ranged from 9–12 °C which are cool for summertime baseflow temperatures in many portions of the Methow River subbasin (Crandall 2019) and as observed in the 4-5.4 °C range in average differential between the colder CWP and the mainstems. While there were some noticeable spatial differences in maximum, minimum, and average CWP temperatures across the assessment units this should be expected across the large spatial area and elevational gradient covered by both the TIR-imagery and our recent sampling. Tributary confluence CWP were the warmest of all with an average temperature of 12 °C (range 9.5-18.6 °C). These data suggest that the waters within the CWP could serve as important cold-water refugia for fish seeking cold-water habitat during periods of warm ambient conditions in adjacent waters.

While higher elevation CWP were mostly colder relative to lower elevation CWP, their overall contributions in cooling mainstem temperatures may be similar as higher elevation mainstem temperatures, in general, are also colder than lower elevation mainstem reaches, so the overall cooling contributions are similar. Certainly, a more thorough investigation into the cooling effects of CWP on mainstem temperatures would help elucidate their ability to cool and maintain mainstem temperatures.

Current minimum and average CWP temperatures in the Methow fall well below Washington State 303(d) criteria for temperature which for salmon and steelhead in the Methow range between 13-17.5 °C (Washington State Department of Ecology 2006). CWP temperatures also fall below the 12 °C criteria for char spawning and rearing even though only a small handful of sites in the Twisp – Upper AU (average 7.5 °C) and one site in the Chewuch – Kay AU (minimum 6.4 °C) were within bull trout spawning areas. These results indicate that the current cold-water inputs from CWP can contribute, not only to site-specific refugia for ESA-listed fish, but also to help maintain broader mainstem temperatures within the water quality criteria further enhancing the spatial and ecological benefits of CWP inputs.

Although not specifically measured during our study, cold-water discharge from most CWP, especially lateral seeps and alcoves, appears of low volume, so it is unknown exactly how much contribution individual CWP can make to significantly influence mainstem temperatures. Plume depth, area, and volume data indicate that many are shallow (<20 cm deep) and cover a small area and volume relative to the mainstem channel. Similar plume characteristics were observed in the Upper Wenatchee River during a thermal refuge study (Roumasset 2020b). The small volume and area of some CWP may limit their ability to serve as cold water refugia for fish during periods of high mainstem temperatures, especially adults, so juvenile life stages may be able to most utilize these thermally beneficial habitats. Our observations suggest this as almost all fish observed within CWP were juveniles.

The largest plumes of cold water in mainstem channels originated from relatively high-volume sources including tributaries and some springbrooks. Cold-water tributary plumes have been observed to provide valuable habitat for salmonids and that value may increase in importance as streams warm under climate change (Wang et al. 2019). Eightmile Creek (CWP #150, Chewuch – Doe AU) had perhaps the highest volume input of any CWP visited with the plume extending several hundred meters downstream with depths up to 90 cm. While no fish were observed within this plume during sampling, previous snorkeling surveys within the plume revealed numerous fish including spring Chinook parr and *O. mykiss* juveniles (J. Crandall, personal observation).

Beyond their mainstem plumes, both tributaries and springbrooks provide additional cold-water habitat within the tributary or springbrook channel which in many cases represents a significant increase in the overall cold-water area provided by those CWP. As they can provide a relatively large area for fish use, maintaining and/or enhancing access into these types of CWP may be an important consideration for restoration activities. Many springbrooks within the study area flow through floodplain channels and are connected on the downstream end at low flows and at the upstream end, and potentially fully laterally inundated, during periods of high flow. The increased connectivity during high flows likely provides access for fish into the springbrooks during certain times of year and where they can the reside for extended periods of time after the connections have shifted to low flow conditions.

CWP Restoration Strategy

A key goal of this project is to raise awareness within the Upper Columbia restoration community about the location, characteristics, and restoration/enhancement, protection, and management opportunities present at the numerous CWP in the Methow River subbasin. To this end, we have already succeeded in providing CWP data and observations to several restoration projects. These were implemented, and in the planning phase, in 2022, and were occurring in close proximity to several CWP in the Methow and Twisp Rivers. Through this communication, and the resulting increased awareness of CWP presence and location within the restoration project areas, restorations designs were influenced to potentially increase their effectiveness at enhancing these CWP habitats.

To develop a relationship between the CWP and regional restoration planning, CWP location information was cross-walked with Upper Columbia Prioritization results including AUs, reaches, limiting factors, and restoration action categories (Table 11). This information provides a spatial template linking CWP locations with current reach-scale restoration planning guidance. Restoration actions are linked for some reaches containing CWP to the limiting factors that were identified through the Prioritization process as unacceptable or at-risk within that reach (UCSRB 2021). Within Prioritization, non-high priority assessment units and reaches did not receive a full analysis of potential restoration treatments, but it is likely that a similar suite of actions would be recommenced for these reaches as were for the higher priority reaches. In general, the restoration action categories are broad and it is recommended that site specific treatment plans, if not yet completed, should be developed prior to implementation.

Interestingly, temperature for either rearing, adult spawning, and adult holding was identified as an unacceptable and/or at-risk limiting factor in every single reach containing an identified CWP. These results suggest that temperature is a pervasive limiting factor in the Methow and that restoration and/or protection of CWP could assist in addressing temperature impairment within these reaches. This type of effort would align with Prioritization's water quality improvement action category.

Site-specific restoration recommendations were made for all CWP visited and these are included in the site descriptions in Appendix A. These recommendations are basic in nature and based solely upon cursory observations of existing conditions at each site. It is probable that in some reaches, a reach-based approach could be developed to more effectively and efficiently achieve habitat quality and quantity improvements. The longitudinal temperature profiles developed from the 2009 TIR data provide a broad view of reach-based temperature patterns and should be reviewed by any entity embarking on temperature related, or other, restoration. These profiles are included in this report in Appendix B.

Entities interested in engaging with restoration of CWP are encouraged to consult additional references that provide additional cold-water related information (Ebersole 2003, Dugdale 2013, Fullerton et al. 2018) and in the case of Torgerson et al. (2012) a detailed outline supporting temperature related restoration.

The majority of our restoration recommendations were to enhance the depth, complexity, and connectivity of CWP. Depth and complexity enhancement were especially relevant to both lateral seeps and alcoves where the cold-water inputs were usually in close proximity to the mainstem channel and where the plume area was often small, relatively shallow, and lacking cover (Figure 4). Restoration actions to increase the depth and cover profiles of many CWP could be beneficial to fish by increasing the area and complexity of the cold-water area.

Table 11. Cold water patch assessment unit, reach, Upper Columbia Prioritization limiting factors and restoration action categories, Methow River subbasin. Bold CWP ID# indicate 2009 TIR-identified CWP, but lacking site visits.

Reach	CWP ID #	Unacceptable LF	At Risk LF	Restoration Action Categories
Methow River McFarland 01	**21**	Cover - Wood, Summer Base Flow, Pool Quantity and Quality, Riparian	Stability, Coarse Substrate, Floodplain Connectivity, Off-Channel/Side-Channels, Temperature - Rearing	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement
Methow River McFarland 02	**151, 74**	Cover - Wood, Summer Base Flow, Pool Quantity and Quality, Riparian	Stability, Coarse Substrate, Floodplain Connectivity, Off-Channel/Side-Channels, Temperature - Rearing	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement
Methow River McFarland 04	**161**	Cover - Wood, Summer Base Flow, Pool Quantity and Quality, Riparian	Stability, Coarse Substrate, Floodplain Connectivity, Off-Channel/Side-Channels, Temperature - Rearing	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement
Methow River McFarland 05	**148, 149**	Cover - Wood, Summer Base Flow, Pool Quantity and Quality, Riparian	Stability, Coarse Substrate, Floodplain Connectivity, Off-Channel/Side-Channels, Temperature - Rearing	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement
Methow River McFarland 06	**41, 166**	Cover - Wood, Pool Quantity and Quality, Riparian	Stability, Coarse Substrate, Floodplain Connectivity, Off-Channel/Side-Channels, Temperature - Rearing	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement
Methow River Alder 05	**20**	Summer base flow, Temperature - Adult Holding/Adult Spawning/ Rearing, Cover – Wood/Undercut Banks, Pool Quantity and Quality, Floodplain Connectivity, Off-Channel/Side Channels	None identified	None identified
Methow River Alder 06	**34**	Summer base flow, Temperature - Adult Holding/Adult Spawning/ Rearing, Cover – Wood/Undercut Banks, Pool Quantity and Quality, Floodplain Connectivity, Off-Channel/Side Channels	Pool Quantity and Quality	None identified
Methow River Thompson 05	10, 75, 912, 911, 48	Temperature - Adult Holding/Adult Spawning, Contaminants	Summer Base Flow, Temperature - Rearing, Cover - Wood/Undercut Banks, Pool Quantity and Quality, Pools - Deep Pools, Floodplain Connectivity, Off-Channel;/Side- Channels	None identified
			Temperature - Rearing, Cover - Wood/Undercut Banks, Pool Quantity and	

Reach	CWP ID #	Unacceptable LF	At Risk LF	Restoration Action Categories
Methow River Thompson 06	143	Summer Base Flow, Temperature - Adult Holding/Adult Spawning, Contaminants	Quality, Pools - Deep Pools, Floodplain Connectivity, Off-Channel/Side Channels	None identified
Methow River Thompson 07	98	Summer Base Flow, Temperature - Adult Holding/Adult Spawning,	Cover - Undercut Banks, Pools - Deep Pools, Floodplain Connectivity, Off-Channel/Side Channels	None identified
Methow River Thompson 08	160, **11**, **69**	Summer Base Flow, Temperature - Adult Holding/Adult Spawning	Cover - Undercut Banks, Pools - Deep Pools, Floodplain Connectivity, Off-Channel/Side Channels	None identified
Methow River Fawn 02	**106, 30, 62, 12, 15, 82, 91, 52**	Temperature - Rearing	Cover - Wood, Summer Base Flow, Floodplain Connectivity, Off-Channel/Side Channels, Riparian	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Bank Restoration, Water Quality Improvement
Methow River Fawn 03	26, 56, 42, 902, 13, 32, 24, 901	Floodplain Connectivity, Temperature - Rearing/Adult Holding/Adult Spawning, Cover - Boulders	Cover- Wood, Summer Base Flow, Off-Channel/Side Channels, Riparian, Pools - Deep Pools	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Bank Restoration, Water Quality Improvement
Methow River Fawn 04	76, 70, 43, 99, 907, 44, 45	Temperature - Rearing/Adult Holding/Adult Spawning	Summer Base Flow, Cover - Wood, Pools - Deep Pools	None identified
Methow River Fawn 05	27, 92, 66, 65, 71, 50, **4**	Summer Base Flow, Temperature - Rearing/Adult Holding/Adult Spawning	Cover - Wood, Floodplain Connectivity, Off-Channel/Side Channels, Pool Quantity and Quality, Riparian, Cover - Wood/Undercut Banks, Pools - Deep Pools	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Bank Restoration, Water Quality Improvement
Methow River Fawn 06	86, 93	Cover - Wood/Undercut Banks/Boulders, Summer Base Flow, Floodplain Connectivity, Off-Channel/Side-Channels, Pool Quantity and Quality, Riparian, Pools - Deep Pools	Stability, Temperature - Adult Holding/Adult Spawning	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management
Methow River Fawn 07	25, 100, 908, 57, 17, 67	Cover - Wood/Undercut Banks/Boulders, Floodplain Connectivity, Off-Channel/Side-Channels	Stability, Summer Base Flow, Pool Quantity and Quality, Riparian, Temperature - Adult Holding/Adult Spawning, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management
Methow River Fawn 08	5, 7, 53, 3, 2, 6, 83, 176	Cover - Wood/Undercut Banks/Boulders, Summer Base Flow, Floodplain Connectivity, Off-Channel/Side-Channels	Stability, Pool Quantity and Quality, Riparian, Temperature - Adult Holding/Adult Spawning, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management
Methow River Fawn 10	87	Cover - Wood/ Undercut Banks, Summer Base Flow, Floodplain Connectivity, Pool Quantity and Quality, Riparian	Stability, Off-Channel/Side Channels, Temperature - Adult Holding/Adult Spawning, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management

Reach	CWP ID #	Unacceptable LF	At Risk LF	Restoration Action Categories
Methow River Fawn 11	102, 909, 16, 101, 51, 35, 108	Cover - Wood/Undercut Banks, Summer Base Flow, Floodplain Connectivity, Pool Quantity and Quality, Riparian	Stability, Off-Channel/Side Channels, Temperature - Adult Spawning, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management
Methow River Rattlesnake 01	146, 131, 68, 1, 38	Summer Base Flow	Stability, Cover- Wood/Undercut Banks/Boulders, Floodplain Connectivity, Riparian, Temperature - Adult Spawning, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management
Methow River Rattlesnake 02	156, 46, 152, 36, 47	Cover - Wood/Undercut Banks, Summer Base Flow, Floodplain Connectivity, Riparian	Stability, Off-Channel/Side Channels, Temperature - Adult Spawning, Cover - Boulders, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management
Methow River Rattlesnake 03	116, 910, 18, 88	Cover - Wood/Undercut Banks, Summer Base Flow, Floodplain Connectivity	Stability, Off-Channel/Side Channels, Riparian, Temperature- Rearing/Adult Holding/Adult Spawning, Cover - Boulders, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Water Quality Improvement
Methow River Rattlesnake 04	154	Cover - Wood, Summer Base Flow	Off-Channel/Side Channels, Pool Quantity and Quality, Riparian, Temperature- Rearing/Adult Holding/Adult Spawning, Cover - Undercut Banks, Pools - Deep Pools	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Bank Restoration, Floodplain Reconnection, Water Quality Improvement
Chewuch River Pearrygin 05	90, 913, 168	Cover - Wood, Temperature - Rearing/Adult Holding/Adult Spawning	Summer Base Flow, Floodplain Connectivity, Off-Channel/Side-Channels, Cover - Undercut Banks	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Water Quality Improvement
Chewuch River Pearrygin 11	150	Cover- Wood, Floodplain Connectivity, Temperature- Rearing/Adult Holding/Adult Spawning	Summer Base Flow, Off-Channel/Side-Channels, Riparian, Cover - Undercut Banks	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Bank Restoration, Water Quality Improvement
Chewuch River Doe 01	61, 914, 140	Cover - Wood, Temperature - Rearing/Adult holding/Adult spawning	Coarse Substrate, Summer Base Flow, Floodplain Connectivity, % Fines/Embeddedness	Channel Complexity Restoration, Channel Modification, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Floodplain Reconnection, Water Quality Improvement
Chewuch River Doe 03	**165**	Cover - Wood, Temperature - Rearing	Coarse Substrate, Summer Base Flow, Floodplain Connectivity	Channel Complexity Restoration, Channel Modification, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Floodplain Reconnection, Water Quality Improvement
Chewuch River Doe 06	113, 135	Cover - Wood, Temperature - Rearing/Adult holding/Adult spawning	Summer Base Flow, Pool Quantity and Quality, Riparian	Channel Complexity Restoration, Channel Modification, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management, Bank Restoration, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Water Quality Improvement

Reach	CWP ID #	Unacceptable LF	At Risk LF	Restoration Action Categories
Chewuch River Doe 07	916, 917, 96, 915	Temperature - Adult Holding/Adult Spawning, Cover - Wood, Pools - Deep Pools	Stability, Coarse Substrate, Summer Base Flow, Floodplain Connectivity, Pool Quantity and Quality, Cover - Undercut Banks, % Fines/Embeddedness, Riparian, Floodplain Connectivity	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement
Chewuch River Doe 08	40, 136, 153, 31	Temperature - Adult Holding/Adult Spawning, Cover - Wood/Undercut Banks, Pools - Deep Pools	Stability, Coarse Substrate, Summer Base Flow, Floodplain Connectivity, Pool Quantity and Quality, Riparian, % Fines and Embeddedness	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement
Chewuch River Thirtymile 03	159, 80, 73		Temperature - Adult Holding, Temperature - Adult Spawning, Coarse Substrate	None identified
Chewuch River Thirtymile 04	23, 8, 9, 19	% Fines/Embeddedness, Pool Quantity and Quality	Temperature - Adult Holding, Temperature - Adult Spawning, Coarse Substrate	None identified
Chewuch River Thirtymile 05	37	% Fines/Embeddedness, Pool Quantity and Quality	Temperature - Adult Holding, Temperature - Adult Spawning, Coarse Substrate	None identified
Chewuch River Kay 01	137	% Fines/Embeddedness, Pool Quantity and Quality,	Temperature - Adult Holding/Adult Spawning, Coarse Substrate	None identified
Chewuch River Kay 03	105, 114	Pool Quantity and Quality	Summer Base Flow, Temperature - Adult Holding/Adult Spawning, % Fines/Embeddedness	None identified
Twisp River Lower 03	175	Cover - Wood/Undercut Banks, Summer Base Flow, Floodplain Connectivity, Pool Quantity and Quality, Temperature - Rearing/Adult Holding/Adult Spawning, Pools - Deep Pools	Stability, Off-Channel/Side Channels, Riparian	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management, Water Quality Improvement
Twisp River Lower 04	58, 109, 28	Cover - Wood/Undercut Banks, Summer Base Flow, Floodplain Connectivity, Pool Quantity and Quality, Temperature - Rearing/Adult Holding/Adult Spawning, Pools - Deep Pools	Stability, Off-Channel/Side Channels, Riparian	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management, Water Quality Improvement
Twisp River Lower 07	78, 84, 39	Summer Base Flow, Temperature - Rearing/Adult Holding/Adult Spawning	Stability, Coarse Substrate, Cover - Wood/Undercut Banks, Floodplain Connectivity, Off-Channel/Side Channels, Riparian, % Fines/Embeddedness, Pools - Deep Pools, Entrainment/Stranding	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement

Reach	CWP ID #	Unacceptable LF	At Risk LF	Restoration Action Categories
Twisp River Lower 10	79, 163	Cover - Wood, Temperature - Rearing/Adult Holding/Adult Spawning	Stability, Summer Base Flow, Floodplain Connectivity, Off-Channel/Side Channels, Pool Quantity and Quality, Riparian, Cover - Undercut Banks, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Riparian Restoration and Management, Instream Flow Enhancement, Upland Management, Fine Sediment Management, Water Quality Improvement
Twisp River Lower 11	72, 162, 89, 110, 103	Cover- Wood/Undercut Banks, Riparian, Temperature-Rearing/Adult Holding/Adult Spawning	Substrate, Floodplain Connectivity, Off-Channel/Side Channels, Pool Quantity and Quality, % Fines/Embeddedness, Coarse Substrate, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Instream Flow Enhancement, Water Quality Improvement
Twisp River Middle 01	905, 94	Temperature - Rearing/Adult Holding/Adult Spawning, Cover - Boulders, % Fines/Embeddedness, Cover - Boulders	Stability, Summer Base Flow, Floodplain Connectivity, Riparian, Cover - Undercut Banks, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Instream Flow Enhancement, Upland Management, Riparian Restoration and Management, Water Quality Improvement
Twisp River Middle 02	906	Temperature - Rearing/Adult Holding/Adult Spawning, Cover - Boulders	Stability, Floodplain Connectivity, Riparian, Cover - Undercut Banks, Pools - Deep Pools	Bank Restoration, Channel Complexity Restoration, Channel Modification, Floodplain Reconnection, Side Channel and Off-Channel Habitat Restoration, Instream Flow Enhancement, Riparian Restoration and Management, Water Quality Improvement
Twisp River Middle 03	904, 60	Cover- Wood, Temperature - Rearing/Adult Holding/Adult Spawning, Pools - Deep Pools	Coarse Substrate, Off-Channel/Side Channels, Pool Quantity and Quality, Riparian, Cover - Undercut Banks/Boulders, % Fines/Embeddedness	Channel Complexity Restoration, Channel Modification, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Side Channel and Off-Channel Habitat Restoration, Bank Restoration, Floodplain Reconnection, Instream Flow Enhancement, Water Quality Improvement
Twisp River Middle 05	63, 95	Cover- Wood, Temperature - Rearing	Coarse Substrate, Off-Channel/Side Channels, Pool Quantity and Quality, Riparian	Channel Complexity Restoration, Channel Modification, Fine Sediment Management, Upland Management, Riparian Restoration and Management, Side Channel and Off-Channel Habitat Restoration, Bank Restoration, Floodplain Reconnection, Instream Flow Enhancement, Water Quality Improvement
Twisp River Middle 06	22, 29	Cover - Wood	Temperature - Rearing/ Adult Holding/Adult Spawning	None identified
Twisp River Upper 02	112, 14, 903, 64	Cover - Wood	Temperature - Adult Spawning, Pool Quantity and Quality	None identified
Twisp River Upper 03	54	Cover - Wood	Temperature - Adult Spawning, Pool Quantity and Quality	None identified

Figure 4. Lateral seep, CWP #093, Methow – Fawn AU, 2 September 2021. Plume area from this seep is ≤0.5 m off cobble bar on left.

During our field sampling, a natural analog of a potential restoration treatment to increase CWP depth and cover was encountered at two CWP sites, including CWP #007 (lateral seep, Methow – Fawn AU) and #057 (lateral seep, Methow – Fawn AU). These two sites had large naturally occurring trees with rootwads lying on top of the CWP. Rootwads were facing upstream which had resulted in significant scour depth on the upstream end and the rootwad providing cover features within the cold-water scour pools (Figures 5 and 6).

Restoration treatments suggesting connectivity restoration/enhancement were more commonly related to both springbrooks (e.g., floodplain side channels) and tributaries. Increasing low flow connectivity into the off-mainstem channels could increase potential for use by target species, especially juveniles, during low flow periods when connectivity potential is generally at its lowest level. Many springbrooks have cold and complex channels flowing through floodplain channels and appear well suited as juvenile rearing habitat (Figure 7). Maximizing the potential for access into these perennial cold-water habitats could help increase the quantity of high-quality rearing habitat.

Actions to increase CWP depth, cover, and connectivity likely fall within the Prioritization channel complexity, and side channel, off-channel, bank, and floodplain restoration action classes.

Figure 5. CWP #007, Lateral seep, Methow – Fawn AU, 14 September 2021. Naturally deposited tree and rootwad on top of cold-water seep created scour pool and cover habitat.

Figure 6. CWP #057, Lateral seep, Methow – Fawn AU, 14 September 2021. Naturally deposited tree and rootwad on top of cold-water seep created scour pool and cover habitat.

Figure 7. Springbrook confluence, CWP #063, Twisp - Middle AU, 26 August 2021. Complex, vegetated habitat was commonly encountered in springbrook channels.

To assist with further integration of CWP locations with on-going restoration planning in the Methow River subbasin, CWP were cross-walked with the reach assessments that have been completed within the project area (USBR 2008, 2010, 2011; Yakama Nation 2010a, 2010b, 2015a, 2015b; Cascade Fisheries 2017, Methow Salmon Recovery Foundation 2019). In total, these nine reach assessments covered almost all of the project area except for the most upstream portions of the Chewuch River including reaches within the Chewuch – Thirtymile and Chewuch - Kay AUs. Based on location, CWP were linked with reach assessment project areas, if present, and the restoration projects that were identified within those project areas (Table 12).

In total, 29 reach assessment project areas identified restoration actions in close proximity to CWP. While only a small handful of these were specifically targeting cold-water enhancement, the integration of CWP information into the planning and design phases of projects can lead to the development of projects that include CWP restoration/enhancement specific project elements. An example of this type of integration was completed by Methow Salmon Recovery Foundation for the 3R project site in the Methow – Thompson AU. A briefing report was developed that summarized the locations and water temperature data from the mainstem Methow River and several CWP within the project area (Crandall 2021, Appendix C). Report information was considered within the planning process and restoration alternatives were developed to specifically enhance the CWP present in the project area.

Restoration has also been completed in and around several other CWP locations in the Methow, Chewuch, and Twisp Rivers with some of these efforts extending back into mid-1990s (CWP #135, springbrook, Chewuch – Doe AU, Figure 8). Other more recent restoration has been occurring in the Methow – Thompson, Methow – Fawn, Chewuch – Doe, Twisp – Middle, and Twisp – Upper AUs. Collectively, these efforts have been able to implement restoration actions that have the potential to enhance the aspects of CWP that are beneficial to fish, although post-project monitoring will be needed to fully determine the effectiveness of these efforts.

More recent efforts have occurred at a suite of CWP locations and have focused on increasing complexity and cover in and around cold-water features. These projects have the potential to significantly influence existing CWP habitat and should serve as reference actions for future efforts. Some relevant project examples include the 3R (Methow – Thompson), Trail Bridge (Methow – Fawn), Chewuch Eightmile Ranch (Chewuch – Pearrygin), Chewuch RM 11 -13 (Chewuch – Doe, Figure 9), Twisp War and Mystery (Twisp – Middle, Figure 10), and Upper Twisp (Twisp – Upper, Figure 11). All of these projects have, to varying degrees, CWP restoration elements included in the design. While a limited amount of post-project monitoring has occurred at some projects, and suggest fish occupancy of the CWP, additional monitoring will be needed to verify their effectiveness at enhancing cold-water habitat areas.

Table 12. Cold-water patch relationships to reach assessments, Prioritization reaches, reach assessment project areas and projects, Methow River subbasin. Assessment unit reaches in bold type denote reaches where CWP specific restoration has been recently implemented or is planned.

Reach Assessment	Assessment Unit Reach	Project Area Name	CWP ID#	Potential Projects
Lower Methow	Methow - McFarland 01	Project Area 11	21	CWP #021 is near side channel, alcove, and groundwater fed off-channel habitat enhancement, install LW
	Methow - McFarland 03	Project Area 24	74, 151	No CWP site-specific project actions
	Methow - McFarland 04	None	161	No CWP site-specific project actions
	Methow - McFarland 05	Project Area 26	149, 148	CWP #148 near cold-water refugia enhancement, install LW
	Methow - McFarland 06	Project Area 32	41	Perennial side channel enhancement, install LW
	Methow - Texas 01	Project Area 35	166	Coldwater refugia enhancement, install LW, alluvial fan regrading
Twisp to Carlton	Methow - Alder 05	None	20	CWP #020 near in-channel wood placement
	Methow - Alder 07	None	34	CWP #034 near in-channel wood placement
Middle Methow	**Methow - Thompson 05**	RM 49.25-48.10, MM-IZ-3	10, 911, 912	CWP #010, 911 near recommended LWD placement
	Methow - Thompson 05	RM 49.25-48.10, MM-OZ-7	48, 75	CWP #075 near recommended LWD placement
	Methow - Thompson 06	RM 49.25-48.10, MM-OZ-4	143	CWP #143 near recommended LWD placement
Winthrop Area	Methow - Thompson 07-08	None	160, 98	No CWP site-specific project actions
	Methow - Thompson 08	M7-OZ-8	11	No CWP site-specific project actions
	Methow - Thompson 08	M7-OZ-6	69	No CWP site-specific project actions
Big Valley	Methow - Fawn 02	MR_Prj-56.0	30, 106	No CWP site-specific project actions
	Methow - Fawn 02	MR_Prj-56.5	52, 91, 82, 15, 12, 62	No CWP site-specific project actions
	Methow - Fawn 04	MR_Prj-58.6	56, 13, 42	No CWP site-specific project actions
	Methow - Fawn 04	MR_Prj-58.9	26, 901, 902, 32	No CWP site-specific project actions
	Methow - Fawn 04-05	MR_Prj-59.6	50, 92, 70, 44, 45, 43, 907, 24	No CWP site-specific project actions
	Methow - Fawn 03-05	MR_Prj-60.25	99, 76	No CWP site-specific project actions
	Methow - Fawn 05	MR_Prj-60.85	66, 27, 71	No CWP site-specific project actions
	Methow - Fawn 05	MR_Prj-62.4	4, 65	No CWP site-specific project actions
Upper Methow	Methow - Fawn 06-07	Weeman project	17, 57, 908, 67, 100, 93, 86	CWP #057, 067 near large wood margin complexity, #908 near enhance side channel connectivity
	Methow - Fawn 07-08	Fawn Creek project	176, 25	No CWP site-specific project actions
	Methow - Fawn 08	Trail Bridge project	83, 7, 3, 53, 6, 5, 2	CWP #176 near large wood margin complexity
	Methow - Fawn 10	Lower Mazama project	87	CWP #083, 0066, 002 near large wood margin complexity

Reach Assessment	Assessment Unit Reach	Project Area Name	CWP ID#	Potential Projects
Upper Methow	Methow - Fawn 11	Upper Mazama project	108, 16, 102, 35, 101, 909, 51	CWP #102, 35 near enhance side-channel connectivity
	Methow Rattlesnake 01	A-Wall project	1, 38, 68, 146, 131	CWP #001, 131 near large wood margin complexity, 38 near large wood capture structure
	Methow - Rattlesnake 02	Gate Creek project	36,47,46	CWP #036, 047 near individual log placement, #046 near channel margin log jam
	Methow - Rattlesnake 02	Cedarosa project	152, 156	No CWP site-specific project actions
	Methow - Rattlesnake 03	Lost River project	116, 88, 910, 18	CWP #018 near enhance connectivity of side-channel, #116 near bar apex log jam
	Methow - Rattlesnake 04	Two Rivers project	154	No CWP site-specific project actions
Chewuch River	Chewuch - Pearrygin 05	Reach C2b	90, 913, 168	CWP #090 near Project RM 6.39R LWD enhancement, #913 and #168 near Project RM 6.95R: LWD enhancement
	Chewuch - Doe 01	Reach C5a	150, 914, 140, 61	CWP #914 near Project RM 11.83L: Off-channel/side-channel habitat enhancement
	Chewuch - Doe 03	Reach C6	165	No CWP site-specific project actions
	Chewuch - Doe 06	Reach C9	113, 135	CWP #135 near Project RM 18.34L: LWD enhancement
Upper Chewuch	Chewuch - Doe 07-08	Reach C10	915, 96, 916, 917, 136, 40, 153, 31	No CWP site-specific project actions
	Chewuch - Thirtymile 03-05, Chewuch - Kay 01-03	Outside RA boundary	73, 80, 159, 9, 8, 23, 19, 37, 137, 114, 105	No CWP site-specific project actions
Lower Twisp	Twisp - Lower 03	Reach T2b	175	CWP #175 near RM 2.0R: Wetland habitat reconnection
	Twisp - Lower 04	Reach T2b	58, 109, 28	CWP #058 near Project RM 2.93L: LWD enhancement
	Twisp - Lower 07	Reach T3c	84, 39, 78	CWP #078 near RM 7.5R: LWD enhancement
Middle Twisp	**Twisp - Lower 10**	Newby to Bridge Project	163	No CWP site-specific project actions
	Twisp - Lower 10	Horseshoe Project	79	CWP #079 near side channel reconnection
	Twisp - Lower 11	Buttermilk Fan Project	72, 110, 103, 89, 162	CWP #072, 110, 103, 089 near riparian restoration, push-up levee removal
	Twisp - Middle 01-02	Buttermilk Bends Project	94, 905, 906	Whole tree placement throughout project area
	Twisp - Middle 03	Eagle Project	60, 904	CWP #060, 904 near whole tree placement
	Twisp - Middle 05	War Project	95, 63	CWP #095, 063 near whole tree placement
Upper Twisp	Twisp - Middle 06	None	22, 29	No CWP site-specific project actions
	Twisp - Upper 02	None	64, 903	No CWP site-specific project actions
	Twisp - Upper 02	None	112	No CWP site-specific project actions
	Twisp - Upper 02	RM 24.2 - 24.5	14	CWP #014 near beaver management
	Twisp - Upper 03	RM 24.8 - 25.5	54	CWP #054 near side increase side channel connectivity

Figure 8. CWP #135, Chewuch - Doe AU, 24 August 2022. Large wood was installed in this springbrook side channel in the mid-1990s and prior to ESA-listings for spring Chinook salmon, steelhead, and bull trout. Coho salmon parr were observed in this CWP during the site visit in 2022. The site burned in the 2021 Cub Creek fire but much of the installed wood remained functional.

Figure 9. CWP #061, Chewuch – Doe AU, 22 August 2022. Large wood was installed in this springbrook wetland complex for cover and complexity in the Chewuch RM 11-13 project in 2013. Coho salmon parr were observed in this CWP during the site visit in 2022.

Figure 10. CWP #904, Twisp – Middle AU, large wood was placed (via helicopter and felled) up and downstream of the Eagle Creek confluence in 2022. These actions may improve complexity, cover, and relative depth of the tributary plume. Imagery courtesy of Yakama Nation Fisheries.

Figure 11. CWP #903, Twisp – Upper AU, large wood was placed (via helicopter) around this cold-water area to potentially increase depth, cover, and channel complexity in close proximity to the cold-water alcove. Several other cold-water areas exist in this reach. Imagery courtesy of Confederated Tribes and Bands of the Colville Reservation.

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