# A visualization and analysis of the Salmon Creek Watershed for resource managers and community outreach

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## Abstract

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Abstract

Intermittent streams are low-order creeks that experience seasonal reductions in flow; upon flow reduction, pools of water are separated by dry stream bed. These residual pools are important habitat during dry months for the aquatic organisms living the watershed. The Salmon Creek Watershed is located in central coastal California and creek flow becomes intermittent over the summer months; Endangered Species Act listed species Coho salmon (*Oncorhynchus kisutch*) and Steelhead trout (*Oncorhynchus mykiss*) spawn and rear in the watershed. This study contains to two reports that examined juvenile salmonid habitat over the course of a 5-year drought that occurred in this region. The

first report- Assessing late-summer juvenile salmonid abundance, a report for the Gold Ridge Resource Conservation District- used Poisson regressions to determine which variables – dissolved oxygen, temperature, surface area, maximum depth, and three variations on cover- were most important for late-summer juvenile salmonid abundance. Surface area and depth were most important for both steelhead trout and coho salmon abundance, supporting previous research. Management efforts should focus on lower creek reaches to support habitat during low flow periods and habitat connection to upper reaches.

The second report- A GIS story of Salmon Creek- visualized and assessed the Salmon Creek Watershed Council's data archive. Surveying has been ongoing since 2013; and this report looked at years 2013,2015,2016, and 2017. From the data, three different map types: time-series maps, ecological observation maps and watershed wide views. I identified that three of the consistently surveyed creeks- Nolan, Fay and Tannery- showed reductions in dry lengths from 2015 to 2017. The ecological observation maps were designed as community outreach tools to garner community interest and support in protecting critical habitat for the salmonids. The Watershed Council's continuous survey of the creeks provides valuable information for management planning that is of use for agencies such as the Gold Ridge Resource Conservation District.

## Acknowledgments

First, I would like to thank the wonderful members of the Salmon Creek Watershed Council whose hospitality, expertise, and dedication to their volunteer work made both reports possible. They are truly an asset to the community and to achieving the region's conservation goals. Thank you to the Gold Ridge Resource Conservation District for their assistance during data collection and their ongoing and innovative work within the region. I want to thank my advisors for their belief in me, vison for this project, patience with my struggles, and ultimately their dedication to their profession. I have truly grown as a person and a professional throughout this process. This would not have been possible without the University of Washington and its many resources available to me. The multiple writing centers, Rstudio help rooms, GIS consultants, IT personal and other specialized staff throughout the University were all major contributors to the success of this project in more ways than they might know. Finally, my family and friends for the many resources they contributed and the support they provided. Many thanks are in order and my gratitude overflows.

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**Report 1**

## Assessing late-summer juvenile salmonid abundance- A report for the Gold Ridge Resource Conservation District

### Introduction

The Salmon Creek Watershed community, management partners, and scientists are striving to restore species abundance and necessary habitat for steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*), both Endangered Species Act (ESA)-listed species. Coho salmon populations were decimated in the mid-1990s and captive broodstock reintroduction efforts have been ongoing since 2008 (Fawcett, Cantor, & Michaud, 2013). In 2008 the California Department of Fish and Game conducted a series of stream inventory reports of all seven main tributaries in the Salmon Creek Watershed, including the mainstem (California Department of Fish and Game, 2008a, California Department of Fish and Game, 2008c, California Department of Fish and Game, 2008b). Their recommendations included pool enhancement and installing large woody debris structures (LWD) – which provide instream habitat for these salmonid species and other aquatic wildlife – for Fay, Tannery and Nolan creeks. The Gold Ridge Resource Conservation District (GRRCD) then prioritized instream and riparian enhancement in their 2010 management plan by encouraging landowners to leave already present LWD structures in place, installing additional LWD structures and planting riparian species to stabilize bank sediment (Gold Ridge Resource Conservation District, 2010). Habitat improvements such as conserving water, restoring instream and riparian habitat, and educating fellow community members about ESA listed salmonids continue to be major regional conservation goals.

This study seeks to provide insight on how the pool conditions and salmonid populations changed in three intermittent creeks during a severe drought year in 2015 and a non-drought year in 2017. During higher water flows in the fall and winter months, adult salmonids return to low-order creeks like Salmon Creek where then the juvenile salmonids grow before returning to the ocean (Boughton, Fish, Pope, & Holt, 2009; Grantham, Newburn, McCarthy, & Merenlender, 2012; Rosenfeld, Porter, & Parkinson, 2000; Wigington et al., 2006; Woelfle-Erskine, Larsen, & Carlson, 2017). It is important to study intermittent streams because they account for half of the total river networks in the United States; additionally, before being able to understand the future effects of climate change on these systems, it is necessary to have fundamental knowledge of how they function (Jaeger, Olden, & Pelland, 2014; Nadeau & Rains, 2007; Robson, Chester, Mitchell, & Matthews, 2013; Woelfle-Erskine et al., 2017).

Intermittent streams by definition experience seasonal reductions or total loss of surface flow; residual pools that remain may serve as a refuge for biota (Boughton et al., 2009; Wigington et al., 2006; Woelfle-Erskine et al., 2017). Larger residual pools play an important role in juvenile salmonid survival because they often support more complex habitats that can sustain necessary conditions for the salmonids during challenging summer months (Woelfle-Erskine et al., 2017). Creeks with LWD sites are well understood to create deeper pools and complex habitat for stream and salmon restoration (Abbe & Montgomery, 1996; Collins, Montgomery, Fetherston, & Abbe, 2012; Mossop & Bradford, 2006; Pess G. R., Liermann M. C., McHenry M. L., Peters R. J., & Bennett T. R., 2012). Bottom cover, such as cobble and gravel, is important for spawning adults when they are making their nests; once the juveniles hatch out, bottom cover and LWD cover function as protection from predators (Quinn, 2011). Pool geomorphology and dissolved oxygen (DO) levels are key predictors of over-summer juvenile survival among intermittent pools (Woelfle-Erskine et al., 2017). Juvenile salmonids can withstand drying conditions in pools that have DO levels of greater than 5 ppm before experiencing metabolic problems; (sublethal) and lethal DO levels are considered to be 2 ppm or less (Woelfle-Erskine et al., 2017). The ecological drivers of intermittent streams like Salmon Creek are different than those of larger river system and are important considerations when making management decisions.

Salmon Creek and the central coast of California experience a Mediterranean climate that is characterized by dry summers and rainy winters. While intermittent flow is typical in these creeks over the summer months, drought conditions can lead to persistent periods without surface flow. In 2014 California declared a state of emergency during a 5-year drought (U.S. Geological Survey, 2018). In 2015 Sonoma County experienced severe and extreme drought conditions, two of the three highest drought categories (The National Drought Mitigation Center, n.d.). 2016 was an abnormally dry year, the lowest on the drought gradient; eventually, precipitation returned and 2017 saw no drought-like conditions (The National Drought Mitigation Center, n.d.). Further study of intermittent creeks is necessary to better inform management decisions that increase habitat complexity and keep higher summer base flows to ensure the wellbeing of salmonids and other species (Gold Ridge Resource Conservation District, 2010; Woelfle-Erskine et al., 2017; Yoon et al., 2015).

Woelfle-Erskine et al. (2017) focused on this watershed, concluding that pool geometry (larger and more complex pools) and higher minimum daily DO levels were important to over-summer juvenile salmonid survival; greater surface area specifically was most important for steelhead and greater depth was most important for coho. The present study grew out of Woelfle-Erskine et al. (2017) findings and methodologies to further assess late-summer abundance and the possible influence of drought conditions. This research will add to the growing body of knowledge of juvenile salmonids in intermittent streams and provide useful insight into the Salmon Creek Watershed, specifically.

**Study area**

The Salmon Creek Watershed is located about 80 miles north of San Francisco, California. The watershed's 35 square miles include seven main creeks, if including the upper main stem (Gold Ridge Resource Conservation District, 2010). Of those, three were selected for this study: Fay, Tannery, and Nolan. Lush riparian corridors in these creeks contain combinations of mixed evergreen woodland species, Alder (*Alnus rubra*) and Redwood (*Sequoia sempervirens)* trees, that effectively conceal, cool and provide resources for Salmon Creek (Gold Ridge Resource Conservation District, 2010). Where riparian vegetation ends, open grazing land dotted by shrubs and pasture animals dominates; 95% of the watershed is a privately owned mix of acreages, pastures and dairy operations (Gold Ridge Resource Conservation District, 2010). All three of the study reaches begin with wider floodplains that narrow as they move upstream. The lower reaches of Fay, Nolan, and Tannery are all alluvial channels with variations on confinement and pool channels (Woelfle-Erskine et al., 2017). Fay Creek begins with wide, alluvial, pool riffle channels that contain large gravel banks, and long pools that are covered by alder trees; the upper reaches narrow and become more confined step-pool channels (Montgomery & Buffington, 1997; Woelfle-Erskine et al., 2017). Nolan Creek too begins wider and narrows as it moves through step pool and pool riffle channel types (Montgomery & Buffington, 1997). The bank walls are often steep with redwood dominated canopies, large boulders and LWD installations that create occasional deep pools.  Finally, Tannery Creek has significant bedrock presence and LWD installations put in place by the RCD scour large and deep pools; the bank vegetation is dominated by redwoods and ferns (Montgomery & Buffington, 1997; Woelfle-Erskine et al., 2017).

**Methods**

The data collection took place twice a year; first in June-July and again in September-October just before the anticipated return of the fall rains. Data collection has been ongoing for seven years; data from 2012 - 2014 was analyzed by Woelfle-Erskine et al. (2017). For this study, I analyzed two years of data (2015 and 2017) from the second collection period on Fay, Tannery, and Nolan creeks. Teams of two people or more collected data with Cleo Woelfle-Erskine, Ph.D. serving as the principal investigator and also with the assistance of the GRRCD. Snorkel surveys were used to count steelhead and coho abundances in each pool using a one-pass method following the protocol of Woelfle-Erskine et al. (2017). Pools were delineated based on riffle boundaries and depth characteristics. Surveyors additionally collected water quality data (dissolved oxygen, conductivity and temperature) and habitat data (length, width, depth, habitat cover, and substrate) at each pool.

Using a combination of Poisson regressions in RStudio, ArcGIS modeling and ecosystem functioning knowledge I explored the following questions:

1. Which pool conditions are correlated with late-summer salmonid abundance?
2. How do fish densities and pool conditions change between years?

I hypothesize that maximum depth and dissolved oxygen will be the most important predictors of salmonid abundance in the late summer. Due to drought alleviation in 2017, I predict coho and steelhead abundances will be greater in 2017 than in 2015 as well as the means of pool conditions.

*Which pool conditions are correlated with late-summer salmonid abundance?*

I selected the following variables as a focus for this study, based on my field experience, literature review and the findings of Woelfle-Erskine et al. (2017): dissolved oxygen (DO), temperature (C), surface area ($m^2$), maximum depth (m), boulder cover, LWD cover, total cover, steelhead totals and coho totals. For the rest of the report, the variables of DO, temperature, surface area, max depth will collectively be referred to as "pool conditions." Due to the numerous pools with low fish counts in my data, I used partioned species-specific Poisson regression to address the non-normal distribution to assess which pool conditions were most important for abundance. Steelhead and coho counts were each response variables in my model. Additionally, I included three variations of pool surface cover using data from the habitat and substrate assessments: (1) total cover as a percentage of 100 (including LWD), (2) total cover in addition to boulder cover and (3) only LWD cover. I highlighted 6 pools throughout the watershed and compared those characteristics to the survival thresholds identified by Woelfle-Erskine et al. (2017).

*How do fish densities and pool conditions change between years?*

This section provides a general summary of the ecosystem between the two years. I compared the distributions of steelhead and coho totals between sampling years and creeks. I also compared distributions of the two most important ecological variables, given the model results. Finally, I mapped the spatial distributions of fish abundance to identify possible key habitats or areas to focus management efforts.

**Results and Discussion**

My regression results supported the findings of Woelfle-Erskine et al. (2017) that surface area and maximum depth emerged as the most important variables for steelhead and coho abundance. The models further predicted that an additional 0.5 $m^2$ increase in surface area per pool would result in one additional steelhead and coho on average; further model specifics can be found in Tables 1 and 2 in the Appendix. Large pools throughout the watershed are critical habitat during many stages of the salmonid life cycle, but these results further establish the crucial role they play in creating late-summer habitat. Following surface area and depth, temperature and cover were also significant for steelhead and coho respectively, but these had little influence on the model. The lack of influence of LWD and other cover variables suggests that predation is perhaps not a serious threat to the salmonids over the summer months.

With the relief from drought in 2017, all three creeks showed an overall improvement in pool conditions. As predicted, mean DO levels, temperature, and maximum depths increased for all three creeks in 2017, but curiously mean surface area in Nolan decreased in 2017. This is likely due to water demands elsewhere in the watershed, changes in the surveyed area as a result of access restrictions, or a combination of the two. Pool depths in 2017 across all three creeks increased drastically. Surface area behaved less uniformly between the two years. A comprehensive table of pool conditions and fish totals can be found in Tables 3 and 4 in the Appendix.  The figure below shows the distributions of surface area (A), depth (B) and fish totals (C and D) for all three surveyed creeks for both years. It is worth noting the multiple outliers in surface area in Fay creek in 2017: these pools are likely the result of higher flows connecting multiple pools that were disconnected in the drier years. Fish totals between all three creeks during both years were quite variable, specifics can be found in the Appendix, Table 4.

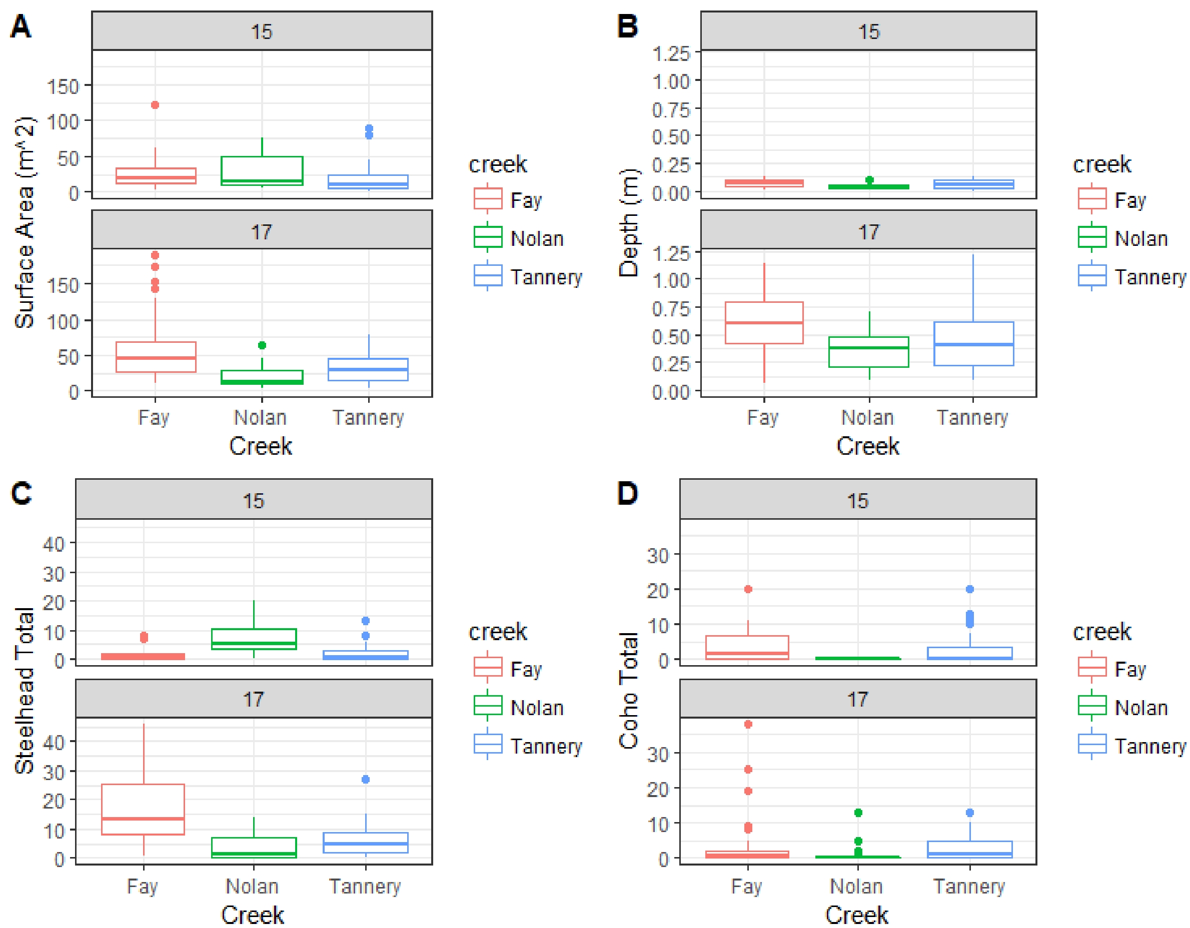
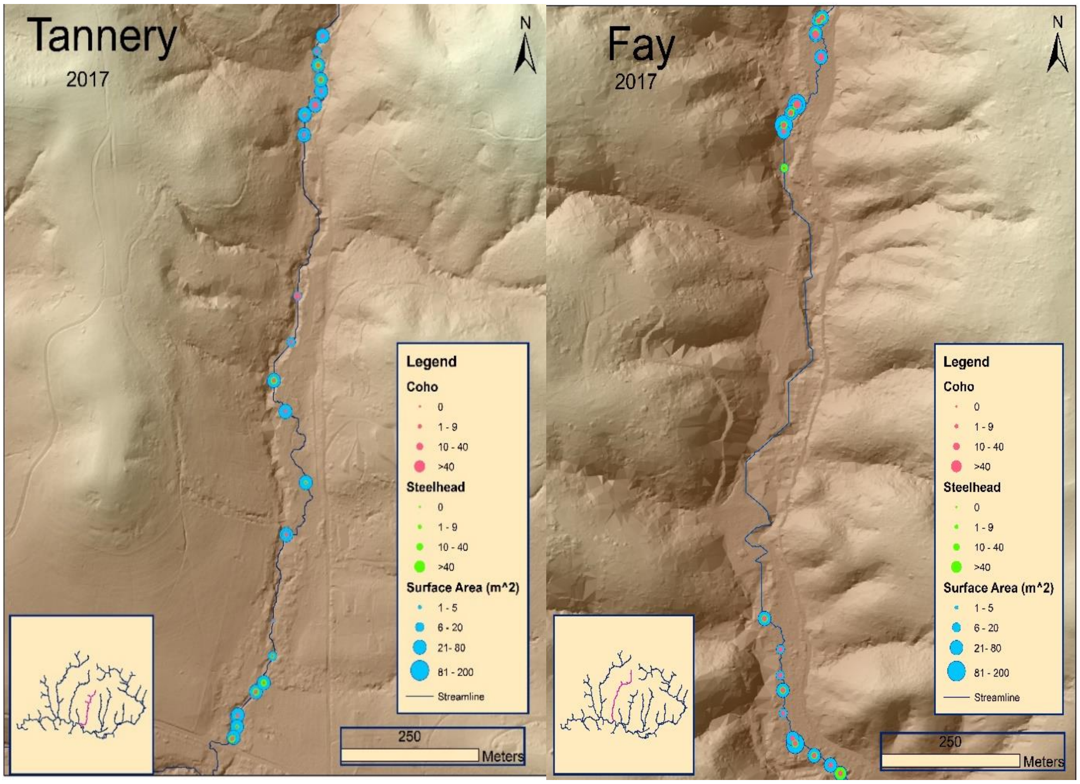



**Figure 1:** A) and B) display the distributions of surface area depth, the two most significant variables for juvenile salmonid abundance between the two years. C) and D) display the distributions of steelhead and coho between the two years.

Map 1 shows the fish totals per pool in 2017 for Tannery and Fay creek, the steelhead totals are displayed in green and the coho totals are displayed in pink. Steelhead were dominant in lower Tannery and larger coho totals appeared more dominantly in upper Tannery in 2017. It is possible that low flows in 2015 made spawning in the upper reaches for coho challenging which is why they are observed in greater abundances in 2017. The strong presence of coho in the upper reaches versus the lower also suggests that the upper reaches of Tannery are more suitable habitat, according to this dataset. This is likely due to it being more confined, and containing often deeper pools that tend to be preferred habitat for juvenile coho (Woelfle-Erskine et al. 2017).

A similar spatial story emerged in Fay 2017. Coho appear to be more dominant in the upper reaches in 2017 for likely the same reasons as Tannery Creek. Coho dominance in the upper reaches of Tannery and Fay is important information when designing management strategies for assisting coho populations. Very dry years, such as 2015 may create barriers to coho spawning in the upper reaches and thus limit the success of the population.  Nolan had less obvious spatial patterns emerge. Larger pools appeared to have larger totals of fish across all three creeks. Management efforts should be directed towards ensuring these upper reaches are accessible and protected habitat. Addition maps of Nolan (2015 and 2017) and Tannery (2015) can be found in the Appendix.




**Map 1:** These maps are spatial representations of the steelhead totals, coho totals and surface area distribution in Tannery and Fay creeks in 2017, per pool. In both creeks, coho appear more dominant in the upper reaches than the lower reaches.

Table 1 an examination of the pools with the most steelhead and coho in each creek during the survey years. The columns with blue highlights are the variables identified by Woelfle-Erskine et al. (2017) as most critical for juvenile salmonids. The red indicates if the value of that pool was below the identified threshold, and most of the pools had all critical variables above the identified thresholds. LWD and cover percentages were low in these high abundance pools, which is in agreement with my model that showed this variable to have little influence. Finally, all pools featured here had 3 or more different types of substrate types and coho abundant pools had 4 or more. While this is just a subset, it perhaps indicates that a varied bottom habitat is likely important to juvenile salmonid abundance and should be pursued in further research.

| Creek | Year | Coho Total | DO | Max Depth (m) | Volume (m^3) | Temperature (C ) | LWD cover (%) | Cover (%) | Substrate |
|---|---|---|---|---|---|---|---|---|---|
| Tannery | 2015 | 20 | 6.31 | .121 | 2.81 | 15.5 | 0 | 6 | 4/7 |
| Fay | 2017 | 38 | 3.83 | .74 | 140.23 | 18.0 | 2 | 14 | 5/7 |
| Nolan | 2017 | 13 | 2.8 | .71 | 10.01 | 17.8 | 30 | 30 | 5/7 |
| | | | | | | | | | |
| Creek | Year | Steelhead Total | DO | Surface Area ($m^2$) | Volume (m^3) | Temperature (C ) | LWD cover (%) | Cover (%) | Substrate |
| Tannery | 2017 | 27 | 6.78 | 31.62 | 15.81 | 17.7 | 5 | 20 | 3/7 |
| Fay | 2017 | 46 | 2.99 | 56.52 | 25.43 | 16.6 | 7 | 14 | 3/7 |
| Nolan | 2015 | 20 | 3.09 | 10.32 | .33 | 14.8 | 0 | 0 | 5/7 |

**Table 1:** The characteristics of pools with the highest steelhead and coho totals in each creek are displayed in a table above. The pool characteristics are then compared to the thresholds identified by Woelfle-Erskine et al. (2017); blue indicates the threshold variables that are species-specific and red indicates if this pool had a value below the identified threshold.

### Implications for future research

In conclusion, the alleviation of drought improved aggregate watershed conditions. This study further supports the conclusions of Woelfle-Erskine et al. 2017 that surface area and depth are crucial to juvenile salmonid survival and their abundance in late summer. And while this report does not conclusively find LWD is a predictor of juvenile salmonid abundance in late summer, it is very likely the LWD contributes to the ecosystem by creating habitat complexities and scouring larger pools. I recommend further investigation of pool-specific characteristics, including the impact of different variations of substrate, canopy cover related to DO, and interactions between species and the slope. This report has provided the interested ecosystem managers with a snapshot of the watershed in 2015 and 2017. It was clear that overall pool conditions and species distributions were varied in 2015 and 2017; in the future, this analysis of drought and non-drought years could serve as a reference for future predictions.

**Recommendations for future GRRCD LWD projects**

I recommend the GRRCD focus their LWD projects on the lower parts of Tannery, Fay and Nolan creeks. I would specifically focus efforts on the lower portions of Fay where the pools are often very wide and likely to suffer larger reductions in pool surface area during drier years. This suggestion also draws on conclusion from my report for the Watershed Council- A GIS Story of Salmon Creek- that Fay was the only creek observed to have dry segments in 2017 after intermittency delineation. LWD in the lower portions of Fay and Tannery would also help foster viable spawning ground coho in drier years when they cannot make it up further in the creek.

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**Appendix**

| **Table 1:** Steelhead Regression | |
|---|---|
| Variable | Coefficients |
| (Intercept) | -1.85 |
| Surface area (log10) | 0.61 |
| Max depth (log10) | 0.18 |
| Temperature | 0.16 |
| DO | -0.08 |
| Cover with boulder | -0.02 |

**Table 1:** Results from steelhead Poisson regression performed using StepAIC in Rstudio, above are the best-fit model results for steelhead totals.

| **Table 2:** Coho Regression | |
|---|---|
| Variable | Coefficients |
| (Intercept) | -0.79 |
| Surface area (log10) | 0.58 |
| Max depth (log10) | 0.13 |
| Cover | 0.06 |
| Cover with boulder | -0.05 |

**Table 2:** Results from steelhead Poisson regression performed using StepAIC in Rstudio, this is the best-fit model result for steelhead totals.

| **Table 3** | DO | | Temperature (C) | | Surface Area ($m^2$) | | Max depth (m) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Tannery 2015 | 4.09 | 2.81 | 14.25 | 0.98 | 19.52 | 20.46 | 0.06 | 0.04 |
| Tannery 2017 | 6.9 | 1.02 | 16.73 | 1.05 | 30.21 | 19.42 | 0.49 | 0.29 |
| Fay 2015 | 2.75 | 1.26 | 13.7 | 0.57 | 31.08 | 32.63 | 0.08 | 0.04 |
| Fay 2017 | 3.16 | 1.22 | 17.68 | 1.02 | 60.11 | 50.91 | 0.61 | 0.27 |

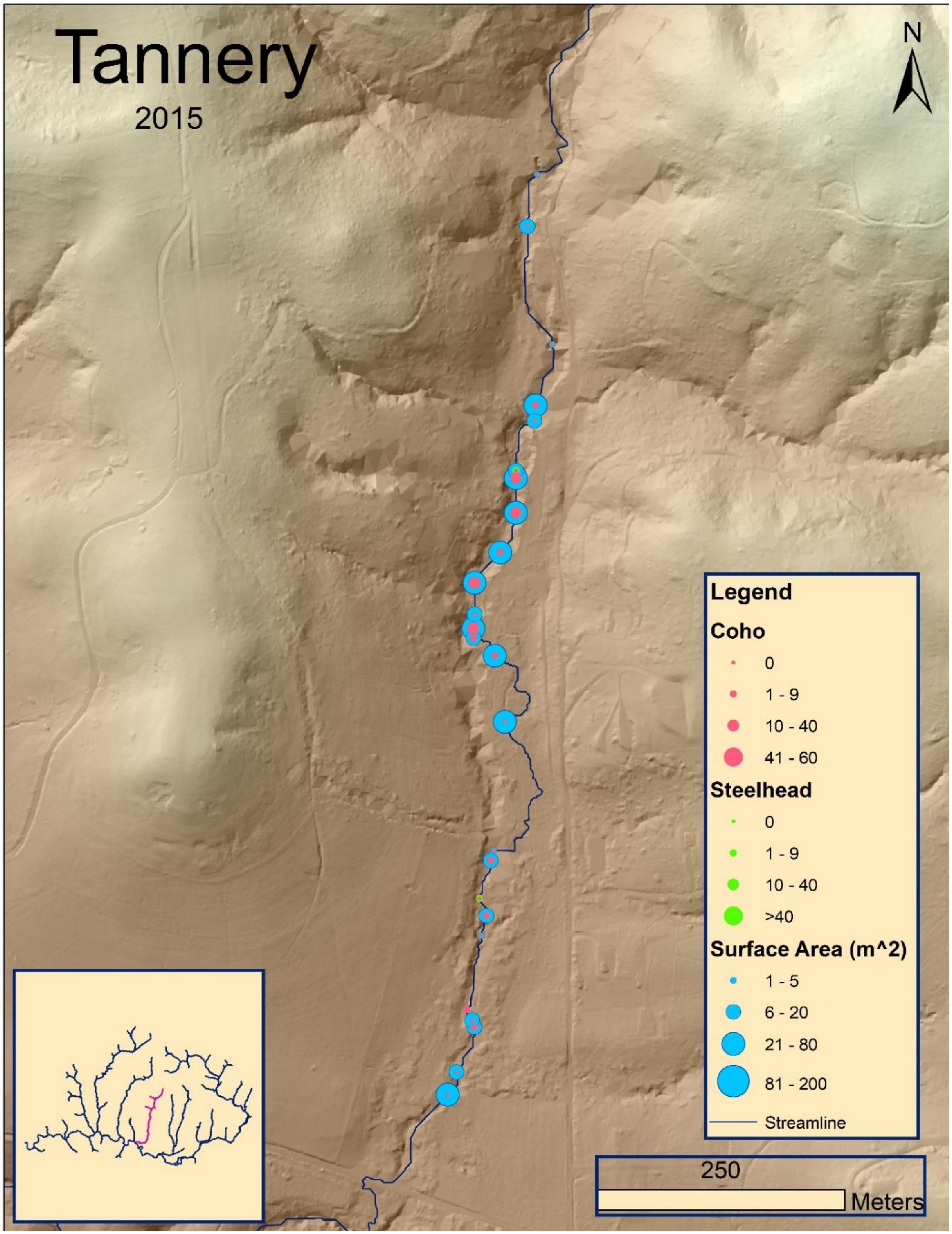
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Nolan 2015 | 3.8 | 1.6 | 15.32 | 0.83 | 27.9 | 25 | 0.04 | 0.03 |
| Nolan 2017 | 5.21 | 1.85 | 17.72 | 0.8 | 20.91 | 15.59 | 0.35 | 0.18 |

**Table 3:** Summary table of means and standard deviations of all variables included in this analysis for each creek and year.

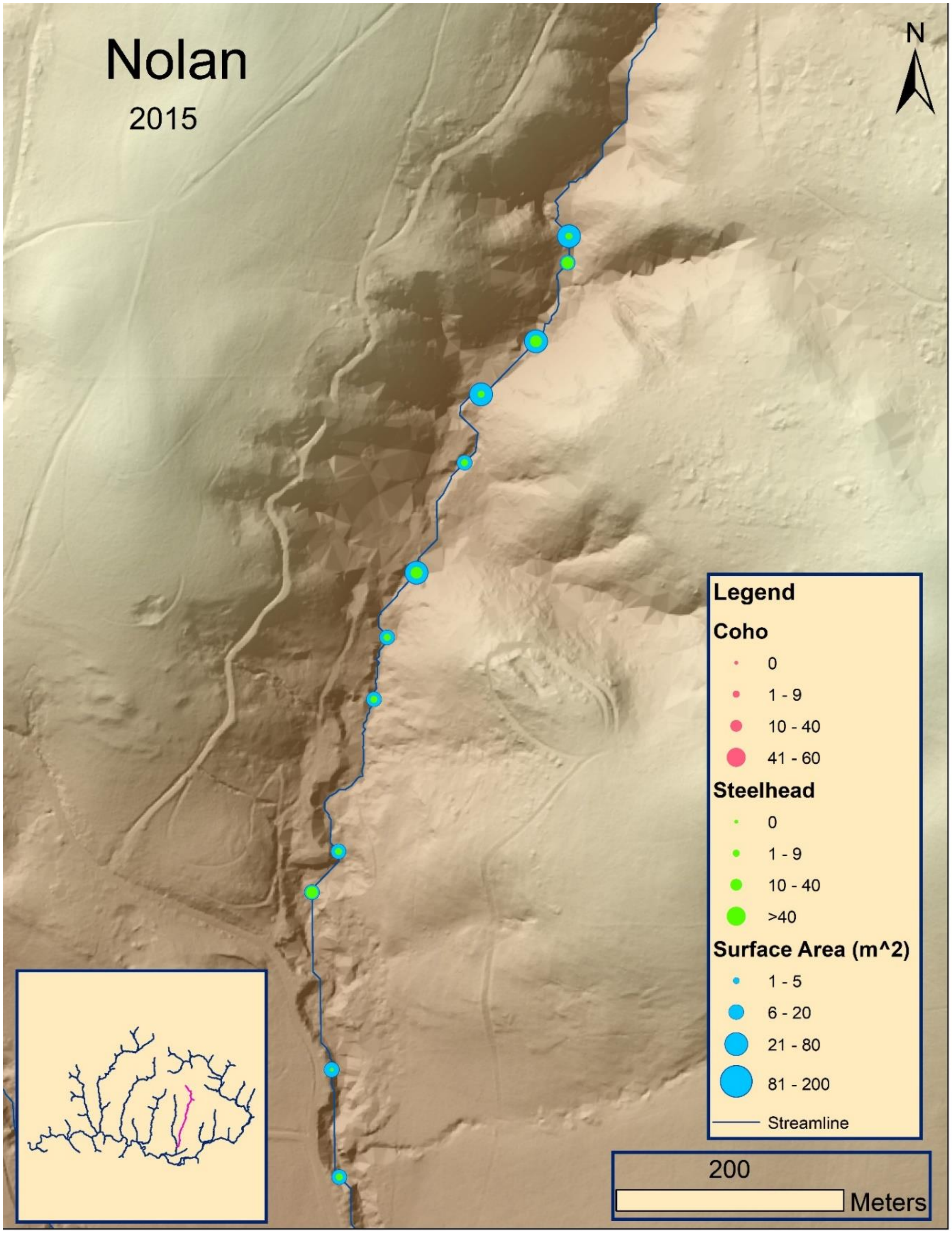
| **Table 4** | Steelhead density (fish/ $m^2$) | | Coho density (fish/$m^2$) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Tannery 2015 | 0.22 | 0.5 | 0.13 | 0.22 |
| Tannery 2017 | 0.2 | 0.21 | 0.1 | 0.16 |
| Fay 2015 | 0.22 | 0.57 | 0.19 | 0.29 |
| Fay 2017 | 0.35 | 0.24 | 0.06 | 0.12 |
| Nolan 2015 | 0.46 | 0.59 | 0 | 0 |
| Nolan 2017 | 0.24 | 0.48 | 0.07 | 0.22 |
| | Steelhead total (fish/pool) | | Coho total (fish/pool) | |
| | Mean | SD | Mean | SD |
| Tannery 2015 | 2.06 | 2.98 | 2.97 | 5.1 |
| Tannery 2017 | 5.97 | 5.98 | 2.9 | 3.78 |
| Fay 2015 | 1.75 | 2.8 | 4.33 | 6.23 |
| Fay 2017 | 16.8 | 11.75 | 4.13 | 8.65 |
| Nolan 2015 | 7.08 | 5.78 | 0 | 0 |
| Nolan 2017 | 3.94 | 4.62 | 1.17 | 3.2 |

**Table 4:** Summary table of means and standard deviations for fish densities and fish totals totals per pool for all three creeks during analysis years.

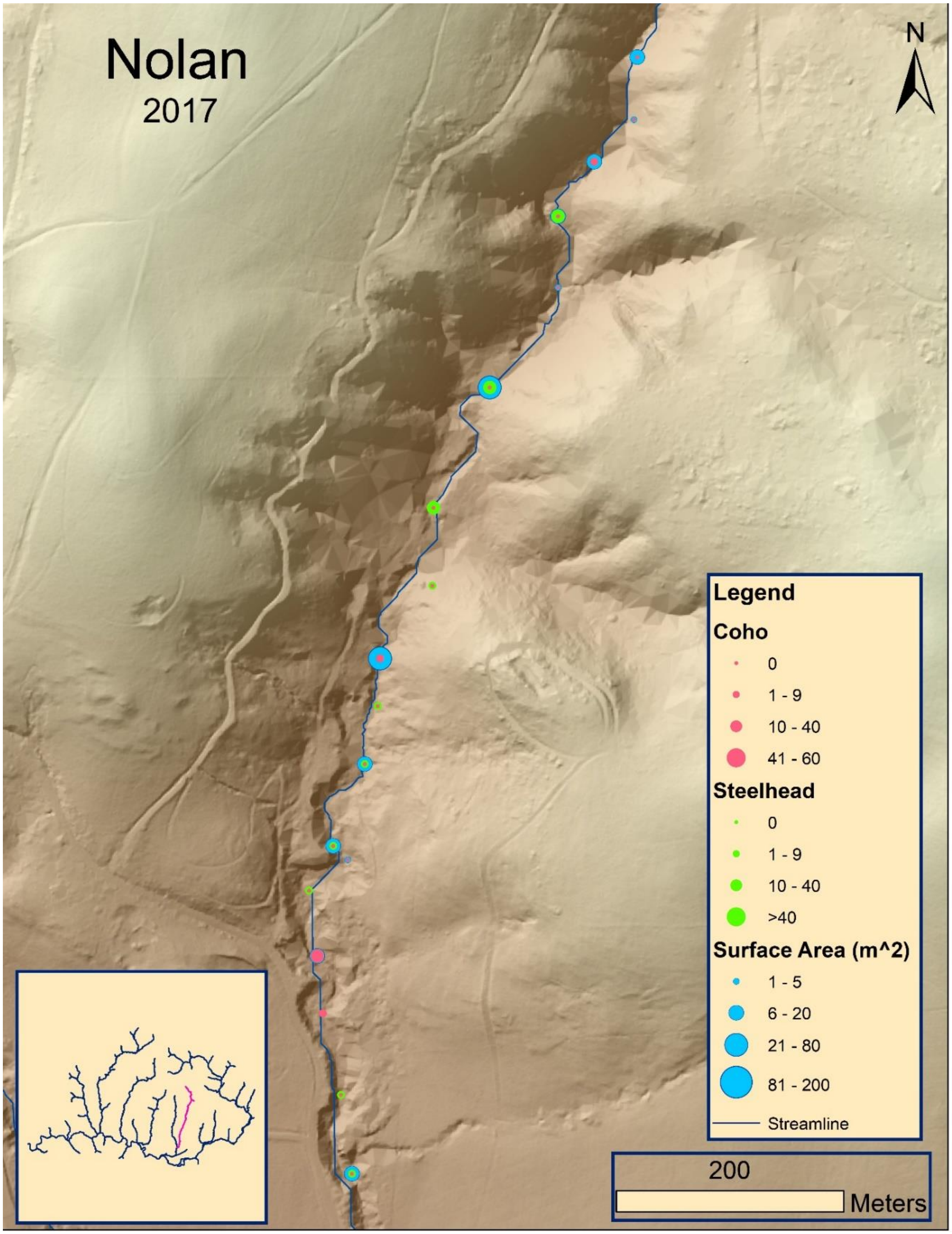
**Map 1:** Tannery 2015 shows graduated symbols for surface area, coho totals and steelhead totals per pool layered on top of one another and their distribution along the creek from the late-summer collection period. The top of the map is upstream of the bottom of the map. Coho totals per pool were greater in the middle to upper reaches, and both species appeared in greater numbers in larger pools generally speaking.



**Map 2:** Map of 2015 late-summer survey pools in Nolan creek shows graduated symbols of surface area, coho totals and steelhead totals per pool layered on top of one another and their distribution along the creek. The top of the map is upstream of the bottom of the map. Note there are no coho symbols because there were none observed during the late-summer collection period. Generally, pools with greater surface area contained more steelhead.



**Map 4:** Map of Nolan late-summer survey pools shows surface area, coho totals and steelhead totals per pool as graduated symbol and their distribution along the creek. The top of the map is upstream from the bottom of map. While larger pools generally contained highter totals of fish this relation appears less strong, and there no obious pattern of species distribution in relation to the location along the creek.



## Report 2

## A GIS story of Salmon Creek

### Introduction

The Salmon Creek Watershed Council is a dedicated team of concerned volunteers that monitors and advocates for the restoration of the watershed. While their efforts are broad, in recent years they have focused on monitoring the creeks at the end of the summer when flow ceases and becomes intermittent; at which point pools of water serve as refuge for aquatic animals but may dry up if too shallow. Every September, volunteers survey and mark the wet and dry segments of the creek, count coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), and make other ecological observations such as the amount of large woody debris and refuge pools. This report is a collection of data visualizations and accompanying explanations of the Watershed Council's data to be used as a tool in community outreach and assisting other local restoration efforts.

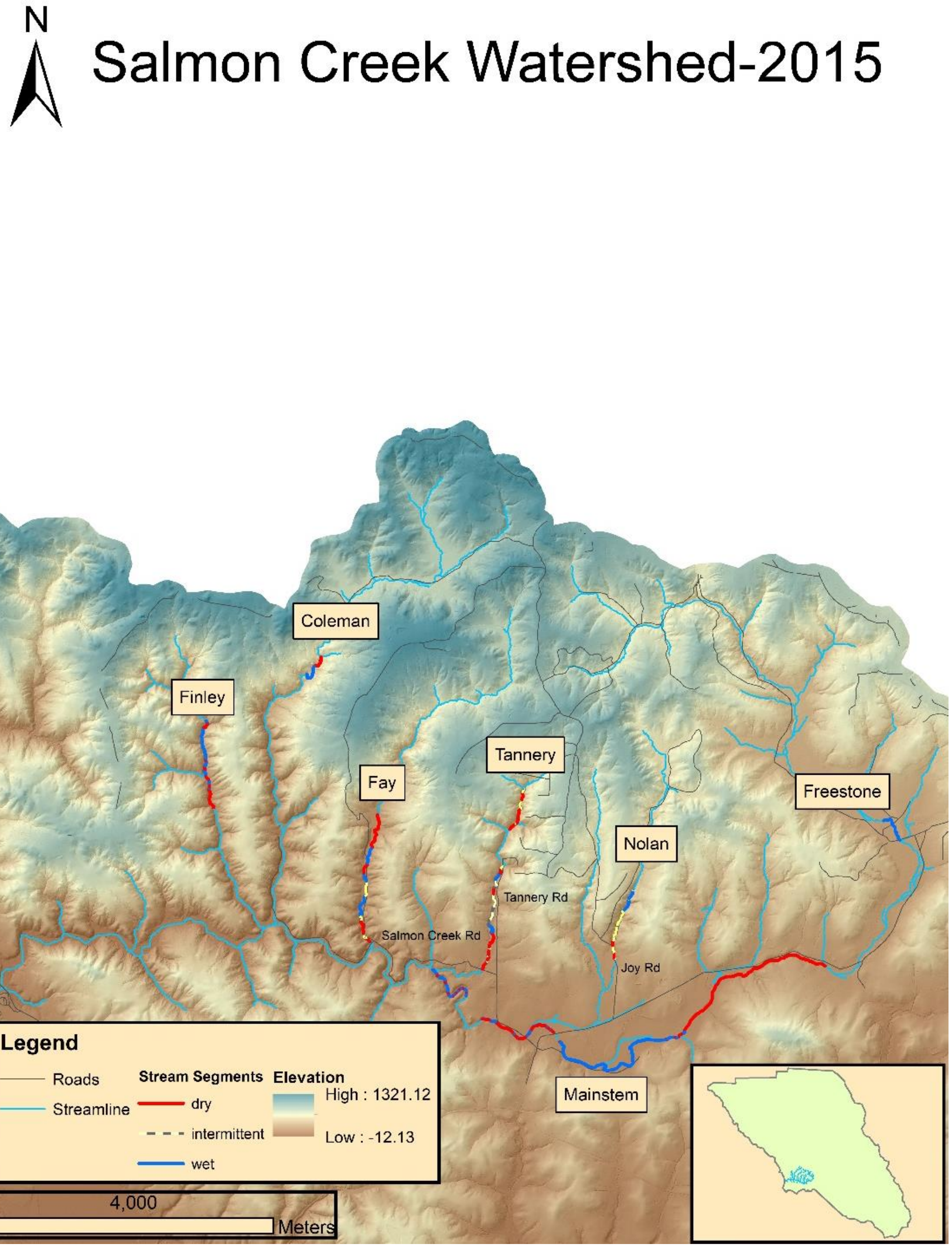
Salmonids, the generic term for salmon and trout, are charismatic species known for their strength, adored for their beauty, and revered as sacred for many. Perhaps lesser known is that steelhead and coho make their first attempt at life in small creeks, far away from the ocean and its coastlines. Among the numerous salmonid species found throughout California's watersheds, steelhead are found in streams all along California's coastlines, while coho have a southern range limit of Santa Cruz, California (National Marine Fisheries Service, 2012). Coho salmon populations were decimated in the mid-1990s due to poor water quality and habitat disappearance (Fawcett, Cantor, & Michaud, 2013). Hatchery and release efforts have been ongoing since 2008 to increase population numbers in Salmon Creek and the Russian River (Gold Ridge Resource Conservation District, 2010). Despite restoration efforts like harvesting rainwater, installing large woody debris, and doing bank stabilization, the juvenile salmonids who rear in the watershed are still threatened by human water withdrawals, land-use that continues to affects water quality and climate change. Scientific research conducted in the watershed has been instrumental in developing innovative restoration designs to aid in recovery plans to achieve federal, state, and local recovery goals. The community, management partners, and scientists are striving to restore both species abundance and the necessary habitat for both Endangered Species Act (ESA)-listed salmonid species (Gold Ridge Resource Conservation District, 2010).

Northern California rainfall ceases over the summer months, severely reducing creek-flow to the point of intermittency or wet pools that are separated by dry streambed. Intermittent streams are often smaller creeks that contain residual pools that serve as refuge for biota like the salmonids, California freshwater shrimp (*Syncaris pacifica*), California red-legged frogs (*Rana draytonii*), and northwestern pond turtles (A*ctinemys marmorata marmorata*) (Boughton, Fish, Pope, & Holt, 2009; Gold Ridge Resource Conservation District, 2010; Wigington et al., 2006; Woelfle-Erskine et al., 2017). Local conservation efforts by the Gold Ridge Resource Conservation District (GRRCD) have been placing log jams to create large pools which often have greater densities of salmon (Pess G. R., Liermann M. C., McHenry M. L., Peters R. J., & Bennett T. R., 2012). Creeks with large wood jams contain deeper pools and complex habitat necessary for stream and salmon restoration (Abbe & Montgomery, 1996; Collins, Montgomery, Fetherston, & Abbe, 2012; Mossop & Bradford, 2006; Pess G. R. et al., 2012). Conversely, smaller pools may dry up completely over the summer, or become extremely low in oxygen creating a noxious environment for the aquatic life within (Woelfle-Erskine et al., 2017). Larger pools play an important role in facilitating greater juvenile salmonid survival at the end of the summer months (Grantham, Newburn, McCarthy, & Merenlender, 2012; Woelfle-Erskine et al., 2017).

While intermittent flow is typical in these creeks, human-induced pressures and climate change may cause streams to dry to a greater extent than they would otherwise. California declared a state of emergency in 2014 amidst a 5-year drought (U.S. Geological Survey, 2018). In 2015, Sonoma County experienced severe and extreme drought conditions, the most extreme among drought categories; 2016 was again an abnormally dry year (The National Drought Mitigation Center, n.d.). Eventually, precipitation returned and 2017 saw no drought-like conditions (The National Drought Mitigation Center, n.d.). The Watershed Council began surveying the streams and documenting the wet and dry segments in 2013. Data collection has continued through the return of wetter years, offering crucial insights into flow changes during different conditions. The conclusions from this report and the ongoing monitoring done by the volunteers of the Watershed Council will provide important insights to further understand this type of ecosystem and how it will adapt to drought conditions in the future.

**Methods**

To collect the stream survey data, the members of the Watershed Council go in teams out to the creek with a handheld GPS and data sheets to mark where water is flowing and where the creek bed is dry. Ecological observations (salmonids, noxious pools (black and stinky pools lacking oxygen, large wood in installments, springs and tributaries, riffles, and refuge pools) are also marked with the GPS and recorded for data entry later. 2013 and 2014 surveys of sections of the mainstem found continuous flow in most reaches, so beginning in 2015, the Council focused survey efforts on tributary habitats. The Council's goal is to survey all tributary habitats from their confluence with Salmon Creek to the limit of possible salmonid spawning areas (a barrier such as a waterfall or low flow reach). Reaches, where landowners have not granted access, are not surveyed. A Watershed Council member then enters the collected data into an excel spreadsheet that is then achieved in Dropbox for future access. The survey protocols and samples of these datasheets can be found in the Appendix.




**Map 1:** This map shows all creeks that were survey in 2015, only three of the creeks- Fay, Tannery and Nolan- were assessed for intermittency.

Using the Salmon Creek Watershed Council data from 2013 and 2015-2017, I generated a collection of maps in ArcGIS 10.6. For each creek that was surveyed I generated a map that contained all collected data points and observations; this required creating wet-dry segments on the streamline that were represented by the colors blue and red respectively and symbolizing all ecological observations. Additionally, I created a detailed Standard Operating Procedure (separate from this report) for those in the Watershed Council that wish to replicate this process with additional years. Once the data from each creek was fully represented in ArcGIS I was able to create three types of map documents; these included reach-scale wet-dry times series maps, maps that highlighted ecological observations, and a watershed-scale map that showed all survey reaches within a year (Appendix Figure 1). A sampling of those methods, maps, and conclusions are discussed in the remainder of the report.

*Wet-dry time series maps*

Tannery, Fay, and Nolan were consistently surveyed 2015-2017 and thus were selected for the time series maps; additionally, Fay and Tannery each had survey data from 2013 that I also chose to include. To begin creating the time series maps, I displayed the watershed councils' marked waypoint coordinates in ArcGIS, selected for the points marked wet and dry and assigned the stream segments in between the points as red for dry and blue for wet.

A watershed view of the 2015 surveyed creeks can be seen in Map 1 to the right. Next, I added the observed dry riffles to identify where flow may have been intermittent. I considered a section of creek to be intermittent if a wet segment was less than 100m or contained a dry riffle less than 100m up or downstream of another dry riffle.  A segment was considered wet if it was greater than 100m with no dry riffles. Dry reaches that contained a dry riffle or were less than 50m were considered intermittent. From those segments, I calculated total creek survey length, and intermittent, dry and wet length totals. Next, I calculated wet, dry and intermittent percentages based on the total surveyed length, which was less than the total available habitat due to access limitations. I then used these comparisons to assess changes in the creek across years. These criteria were based on my data and field observations, literature review and conversations with others familiar with the watershed.

*Ecological observation maps*

Beyond documenting wet and dry segments of the creek, the Watershed Council also notes the presence of a series of ecological observations that were noted at the beginning of the Methods section. I visualized all of the listed observations for each creek surveyed in 2015-2017 in the data archive. For this report, I have included a snapshot of lower Tannery in 2015 as an example of a map document that is locally-relevant and can be created by the Watershed Council with other data years. Also included on that map is a table that displays the Watershed Council’s in situ fish count notes.

| Layer | Resolution | Source |
|---|---|---|
| Digital Elevation Model | LiDAR | Sonoma Veg Map |
| Hillshade | LiDAR | Sonoma Veg Map |
| Waypoints | Easting and Northing; Latitude and Longitude | Garmin; hand-held device |

**Table 1:** Summary of GIS layers used in map creation.

**Results and Discussion**

*Wet-dry time series maps*

The figure below summarizes the percentages of wet, dry and intermittent lengths to illustrate the differences in wetted habitat between years in all three creeks. Generally, 2015 had a greater total lengths of dry and intermittent reaches than in 2017, likely as a result of the return of precipitation in 2016 and 2017. Nolan and Tannery both had no dry segments of the creek in 2016 and 2017. Alternatively, a portion of Fay remained dry throughout all survey years; this is likely due to Fay's wider channel widths. The Appendix contains Tables 1, 2, and 3 with additional information on the surveyed lengths of each year for each creek, including GPS errors.

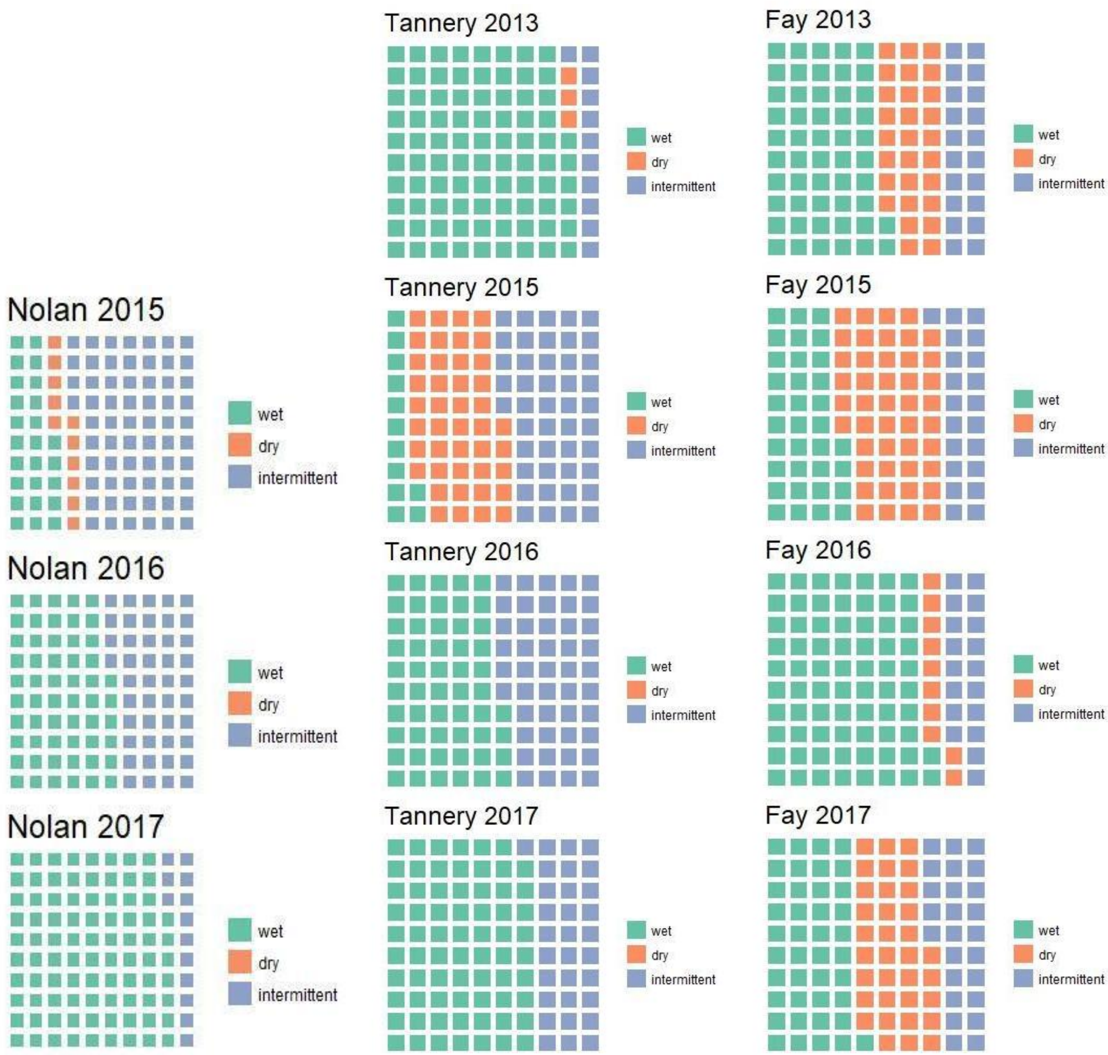
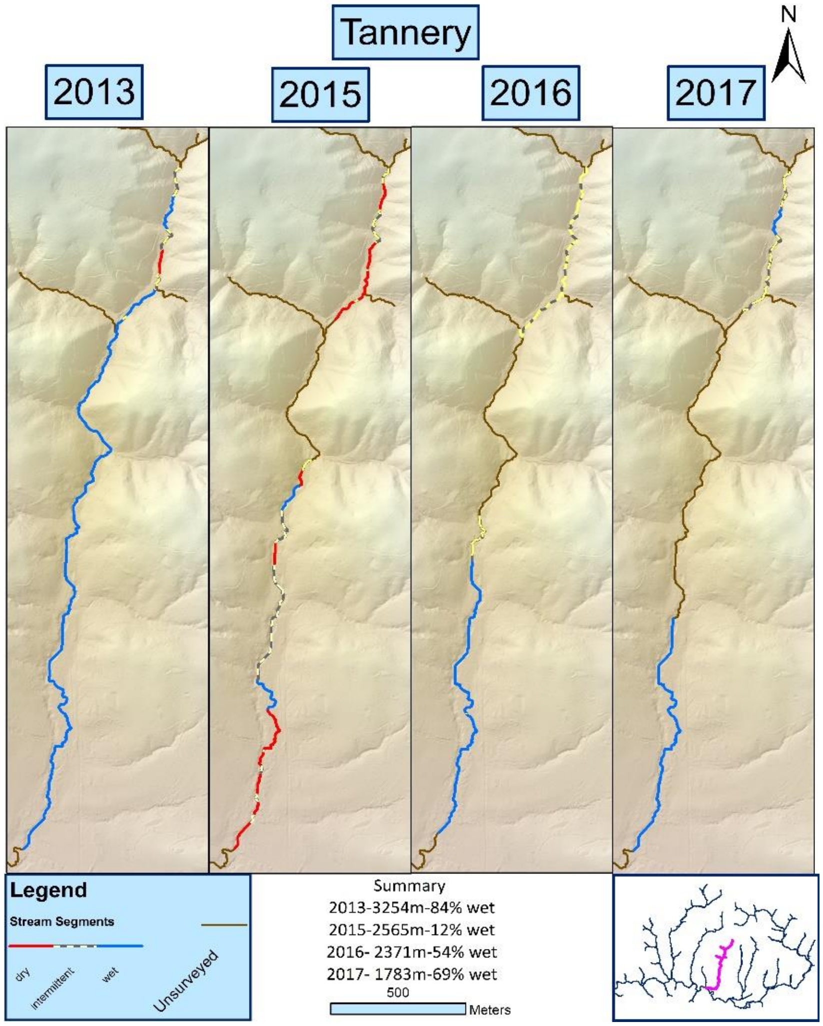



**Figure 1:** The figures above visually represents the percentages of the surveyed length of the creek that was wet, dry or intermittent in all three creeks assessed. Each box represents one percent; the percentage of dry creek observed was greatest in all three creeks in 2015 when drought was the most severe.

A general visual assessment revealed the lower reaches of Tannery appeared wetter throughout the times series and Nolan appeared wetter in the upper reaches; Fay creek was more variable and had less obvious locations of consistently wet areas. The time series map of Tannery can be found seen in Map 2 of this document; Fay, Nolan and Tannery time series maps can be found in the Appendix. As the Watershed Council continues to survey the creeks, obvious flow patterns may begin to emerge.



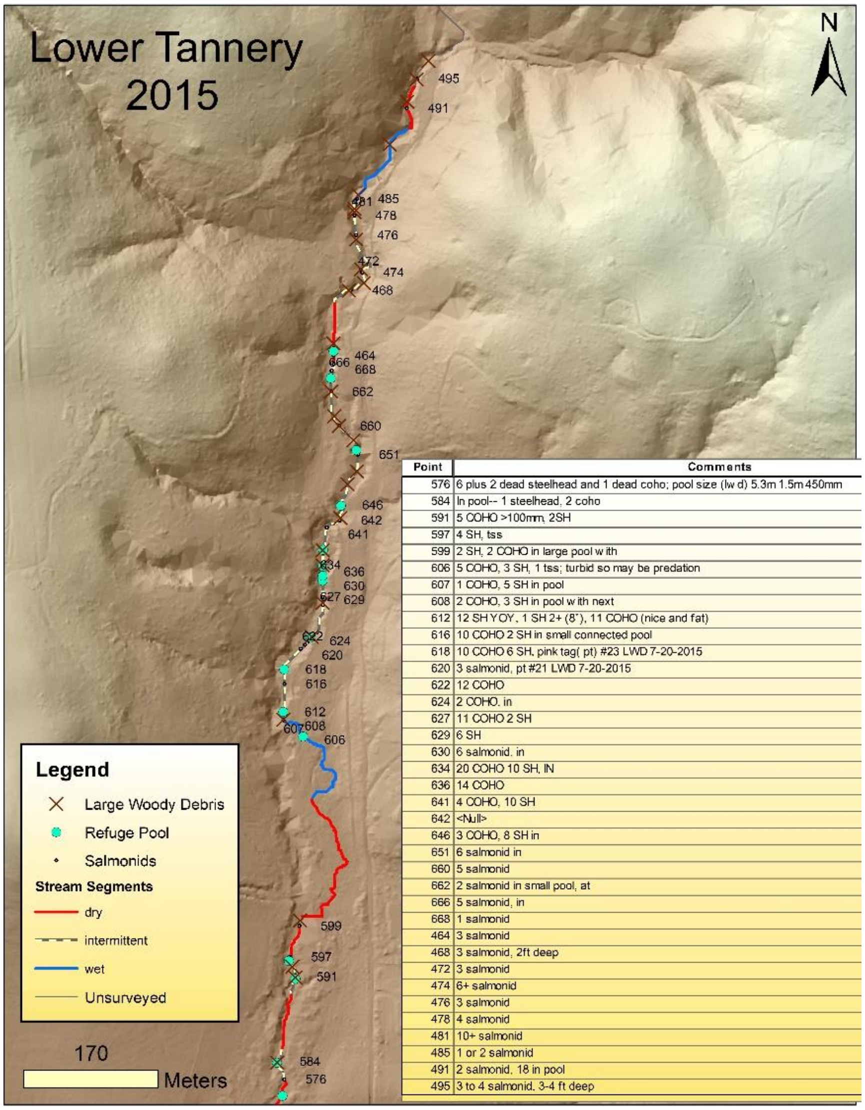

**Map 2:** Post-monitoring, stream segments were delineated into dry, wet or intermittent based on observations recorded on the datasheet, and then intermittent was delineated based on segment length and riffle presence. 2015, the most severe drought year of the time-series, had the greatest amount of dry segments.

In order to move towards identifying flow patterns and antecedent precipitation that create consistently wet, dry or intermittent sections of the creek the Watershed Council should consistently survey the same sections and assess flow conditions in the same manner year after year. The Watershed Council should continue to further monitor flow patterns because they are valuable assessments that will assist managers such as the Gold Ridge Resource Conservation District when making management decisions. The Watershed Council is effectively surveying 40-85% of the creek that is within possible salmon spawning habitat. This means the survey work they are doing is actually covering a good portion of the viable salmonid habitat; specifics can be found in the Appendix (Tables 1,2 and 3 and Map 7).

By identifying which sections of the creek struggle to maintain flow in dry years, management agencies can determine where LWD installations might add the most value to or alternatively, where water withdrawals may have the most negative effect on flow. The Watershed Council and Cleo Woelfle-Erskine adapted the Turner & Richter (2011) protocol; in that study, the intermittent creeks in the San Pedro River in Arizona were surveyed consistently for 12 years which could also become the baseline goal for Salmon Creek. That consistent monitoring led to identifying localized changes in stream segments over the collection period and then comparisons of those stream segments to various weather conditions; similar analyses could be conducted by the Watershed Council (Turner & Richter, 2011). This information is beneficial for achieving the overall salmonid recovery plans throughout the region and also assessing the effectiveness of previous management endeavors (Turner & Richter, 2011).

*Ecological observation maps*

Map 3 is a snapshot of lower Tannery in 2015 demonstrating relevant information that will likely be interesting to members of the community. These observations and the map design were determined after multiple conversations with members of the Watershed Council. This map displays large wood jams, refuge pools and salmonid totals in the form of a table to demonstrate a relationship between large wood jams and refuge pools. The Watershed Council can create maps with different combinations of variables to use as a tool to tell a particular story or narrative. An interesting combination would be the proximity of noxious pool to large wood sites which can be found in the Appendix, Map. These all would serve as great education and outreach tools for community residents who are interested or may be unaware of the ecosystem in their backyard.




**Map 3:** This map is an example of the kinds of ecological observation maps the Watershed Council can create with their data to show more specific and detailed observations within a creek. Depending on the goal, there are numerous observation combinations and informative tables that can be added to these maps depending on the desired message.

**Future Use**

It is my hope that these maps and this report will assist the Watershed Council with their community outreach goals. The information the Watershed Council collects annually will continue to assist restoration managers in learning more about the watershed, identifying salmonid refuges or challenge areas, and inspire their neighbors to be involved in the conservation of their watershed. Furthermore, the process of creating the maps and working with the data will help the Watershed Council refine and improve their own methodologies. I suggest other research pursuits could include comparing snorkel survey fish counts to

Watershed Council fish counts, assessing fish abundances in relation to large wood structures or other important ecological structures, and continuing to assess the intermittent reaches.

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## Appendix

| **Table 1** | **Tannery 2013** | **Tannery 2015** | **Tannery 2016** | **Tannery 2017** |
|---|---|---|---|---|
| Sum of survey length (m) | 3254 | 2565 | 2371 | 1783 |
| Sum of wet (m) | 2813 | 306 | 1278 | 1232 |
| Sum of dry (m) | 89 | 1095 | 0 | 0 |
| Sum of intermittent (m) | 352 | 1164 | 1093 | 551 |
| % wet | 84 | 12 | 54 | 69 |
| % dry | 3 | 43 | 0 | 0 |
| % intermittent | 11 | 45 | 46 | 31 |
| Total length of creek (m) | 6543 | 65423 | 6543 | 6543 |
| Not surveyed (m) | 3288 | 3978 | 4172 | 4760 |
| Limit of anadromy length (m) | 4234 | 4234 | 4234 | 4234 |
| % of anadromy length surveyed | 77 | 61 | 56 | 42 |
| GPS Error Range | NA | 7 -33 | 9-33 | 9-23 |

**Table 1:** Summary of all creek length calculations in Tannery during years 2013, 2015-2017; while wet and dry segments generally decreased and increased, respectively, intermittent appeared to be a little more variable.

| Table 2 | Fay 2013 | Fay 2015 | Fay 2016 | Fay 2017 |
|---|---|---|---|---|
| Sum of survey length (m) | 2601 | 2259 | 1549 | 1660 |
| Sum of wet (m) | 1343 | 773 | 1121 | 676 |
| Sum of dry (m) | 737 | 1002 | 150 | 571 |
| Sum of intermittent (m) | 520 | 484 | 278 | 413 |
| %wet | 52 | 34 | 72 | 41 |
| %dry | 28 | 45 | 10 | 34 |
| % intermittent | 20 | 21 | 18 | 25 |
| Total length of creek (m) | 7847 | 7847 | 7847 | 7847 |
| Not surveyed | 5246 | 5588 | 6298 | 6186 |
| Limit of anadromy length (m) | 3063 | 3063 | 3063 | 3063 |
| % of anadromy length surveyed | 85 | 74 | 51 | 54 |
| GPS Error Range | NA | 19-29 | 9-19 | 10-29 |

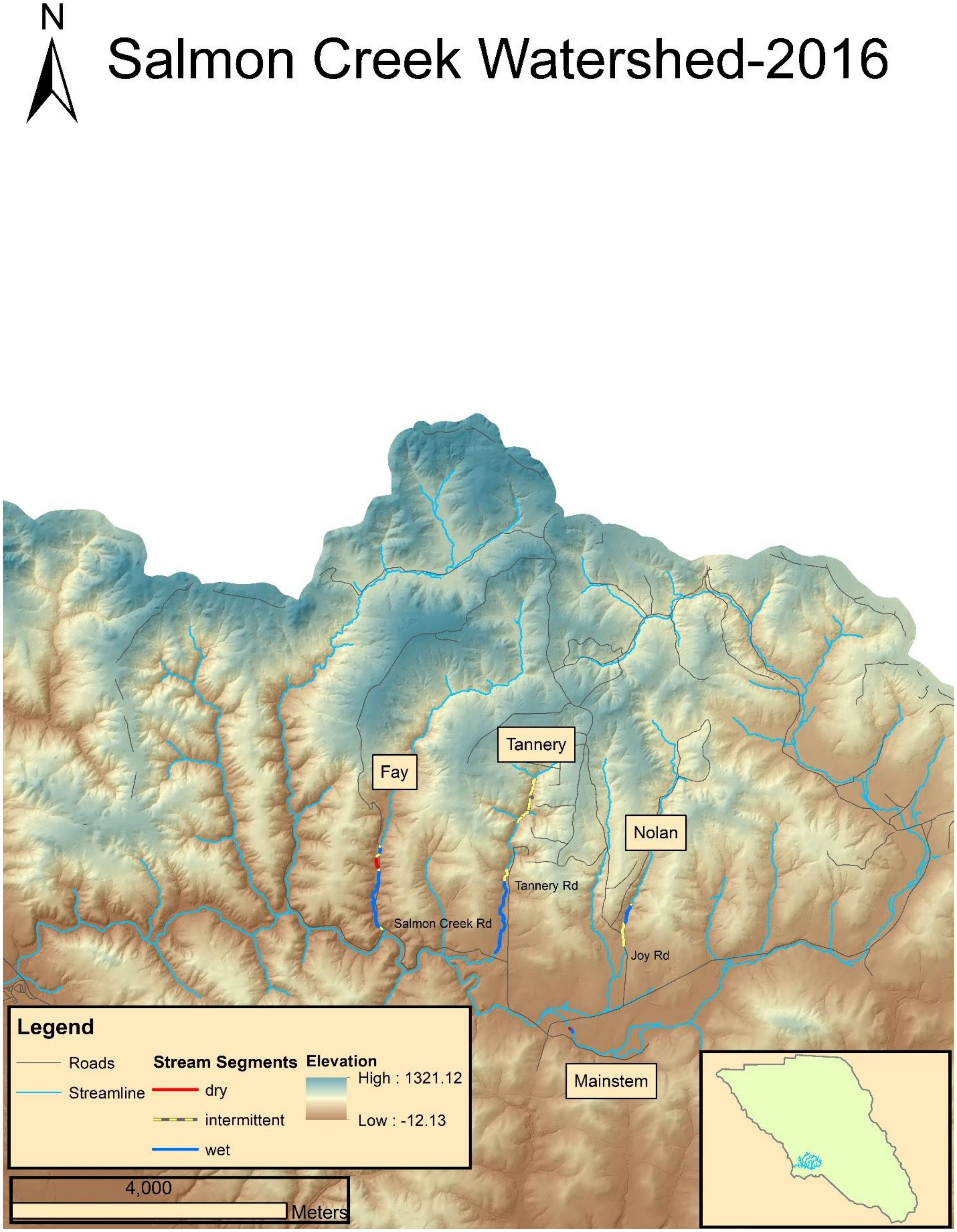
**Table 2:** Summary of all creek length calculations in Fay during years 2013, 2015-2017. Overall, Fay was generally more variable across years and 2016 having the greatest percentage of wet creek, but 2015 still had the greatest amount of dry creek.

| Table 3 | Nolan 2015 | Nolan 2016 | Nolan 2017 |
|---|---|---|---|
| Sum of survey length (m) | 1196 | 925 | 1176 |
| Sum of wet (m) | 306 | 514 | 1021 |
| Sum of dry (m) | 128 | 0 | 0 |
| Sum of intermittent (m) | 761.181311 | 411.561937 | 155 |
| % wet | 25 | 56 | 87 |
| % dry | 11 | 0 | 0 |

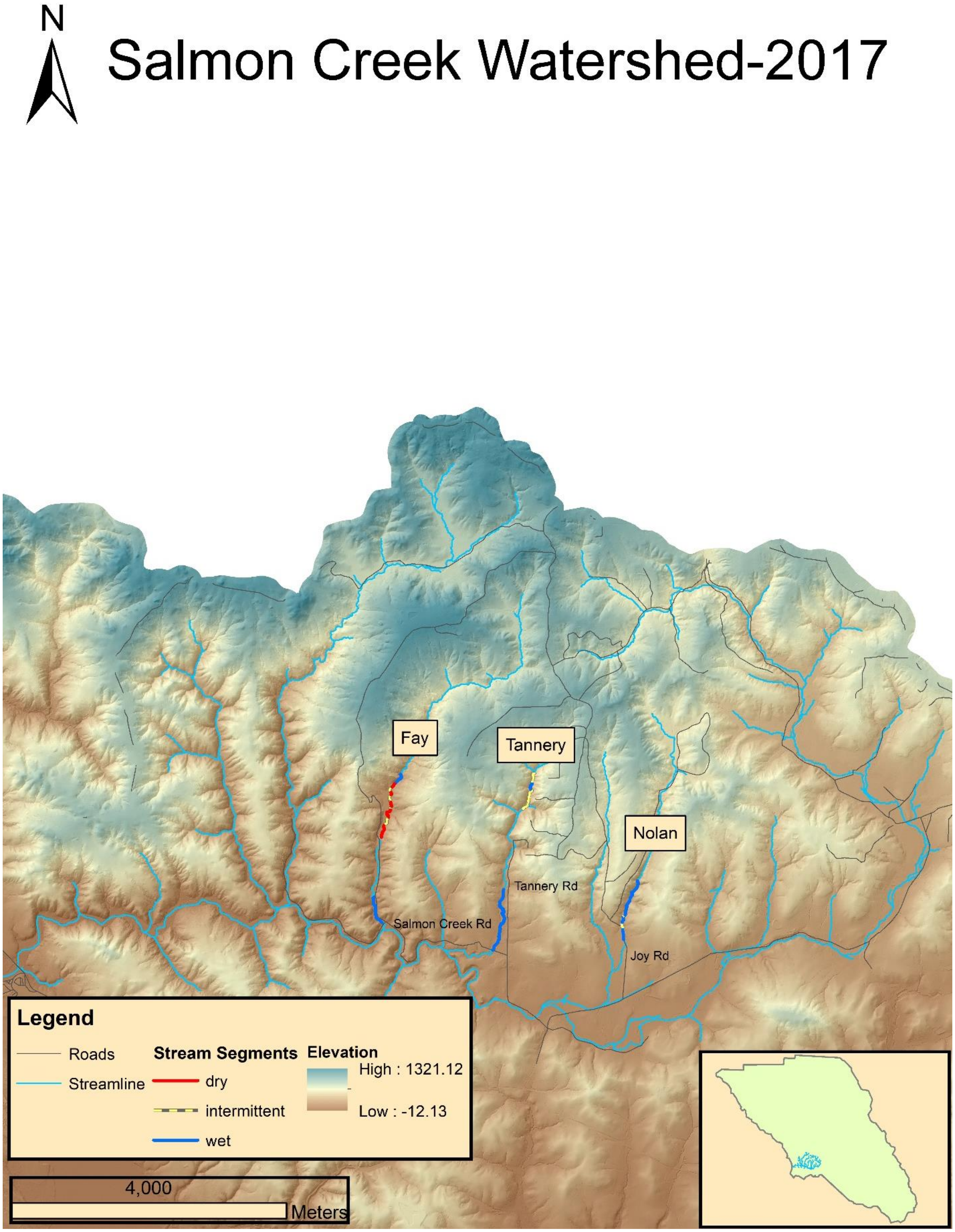
| | | | |
|---|---|---|---|
| % intermittent | 64 | 44 | 13 |
| Total length of creek (m) | 5092 | 5092 | 5092 |
| Not surveyed (m) | 3896 | 4167 | 3916 |
| Limit of anadromy length (m) | 1966 | 1966 | 1966 |
| % of anadromy length surveyed | 61 | 47 | 60 |
| GPS Error Range | 20-48 | 9-22 | 9-27 |

**Table 3:** Summary of all creek length calculations in Nolan during years 2015-2017, the creek was not surveyed in 2013. Nolan was the wettest in 2017 and had no observed dry segments in 2016 and 2017 once intermittent calculations were integrated.

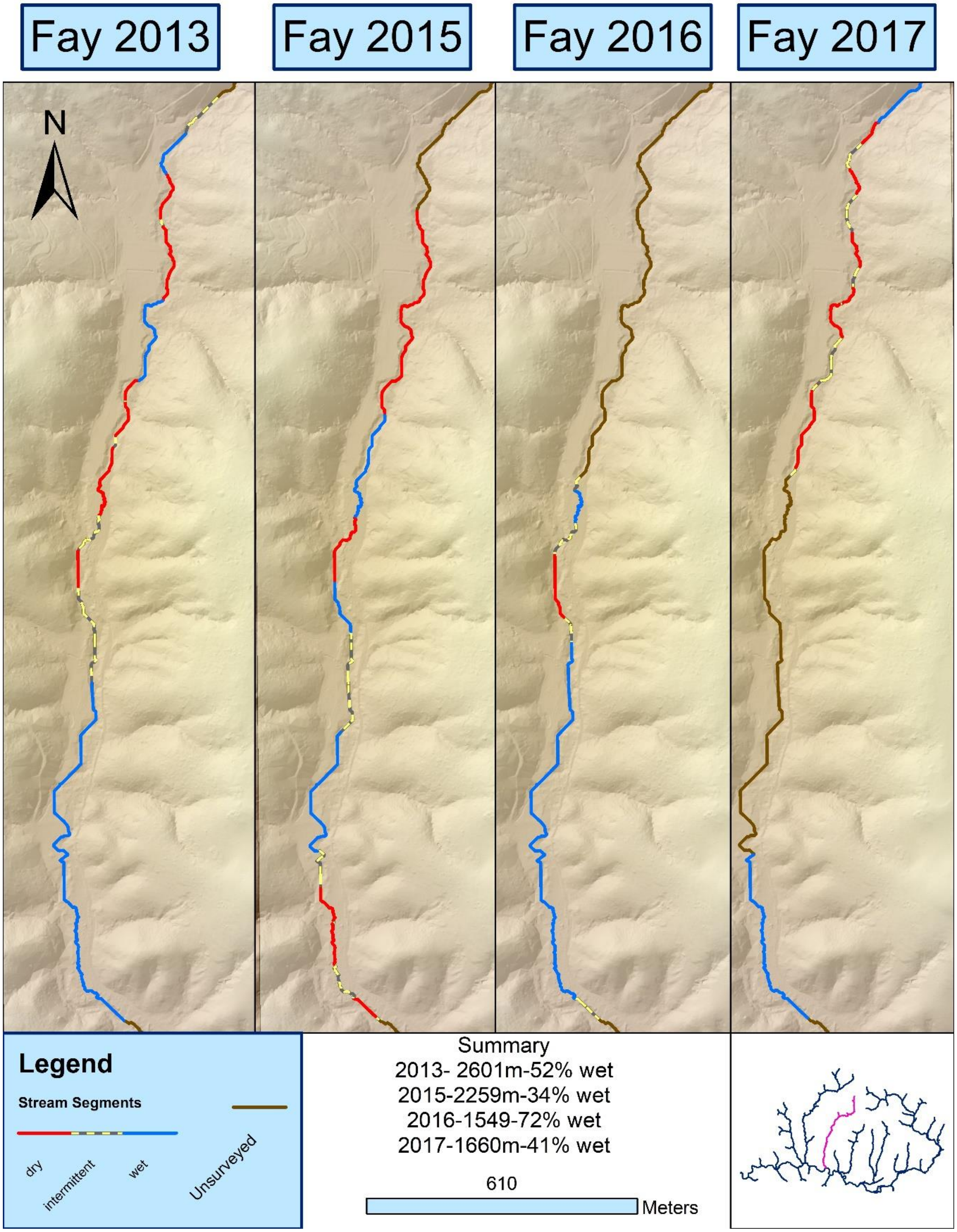
**Map 1:** Displays a watershed wide view of the surveyed creeks in 2016, a small portion of the mainstem was surveyed but not delineated for intermittent segments in this report.



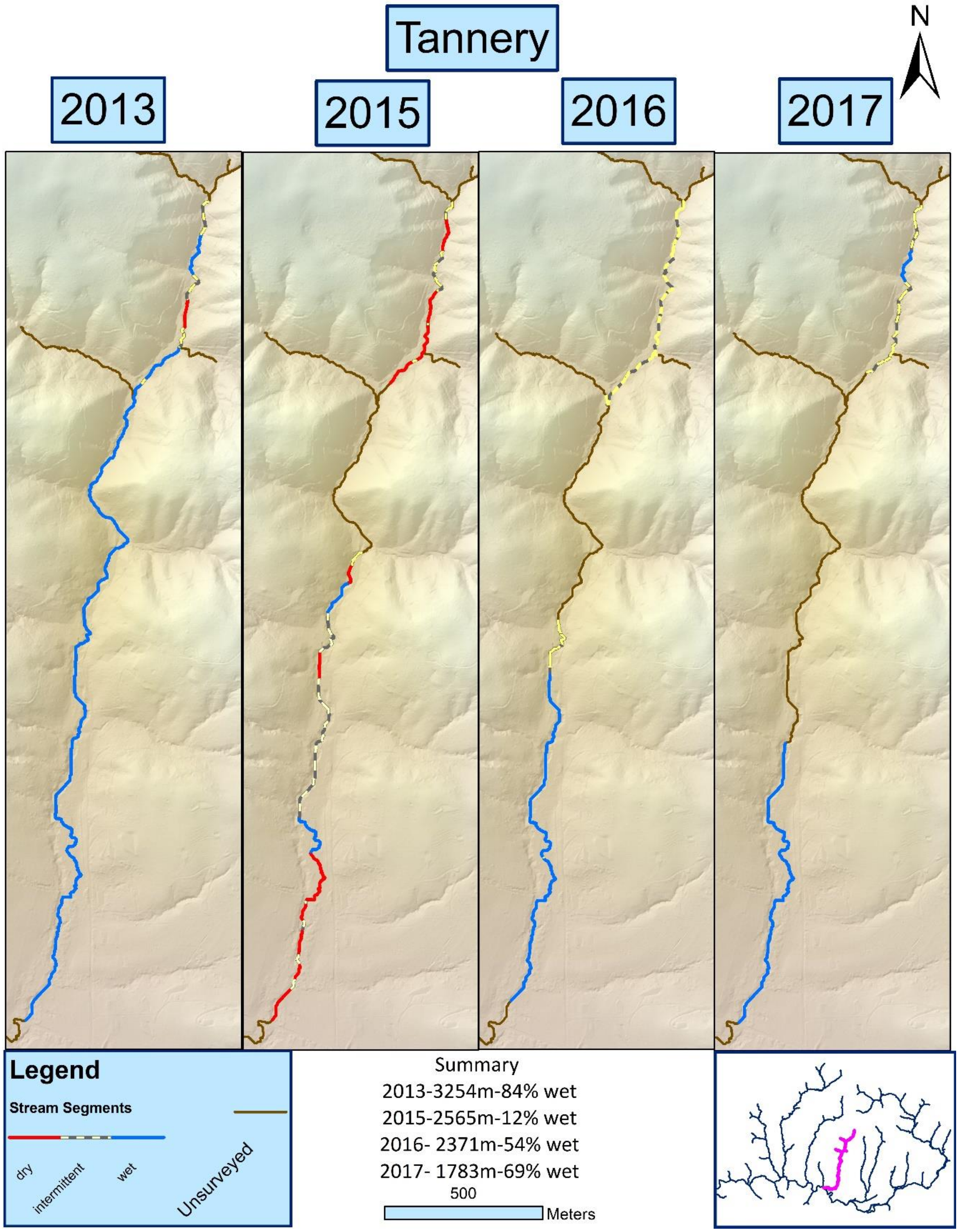
**Map 2:** Displays a watershed wide view of the surveyed creeks in 2017; which only included Fay, Tannery and Nolan.



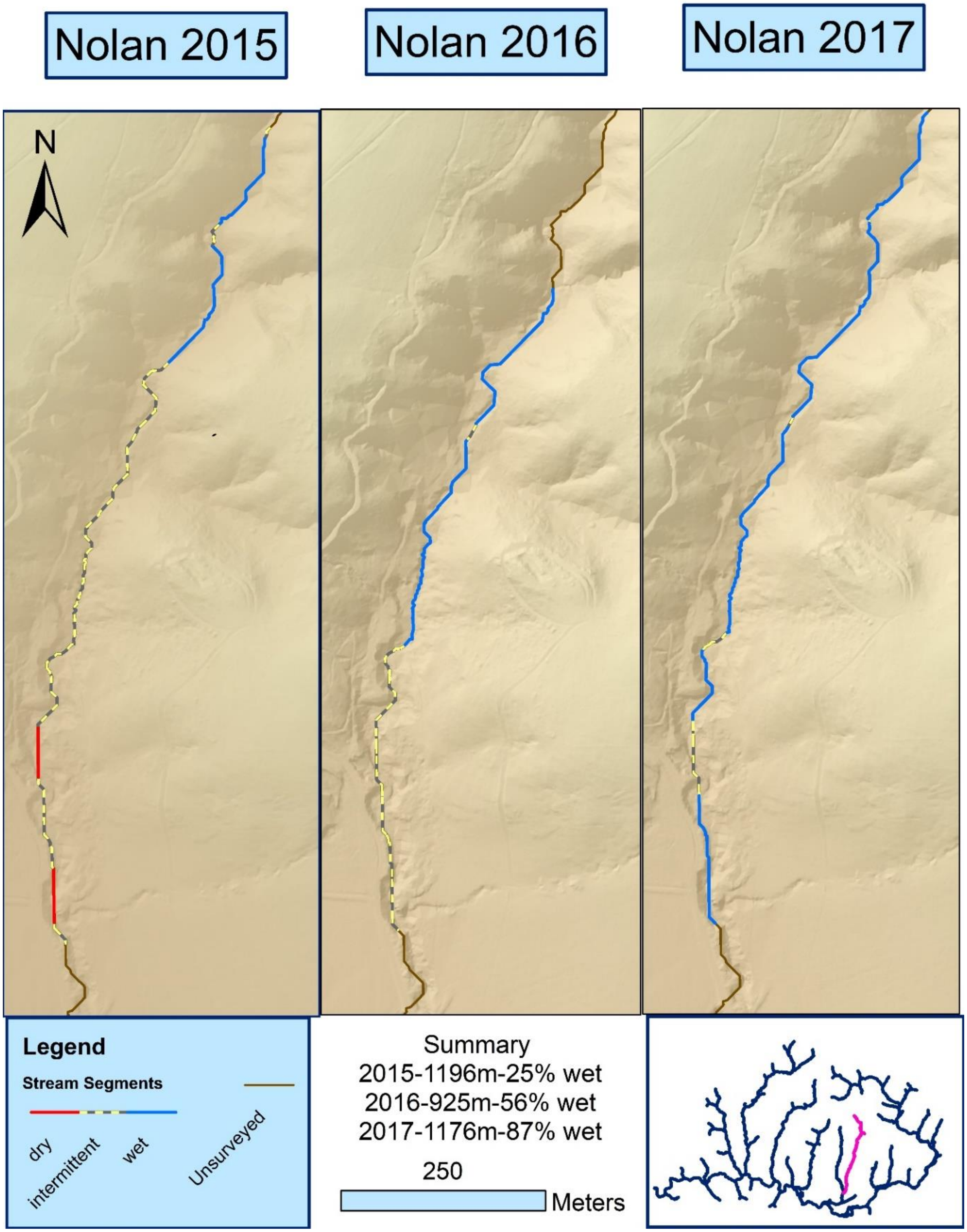
**Map 3:** Shows the surveyed reaches of Fay creek in 2013, 2015-2017 side by side to compare actual reaches surveyed and changes is flow. As indicated throughout the report, 2015 was a much drier for the creek than 2017, but Fay was the only creek to continue to have dry segments in 2017 after intermittent delineation.



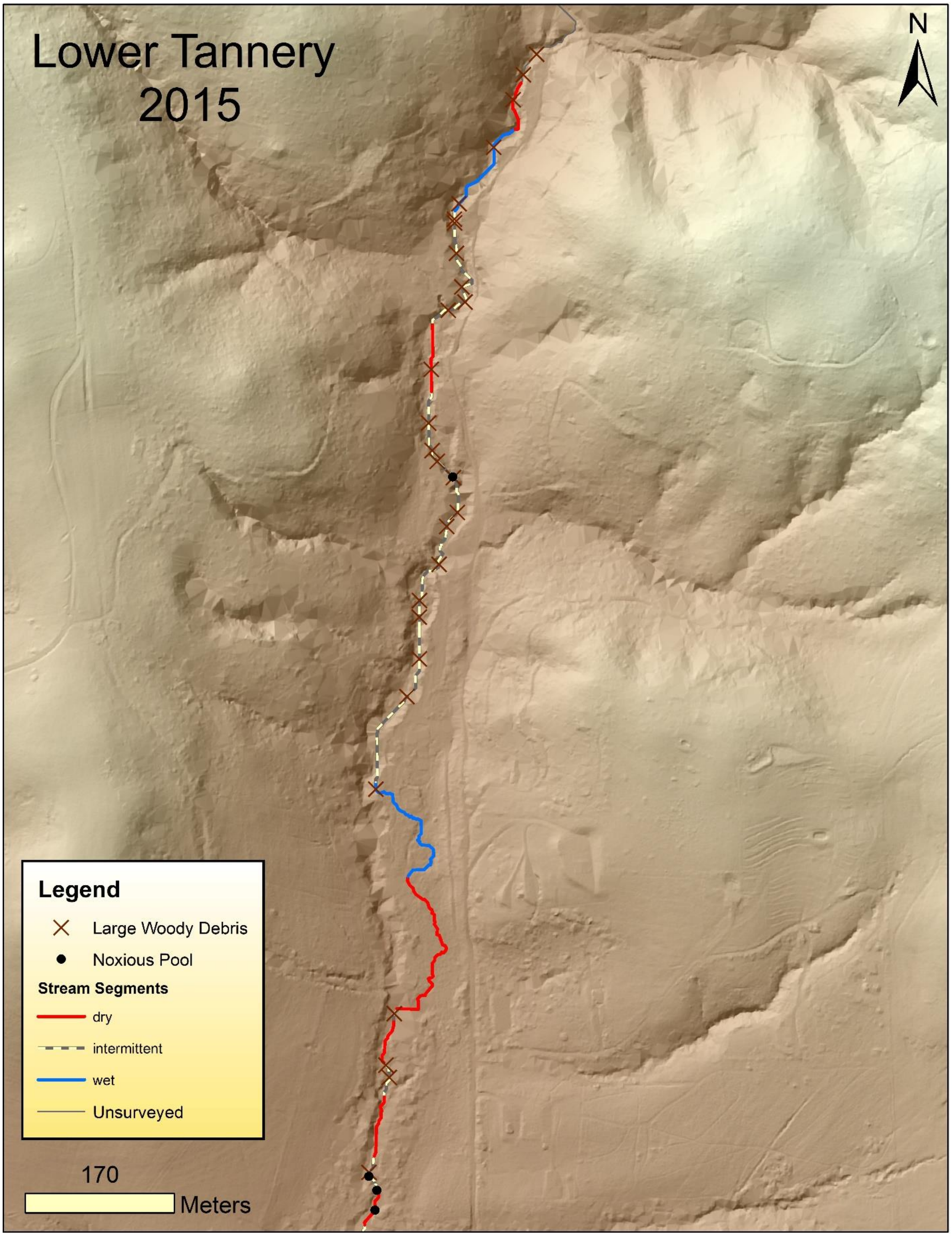
**Map 4:** Shows the surveyed reaches of Tannery creek in 2013, 2015-2017 side by side to compare actual reaches surveyed and changes is flow. As indicated throughout the report, 2015 was a much drier for the creek than 2017.



**Map 5:** Shows the surveyed reaches of Nolan creek in 2015-2017 side by side to compare actual reaches surveyed and changes is flow. As indicated throughout the report, 2015 was a much drier for the creek than 2017.



**Map 6:** An example of another useful combination of ecological observations showing the relation of noxious pools to large wood jams, this also shows the distribution of noxious pools.



**Map 7:** Pushpins depict assumed limits of anadromy, the assessment and layer creation was done by Cleo Woelfle-Erskine**;** highlighted lines indicate viable habitat.