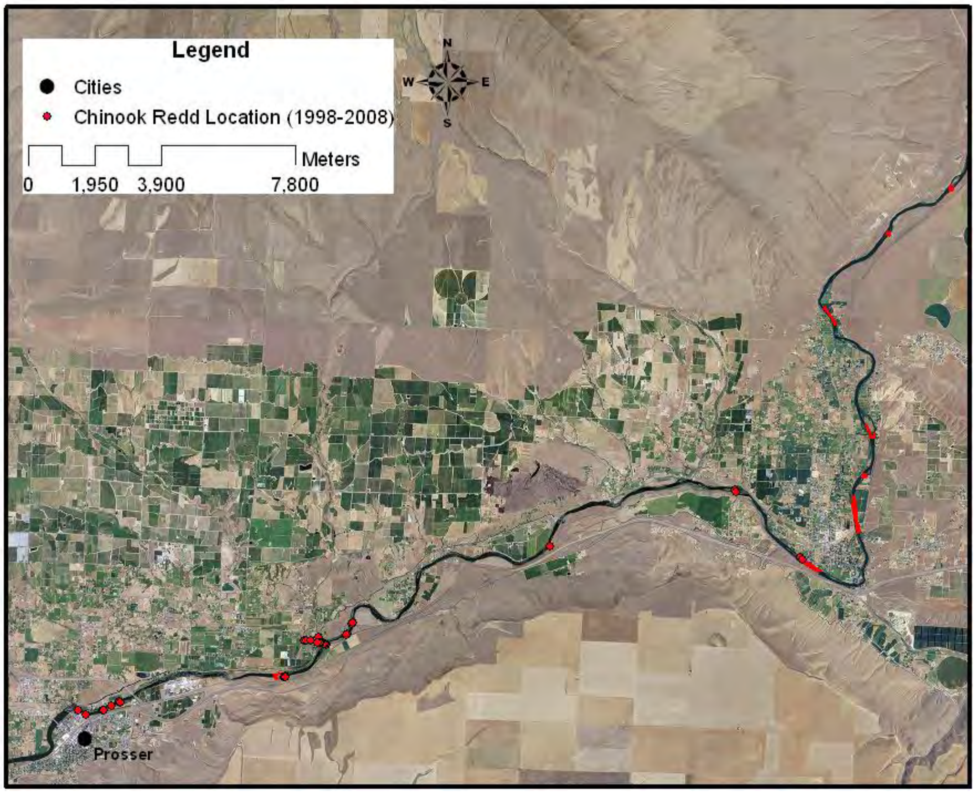

Figure 10. Identified fall Chinook redd locations (recent history), Prosser to Benton City

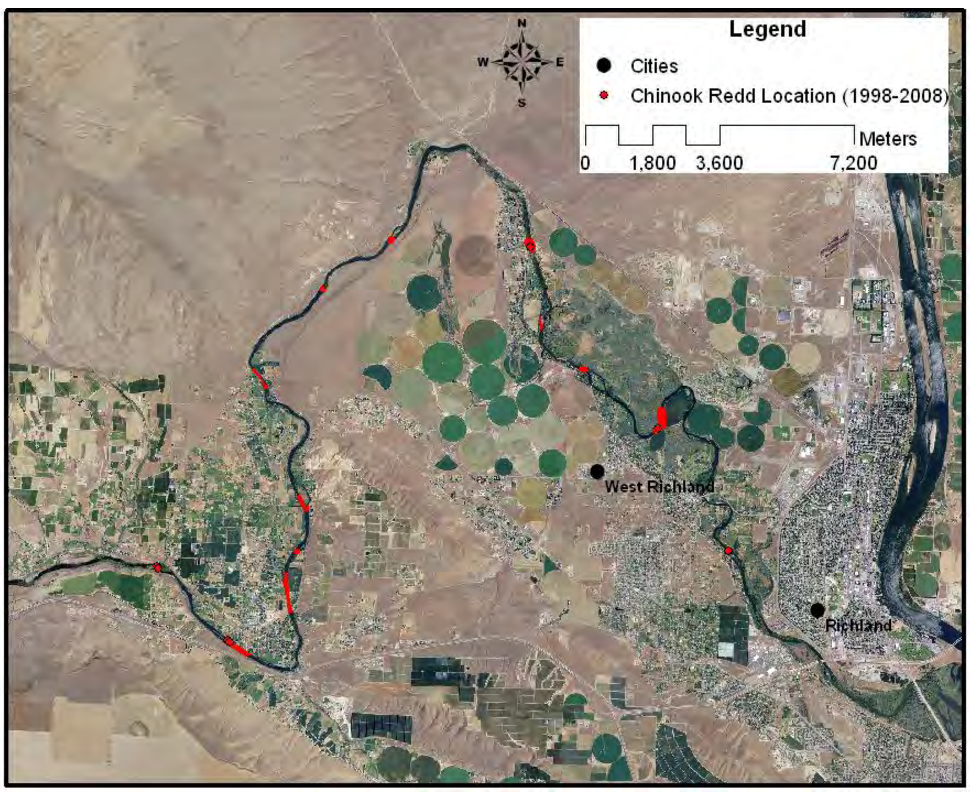

Figure 11. Identified fall Chinook redd locations (recent history), Benton City to Delta

In 2009-2010, aerial redd surveys were conducted by Pacific Northwest Laboratory in conjunction with DC Consulting, LLC to document redd spawning in the lower Yakima River. The aerial redd surveys were conducted over the lower Yakima River in fall of 2009 and 2010. The results of these aerial surveys are presented in Mueller (2010) and Mueller and Child (2011). Previously, only limited aerial surveys could be performed for the lower Yakima River due to limitations resulting from high turbidity and poor water clarity. With recent improvements in irrigation practices and wasteway drainages it is now possible to conduct aerial redd surveys within the lower Yakima River. These results can be used in tandem with ongoing boat surveys performed by the WDFW and the Yakama Nation to quantify redd presence in the lower Yakima River. Knowledge of salmonid utilization within the lower river is imperative for identifying appropriate restoration priorities. Results of these studies are beneficial for federal and state agencies and support ongoing research in the basin (Mueller 2010).

PNNL flights conducted in 2002 counted a total of 176 redds between Wanawish Dam and Highway 240 (PNNL unpublished data as cited in Mueller 2010). This is in stark contrast to the redd counts within this stretch during the 2009 and 2010 aerial flights; no redds were detected in 2009 and only 7 redds were detected in 2010 (Mueller 2010 and Mueller and Child 2011). In both years, redds were primarily located within the stretch of river between Prosser and Wanawish Dam for the lower Yakima River in Benton County. There were 24 redds identified in 2009 (Mueller 2010) and 18 redds identified in 2010 (Mueller and Child 2011). The number of fall Chinook redds counted within this portion of the river pales in comparison, however, to the redd counts above Prosser Dam. In 2009, 449 redds were counted above Prosser Dam (Mueller 2010) and in 2010, 175 redds were located above the dam (Mueller and Child 2011). Note: the lower counts in 2010 are most likely the result of fewer survey flights in 2010 as compared to 2009 because of weather conditions. The aerial flight data highlights the fact that fall Chinook spawning grounds have been greatly diminished in the lower Yakima River within Benton County over the last decade. The final PNNL reports and locations of the identified redds are provided in Appendix A (2009 data) and Appendix B (2010 data).

Summer Chinook

Summer Chinook, as with sockeye, have been eliminated from the Yakima Basin. Reintroduction programs for the return of summer Chinook to the Yakima are underway by the Yakima Nation and Yakima Klickitat Fisheries Program. Extreme thermal temperatures in the lower Yakima River are a primary limitation to the success of summer Chinook returns as warm summer temperatures coincide with their migration timing. Projects to enhance cool water refugia in the mainstem Yakima along with projects to improve temperatures at the delta may increase the success of migration runs for adult summer Chinook.

3.4 Sockeye (*Oncorhynchus nerka*)

The Yakima River watershed historically supported sockeye, but they have been eliminated from the basin as the result of damming lake outlets in the upper watershed for water storage during the early 1900's. Studies are ongoing to determine sockeye reintroduction in the Yakima Basin. Although it may be possible to reintroduce sockeye spawning in the Yakima, the thermal block created by the lower Yakima River during the return of the adult sockeye run would limit success of reintroduction efforts (Haring 2001). Enhancing adult migration in the lower Yakima River from June through September is critical for sockeye returns. Enhancing cool water refugia, removing summer thermal barriers at the mouth, exploring optimal flow parameters and continuing water quality improvement efforts may help with future reintroduction efforts.

3.5 Lamprey (*Lampetra tridentata*)

Pacific lamprey is a cartilaginous, primitive, anadromous fish resembling an eel. Historically three species of lamprey, including anadromous and resident varieties inhabited the middle Columbia Basin. In recent decades, their populations have crashed. Pacific lamprey is a federal species of concern with monitoring status in Washington State. The U.S. Fish & Wildlife Service determined that not enough was known about the Pacific lamprey to warrant an official listing. Currently there is growing interest in documenting and protecting lamprey throughout the Columbia Basin and in the Yakima River. Adult lamprey spawn in freshwater gravel areas similar to salmon spawning habitat. Restoration efforts to enhance spawning gravel for salmonids will likely afford benefits to lamprey as well and vice versa.

Lamprey fulfill several ecological roles, including filtering nutrients, transporting marine nutrients into freshwater, and serving as slow-swimming prey with high fat content. As lamprey numbers have dropped, predators may switch prey choice and exhibit more predatory pressure on juvenile salmonids. Lamprey are fundamentally important to local native cultures as a traditional food source and part of the ecosystem. More information is needed on lamprey distribution, abundance, life history, habitat use and limiting factors in the lower Yakima River.

3.6 Bull Trout (*Salvelinus confluentus*)

The 2010 bull trout critical habitat final rule lists the Yakima River mainstem, including the lower Yakima River, as designated critical habitat for possible migrations of bull trout to the Columbia River.

3.7 Piscine Predators

One of the earliest introductions of smallmouth bass (*Micropterus dolomieu*) in Washington State occurred in 1925 when state game protector N. E. Palmer planted 5,000 juvenile fish in the Yakima River. WDFW has estimated smallmouth predation on salmonids in the lower 68 km of the Yakima River at 202,722 juveniles in the spring, primarily on fall Chinook (WDFW 2000). Fritts and Pearson (2006) also found that Chinook salmon (*O. tshawytscha*) were the most abundant food item in smallmouth bass stomachs in spring and summer, but coho (*O. kisutch*) and steelhead (*O. mykiss*) were also present. Smallmouth bass prefer to eat the smallest fish available, which in the spring and summer are naturally produced fall Chinook juveniles. Although native northern pikeminnow (*Ptychocheilus oregonensis*) were the dominant piscivorous predator on juvenile salmon in the lower Yakima, they have been displaced by non-native smallmouth bass. The average smallmouth bass predator is smaller than the pikeminnow, but the bass are so numerous that they have a larger detrimental effect on juvenile salmonids. Smallmouth bass are capable of consuming salmonids that are up to 56.6% of predator fork length (Fritts and Pearsons 2006). WDFW has removed the individual catch limit on smallmouth bass 12 inches or smaller in an economical attempt to reduce predation on juvenile salmonids. Since approximately 50% of bass anglers practice catch-and-release, this effort is not highly likely to have the desired result. Many people remain cautious about eating Yakima River fish due to past Health Department warnings about residual pesticide levels in fish.

CHAPTER 4 IMPACTS OF THE YAKIMA PROJECT

The Yakima Project has influenced salmonids in the lower Yakima River through altered flow regimes, passage and entrapment issues with diversion dams, while increasing predation issues at diversion facilities. Two diversion dams are present on the lower Yakima River in Benton County. These are the Wamawish (Horn Rapids) Diversion Dam and the Prosser Diversion Dam. The impacts of these diversion dams on salmonid populations are cited in Habitat Limiting Factors (Haring 2001) and are summarized as follows: adult passage delay due to bedload ladder clogging and/or large woody debris at ladder exits, entrainment within Chandler Canal during dewatering for screen maintenance, and dewatering of fall Chinook redds with the onset of fall Chandler power generation in the area known as the –bypass reach.” Prosser Dam diverts up to 1500 cfs into the Chandler Canal removing this flow from the stretch of river downstream of the Prosser Dam. Over half of this flow is routed to the Chandler Power Plant for energy generation prior to its return to the river. The Kennewick Irrigation District uses the remainder of the diverted flow for Tri-Cities irrigation. This diversion of water at Prosser leaves a –hole” in the river between Prosser and Chandler resulting in even lower mainstem flows within this reach. This can negatively impact smolt out-migration and lead to higher than normal water temperatures during times when the river is already under drought conditions (Haring 2001). The diversion dams do have fish passage and screening for juveniles to help mitigate salmonid mortality.

Smolt survival at the Chandler Enumeration Facility has been studied and mortality was found to be higher at warmer water temperatures (Haring 2001). As a result, the Yakama Nation Fisheries Department implements a trap-and-haul operation when water temperatures exceed 70°F and daily air temperatures exceed 90°F. Salmonids are captured and trucked past the lower Yakima River. By implementing trap-and-haul operations, out-migrating salmonids are able to bypass the harsh thermal conditions of the lower Yakima River and delta.

Predation is also problematic with the bypass systems at the diversion dams. At Prosser Dam, northern pikeminnow assemble at the bypass outfall and smallmouth bass congregate at Horn Rapids Dam (McMichaels 1999) (all as cited in Haring 2001). Piscivorous fish also congregate inside the Chandler Canal. This is further exasperated by bird predation on migratory fish by gulls, terns, cormorants and pelicans. California gulls feed at the Prosser Dam and Horn Rapids Dam as the salmonids are discharged back into the river. Phinney (1999, as cited in Haring 2001) found a relationship between higher flows and the decline of gull predation on salmonids. At Chandler, gull feeding declined around 4,000 cfs and at Horn Rapids, gull feeding declined around 3,000 cfs. The decline is likely due to increased turbidity, which decreases the predators‘ ability to see the fish.

CHAPTER 5 FLOODPLAINS AND FLOOD CONTROL

5.1 Floodplain and Habitat in the Lower Yakima River

A thorough analysis of flow and habitat relations in the lower Yakima River from Prosser, WA to the delta (Richland, WA) was completed from 1999-2001 by Stanford, Kimball and Whited (2001). This analysis investigated and quantified the change in aquatic habitat associated with low summer flow (~500 cfs) and high summer flow (~1,000 cfs). The study investigated channel complexity, number and size of identified habitat, water depth and velocity for in-stream habitats, biological aspects (benthic invertebrates) and geomorphological characteristics.

Regional mapping of the Yakima River from Prosser dam to the confluence with the Columbia River showed a total wetted area of 600 ha with 70% of the surface water area classified as deep-slow (Stanford et al. 2001). Horn Rapids to the delta had the greatest amount of backwater/off-channel habitats (6.12 ha) with Prosser to Chandler having the least amount of backwater/off-channel habitat (1.23 ha). The total surface water area was greatest for the reach between Chandler to Horn Rapids (250 ha) with Prosser to Chandler having the least amount of total surface water area (134 ha). The study results indicate that the lower Yakima system reflects a recent history of reduced volume and altered seasonal flow regime that severs the more complex flow pathways within an alluvial, dynamic river/floodplain system (Stanford et al. 2001).

Under measured low flow conditions Stanford et al. (2001) found that off-channel habitats were less abundant, more isolated and had shallower depths relative to high flow conditions. This is significant in the context of the lower Yakima River where off-channel habitats are naturally scarce even at high flow due to its confined river geomorphology. Off-channel habitats decreased by 38% under low flow conditions, with the largest losses occurring within connected habitats (decrease of 2.6 ha) (Stanford et al. 2001). These off-channel habitats such as backwater channels, spring brooks, and floodplain pools are critical to juvenile salmonids. Deep off-channel habitats had the greatest amount of loss under low flow conditions (62%) thereby removing deeper water pools that are likely to provide thermal refugia during mid-summer extremes (Stanford et al. 2001).

For high flow conditions, 12% of the main-channel was classified as riffle habitat whereas only 8% was classified as riffle habitat during low flow analysis (Stanford et al. 2001). Exposed rocks within the main-channel increased significantly at lower flows creating an additional source of in-stream warming.

The number of islands and size of islands fluctuated with high and low flow regimes. At high flow, 140 islands were measured in comparison to 85 at low flow (Stanford et al. 2001); the average island size increased by 11% at low flow. These results reflect aggregation of several small islands into larger islands and smaller near shore islands being absorbed by the shoreline under low flow conditions. As such, channel complexity, channel habitat heterogeneity, and lateral and vertical floodplain connectivity were decreased under low flow conditions (Stanford et al. 2001).

Groundwater seeps within backwater habitats were identified during the study and found to maintain consistently cooler temperatures than the main-stem channel (Stanford et al. 2001). These areas are likely to provide critical thermal refugia for benthic organisms and associated fish populations. Flow of river water through interstitial pathways in floodplains and gravel bars is important for regulating river temperature and salmonid ecology (Giber et al.1994).

The work by Stanford et al. (2001) highlights, that with only moderate changes in flow, substantial gains can be made in regards to floodplain connectivity and off-channel habitats that are important for salmonid rearing in the lower Yakima River below Prosser, WA. This discussion is independent of increased flow for regulating temperature in the lower Yakima River. Even at high flow, floodplain habitat is minimal within the lower Yakima River and as such any degradation to this habitat as a result of decreased flow is likely to have a significant impact on the off-channel habitats, complexity of the reach, and thermal refugia.

5.1.1 Examples of Floodplain Projects on Lower Yakima River

Higher, faster flows would arguably benefit the following examples in terms of habitat and scouring, however, managing flow is outside of the scope of work for this project. Despite flow management issues, there are projects that would benefit disconnected side-channels and prevent further sedimentation and loss of habitat. Projects would need to be developed to capture current flow dynamics and aid in scour. The following are a few aerial photos of side-channels on the lower Yakima River that are experiencing sedimentation.

Figure 12. Disconnected oxbow, Benton City

Figure 13. Dry side channel, West Richland

Figure 14. Side channel, Richland (west bank)

Figure 15. Fox Island side-channel, West Richland. Dry channel in summer (left). 2011 May flood event (right) (photo by Tom Seim, all rights reserved)

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Figure 16. Side channel, I-182 bridge, Richland. Dry side channel (left). 2011 May flood event (right) (photo by Bill Evans and Wendy Shaw, all rights reserved)

5.2 Flooding and Flood Control in Benton County

Floodways and Floodplains along the Yakima River are shown on Figure 17. The flood areas on the Federal Emergency Management Act (FEMA) FEMA map indicate the magnitude of floods. The most damaging floods in Benton County are associated with the Yakima River (Benton Comprehensive Plan 2006). Areas along the lower Yakima River extending from Benton City downstream through West Richland to the delta are especially vulnerable to flooding (Benton Comprehensive Plan 2006). This area is characterized by low-lying river bottomlands and ancient river channels that are the river's natural floodway and flood plain.

The greatest known flood of the Yakima River in occurred in December of 1933 with a depth of approximately 9.5 feet above the top of the riverbank at Benton City (Benton Comprehensive Plan 2006). Other notable floods occurred in 1948, 1974, and 1996. The flood of

At present, there is limited flood control on the lower Yakima. Levees exist on both banks of the Yakima River at its mouth. A levee also exists on the south bank of the Yakima River in West Richland across from Van Giesen Rd (HWY 224). Removal of the levees is not feasible, as it would result in partial flooding of the cities of West Richland and Richland. Hardened levees should be made more ecologically friendly providing both flood protection and habitat for the river.

Yakima River flooding in agricultural and rural areas threatens water quality with the potential for capturing livestock and agricultural pollutants including manure and pesticides, and petroleum products from road surfaces. West Richland and Benton City are especially susceptible to flooding of agricultural and rural areas. Outreach programs targeting these landowners should be developed with the dual purpose of protecting private property and water quality.

Yakima River flooding in rural residential areas threatens water quality due to the potential for floodwater to overwhelm domestic septic systems, January 2011

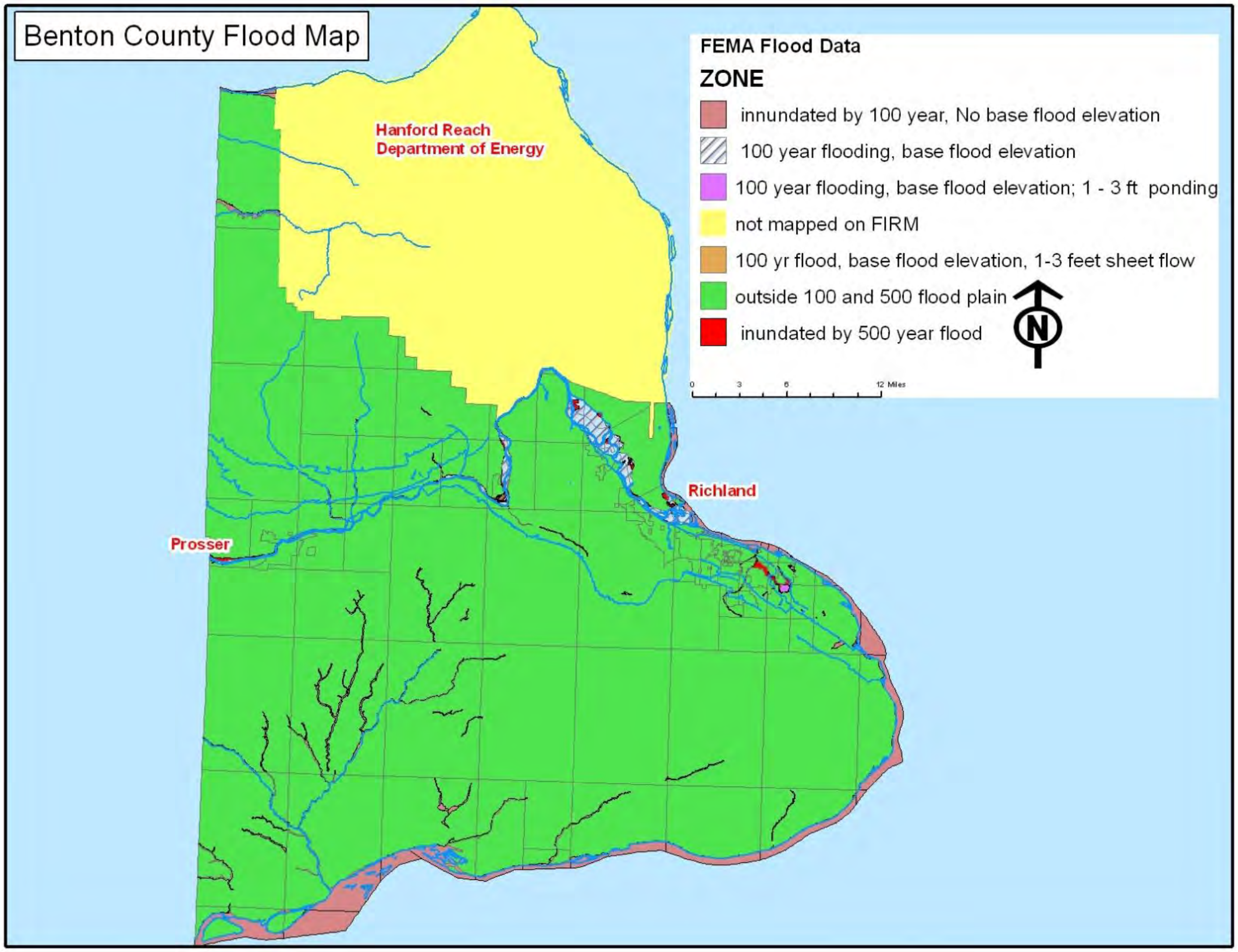


Figure 17. Benton County flood map

CHAPTER 6 MANAGEMENT OF WASTEWAYS

The Yakima River from Prosser to the delta contains four wasteways maintained by local irrigation districts. These irrigation wasteways are:

- Snipes Creek Wasteway and Spring Creek Wasteway - Roza and Sunnyside Irrigation Districts
- Corral Creek Wasteway - Roza Irrigation District and Benton Irrigation District
- Amon Creek Wasteway - Kennewick Irrigation District

As wasteways, they are operated to carry irrigation return flows directly back to the Yakima River and provide a water bypass route in times when there is temporary excess of water arriving down the irrigation district‘s main canal. All four of these irrigation wasteways utilize natural depressions such as draws and ravines that may have historically captured rainfall and runoff but did not seemingly maintain year round flow. With the onset of irrigation in the Yakima Basin, flow within these ravines and draws has increased and is maintained year round through irrigation groundwater recharge and overland return flow. With continued year round flow, salmonids are utilizing these wasteways as spawning and rearing habitat; sparking much debate regarding the best management practices and utilization of these wasteways.

Several recent studies have investigated the various properties of these wasteways to determine fish usage (Monk 2001), natural stream flow estimates (Smith et al. 2002), fish habitat quality (Romey and Cramer 2001, Child and Courter 2010), water quality (BCD 1998, Wagner 2000, Zuroske 2006, Zuroske 2009), and potential for salmon restoration projects within the wasteways (Romey and Cramer 2001 and Child and Courter 2010). Stream habitat was determined by S.P. Cramer and Associates (Romey and Cramer 2001) to be fair to good for natural production of salmonids in Snipes Creek, Spring Creek, and Corral Creek Wasteways but that migration barriers and low flows limit their potential for salmonid production. Monk (2001) confirmed through his findings that salmonids appear to have some success spawning and rearing in Spring Creek, Snipes Creek and Corral Creek Wasteways.

Over the last decade significant improvements have been made in the Spring Creek and Snipes Creek Wasteways regarding water quality. Previously, these wasteways were major contributors of total suspended solids to the Yakima River during the summer months. They additionally provided a source of nutrient loading. Water quality analysis between the years of 1997 and 2008 showed a significant decrease in discharge and concentrations of total suspended solids and nutrients (Zuroske 2009). The improvement of water quality within several irrigation wasteways in the Yakima Basin has led to improved water clarity within the lower Yakima River.

Fewer habitat and fish studies have been completed for Amon Creek Wasteway than its counterparts of Spring Creek, Snipes Creek, and Corral Creek Wasteways. Child and Courter (2010) studied Amon Creek Wasteway‘s suitability for salmonid rearing and determined that Amon does seasonally support a limited number of salmonids, but that carrying capacity is limited. From their results it appears that at this time the mainstem and East Fork of Amon Creek do not appear to be well suited for the rearing of salmonid during summer and early fall when temperatures are well above 21°C.

Habitat projects and targeted salmon restoration efforts within the wasteways are a complex issue. On a basin wide scale, salmon recovery efforts in the wasteways are not a high priority as the population returns are likely to be minor compared to other salmon recovery efforts within the basin. Locally, interest is high to see wasteways with improved salmon habitat for both social and economic reasons; however, restoration efforts must meet the functionality of the wasteways and managing desires of the involved irrigation districts. Given the difficulty of marrying wasteway management with salmon recovery efforts is a problem not likely to be solved in the near term; however, there are interim actions that can be undertaken regarding the wasteways.

1. Implementing projects targeted at improving best management practices (BMPs) on land bordering wasteways for the goal of water quality enhancement and water conservation. BMPs should include livestock fencing and bank management.
2. Improve understanding of the complexity of hydrological flowpaths and nutrient transport process affecting the wasteways during both the irrigation and non-irrigation seasons to develop BMPs targeted at improving water quality (Zuroske 2009)
3. Improved knowledge of the tradeoffs of irrigation canal lining on the influence of removing groundwater recharge and cool water inputs to the Yakima River vs. supplying a greater amount of flow within the river
4. Investigation of wasteways for potential thermal refugia possibilities

CHAPTER 7 WATER STARGRASS (*Heterantera dubia*)

The lower 43 miles of Yakima River below Prosser Dam are dominated by an aquatic macrophyte called water stargrass (*Heterantera dubia*) (Figure 18). In 2008 and 2009, Water stargrass was found to be prolific in the lower Yakima River starting above Whitstran, WA. Water star grass was not as prevalent in the swift boulder sections of the river below Prosser, WA.

Water stargrass is a rooted perennial plant, easily distinguished from terrestrial grasses by the lack of distinct medial vein on the leaf. It is named for the bright yellow, six-petal star-shape flower that blooms just above the water surface in June and July (Figure 19). The thin stem bears alternating short branches, each with a single elongate leaf. The running stems have been observed as long as 3 m, but distinguishing individual plants is difficult because of its tendency to form dense colonies. At intervals, the running stem produces root nodules so that long running stems become anchored to the substrate at multiple points. Water stargrass propagates via running shoots and seeds. The plant is brittle and stem sections with leaves often break off and drift downstream. If broken stem sections contain root nodules, the broken section can develop roots and attach at a new location. Water stargrass is such an aggressive and successful pioneering species that the Army Corps of Engineers uses it to quickly establish lakeshore restoration projects in the Midwest.

Figure 18. Water stargrass in Kiona reach (July)

Figure 19. Yellow blossoms on water stargrass (Yakima River)

7.1 Problems Associated with Water Stargrass

Residents and scientists became increasingly concerned about aggressive plant growth in the lower Yakima River in the late 1990s. The Eutrophication Study (Wise et al. 2009) was implemented in large part due to these concerns about aquatic plants. Water stargrass has been observed thriving in the lower Yakima in a variety of habitats, ranging from finely silted slackwater areas to cobble substrate with high water velocity, even atop boulders in bedrock reaches. Sections detached from the main plant will grow and flourish without the benefit of attachment to the sediment, such as hanging on large woody debris. A contract diver collecting reference plant samples traversed the entire river width near Benton City, just downstream of the decommissioned railroad bridge, and found no limit with depth to the water stargrass distribution. Water stargrass forms a bank-to-bank monoculture in the majority of the lower Yakima, with magnified effect in low water years. In shallow areas, water stargrass plants easily reach the water surface, then continue growing, laying horizontal and forming a canopy at the water surface. In deeper areas, water stargrass plants form straight columns to the surface.

Despite its classification as native, water stargrass in the lower Yakima acts like a non-native invasive species. Water stargrass is exploiting river conditions to the exclusion of other plants. The dominant land use in the Yakima River watershed is agriculture. Decades of intensive agriculture have led to increased nutrients in the Yakima, now coupled with expanding urban development and associated water treatment demands. Wise et al. (2009) theorized that the relatively recent expansion of water stargrass is due to a combination of effects. The excessive nutrient load to support the plant community may have existed for decades, but dramatic recent improvements in water clarity now allow sunlight to penetrate the water column at greater depths. Washington Department of Ecology developed a TMDL for sediment load in the Yakima River. Several simultaneous improvements to agricultural practices significantly reduced the sediment load, including conversion from flood to sprinkler irrigation, scientific irrigation water management and conservation and application of polyacrylomide (PAM) to stabilize soil particles on fields. Although praised nationally as a conservation success story[7], this great improvement in water quality unintentionally opened the door proliferation of water stargrass.

Figure 20. Return flow discharging into the Yakima River before (left) and after (right) irrigation improvements (photos courtesy of SYCD)

Water stargrass causes a host of problems in the lower Yakima River, including physical threats to habitat, chemical threats to water quality and management issues. US Geological Survey has maintained a gauging station at Kiona, Washington measuring both flow and gauge height. As a result of the high amount of plant biomass, USGS measured a change in flow:depth ratio. The large amount of water stargrass was physically displacing the river.

Water stargrass also physically threatens habitat. Beaver, carp and other fishes have been regularly observed traveling along the same narrow confines within dense water stargrass stands, much like terrestrial animals navigate along game trails in a thick jungle. Water stargrass forms dense vegetative mats, approximately 3-4 inches thick over the substrate including cobble. Fall Chinook salmon avoid the ‗carpet' of stargrass and push past traditional spawning grounds in the lower river to find redd-building gravel further upstream. Historical fall Chinook spawning prior to water stargrass was almost entirely below Prosser Dam (Mueller 2009). Now that lower Yakima spawning gravels are covered with water stargrass, almost all fall Chinook spawning occurs above Prosser. This upstream shift in spawning increases migration effort for both adults and juveniles and forces fish to utilize areas other than those the population may be adapted to. Water stargrass' effects on water velocity and suspended particles is also contributing to the covering of spawning gravels.

Large amounts of water stargrass slows stream flow causing fine sediments to settle. Water stargrass was removed in a side channel of the lower Yakima River as part of a BCD spawning habitat restoration project (completed in 2010). The downstream edge of the project area showed a sandy bottom where underneath the root mat of water stargrass was approximately three inches of sand. Underneath this sand layer was a decomposing

[7] http://www.nacdnet.org/policy/environment/water/tmdl/casestudies/washington.phtml

mat of water stargrass that had become covered with sand. The decomposing mat layer was also removed, revealing more sand underneath. Upon returning to the site the next day, staff found cleared cobble in the downstream edge area. The increase in water velocity from removing water stargrass had uncovered and restored the hidden cobble within one night. Water stargrass, by slowing water velocities, is causing significant sedimentation of spawning gravel and critical side channels in the lower Yakima River.

Water stargrass also impacts dissolved oxygen and pH in the lower Yakima River. Water stargrass causes large fluctuations of dissolved oxygen within the lower Yakima, with daily minimum levels occurring in the morning (Wise et al. 2009). Given the large mass of water stargrass, during daylight hours, oxygen production from photosynthesis is greater than the oxygen demand of respiration. During night, however, oxygen consumption is greater leading to low dissolved oxygen levels in the morning. The eutrophication study (Wise et al. 2009) determined that the strongest factor impacting gross primary productivity (GPP) in the Kiona reach was streamflow. Wise et al. (2009) found a negative correlation between streamflow and GPP, with a lower amount of spring GPP occurring at higher streamflows. The high flows are likely to result in increased turbidity and water depth, thereby decreasing light availability to the plants. Water stargrass also affects pH through plant respiration and photosynthesis, causing daily fluctuations in pH that may stress local aquatic organisms. Wise et al. (2009) found that in low flow years, the maximum pH was almost always greater than the Washington State standard of 8.5, whereas in spring of high flow years, there were extended periods when the maximum daily pH levels were less than 8.5.

Water stargrass causes problems for people who rely upon the Yakima River for their livelihood and recreation. The thick vegetation can plug intake screens, forcing irrigators to clean intake areas daily, just to keep their pumps operational or fabricate ―homemade" modifications to existing screens. Washington Department of Fish and Wildlife (WDFW) creel surveys reveal reduced fishing success and reduced fishing effort in both pole-days and fishing hours, as stargrass becomes more abundant. Unsolicited phone calls to Benton Conservation District and personal interviews have detailed the public's frustration with water stargrass. Boating and intertubing are difficult in the thick, stringy jungle of plants. Some residents no longer feel safe wading when the long strands of water stargrass wrap around their legs.

Diver emerges covered in water stargrass in Benton City area near decommissioned railroad bridge. Water stargrass makes navigation and recreation difficult in the lower Yakima

7.2 Recent Removal Efforts

Benton Conservation District has worked on projects to remove water stargrass. Removal methods were considered, including biological, chemical and mechanical techniques. Biological options are limited because the lower Yakima is a free-flowing open system. Biological agents cannot be responsibly introduced because reasonable containment cannot be assured. Chemical applications are also inappropriate because some treatment areas have high water velocities, making it difficult to impossible to ensure adequate plant-chemical contact time. The mechanical techniques that were considered included hand cutting, hand pulling and tilling. Hand cutting was quickly abandoned as ineffective, partly because the brittle stems break away before a person can gather a handful to cut. Therefore pulling on the stems achieved the same effect as cutting, but more quickly. Instream work is most appropriately done in July and August, to avoid disturbing salmonid migrations, when flow is low and biomass is high.

7.2.1 Pilot Scale

This first water small grass project investigated smaller pilot scale plots in 2007-2008. Early water stargrass pilot project sites yielded mixed results a year following treatment. The first treatment site showed a returning monoculture stand of water stargrass, but at reduced plant density (based on dry weight). In the second treatment site, water stargrass did not return one year following treatment but was replaced by curly leaf pondweed (*Potamogeton crispus*), introduced from Eurasia. The third treatment site remained clear of all aquatic macrophytes two years after treatment. It is possible that removal techniques were improved at each subsequent site, but this effect was not evaluated. This pilot study also provided qualitative information about composted harvested water stargrass. Like most aquatic plants, water stargrass is largely water by volume and weight. In the dry summer weather, stargrass desiccates quickly, drastically reducing its volume. A local cherry orchardist was willing to experiment with using composted water stargrass as mulch at the base of his trees. When he decided he was ready to mulch the trees, he was surprised to find that the pile of harvested material had dried and reduced to such a small volume of material that he didn‘t bother moving it.

Volunteer tractor operator making a pile of harvested water stargrass

7.2.2 Large Scale Removal

The second water stargrass removal project investigated large-scale removal of water stargrass in 2010. This project demonstrated the importance of harvest efficiency. Many individual volunteers assisted with this project. Volunteers exhibited a range of diligence, skill and speed at removing water stargrass. If the tops of the plants are removed but the root mass remains, the plants quickly rebound, leafing again within a matter of days. When the root mass was more completely removed, the area remained clear. The most effective technique was to use a cultivator. The cultivator is needed to start pulling the root mass away from the substrate. Once a section of mat is partially lifted, the root mass can be rolled onto itself, much like rolling grass sod. Harvested material was placed on floats to prevent escapement downstream and later towed to shore.

AmeriCorps member towing a raft of harvested water stargrass to unloading area

Treatment area showing exposed cobble substrate in the foreground and the edge of the water stargrass stand in background. Juvenile fish appeared in open water after water stargrass removal

In autumn, following the most recent stargrass removal, staff and volunteers observed fall Chinook redds and adult fish guarding the redds and carcasses within the 1.5 acre project boundary. It was observed qualitatively that water velocity and sedimentation rates varied with removal of a large area of water stargrass. Additional studies need to be performed to qualitatively determine the amount these variables changed with water stargrass removal. Water stargrass removal projects to restore salmonid spawning sites should continue in the absence of more effective management techniques. Continued monitoring and maintenance of these projects is necessary as it contributes to the knowledge basis about water stargrass management.

CHAPTER 8 LOWER YAKIMA RIVER DEPTH

Mainstem lower Yakima River depth was measured at base flow conditions during the last week of July in 2009. Continuous depth data were collected from Prosser to the Confluence using a Lowrance HDS-5 Depthfinder/GPS Chartplotter unit. The unit was attached to a pontoon boat and a rig was assembled with a mounting bracket to allow the transducer to be raised in extremely shallow waters. All depth data were analyzed and charted using ArcGIS Desktop 9.3. Data between Benton City and Horn Rapids were not charted because of mechanical problems with the GPS battery unit.

Lower Yakima River depths typically ranged from 2.5 ft-5.5 ft from Prosser through West Richland (Figure 21, Figure 22, Figure 23). Depth increased to >7 feet west of the HWY 240 Bridge in Richland and continued to the confluence. Depths quickly decreased to 2.5 ft or less within the delta of the Yakima River.

Deeper areas within the lower Yakima River were typically either glide areas or “holes”. Several of the holes identified within the lower Yakima River coincided with the location of incoming seeps and irrigation returns. For example, holes were located at both Knox Creek and Corral Creek Wasteway (Figure 22). “Holes” were also located at the east and west ends of the relic oxbow on Barker Ranch (Figure 21) an area identified by temperature data as having localized cooling. Given that the incoming irrigation returns provide a source of cool water to the Yakima River, these deeper holes need to be further investigated for their potential as thermal refuge areas.

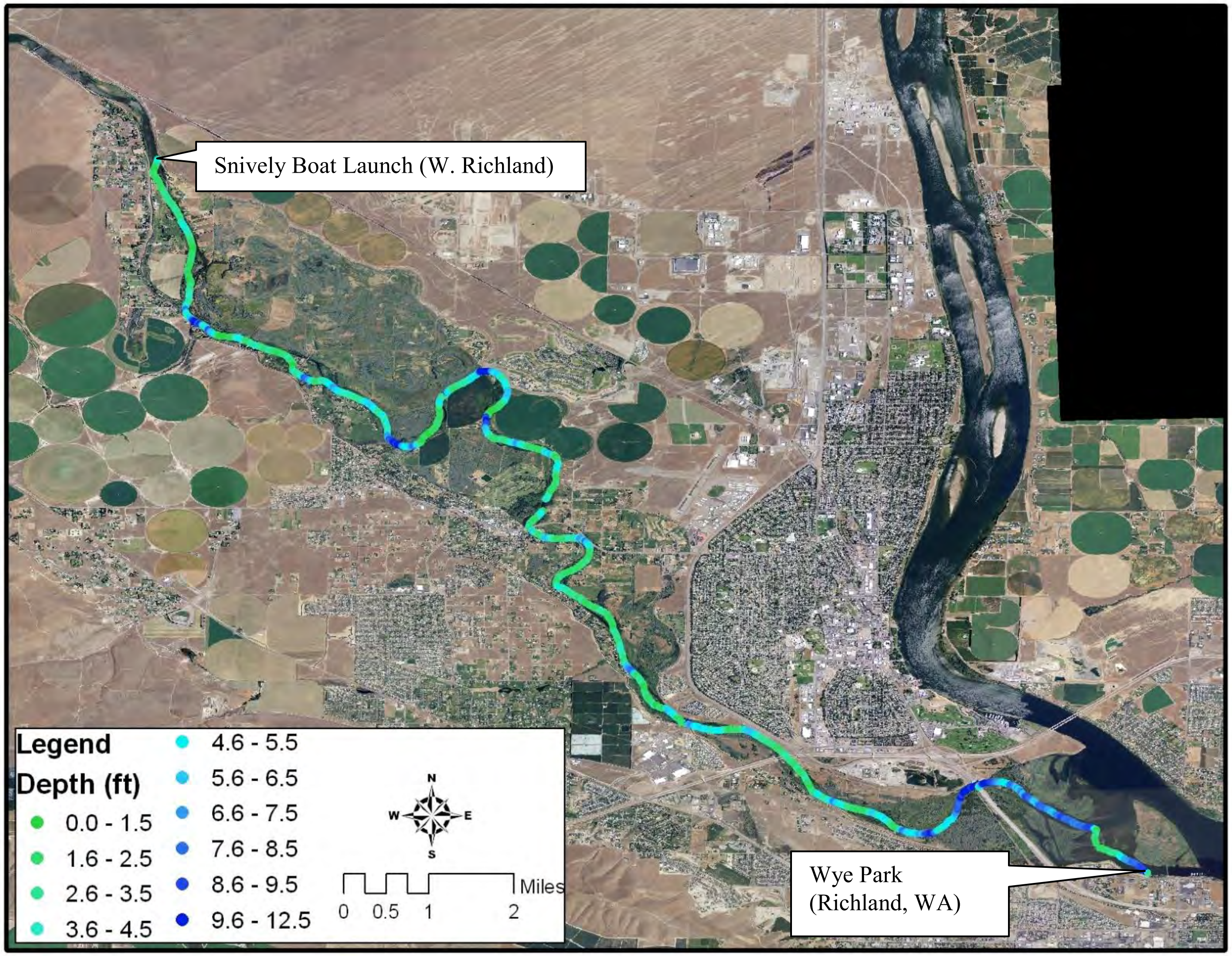


Figure 21. Depth map for lower Yakima River, West Richland to the confluence

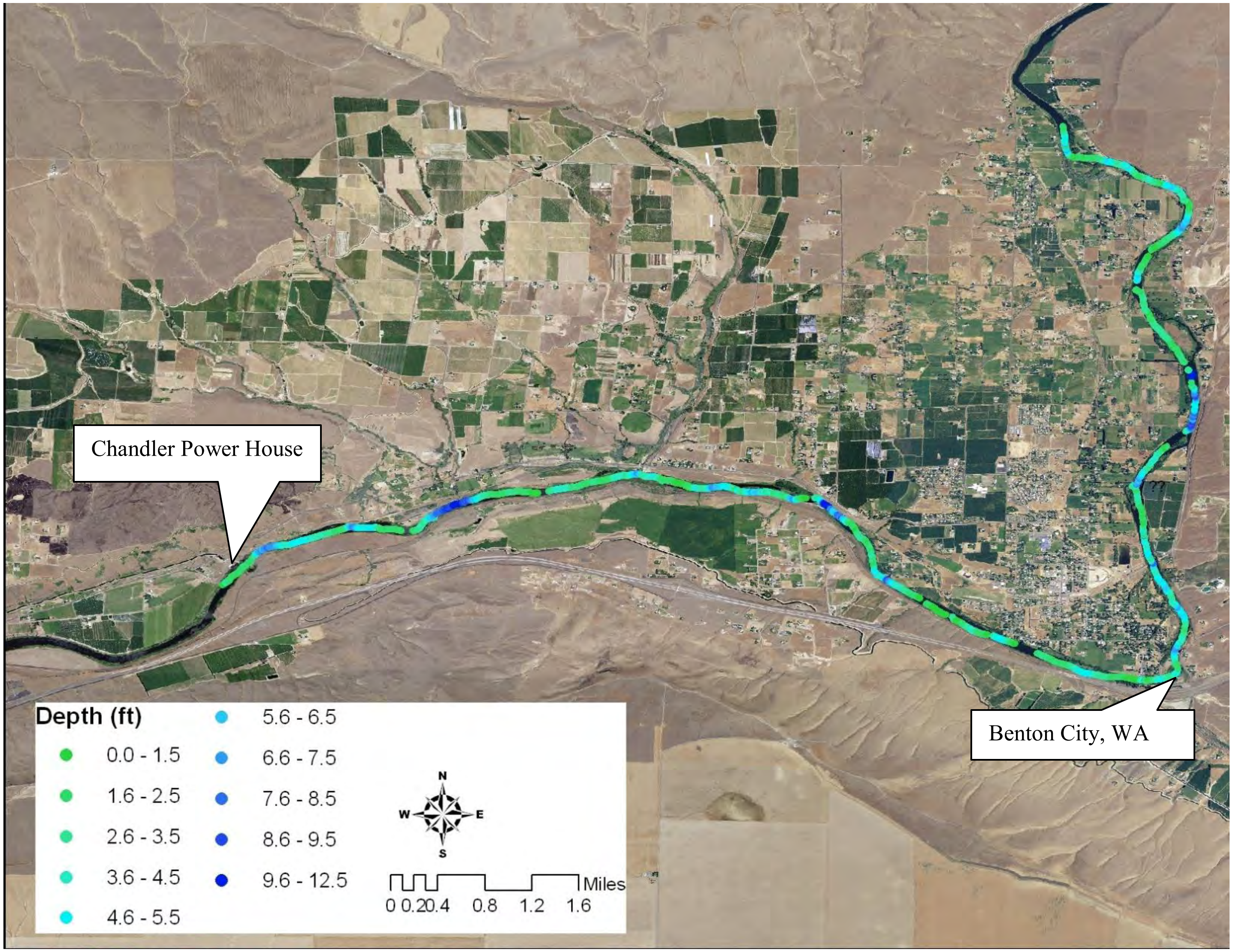


Figure 22. Depth map for the lower Yakima River, Chandler to Benton City

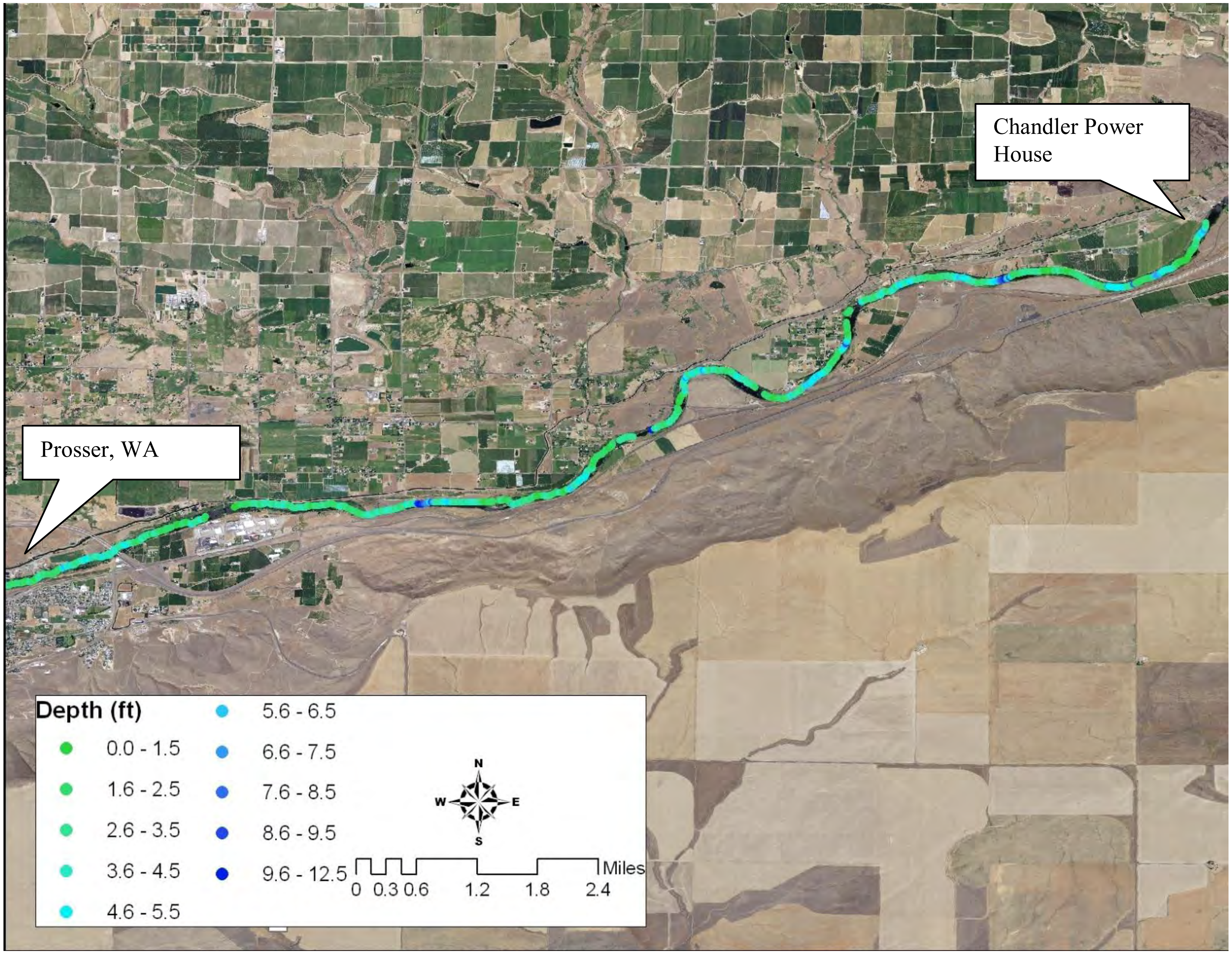


Figure 23. Depth map for the lower Yakima River, Prosser to Chandler

CHAPTER 9 THERMAL PROFILING

Numerous studies have reported extreme temperatures in the lower Yakima River as a limitation to salmon productivity (Lilga 1998; Vaccaro 1986; Wise et al. 2009). In July and August, daily maximum river temperatures often exceed the Washington State Standard of 21°C (Wise et. al. 2009). The lower Yakima River is a migration corridor for most salmonid species (e.g., spring Chinook, steelhead, and coho) and fall Chinook utilize the lower Yakima River for spawning. Spring and autumn are critical migration seasons for salmon entering and exiting the lower Yakima River. Lower river temperatures typically begin to rise towards the end of spring migration (mid June) and remain inhospitable for salmon until early fall.

There has been much discussion on how to manage lethal summer temperatures in the lower Yakima River. The lower Yakima River is a highly regulated system with a landscape dominated by irrigated agriculture, irrigated pasture, and residential areas. The current flow regime is designed to meet competing needs within the river (e.g., irrigation, fish survival, and flood management). As such, the hydrograph is quite different than what would have occurred historically within the basin. Several studies have investigated the impact of altering flow management as a way to lower summer river temperatures. Vaccaro (1986) modeled several different flow regimes and analyzed their impact on river temperatures. Vaccaro found that mean temperatures throughout the irrigation season would be lower at Prosser and Kiona with natural flows except in August when temperatures would be higher than current temperatures. While lower flows and slow moving water aid in the lower river temperature problem, Lilga (1998) estimated that approximately 70% of the variation in water temperature could be explained by ambient air temperature. Because of the width of the lower Yakima River, riparian shading does not inhibit full sun exposure and is not likely to decrease in stream temperatures. Ring and Watson (1999) argue that reduced river-floodplain interactions may be part of the problem for increased river temperatures. They argue that removal of the frequency and timing of alluvial aquifer recharge by cutting off natural river-floodplain interactions may result in higher summer temperatures and decreased areas of thermal refugia (1999). While important, alterations in timing and flow of river management for temperature alteration are a complex issue that is beyond the scope of work of this project.

This assessment investigated current temperature dynamics of the lower Yakima River and the presence of temperature heterogeneity (i.e., the presence of localized cool and warm areas) for the possibility of thermal refugia (cool pockets for refuge). While there is a vast amount of literature on the extreme summer temperatures in the lower Yakima River most of the data are collected from a few discrete locations. Typically temperature data are cited from the USGS monitoring station at Kiona. While there is great value in these studies, there is heterogeneity within rivers that cannot be captured by synoptic sampling. This project utilizes methods developed by Vaccaro (2006) to capture a thermal profile of the lower Yakima River (Prosser to the delta) and investigate the potential for refuge areas to help migrating salmon potentially navigate through inhospitable waters. Vaccaro (2006) developed a thermal profile method designed to locate cool water pockets from ground water discharge. Vaccaro argued that the profile method displays diversity and structure within the river that cannot be captured by fixed station data. This method was created to locate patches of cool water that may provide salmonid habitat and refuge (Vaccaro 2006).

Few studies have investigated this possibility of thermal heterogeneity (i.e., the presence of cool and warm areas) and thermal refugia (i.e., cool pockets for salmonid refuge) in the lower Yakima River. In August of 1997, the Bureau of Reclamation collected aerial thermal images of the lower Yakima River. These data looked at the general trends in surface temperature and provided insight into river temperature heterogeneity. The thermal imaging results suggested that there was a slight cooling of the Yakima River from the delta to Prosser and that a local warm anomaly is present at Prosser downstream of the Prosser Dam (Holroyd 1998). Additionally, this study detected a 3°C difference between the mouth of the Yakima River and the Columbia River with warmer water pooling in stagnant areas of the Yakima near the confluence (Holroyd 1998). Another study, performed in 1991, by Berman and Quinn tracked the migrating patterns of adult spring Chinook in the Yakima River. They found that fish modified homing behavior to exploit cooler water areas, thereby optimizing internal body temperature. Locating areas of thermal heterogeneity within the lower Yakima River may provide an opportunity to determine areas of high priority importance for salmon habitat projects based on their potential for salmon refuge.

9.1 Importance of Thermal Heterogeneity In Rivers

According to Washington Department of Ecology, the upper Yakima River is on the 303(d) list for elevated water temperatures that exceed state standards. The most significant determinant of water temperature in the lower Yakima River is the temperature of incoming water from the upper Yakima (Wise et al. 2009). U.S. Geological Survey maintained continuous water temperature monitors at Kiona in the lower Yakima River from April 4, 2004 until September 30, 2008.

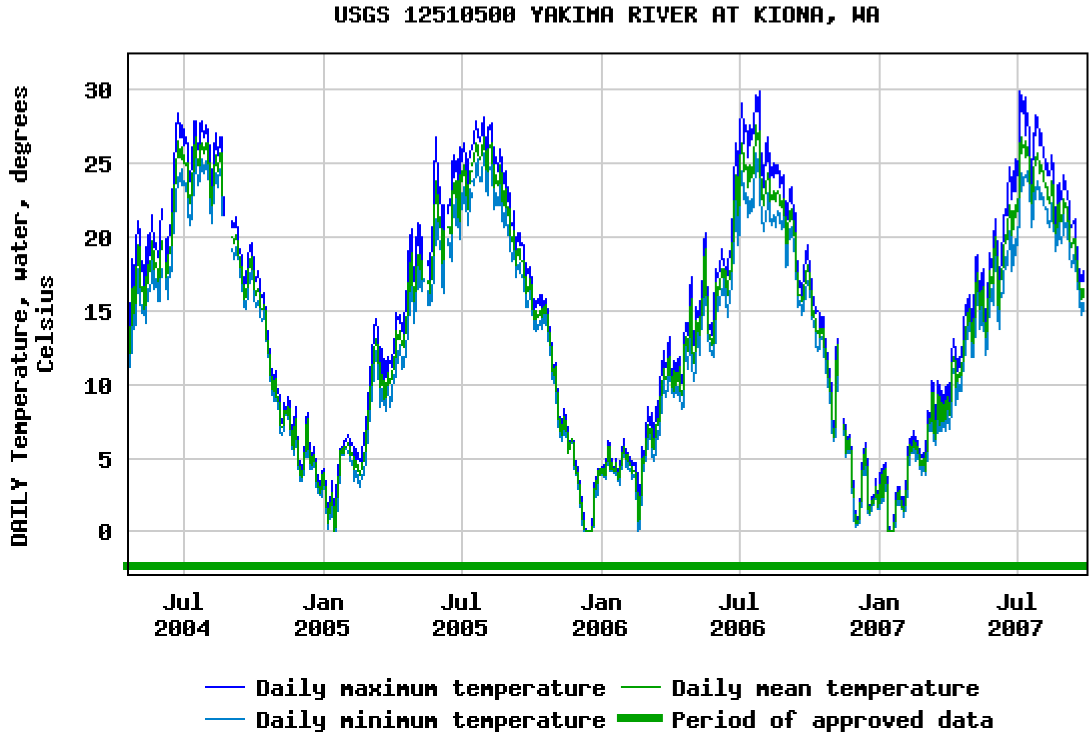


Figure 24. River temperatures at Kiona (2004-2007)

As poikilothermic organisms, fish cannot regulate their internal body temperature independent of ambient water temperature. Thermal stress has real energetic costs associated with metabolic rate and energy storage capacity decreases with thermal stress (Heppell 2010). Therefore, even non-lethal thermal stress may compromise long-term fitness. Berman and Quinn (1991) tracked adult spring Chinook in the Yakima River with temperature-sensitive radio and ultrasonic transmitters to relate fish movements to specific water temperatures. They found that fish modified homing behavior to exploit cooler water areas, thereby optimizing internal body temperature. Freshwater fish are capable of detecting changes in water temperature as little as 0.05° C. During the study, the migrating adults maintained an average of 2.5°C body temperature below ambient water temperature. This 2.5° C average temperature difference enabled fish to lower basal metabolic rate by 25%. Since adult migrating salmonids do not feed for months during upstream migration, a 25% energy savings may be critical to completing migration to spawning grounds. Longer adult exposure to elevated temperatures may result in higher pre-spawn mortality due to infection or disease, reduced gonadal development or egg viability (Kinnison et al. 2001).

Berman and Quinn (1991) speculated there might be a trade-off between groundwater-fed cool water with low dissolved oxygen (DO) and warmer but more oxygenated water. Matthews and Berg (1996) tested this trade-off between relatively cooler water with low, possibly lethal levels of DO and lethally higher water temperature but high DO. They found that rainbow trout in thermally stratified pools significantly and consistently selected cooler water despite potentially lethally low DO. Berman and Quinn (1991) concluded that the practice of resting in cold-water refugia would enable fish to conserve energy for reproductive success including gamete production, mate selection, redd construction, spawning, and redd guarding. Berman and Quinn (1991) eloquently described that habitat restoration on spawning and rearing grounds may not be sufficient to ensure long-term survival of Yakima River salmonids without also protecting a series of cool water thermal refugia for migrating fish.

Thermal stratification has been shown to occur in riverine pools. Nielsen et al. (1994) measured surface water temperatures in stratified pools commonly 3-9° C higher than pool bottom water temperatures. They found that sixty-five percent of juvenile steelhead (*O. mykiss*) moved from adjacent reaches into stratified pools during periods of high ambient water temperatures (23-28° C). Juvenile steelhead remained in thermally stratified pools with little or no cover, making them extremely vulnerable to predation yet gaining benefits from thermal regulation. Stratified pool thermal refugia would also be critical to adult steelhead, since Fowler et al. 2009 found adult *O. mykiss* to be more susceptible to thermal heat shock than juveniles. This hypothesis was further supported by Nielsen et al. (1994) when they found adult steelhead deep in stratified pools when midday ambient stream temperatures ranged from 26-29° C and coldwater pockets averaged 3.5°C cooler. Even a shallow pool (<1 m deep) and completely exposed to solar radiation can stratify, with temperatures up to 4°C lower than mainstem temperatures. Although this study was conducted outside of the Yakima River, the watershed was characterized by high sediment loads, low summer flows and ambient summer temperatures at upper incipient lethal levels, similar to conditions in the Yakima.

Torgersen et al. (1999) asserted that thermal patchiness in streams should be recognized for its potential to provide habitat for species existing at the margin of their environmental tolerances, such as salmonids in the lower Yakima. Annual summer water temperatures regularly rise above 25° C, which is generally considered a lethal temperature for salmonids. Torgersen et al. (1999) noted that cool water pool availability and stream temperatures play important roles in determining carrying capacity of spring Chinook holding habitat. If thermal refugia in the lower Yakima are not adequately numerous or sufficiently proximate, then late spring, summer and early fall migrating life histories of salmonids will disappear. The size, quality, abundance and proximity of thermal refugia are critical considerations in restoration potential.

9.2 Study Area

Temperature profiling and depth studies were performed on the lower Yakima River from Prosser, Washington to the Yakima River Delta (Richland, Washington). The study area was divided into five reaches based on river access points. The five reaches are shown on Figure 26 and are as follows:

1. Prosser Wastewater Treatment Plant to Chandler Power House
2. Chandler Power House to Benton City
3. Benton City to Horn Rapids Park (West Richland, WA)
4. Snively Access (West Richland, WA) to Duportail Access (Richland, WA)
5. Duportail Access to Columbia River Confluence (Richland, WA)

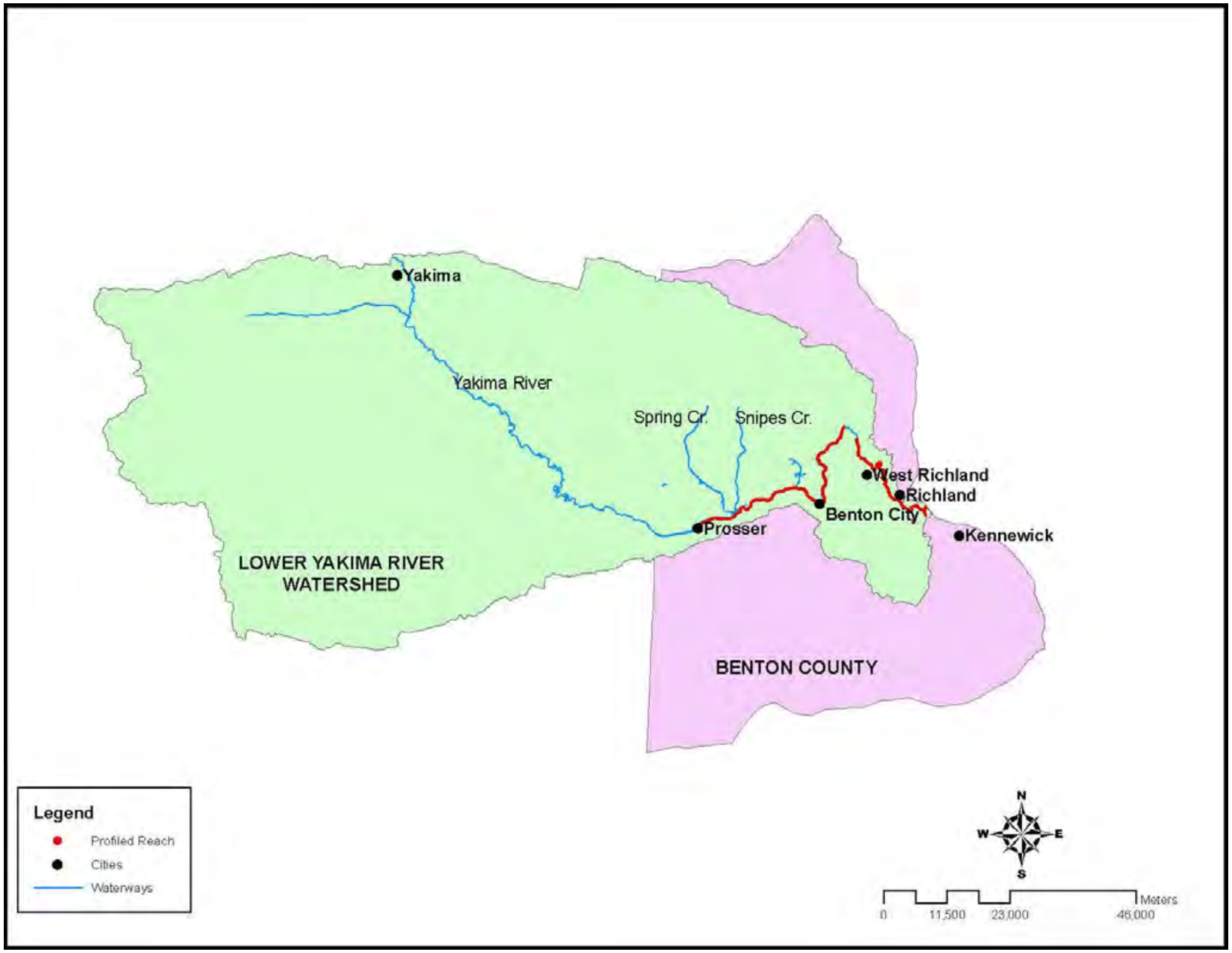


Figure 25. Profiled reach for collection of thermal data

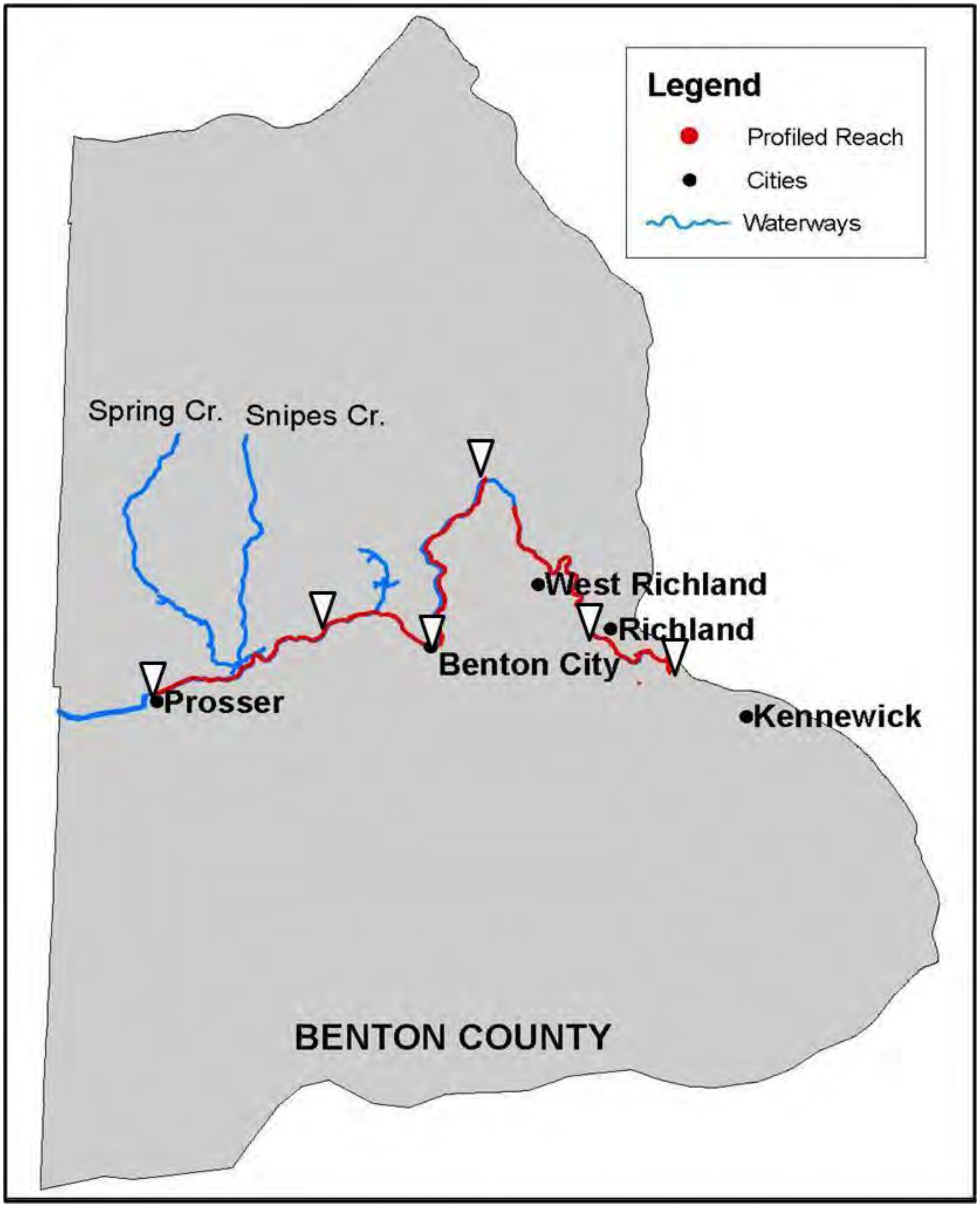


Figure 26. Profiled reach on Yakima River. Arrows indicate access points to the river

9.3 Methods

Temperature profile data were collected on the lower Yakima River from Prosser, WA to Richland, WA during the summer of 2008 and 2009. Methods were adapted from Vaccaro and Maloy (2006) that allow for profiling the temperature regime of a longer river reaches by towing temperature probes while simultaneously recording GPS coordinates. Vaccaro and Maloy (2006) profiled within a Lagrangian framework (moving downstream at the same velocity of the river), which allows for tracking temperature of a parcel of water as it moves downstream. For this work, when possible, boats floated with the velocity of the river; however, due to slow river velocities of the Lower Yakima River this was not always feasible.

Six continuous temperature monitoring probes (dipperLogs), made by Heron Instruments, Inc., were utilized for this study. The dipperLog probes are rated by Heron Instruments, Inc. with an accuracy of ±0.5°C and a resolution of 0.0625°C. All probes were calibrated prior to use to ensure that temperature differences were not the result of systematic differences between probes. Probes were encased in slotted PVC containers to protect the probes while traveling along the riverbed as described in Vaccaro and Maloy (2006). Probes were set to record temperature measurements every 3-5 seconds based on length of river segment and river velocity. A Garmin Rino 530HCx Global Positioning System (GPS) recorded position at the same interval as the temperature loggers. This allowed for a set of location coordinates to be linked to each temperature measurement.

When possible, four temperature probes were utilized to capture measurements within a stream segment in order to record right bank, left bank, and center of the river with a duplicate attached to the center boat. Additional probes were deployed at the upstream and downstream ends of a profiled reach to capture the diurnal change in temperature of the water entering and leaving the reach. For safety and logistic reasons, it was not possible to float three watercraft vessels on the Prosser to Chandler Powerhouse reach. This reach is characterized by large boulders and several small rapids that make it treacherous to navigate at lower flows. As such, only two pontoon boats were used to float this stretch of river capturing data on the left and right bank.

The 2008 floats were performed during the second and third weeks of August, with the Prosser to Chandler float occurring within the first week of September. The 2009 float data were collected consecutively during the last week of July to provide greater consistency within the 2009 data set. Thermal profiles of the lower Yakima River were collected during summer base flow when river temperatures are at their greatest. During the 2009 float, continuous depth data were collected using a Lowrance HDS-5 Depthfinder/GPS Chartplotter unit. The unit was attached to the center pontoon boat and a rig was assembled with a mounting bracket to allow for the transducer to be raised in extremely shallow waters or when traveling over boulders. All temperature and depth data were analyzed and charted using ArcGIS Desktop 9.3.

9.4 Weather and River Conditions

The 2008 and 2009 floats were timed to coincide with base flow temperatures in the lower Yakima River. For both the 2008 and 2009 floats, flows were less than 2,000 cfs as measured at the Kiona USGS gauging station (Figure 27 and Figure 28). In 2008 the daily discharge was between 810 cfs and 1,558 cfs on float days. Daily discharge ranged between 848 cfs and 1560 cfs for the 2009 floats.

Maximum daily ambient air temperatures during the 2008 float were between 83°F and 97°F except for the Prosser to Chandler float which had a maximum daily ambient air temperature of 79°F. This float was later in the season after ambient air temperatures had began to decline. Maximum daily ambient air temperatures were greater during the 2009 float period and ranged between 96°F and 99°F.

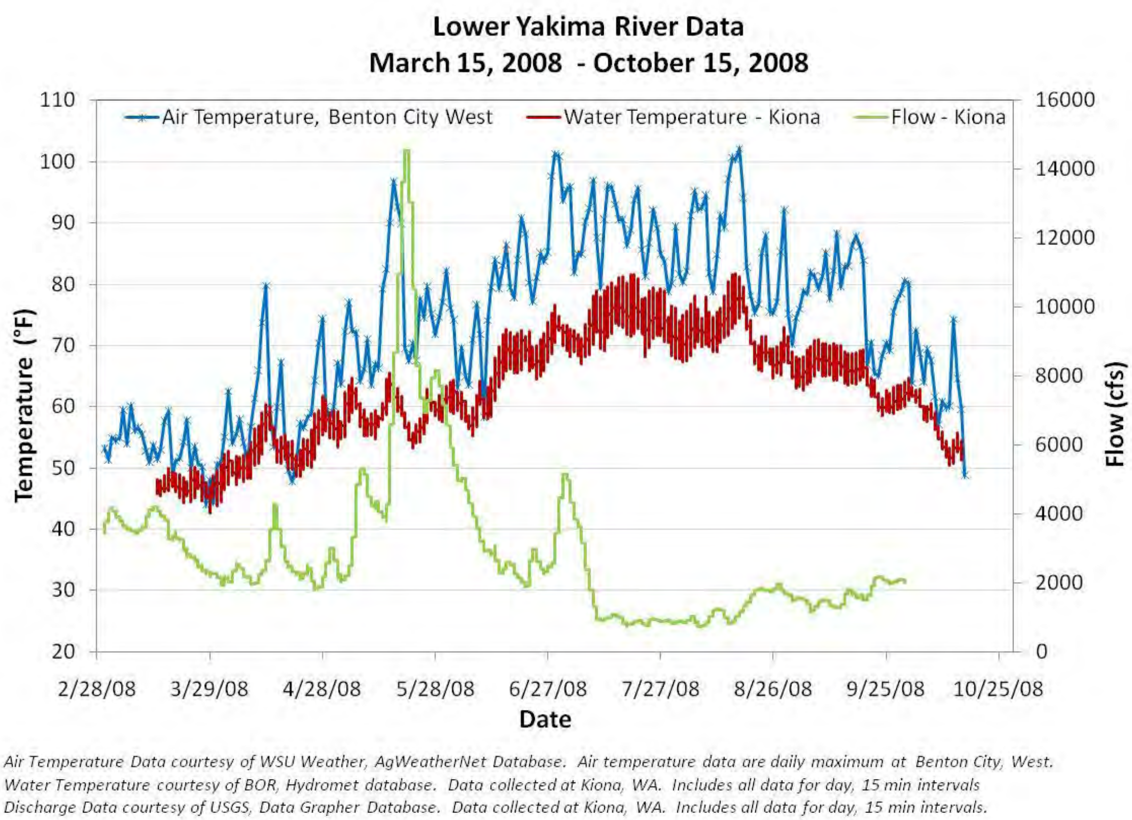
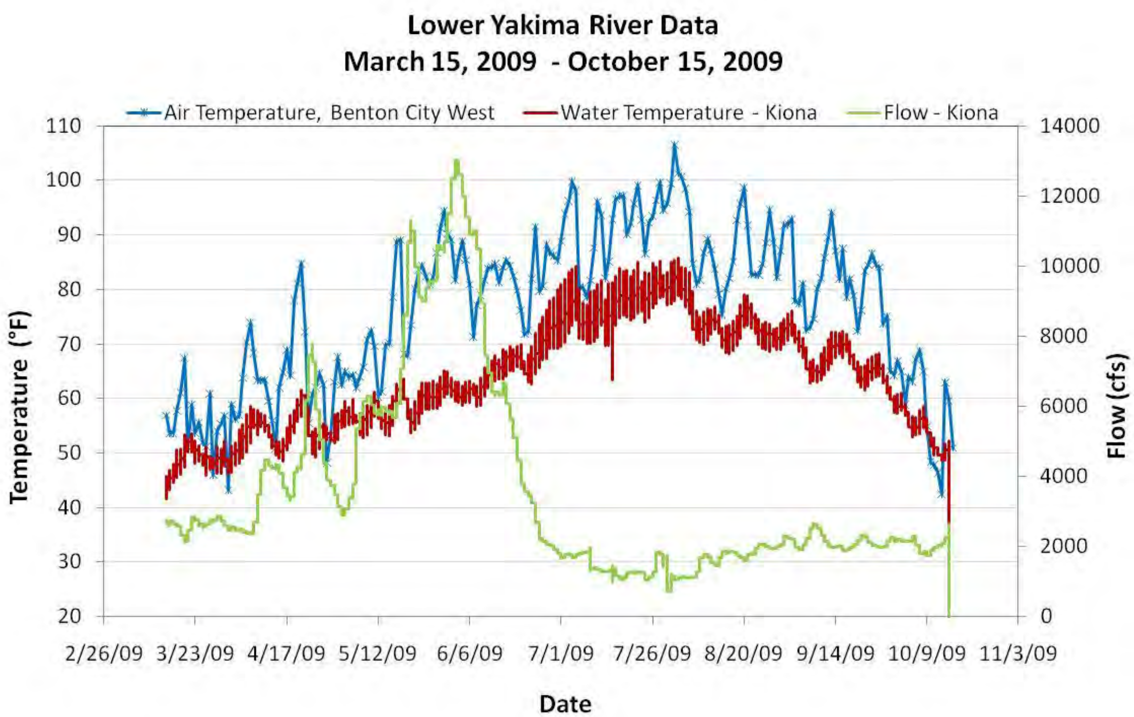


Figure 27. Flow, air temperature and water temperature during irrigation season 2008



Air Temperature Data courtesy of WSU Weather, AgWeatherNet Database. Air temperature data are daily maximum at Benton City, West.
Water Temperature courtesy of BOR, Hydromet database. Data collected at Kiona, WA. Includes all data for day, 15 min intervals
Discharge Data courtesy of USGS, Data Grapher Database. Data collected at Kiona, WA. Includes all data for day, 15 min intervals.

Figure 28. Flow, air temperature, and water temperature during irrigation season 2009

During the 2009 floats, flow increased significantly between Prosser and as a result of a break in the Kennewick Irrigation District (KID) Canal. Flow that would normally have been diverted for irrigation remained in the river and increased the lower Yakima River flow by approximately 400 cfs between Prosser and Benton City. This —bump” in flow can be seen in the hydrograph on 7/27/2009 (Figure 28, Table 4). This increased flow between Prosser and Benton City during the KID shutdown could not be positively correlated with a decrease in river temperature. Median float temperatures did decrease slightly, but this is more likely to be the result of a decrease in ambient air temperature and increased wind velocity during the period of the KID shutdown than from increased river flow (Table 4).