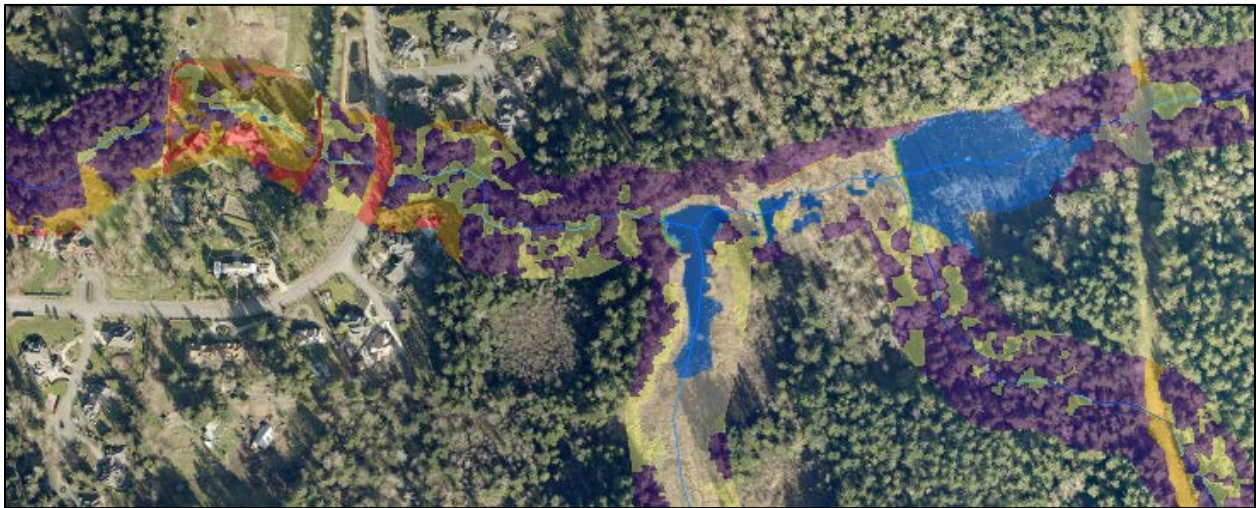

Assessment of Bear Creek Watershed Riparian Areas



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Assessment of Bear Creek Watershed Riparian Areas

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King County

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Natural Resources and Parks

Water and Land Resources Division

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EXECUTIVE SUMMARY

King County is required to conduct a watershed-scale stormwater planning effort to satisfy permit obligations under section S5.C.5.c.ii in the National Pollutant Discharge Elimination System Phase I Municipal Stormwater Permit issued by the Washington State Department of Ecology, effective August 1, 2013, modified January 16, 2015, and expiring July 31, 2018. This report characterizes riparian vegetation along Bear Creek and its larger tributaries within the study area and is intended to support development of the Bear Creek Watershed-Scale Stormwater Management Plan.

A riparian zone or riparian area is the interface between land and a river or stream. Natural riparian corridors provide an extremely wide range of highly valuable functions, including helping maintain good water quality and providing important habitat for a wide range of fish and wildlife. A riparian assessment was conducted to examine the current land cover in the riparian zone of the Bear Creek watershed, then the current land cover was compared to land cover in 1972 to see how the riparian corridor changed in that 43-year period.

Methods

All riparian analyses were conducted using a geographic information system (GIS) in ArcMap.

Stream Extent. All known streams where Chinook, sockeye, coho, kokanee, steelhead, and cutthroat trout were recorded in the study area were included in this analysis. Additionally, those reaches with suitable habitat were included, even if no salmonids had been documented or if an artificial barrier was present. A buffer size of 200 feet on each side of the stream centerline was chosen as the width of the riparian corridor to be analyzed because a buffer this size will capture any regulated riparian buffer critical area and generally capture the area regulated under Shoreline Management.

Study Corridor. To create the corridor study extent for riparian analysis in GIS, a uniform buffer of 200 feet on both sides of the streams centerline was created around the new stream study extent file. The resulting riparian study area totals 2,172.7 acres.

Land Cover Data. Existing federal and state land cover datasets were examined for possible inclusion in this riparian analysis. Those datasets were compared to a subsample dataset of visually verified land cover data in 16 reaches, and it was determined that none of the existing datasets were accurate enough at the scale of the riparian area to use for this analysis. Therefore, a new dataset was needed.

Washington Department of Fish and Wildlife impervious and forest land cover data were used as the basis of the new dataset. Aerial pictometry from 2015 was used to inspect the data systematically for errors of commission and omission, which were corrected as appropriate. Shrub, Water, Non-forested Wetland, Pasture, and Potential Beaver Dams were added during subsequent phases. All remaining unassigned polygons were classified as Other, which may include bare area, grass, mud, lawn/yard, landscaping, or roadside mowed areas.

After the land cover dataset was created, Shrub, Pasture, Other, and Non-forested Wetland polygons were attributed for the following conditions:

- Presence of invasive species (Himalayan blackberry or reed canarygrass)
- Clearing of native vegetation all the way to the stream edge, or lack of streamside vegetation shading.

The 2015 land cover data was clipped by catchments and regulated buffers. The study area is composed of 140 catchments; however, the riparian study extent extend into 70 catchments, and the 200-ft riparian study corridor extends into a total of 79 catchments. Corridors corresponding with regulated buffer widths of 165 ft and 150 ft of the stream centerline were clipped out of the riparian study corridor land cover, and they were further separated by County.

All land cover types attributed as having invasive species were analyzed by tabulating the total amount of area of each land cover type with invasive species. All polygons attributed as having no shade were intersected with the stream file to generate a line file that shows those reaches of streams and water bodies lacking of shade/native vegetation.

Change Analysis. Aerial infrared photos from 1972 were compared to 2015 pictometry to examine change in the riparian area over time. Because the resolution of the 1972 imagery is much lower (1.5 ft x 1.5 ft) than the 2015 imagery (0.25 ft x 0.25 ft), the exact same land cover classes could not reliably be used. With the 1972 classification, all impervious surfaces and disturbed areas (with the exception of pasture) were combined into a single class, Disturbed. The remaining 1972 land cover classes include Forest, Shrub, Water, and Non-forested Wetland.

Results and Discussion

Land Cover. The riparian study corridor in 2015 is composed of 2,172.7 acres with approximately 6.9 percent impervious surface and 46.7 percent forest/trees (see table below).

Land cover class	total acres	percent
Impervious	149.3	6.9
Trees/Forest	1015.2	46.7
Shrub	394.5	18.2
Non-forested Wetland	115.8	5.3
Other	265.3	12.2
Pasture	137.3	6.3
Possible Beaver Dam	0.6	0.03
Water	94.7	4.4
Total	2172.7	

An examination of land cover within the narrower buffers of 165 ft and 150 ft of the stream center line reveals that percentage of impervious surface decreases the narrower the corridor is—meaning, as the distance to the stream decreases, so does the amount of impervious surface. Impervious surface decreases from 6.9 percent in the 200-ft corridor to 5.8 percent in the 150-ft corridor. The percentage of forested area increases from the 200-ft corridor to the 165-ft corridor, but it does not increase further in the 150-ft corridor.

The northern portion of the watershed is in Snohomish County, which regulates stream buffers within 150 ft of the stream when salmonids are present. Impervious surface in the 150-ft riparian corridor in Snohomish County was 2.7 percent versus 5.8 percent in the 150-ft corridor throughout the study area. King County, which contains the largest portion of the watershed, regulates buffers within 165 ft of the stream when salmonids are present. Impervious surface in the 165-ft corridor in the King County portion of the watershed was 6.6 percent versus 6.2 percent in the entire study watershed.

The amount of area covered by invasive species is presented by land cover type for the 200-ft riparian study corridor in the table below.

Land cover class	Area (acres) covered by invasive species	Total riparian study area (acres) in land cover class	Percent of land cover class covered by invasive species
Non-forested Wetland	105.9	115.8	91.5
Other	15.1	265.3	5.7
Pasture	43.9	137.3	32.0
Shrub	158.5	394.5	40.2
Total	323.3	912.9	

Out of the 46.9 stream miles in the riparian study area, 17.3 miles (36.9 percent) were identified as lacking shade on one or both sides of the stream channel (Figure 8). Appendix B presents a table showing acreage lacking shade by catchment.

Change in Riparian Area over Time. Approximately 69 percent of the riparian zone in 1972 was native forest/shrub cover, compared to 2015’s total of approximately 58 percent, and disturbed areas (not including pasture) have increased from 13 percent to 27 percent over this time period (see table below).

Land cover	1972	2015
Disturbed (Impervious + Non-native Shrub + Other)	13.5%	26.4%
Native Vegetation (Forest/Trees + Native Shrub)	69.1%	57.6%
Forest/Tree only	68.6%	46.7%
Pasture	11.2%	6.3%

The infrared photos used in the change analysis were taken in 1972. Development in the study area was also just beginning to take off in the early 1970s. King County's Sensitive Areas Ordinance did not go into effect until 1990 and added 100-ft protective buffers to streams with salmonids. King County's Critical Areas Ordinance went into effect in 2005 and increased buffer size on streams with salmon or salmon habitat to 165 ft. Until 1990, the streams were afforded no protection from development in their riparian zones, and it wasn't until 2005, just 10 years prior to current conditions land cover, that buffer sizes were expanded to 165 ft. Although this part of the discussion is focused on King County regulations, the story is emblematic of the entire study area: much development had already occurred in the watershed by the time stream regulations were enacted.

Recommendations

The information presented in this report is to be used in the Bear Creek watershed plan, and any or all of the following recommendations could be conducted/implemented to improve and enhance our knowledge of the riparian area in the Bear Creek watershed and therefore contribute to any protection and restoration plans:

- **Improved study corridor extent.** Future work may include generating an updated study corridor extent by (a) correcting any stream channel locations that are mapped incorrectly, and (b) expanding the study corridor so it is based on ordinary high water mark (OHWM) of the streams.
- **Field Checking.** Field verification of (a) a subsample of the land cover areas attributed as having invasive species, and (b) a subsample of the Non-forested Wetland land cover is recommended in order to increase the veracity and reliability of the data.

1.0 INTRODUCTION

King County is required to conduct a watershed-scale stormwater planning effort to satisfy permit obligations under section S5.C.5.c.ii in the National Pollutant Discharge Elimination System Phase I Municipal Stormwater Permit issued by the Washington State Department of Ecology, effective August 1, 2013, modified January 16, 2015, and expires July 31, 2018. This report characterizes riparian vegetation along Bear Creek and its larger tributaries within the study area and is intended to support development of the Bear Creek Watershed-Scale Stormwater Management Plan.

A riparian zone or riparian area is the interface between land and a river or stream. Natural riparian corridors provide an extremely wide range of highly valuable functions. Healthy riparian areas, defined as being vegetated in native trees and shrubs, provide several functions that help maintain good water quality by filtering nutrients, sediments, and pathogens before they reach waterways. In addition to being important habitats for a wide range of wildlife (Knutson and Naef 1997), they are also considered essential for sustaining wild fish populations (Naiman et al. 1993).

Specifically, healthy riparian areas are important because they:

- improve water quality by filtering pollutants
- reduce stream bank erosion
- increase instream shade, which decreases water temperatures, which in turn support the higher dissolved oxygen levels important to salmonids
- provide a source for the natural recruitment of large wood into streams to create channel complexity needed for salmonid refugia and protection from predators
- provide over-hanging vegetation, a source of food (invertebrates) for juvenile salmonids

These riparian functions contribute to the health of the watershed and its biodiversity, including fish populations. The decline of native salmonid populations in the Pacific Northwest has been largely attributed to habitat loss and degradation (Yeakley et al. 2014). Riparian corridors contribute to instream functions and are a key component to improve salmonid habitat. Ultimately, restoring riparian areas will contribute to the restoration of the watershed, including fish, wildlife, and vegetation communities.

This riparian assessment will first examine the current land cover in the riparian zone. Then current land cover within the riparian study extent is compared to land cover in 1972 to see how the riparian corridor has changed in that 43-year period. The riparian land cover data may subsequently be used to help prioritize specific areas for restoration.

2.0 METHODS

This section describes how the extent of the riparian area selected to be analyzed was determined. Next, available GIS land cover data and the methods for generating new land cover data for this study are described. Finally, methods for conducting a change analysis are presented.

2.1 Extent of Riparian Analysis

The first step in conducting an analysis of land use/land cover in the riparian corridor is to establish the extent of the analysis. That is, it needs to be determined which streams and tributaries will be included in the analysis and how wide the corridor will be.

2.1.1 Stream Reaches

A Water Resource Inventory Area (WRIA) 8 salmonid distribution mapping project was undertaken in 1999 to map salmonid observations occurring between 1970 and 2000 (Kerwin 2001). All known stream extents within the study area where Chinook, sockeye, coho, kokanee, steelhead, and cutthroat trout were recorded in the study area were included in this analysis. Additionally, those reaches with suitable habitat were included, even if no salmonids had been documented or if an artificial barrier was present. The assumption for including those reaches is that salmonids could be present even if they had not been observed, or they could be there in the future with fish passage improvements.

Although the results from the salmonid mapping project provide the most comprehensive dataset in the study area for salmonid distributions, the locations of mapped reaches from those earlier observations do not match current stream locations (in some cases the streams were not originally mapped correctly and in other cases the stream channels have moved or been relocated). Stream data was last updated in 2006¹ and is currently the most accurate data available for stream channel location. The following methods were used to create this new dataset:

- Current stream reaches were clipped to the Bear Creek watershed study area.
- Salmonid presence and habitat data was compared to current stream reaches.
- Current stream reaches without salmonid presence or habitat data were removed.
- The salmon mapping project data included some reaches with no salmonid data (presumably mistakenly), so those reaches were eliminated.
- Two small tributaries with reported fish sightings in the Cottage Lake Creek basin in the fish mapping project were not in the stream file and were not included in the study extent.
- Because the current stream locations and the reaches in the salmon maps were not identical, some estimates had to be made about where to end the reaches – that is, where the fish distribution would have ended.

¹ Metadata may be found here: <http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=wtrcrs>.

- One large known mistake in the stream file was located at Lake Leota; in this instance the stream channel was corrected to reflect the actual stream flow path.
- The final stream extent is a total of 46.9 stream miles (Figure 1).

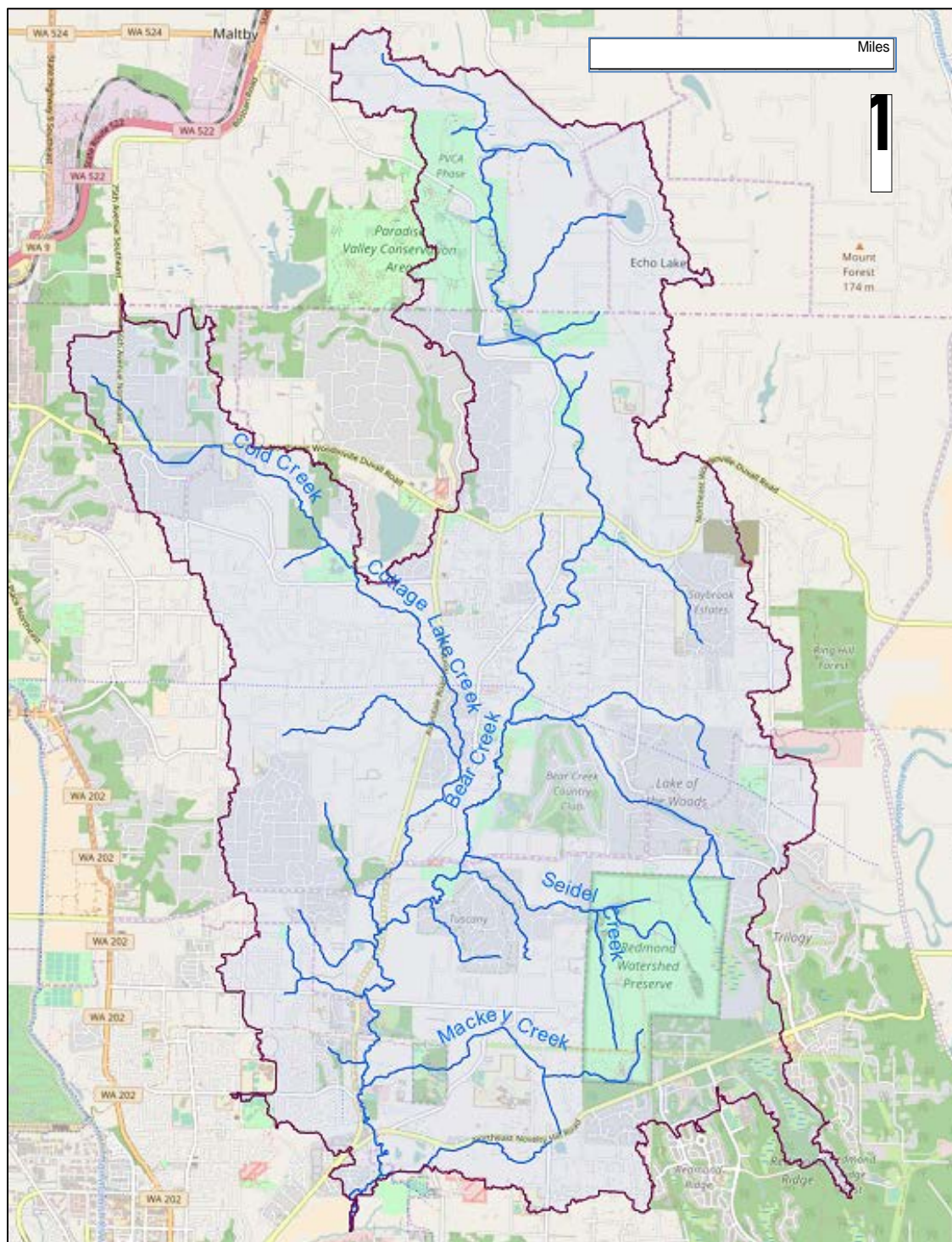


Figure 1. Stream reaches with salmonid presence or salmonid habitat in the study area.

Several caveats and assumptions were made regarding current stream reaches and salmonid survey data while creating this new dataset. It is assumed the stream data correctly represents the locations of streams. However, some stream reaches are not correct; for example, the stream attributed as the outlet of Echo Lake is drawn incorrectly (King County et al. 1989). Additionally, it is possible that some tributaries and reaches that were removed from the study extent because of a lack of salmonid data do in fact have salmon habitat and possibly salmon usage. And conversely, it is possible that some of the streams with historic observations of salmonids no longer sustain salmon usage. Nonetheless, the final stream study extent reflects the best available estimate of salmon and salmon habitat distribution based on the most current stream GIS data.

2.1.2 Regulatory Context

In both King and Snohomish counties, riparian areas are regulated as critical areas through the jurisdictions' respective ordinances and code. Both jurisdictions apply protective stream buffers based on the type of fish use in the stream. If salmonids are present, the following regulated buffers apply:

- 165 ft in King Co.
- 150 ft in Snohomish Co.

Another type of regulation that is relevant to riparian areas in the study area come from the state's Shoreline Management Act. All local jurisdictions with shorelines of the state present in them must establish their own Shoreline Master Program. Within the Bear Creek watershed, areas regulated under Shoreline Management jurisdiction are a minimum of 200 feet from ordinary high water mark (OHWM) in these locations:

- Streams larger than a mean annual flow of 20 cfs and their associated wetlands and floodplains (Bear Creek upstream to its confluence with Struve Creek, approximately the downstream-most 1.3 miles of Cottage Lake Creek, and approximately the downstream-most mile of Seidel Creek, plus the associated wetlands and floodplains of these water bodies).
- Lakes larger than 20 acres and their associated wetlands and floodplains (Cottage Lake plus adjacent wetlands).

2.1.3 Riparian Buffer Analyzed

A buffer size of 200 feet on each side of the stream centerline was chosen as the width of the riparian corridor to be analyzed because a buffer this size will capture the area regulated as critical areas and generally capture the area regulated under Shoreline Management. Because the corridor file was created based on stream centerlines and not OHWM, the entire Shoreline Management regulated area is typically not fully within the 400 foot corridor. Therefore, if there were ever a specific request to study land cover within the Shoreline Management jurisdiction regulated area in the watershed, some portions of the study corridor would need to be expanded.

To create the corridor file for riparian analysis, a uniform buffer of 200 feet on both sides of the streams centerline was created around the new stream study extent file (Figure 2). All segments in this file were merged into a single polygon. At the study area's watershed outlet, the watershed boundaries are narrower than 200 feet on each side of the stream, so in that location, only the riparian area within the watershed boundaries was included. The resulting riparian study area totals 2172.7 acres.

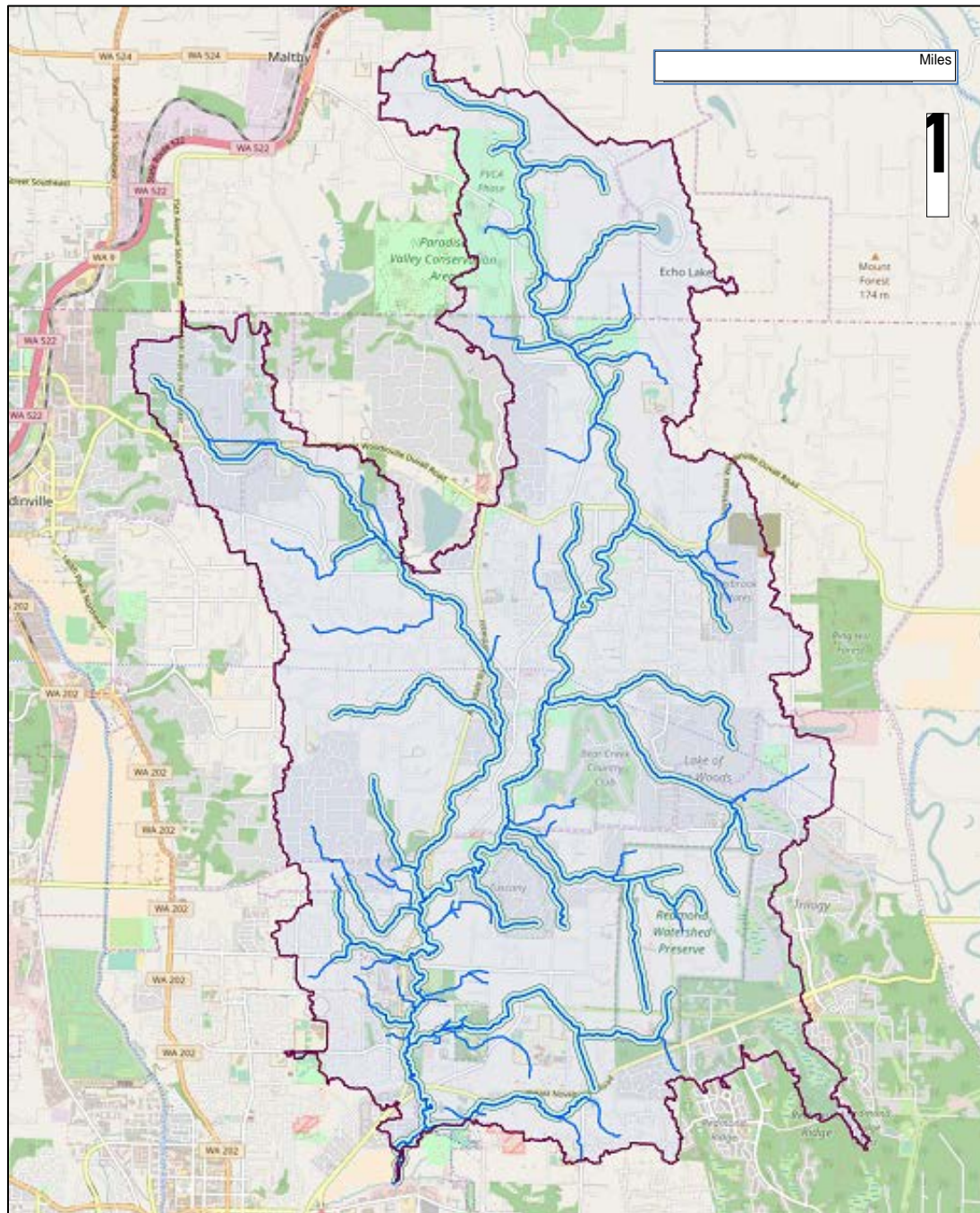


Figure 2. Stream corridor study extent is shown in light blue. Streams shown without the buffer corridor were not analyzed in this study.

There are at least two reasons why the riparian corridor might be misrepresented using this mapping method. First, any errors in mapping the location of stream channels would produce in-kind errors in the study corridor. These types of errors would exclude portions of the actual riparian corridor in the analysis and include non-riparian zone land cover.

The second potential cause of incorrectly mapped riparian areas is related to how the corridor was established. The study corridor was created based on stream centerlines; the widths of the actual streams (based on OHWM) were not taken into consideration, and therefore land cover in the entire 200-ft buffer from each side of the streams' OHWM was not mapped. Furthermore, in places where the stream centerline is drawn through a lake, the entire corridor shows as water. This approach falsely generates a higher percentage of water in the riparian zone.

Despite these sources of imprecision in reporting the riparian land cover, for the purposes of this land cover analysis, it is assumed that the riparian study corridor is generally representative of the riparian corridor in the study area.

2.2 Land Cover Datasets

Land cover datasets that were examined for possible inclusion in this riparian analysis are shown in Table 1 and described in detail below.

2.2.1 Coastal Change Analysis Program

The NOAA Coastal Change Analysis Program (C-CAP) produces national standardized land cover and change raster-based products for the coastal regions of the U.S. Data is based on 30-meter resolution Landsat imagery. In Washington, a dataset has been produced every 5 years (1992, 1996, 2001, 2006, and 2011). The 2011 C-CAP dataset uses a 25-class land cover classification scheme (NOAA 2011); there are 15 C-CAP land cover classes represented in our study extent (Table 1). The C-CAP dataset was examined for possible use in this analysis because it is an available land cover dataset covering the study area. However, because of the 30-meter resolution, C-CAP data is not intended for use at the scale of the riparian zone.

2.2.2 National Land Cover Database

The Multi-Resolution Land Characteristics (MRLC) Consortium is a group of federal agencies (including NOAA C-CAP) who coordinate and generate consistent land cover information at the national scale. This consortium has created a comprehensive raster-based land cover product termed the National Land Cover Database (NLCD) from decadal Landsat satellite imagery and other supplementary datasets. The 2011 dataset from NLCD is based primarily on a decision-tree classification of circa 2011 Landsat satellite data and is produced at a resolution of 30-meter pixels. The 2011 NLCD dataset uses a 16-class land cover classification scheme (Homer et al. 2015); 15 of the NLCD land cover classes are represented in our study extent (Table 1). Because of the 30-meter resolution, NLCD data is not intended for use at the scale of the riparian zone. Nonetheless, it was examined for possible use in this analysis.

Table 1. Available land cover datasets.

Dataset*	Description	# of classes	Coverage in study area	Years Available
Coastal Change Analysis Program (C-CAP)	30-meter resolution based on Landsat data	25; only 15 are found in study area	Complete	1992, 1996, 2001, 2006, 2011
National Land Cover Database (NLCD)	based upon CCAP data and the Anderson Level II scheme ; 30-meter resolution based on Landsat data	16	Complete	2001, 2006, 2011
Washington Department of Fish and Wildlife (WDFW)	Based on National Agriculture Imagery Program (NAIP) data; still in “draft” stage	12 in 2011 10 in 2013 both include “unclassified”	Partial; missing areas at north end of watershed	2011 2013

2.2.3 Washington Department of Fish and Wildlife Data

The Washington Department of Fish and Wildlife (WDFW) obtained National Agricultural Imagery Program (NAIP) orthoimagery data and used modeling tools to assign land cover classes (K. Pierce, pers. comm.). WDFW conducted this process with 2011 and 2013 NAIP data, and worked to refine their methods from 2011 to 2013. As a result of their changes in methodology, the land cover class categories changed slightly, and the assignment of land cover classes to polygons also changed in many locations despite the landcover itself not changing. These data are unmoderated (are modeled and not spot-checked for accuracy) and therefore are considered draft. The 2011 and 2013 NAIP data is at 1-meter resolution and includes much of the study area but not all of it.

2.3 Checking the Accuracy of Available Land Cover Data

To determine whether any of the available datasets were adequate for this riparian analysis, a grid method was established for checking the accuracy of land covers.

2.3.1 Reach Grids

A subsample dataset of the riparian area land cover was made by utilizing 16 reaches that had been established via random selection for an earlier WRIA-8 land cover study (King County 2011; Figure 3). Subsample stream reaches are 500m in length and are approximately 70 meters wide on each side of the stream centerline (for a buffer size of approximately 200 feet on each side of the stream centerline). Each stream reach was gridded into 10x10 meter squares to visually determine and hand select land cover classes based on 2015 King County natural color imagery (pictometry).

The same five land cover classes established for the 2011 study were used for the reach grid classification:

- Forest/Tree
- Shrubs
- Impervious
- Water
- Other (may be grass, lawn, ornamental landscaping, rock, mud)

The 16 reach grid sets represent all grid sets previously established for the 2011 study that fell within the current study area. Because the reach grid sets were previously established only on streams and tributaries that had known (including past) use by Chinook and coho salmon, the stream coverage was not as extensive as that of this riparian study area, which includes all streams and reaches with known or potential presence of any salmonid, including cutthroat trout. In one instance, a reach grid set from the 2011 study inadvertently included an area with no salmonid use; that set was trimmed for this study to

only cover the reach length with presumed salmonid distribution. That particular resulting reach grid set was only 315 meters in length.

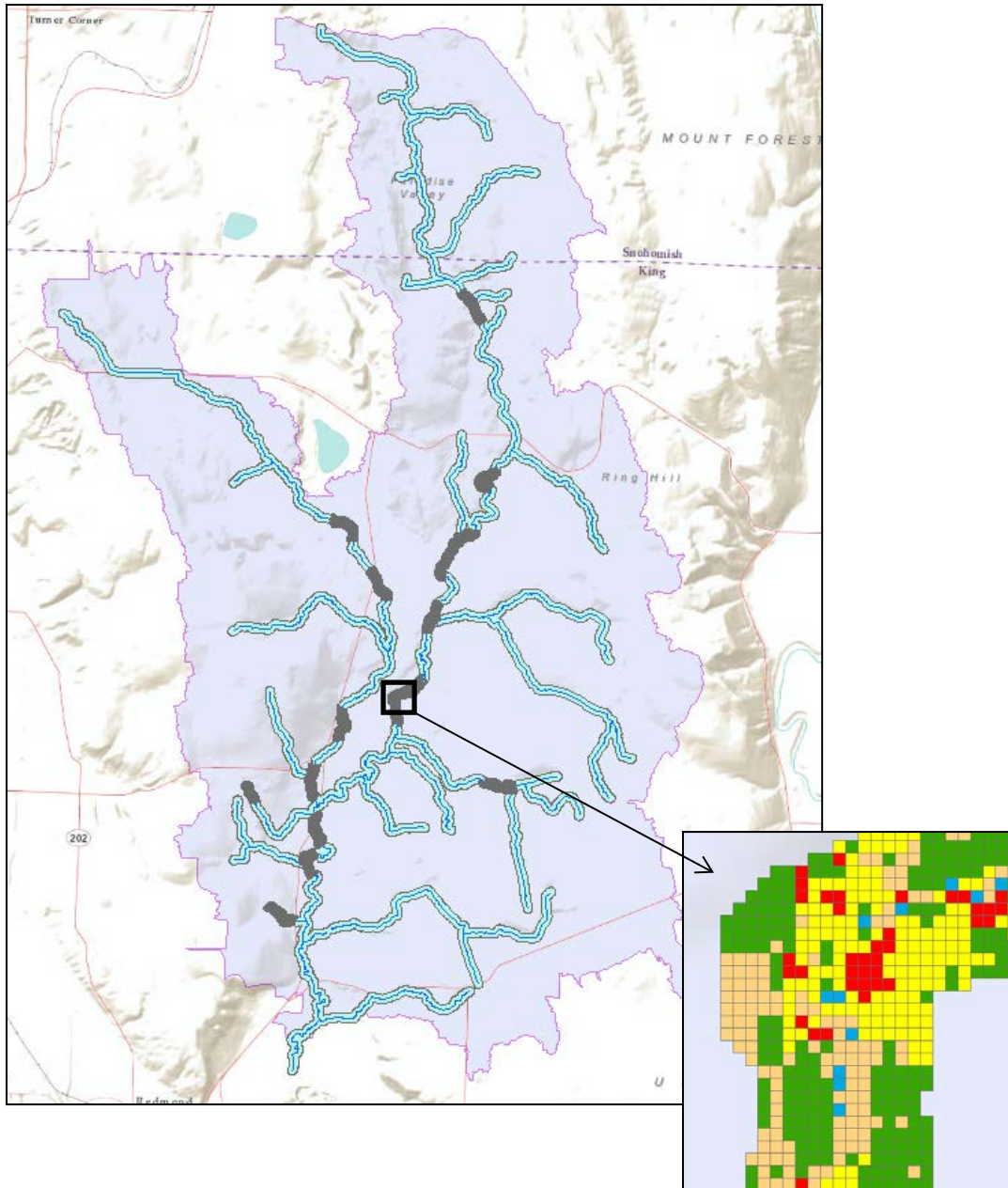


Figure 3. Gray areas along the riparian corridor indicate the locations of the grid reaches. An inset example shows how the reach grids appear close up once land cover classes have been assigned.

For those grid squares with more than one land cover type present, the land cover class with the largest percentage coverage as determined visually was chosen. As with all pixel-based land cover data, a certain percentage of error is assumed, because the landscape does not exist in pixel-shaped features. That is, even with the relatively small resolution size of 10x10m, any feature covering less than half that size within a particular square will

potentially be subsumed into an adjacent land cover class, even if the feature is larger than 10x10m but is split across multiple squares. It is assumed that over large areas, these errors of scale cancel each other out, and the resulting totals and averages are relatively accurate representations of what is on the ground. A summary of reach grid land cover data from 2015 is presented in Table 2.

Table 2. Percent of land cover classes in the reach grid land cover dataset.

Land cover class	Percent
Forest/Tree	46.0
Shrub	19.2
Impervious	12.7
Water	2.8
Other	19.3

The grid square data generated using these methods could be used to extrapolate the percent land cover classes throughout the riparian corridor. However, because other more extensive datasets are available, the best use of the grid square data is to gauge the accuracy of those other datasets, which have more land cover classes and would be more useful overall in analyzing riparian land cover.

2.3.2 Comparing Land Cover Datasets

Because the grid square land cover classes were manually assigned based on aerial imagery, the grid square land cover dataset is assumed to be the most accurate land cover dataset available for the study area. Because of its relatively high level of accuracy, it can be compared to the other available land cover datasets to potentially identify which is the most accurate and should be used for the riparian land cover analysis.

To compare the reach grid land cover data with other available land cover datasets, each of the land cover datasets were clipped to the same subsample grid reach extent. Once each dataset was clipped, the next step was to check to see how closely the percentages of each land cover class matched up. However, because of the very few land cover classes (five) in the reach grid dataset, in order to compare that dataset to other land cover datasets, land cover classes in the other datasets were grouped together. This grouping involved a fair degree of subjectivity.

The 2013 WDFW data is presented in Table 3 as an example of grouping. That dataset had the fewest land cover classes of the other available datasets so it required the least amount of grouping.

Table 3. Example scheme for translating 2013 WDFW land cover classes into the five reach grid classes.

WDFW categories	WDFW Descriptions	Translated reach grid categories
FinalBuilt	Impervious	Impervious
FinalBuiltBrownRed	Impervious	Impervious
FinalCoarseVegetation	Tree	Forest/Tree
FinalDirt	Bare Ground	Other
FinalFineVegetation	Herbaceous	Other
FinalMedium	Shrub	Shrub
FinalWater	Water	Water
PotentaiNonVegetatedWetland	Near stream/riparian area	Water
PotentaiVegetatedWetland	This class, which is land cover near stream/riparian areas, has errors (K. Pierce, pers. comm.)	To account for vegetation, this class is estimated to be 35% Shrub, 30% Forest/Tree, and 35% Other.
Unclassified	No data	Other

Once land cover classes were translated for each dataset into the five-class scheme of the reach grid land cover data, the results were compared (Table 4). Note that the C-CAP and NLCD datasets are at a resolution of 30 meters. Because the C-CAP and NLCD classification schemes are used to describe relatively large areas, those datasets include three separate impervious classes, which include varying amounts of non-impervious land cover. Translating those classes involved using math formulas and averages based on the class definitions and assumptions about what other land covers was in each class besides impervious surface.

Table 4. Results of translating available land cover data into reach grid land cover classification.

Land cover Class	Reach grid data	Translated land cover data			
		2011 WDFW	2013 WDFW	2011 NLCD	2011 C-CAP
Forest/Tree	46.0%	34.90%	60.36%	30.29%	39.43%
Shrub	19.2%	17.90%	18.93%	12.99%	18.84%
Impervious	12.7%	10.90%	8.66%	56.27%	21.39%
Water	2.8%	0.23%	0.39%	0.20%	0.31%
Other	19.3%	36.07%	11.67%	0.26%	20.02%

The land cover dataset that comes closest to matching the reach grid land cover data is the 2013 WDFW data. But when that data was visually checked against the 2015 pictometry, there were numerous large errors throughout the riparian corridor. Therefore, none of the available external datasets matched the reach grid data well enough across all five cover classes to confidently use as the basis of this riparian analysis. Part of the reason for such variable results may be the translations, which would be challenging to confidently improve on. Plus, as noted above, the C-CAP and NLCD data are not intended for use at this scale (the entire 400 foot corridor is only 4 pixels wide). This exercise made it clear that for

a relatively accurate picture of land cover in the riparian corridor, none of the available external datasets are considered adequate.

2.4 New Riparian Land Cover Dataset

After it was determined that none of the available land cover datasets are well suited for this riparian analysis, the creation of a new riparian land cover dataset was undertaken.

2.4.1 Building the New Dataset

Arguably, the two most important land cover classes in this analysis are forest/trees and impervious surface. If those were the only two classes used in a classification scheme, one would be able to determine not only where forest is present, but where it is absent. And the impervious data may be used to account for the amount and location of impervious surface in the riparian area. The available land covers were inspected to select the best available source for forest/tree and impervious land cover classes to use as the basis for the new dataset.

The 2011 WDFW forest/tree land cover was used as the basis of the new dataset because it appeared to be the best available source for forest data. The “FinalCoarseVegetation” was clipped to the riparian corridor and exported into its own shapefile. For impervious surfaces, the 2013 WDFW dataset appeared to be best available data of the four datasets. So the “FinalBuilt” and “FinalBuiltBrownRed” polygons were clipped to the riparian corridor and exported into a new file.

The impervious data in entire riparian study area was examined systematically, and errors of commission and omission were edited to improve the data. Aerial pictometry from 2015 was primarily used during this process, but 2013 King County orthoimagery was also used where shadows in the 2015 imagery made it difficult to identify the land cover class or boundaries. Houses, buildings, tennis courts, sidewalks, and other impervious surfaces that were missing in the dataset were added.

Because it was observed that many road surfaces were missing from the impervious file, the King County roads line file was used to ensure all roads (one component of impervious surfaces) were captured. Every road segment that fell within the riparian study area was systematically checked and all missing road surfaces were added to the impervious file. As the road segments were checked, other improvements to the data were made simultaneously. That is, revisiting many of the areas in the riparian corridor allowed for a second sweep of the built environment, and more corrections were made to the impervious data. Gravel and dirt roads and gravel parking areas were also included in the impervious layer. Some gravel roads were likely incomplete because they were obscured by tree canopy cover.

Once the impervious layer was considered complete, it was combined with the forest data. Anywhere impervious surface overlapped vegetation, the vegetation was automatically removed. In other words, there are no overlapping polygons, and impervious surface was

always prioritized over vegetation, because although trees absorb some rain, impervious surface never absorbs water and creates runoff.

Because the base forest/tree and impervious features came from the WDFW data, which is based on pixels, the resulting file contains a mix of pixelated and hand-drawn edges. In many instances the WDFW polygons were off-set slightly from the pictometry images, but polygons were not redrawn if they appeared to generally capture the correct amount of area.

The entire riparian study corridor was then systematically viewed at a scale of about 1:1,500. Where forest/trees were missing, they were hand drawn in, and where forest/trees were identified in the data but were not actually present, the land cover data was edited accordingly. A portion of the riparian corridor within Snohomish County was incomplete, so forest/trees were hand drawn in that entire area. During the process of refining the forest/tree data, the impervious data was further refined: errors of both omission and commission continued to be corrected.

Next, the entire corridor was examined systematically so that additional land cover classes could be added and assigned. Shrub, Water, Non-forested Wetland, and Pasture were added during this process. Additionally, Potential Beaver Dams were also added where they were apparent. All remaining unassigned polygons were classified as "Other," which may include bare area, grass, mud, lawn/yard, landscaping, or roadside mowed areas.

The final set of land cover categories in the new dataset are:

- Trees
- Impervious
- Shrub
- Water
- Non-forested wetland
- Pasture
- Potential beaver dam
- Other

Figure 4 provides an example of what the new dataset looks like.



Figure 4. Example detail of the new riparian land cover dataset.

After the above steps, hundreds of sliver (very small) polygons resulted from the merging and clipping of the two base datasets. A few hundred polygons registered as smaller than 0.000025 acres, and these polygons were systematically merged with the appropriate adjacent polygons. Although it is unlikely that any meaningful polygons would be smaller than 0.00009 acres (4 ft²) in size, no specific effort was made to merge polygons that were 0.000025 acres or larger.

2.4.2 Attribute Table

The main focus in creating the new riparian land cover dataset was to delineate and classify the land cover in the riparian study area. After the land cover dataset was created, Shrub, Pasture, Other, and Non-forested Wetland polygons were attributed for the following conditions:

- Presence of invasive species (Himalayan blackberry or reed canarygrass)

- Whether the riparian zone has been cleared of native vegetation all the way to the stream or pond edge, or whether the vegetation present did not create shade over the stream edge
- Whether the polygon/habitat patch is on publicly owned lands (and if only partially, the approximate percentage)

Because there were over 5,000 Shrub, Pasture, Other, and Non-forested Wetland polygons, it was not feasible to view all of them for attribution. Pasture and Non-forested Wetland polygons attribution was completed. Shrub and Other polygons were attributed beginning with polygons closest to the stream centerline and working outwards. At the time of writing, 451 Shrub polygons totaling 19.0 acres and 1482 Other polygons totaling 26.4 acres had not been examined for attributing. Altogether, a total of 45.4 acres have not been attributed. These 45.4 unattributed acres account for only 5 percent of the total area of Shrub, Pasture, Other, and Non-forested Wetland polygons but for 38 percent of the polygons (average unattributed polygon size is 0.02 acres). Note these numbers will be reduced as the data is analyzed, modified, and further corrected.

Impervious, Trees, and Water polygons were not checked for invasive species or lack of vegetation to the stream edge.

This process afforded yet another opportunity to check the data: during the attribution process, any obvious errors detected in labeling or polygon boundaries were corrected.

2.4.3 Clipping the Land Cover Data

The land cover data may be clipped in different ways for analysis. For example, it may be clipped to examine catchments or subbasins or regulated buffers.

2.4.3.1 Catchments

A catchment is defined as an area of land where all rain falling on the ground eventually ends up at the same point. The contributing area of a catchment generally is defined at junctions of other streams, features in the landscape that control runoff (road crossings, stormwater ponds, etc.), or geographic constraints. Multiple catchments can make up a basin, multiple basins can make a watershed. Identifying land cover by catchment enables analysis of riparian conditions at the catchment level.

The study area is composed of 140 catchments; however, the riparian study extent does not extend into all 140 catchments. Streams in the riparian study extend into 70 catchments, and the 200-ft riparian study corridor extends into a total of 79 catchments. In many instances, the 200-ft buffer around a stream reach in one catchment extends partially into one or more adjacent catchments.

Once the new riparian land cover dataset was completed, the Union function in ArcMap was applied to it so that all land cover polygons were clipped to the catchments they are in and identified as such.

2.4.3.2 Regulated Buffers

Regulated riparian buffers smaller than 200 feet can be clipped out and analyzed separately. Corridors corresponding with regulated buffer widths of 165 ft and 150 ft of the stream centerline were clipped out of the riparian study corridor land cover (Figure 5).

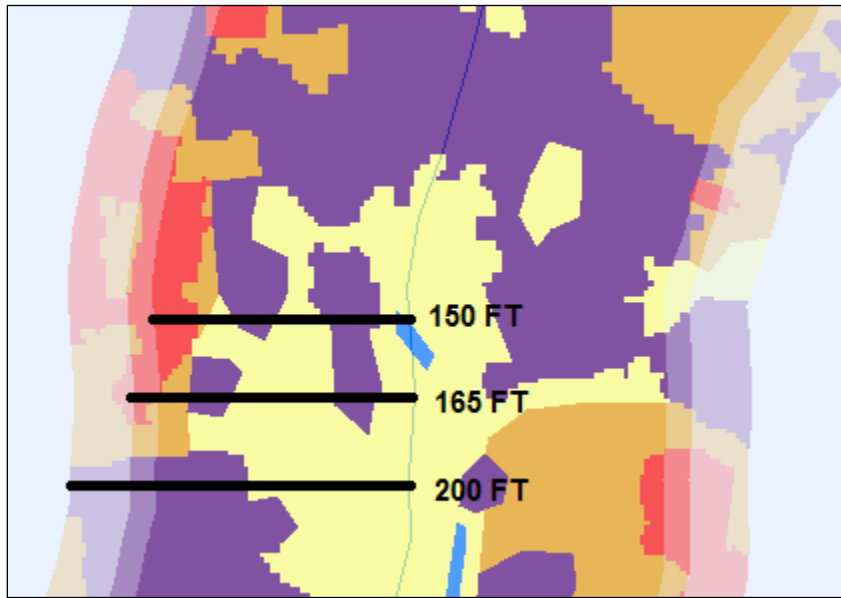


Figure 5. The riparian land cover data can be clipped at different distances from the stream center line.

2.4.4 Invasive Species

Because the land cover dataset is attributed with whether invasive species are present (reed canarygrass and Himalayan blackberry), it is possible to account for infested acreage by invasive species. All land cover types attributed as having invasive species was tabulated.

Stream surveys in the Bear Creek system have been undertaken by Forterra to locate and map Japanese knotweed with the intention of long-term systematic control and removal. Those data are presented in this report.

2.4.5 Unshaded Stream Analysis

As described above, all Shrub, Pasture, Other, and Non-forested Wetland polygons were attributed for whether the riparian zone had been cleared of native vegetation all the way to the stream edge or whether the vegetation present did not create shade over the stream edge. Polygons vary in shape and location with respect to the stream: some may be located on only one side of the stream, whereas others span both sides of the stream. When a polygon was attributed as lacking shade, the portion not providing shade could encompass the entire polygon or just a portion of it. Therefore, rather than rely on polygons for the

unshaded stream analysis, it was determined that a line file to represent the portions of the stream lacking shade would be most useful in analyzing and reporting on locations lacking in the riparian study area.

All polygons attributed as having no shade (unshaded) were intersected with the watercourse file to generate a line file that shows those reaches of streams and water bodies lacking of shade/native vegetation. Land cover polygons classified as “Water” were also used in the creation of this unshaded line file, because typically if the stream was visible enough to be mapped as a polygon, that meant it lacked shade. Because of the way the polygons were attributed and the line file built, it is not possible to indicate whether the shade is lacking on one or both sides of the stream.

Once the unshaded line file was built, the entire study corridor was visually inspected for mistakes (streams lacking shade that had been missed during the intersection process) and corrected as needed (polygons attributes were corrected and associated reaches added to the line file). The unshaded line file was then clipped to the catchments to account for where the unshaded stream reaches are located.

2.5 Land Change

Vegetated riparian areas serve numerous functions (see Introduction), and loss of native vegetation and increases in the amount of impervious surface inside riparian corridors can negatively impact riparian functions. A land change analysis can provide information about how much the riparian corridor has changed over time and provide historical context for potential changes in the watershed’s riparian function.

Comparing today’s riparian conditions with historic aerial images can be challenging. Aerial photos covering the entire watershed from more than 10 years ago are lower resolution compared with what is available today. The oldest available aerial imagery in GIS and covering the entire study area is infrared photos from 1972. The pixel resolution is 1.5 ft x 1.5 ft, as compared to the 2015 photo resolution of 0.25 ft x 0.25 ft.

Because the resolution of the 1972 imagery is much lower than the 2015 imagery, the exact same land cover classes could not reliably be used. The main difference in classification is that with the 2015 photos, it is possible to distinguish clear lines between buildings, driveways, sidewalks, lawns, and surface types such as gravel, cement pavement, and bare ground. In the 1972 photos, the boundaries of specific features can generally not be distinguished (Figure 6). With the 1972 classification, all impervious surfaces and disturbed areas (with the exception of pasture) were combined into a single class, Disturbed.

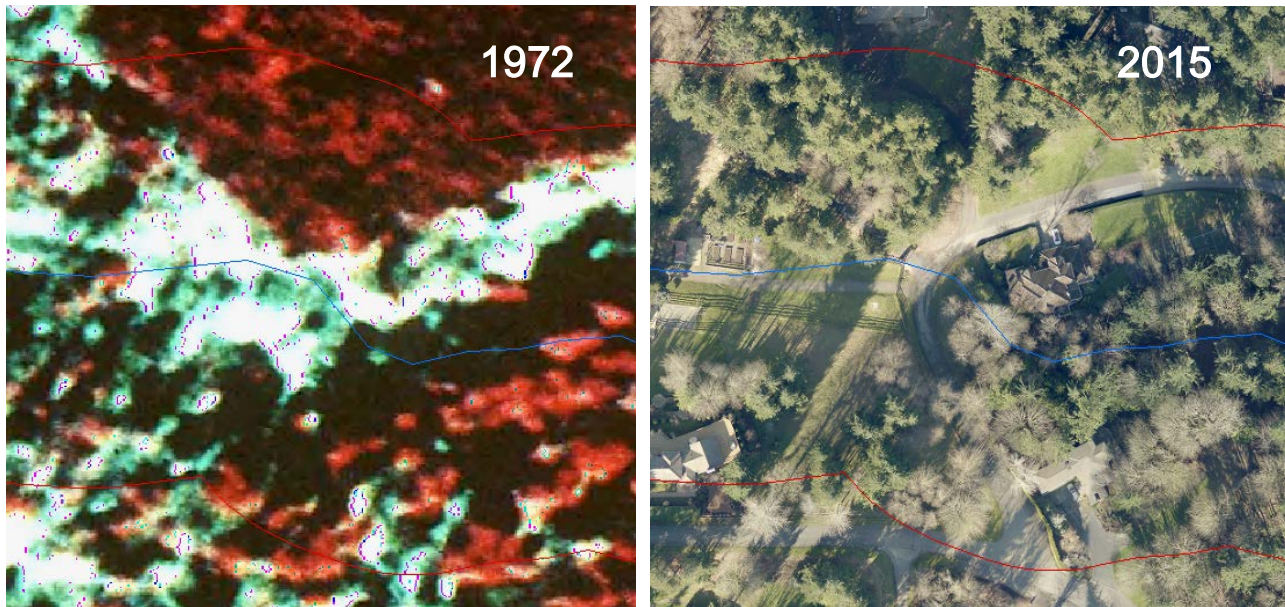


Figure 6. Detail showing the difference between 1972 and 2015 aerial imagery. In the 1972 photo, disturbed areas appear white or light aqua blue, whereas different types of disturbed areas can be easily distinguished in the 2015 photos.

For the 1972 classification, the following land cover classes were used:

- Disturbed
- Forest
- Shrub
- Pasture
- Water
- Non-forested Wetland

In order to compare land cover across aerial imagery years made with very their different resolutions, it was necessary to group some of the classes together. Table 5 presents the land cover type cross-walk.

Table 5. Grouping of land cover classification types used in 1972 and 2015.

1972	2015
Disturbed	Impervious Shrub - invasive Other
Forest Shrub	Forest/Trees Shrub - native
Non-forested Wetland	Non-forested Wetland Possible Beaver Dam
Pasture	Pasture
Water	Water

Percentages were calculated to compare the composition and area of each land cover type between years 1972 and 2015 to look at changes in the riparian corridor.

3.0 RESULTS AND DISCUSSION

This section provides the results of the current conditions and change analyses. Each set of results is accompanied by a discussion of the findings.

3.1 Land Cover in the Riparian Area

The riparian study area in 2015 is composed of 2,172.7 acres with approximately 6.9 percent impervious surface and 46.7 percent forest/trees (Table 6).

Table 6. Landcover within the 400 ft corridor (200 ft on each side of stream centerline) in the 47-mile riparian study extent.

Land cover class	total acres	percent
Impervious	149.3	6.9
Trees/Forest	1015.2	46.7
Shrub	394.5	18.2
Non-forested Wetland	115.8	5.3
Other	265.3	12.2
Pasture	137.3	6.3
Possible Beaver Dam	0.6	0.03
Water	94.7	4.4
Total	2172.7	

3.1.1 By Catchment

The total amount of area of land cover in the riparian study extent is presented by catchment in Appendix A. Riparian data by catchment is reported for whichever catchment the riparian land cover falls in, even if the stream reach itself is in a different catchment.

3.1.2 By Regulatory Buffer

Land cover in corridors corresponding with regulated buffer widths were examined. Riparian land cover within 165 ft and 150 ft of the stream center line were clipped to compare against the 200-ft corridor (Table 7). The percentage of impervious surface decreases the narrower the corridor is – meaning, as the distance to the stream decreases, so does the amount of impervious surface. Impervious decreases from 6.9 percent in the 200-ft corridor to 5.8 percent in the 150-ft corridor. The percentage of forested area increases from the 200-ft corridor to the 165-ft corridor, but it does not increase further in the 150-ft corridor. Land cover types that do occupy consecutively larger percentages as the corridor narrows include Shrub, Non-forested Wetland, and Water. In addition to impervious, other land cover types that decrease as the corridor narrows include Other and Pasture.

Table 7. Landcover within three different distances from the stream center line: 200 ft, 165 ft, and 150 ft in the 46-mile riparian study extent.

Land cover class	200 ft		165 ft		150 ft	
	acres	percent	acres	percent	acres	percent
Impervious	149.3	6.9	111.7	6.2	95.8	5.8
Trees/Forest	1015.2	46.7	846.0	46.8	771.6	46.8
Shrub	394.5	18.2	351.2	19.4	331.5	20.1
Non-forested Wetland	115.8	5.3	104.3	5.8	98.7	6.0
Other	265.3	12.2	199.7	11.1	173.4	10.5
Pasture	137.3	6.3	106.4	5.9	93.6	5.7
Possible Beaver Dam	0.6	0.03	0.6	0.04	0.6	0.04
Water	94.7	4.4	86.2	4.8	82.1	5.0
Total	2172.7		1806.1		1647.3	

Different jurisdictions use different protective buffer sizes, so the data may be separated out by jurisdiction. Snohomish County regulates buffers within 150 ft of the stream when salmonids are present. As a jurisdiction, the data in Table 8 may be much more useful, as it is quite different in terms of impervious surface in the riparian corridor (5.8 percent in the 150-ft corridor throughout the study area versus 2.7 percent in the 150-ft corridor in Snohomish County).

Table 8. Land cover within 150 ft of stream center line in Snohomish County.

Land cover class	total acres	percent
Impervious	5.3	2.7
Trees/Forest	89.6	46.0
Shrub	18.2	9.4
Non-forested Wetland	47.8	24.5
Other	16.3	8.4
Pasture	6.4	3.3
Possible Beaver Dam	0.2	0.1
Water	11.1	5.7
Total	195.0	

King County regulates buffers within 165 ft of the stream when salmonids are present. Table 9 reveals a higher percentage of impervious surface in the 165-ft corridor in the King County portion of the watershed (6.6 percent) versus in the entire study watershed (6.2 percent).

Table 9. Land cover within 165 ft of stream center line in King County.

Land cover class	total acres	percent
Impervious	105.5	6.6
Trees/Forest	746.3	46.9
Shrub	331.0	20.8
Non-forested Wetland	53.7	3.4
Other	181.3	11.4
Pasture	99.3	6.2
Possible Beaver Dam	0.4	0.03
Water	74.6	4.7
Total	1591.9	

3.1.3 Invasive Species

The amount of area covered by invasive species is presented by land cover type for the 200-ft riparian study corridor in Table 10 and illustrated in Figure 7. Appendix B presents a table showing invasive acreage by catchment.

Table 10. Area within the riparian study extent with invasive species present. Invasive species here are Himalayan blackberry and reed canarygrass.

Land cover class	Area (acres) covered by invasive species	Total riparian study area (acres) in land cover class	Percent of land cover class covered by invasive species
Non-forested Wetland	105.9	115.8	91.5
Other	15.1	265.3	5.7
Pasture	43.9	137.3	32.0
Shrub	158.5	394.5	40.2
Total	323.3	912.9	

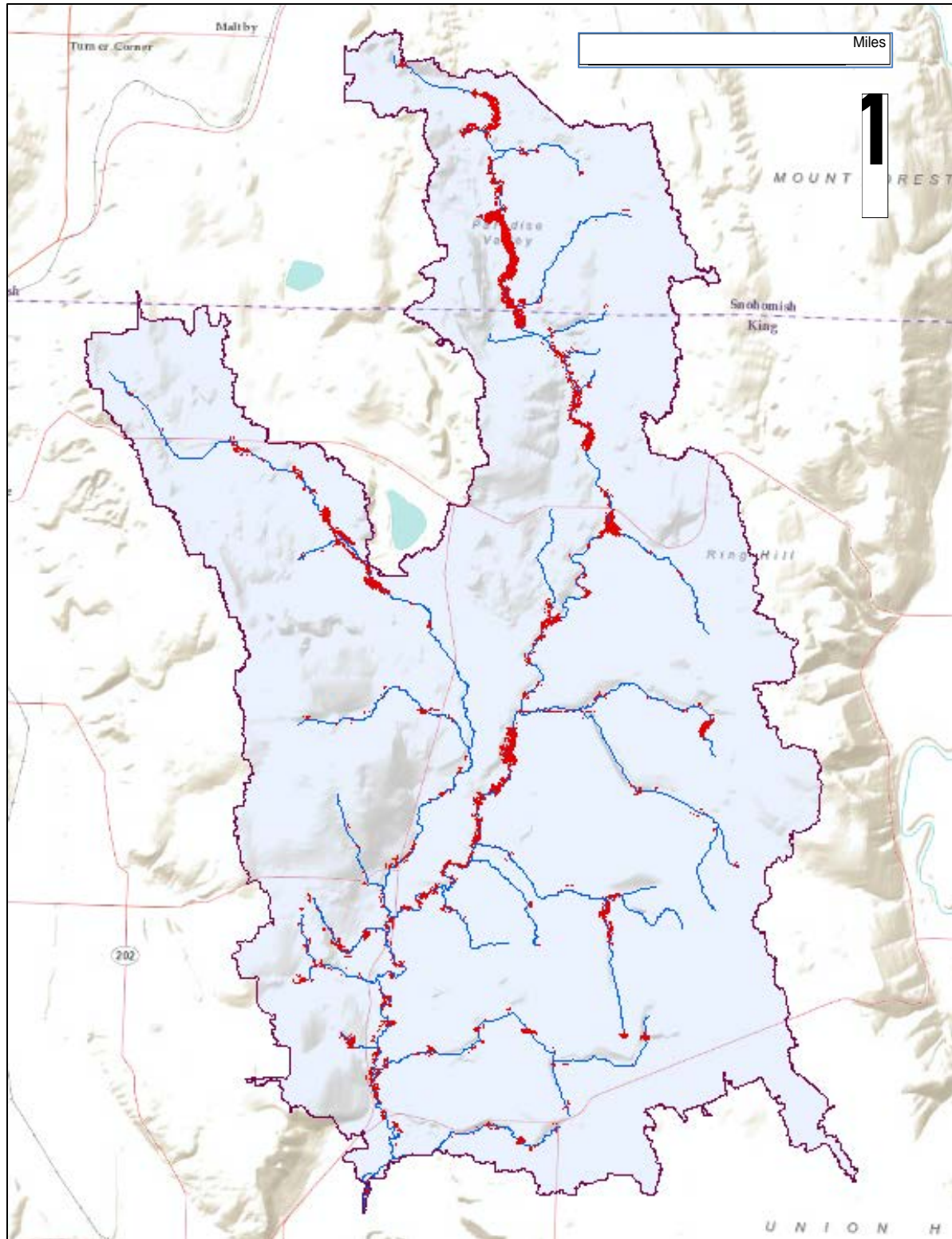


Figure 7. Areas with invasive species (Himalayan blackberry or reed canarygrass) present shown in orange.

3.1.4 Streams Lacking Shade

Out of the 46.9 stream miles in the riparian study extent, 17.3 miles (36.9 percent) were identified as lacking shade on one or both sides of the stream channel (Figure 8). Appendix B presents a table showing acreage lacking shade by catchment.

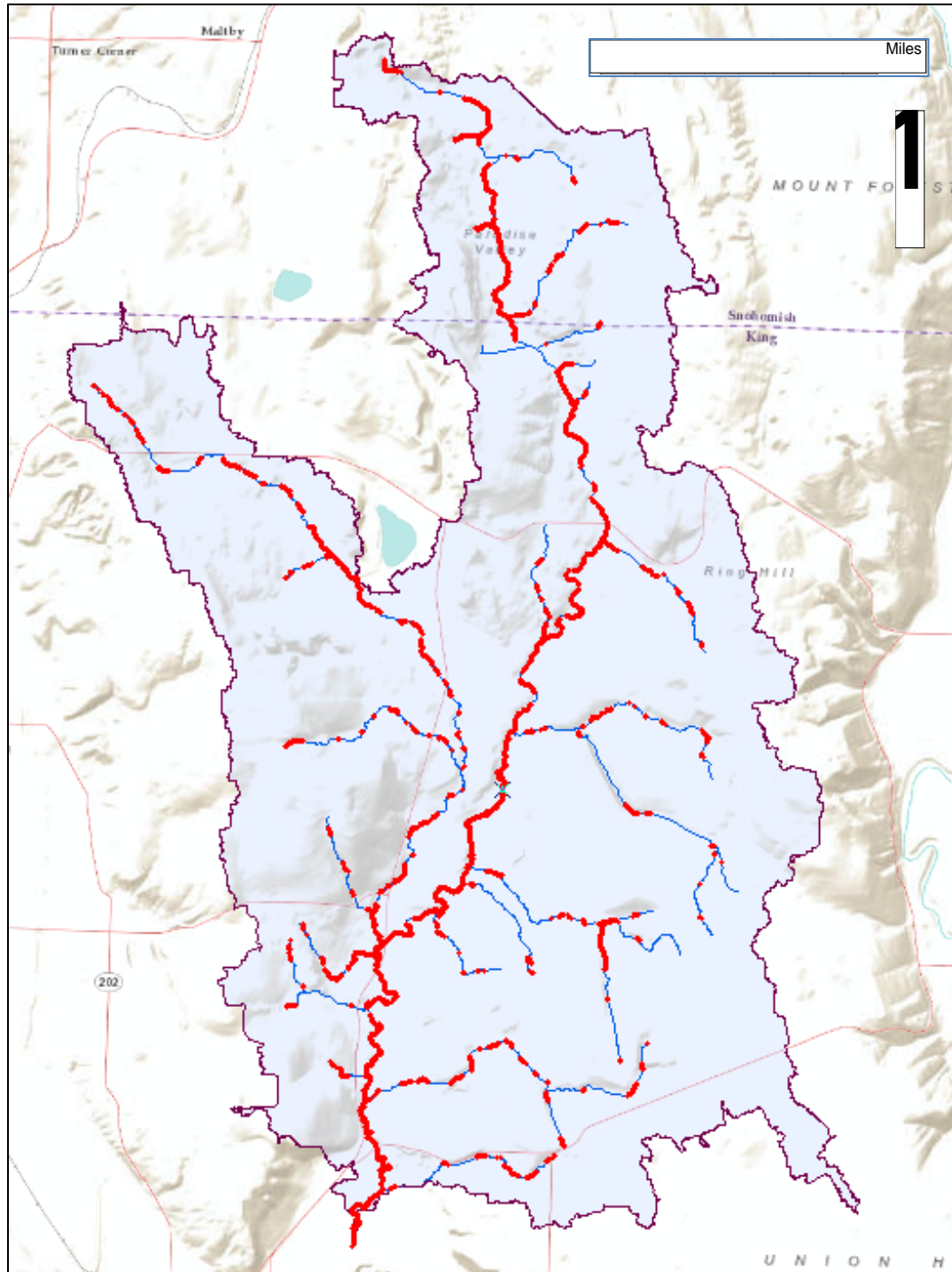


Figure 8. Stream lacking shade on one or both sides is shown in red.

3.2 Change in the Riparian Area Over Time

Land cover within the riparian study extent based upon 1972 aerial infrared photos is shown in Table 11.

Table 11. 1972 land cover within the 400 ft corridor based on color infrared aerial imagery.

1972 Land cover	Acres	Percent
Disturbed	290.3	13.4
Forest	1491.5	68.8
Wet Vegetation	61.6	2.8
Shrub	6.3	0.3
Pasture	247.1	11.4
Water	70.0	3.2
Total	2166.9	

Table 12 summarizes the changes in land cover between 1972 and 2015. Approximately 69 percent of the riparian zone in 1972 was native forest/shrub cover, compared to 2015's total of approximately 58 percent, and disturbed areas (not including pasture) have increased from 13 percent to 27 percent over this time period.

Table 12. Comparison of major classes of land cover between 1972 and 2015 (numbers are percent of riparian study extent).

Land cover	1972	2015
Disturbed (Impervious + Non-native Shrub + Other)	13.5%	26.4%
Native Vegetation (Forest/Trees + Native Shrub)	69.1%	57.6%
Forest/Tree only	68.6%	46.7%
Pasture	11.2%	6.3%

When examining land cover change in the study area, it is important to put the watershed into its historical context. The Bear Creek watershed, like much of western Washington, was logged around the turn of the 20th Century. Much of the land was subsequently converted to agriculture by the 1930s (Figure 9). Forest was re-growing in many parts of the watershed by the 1970s, and development was just beginning to increase significantly. By the turn of the 21st Century, much of the watershed was as developed as it is today. Figure 9, however, does not show the old-growth forest that preceded European settlement of the area, nor does it show the landscape immediately after logging. Likely now in all cases, forest now lost to new development is second- or third-growth forest, and most of the forests that are in the riparian areas are these same second- or third-growth forests. In other words, this comparison of forest from 1972 to today is an examination of quantity only – not of forest quality. The trees that help create shade and provide large wood to the streams are much smaller in general than they would have been historically.

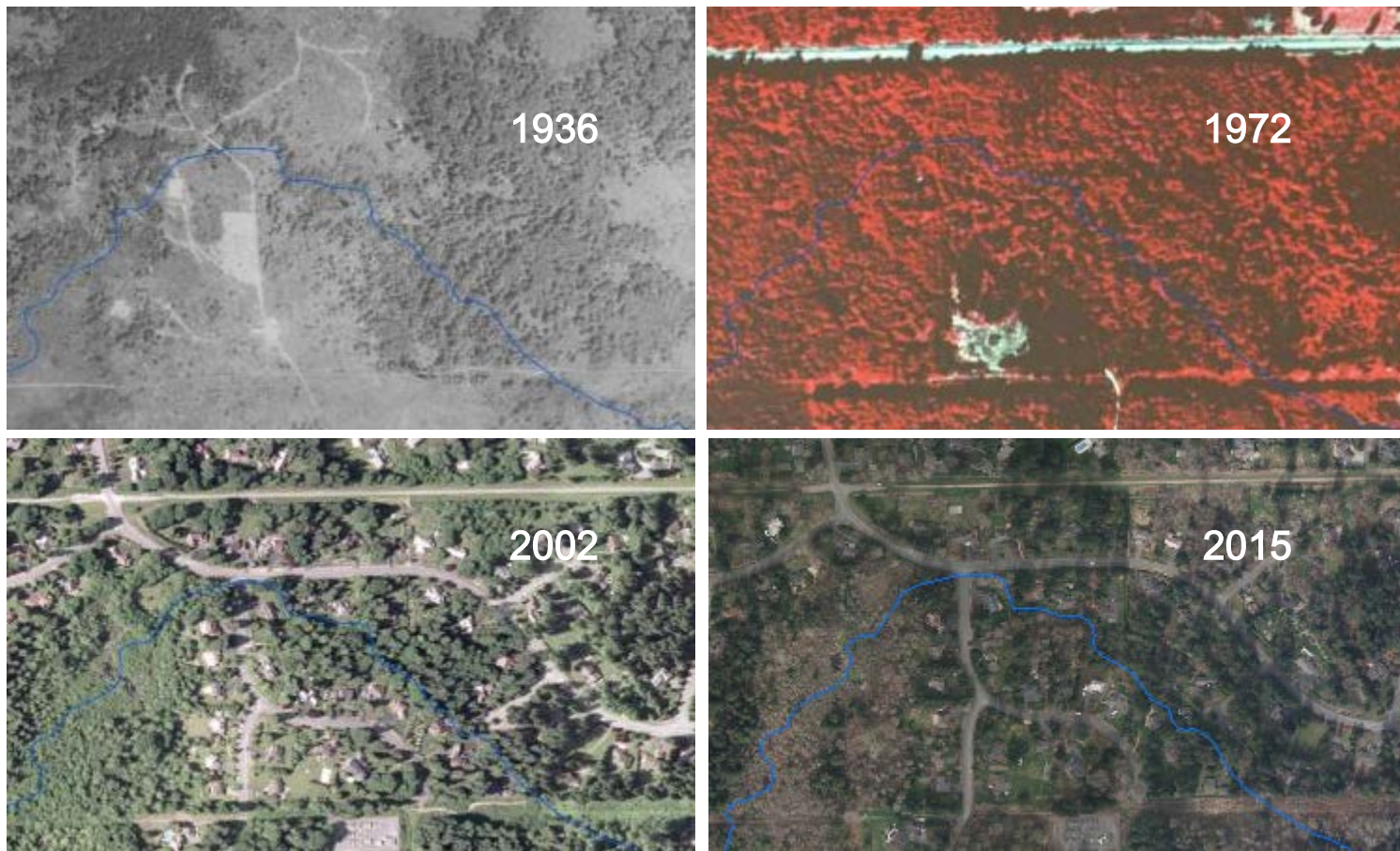


Figure 9. 80-year progression of photos at NE 146th Way & 186th Place NE.

Although a great deal of the watershed's forest had been removed around 1900 (USGS 1897), the land would have had an extremely low percentage of impervious surface. The graph in Figure 10 shows when and how much development in the watershed study area was occurring beginning in 1900.

The star marking 1972 indicates the year the infrared photos were taken and the start time of the change analysis. The graph shows that development in the study area was just beginning to take off at about the same time, in the early 1970s. The 1990 star marks when King County's Sensitive Areas Ordinance went into effect and added 100 ft protective buffers to streams with salmonids. The 2005 star marks when King County's Critical Areas Ordinance went into effect and increased buffer size on streams with salmon or salmon habitat to 165 ft. Until 1990, the streams were afforded no protection from development in their riparian zones, and it wasn't until 2005, just 10 years prior to our current conditions land cover, that buffer sizes were expanded to 165 ft. Although this latter part of the discussion is focused on King County regulations, the story is emblematic of the entire study area.

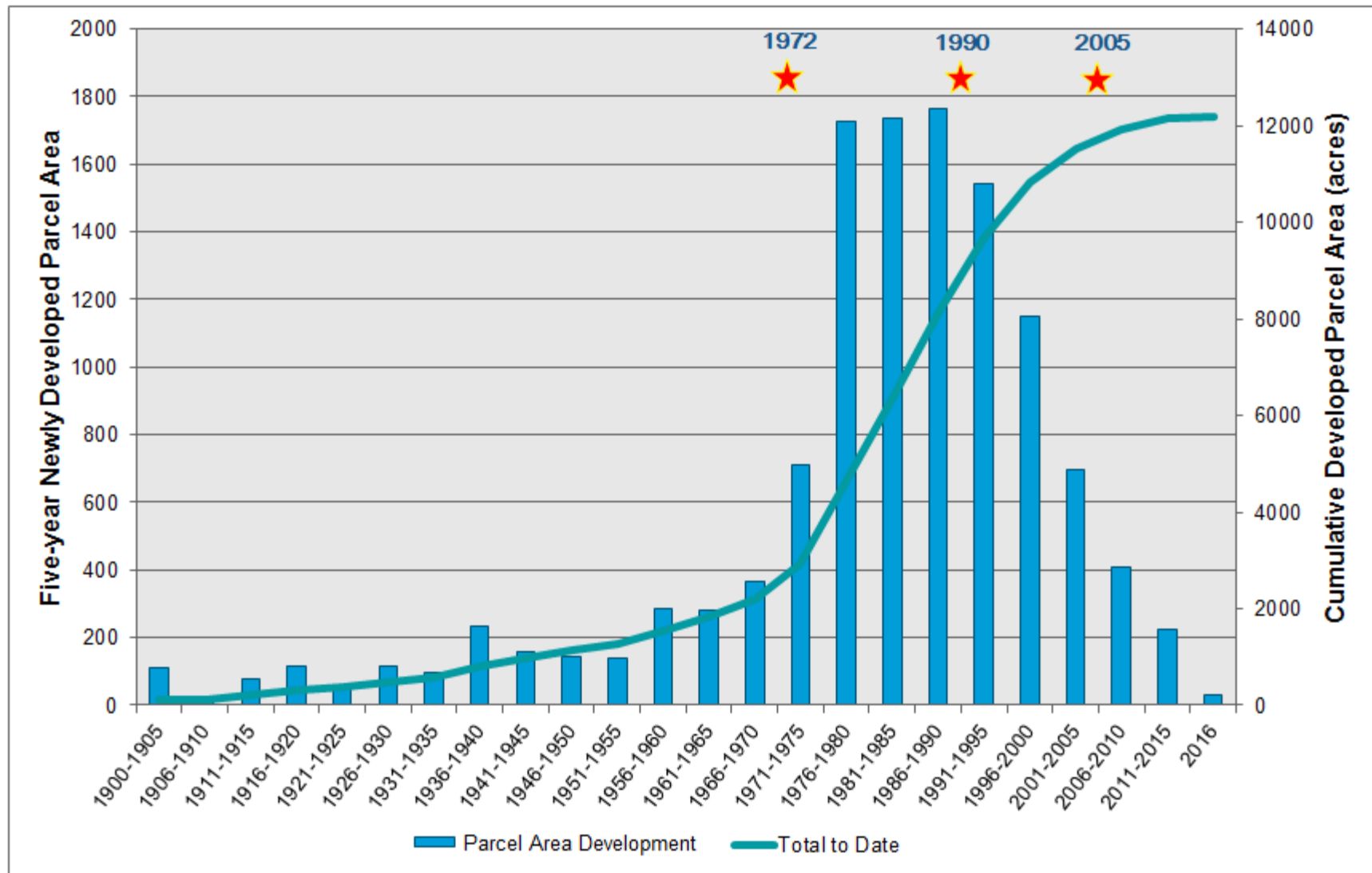


Figure 10. Urbanization over time in the study area. The star marked 1972 shows when the infrared photos were taken that were used in the change analysis. The other two stars indicated when protective regulations were put into place in King County only; 1990 was when the Sensitive Areas Ordinance was enacted, and 2005 is when the Critical Areas Ordinance went into effect

4.0 SUMMARY

This section provides a summary of the primary findings of this riparian analysis.

Landcover

- As of 2015, 47 percent of the riparian corridor (200 ft on each side of the stream center line) is forested or covered in trees, and 7 percent is impervious surface (Section 3.1).
- Approximately 15 percent of the riparian corridor is covered in invasive species (Section 3.1.3).
- Out of the 46.9 stream miles in the riparian study extent, 17.3 miles (36.9 percent) were identified as lacking shade on one or both sides of the stream channel (Section 3.1.4).
- Approximately 69 percent of the riparian zone in 1972 was native forest/shrub cover, compared to 2015's total of approximately 58 percent, and disturbed areas (not including pasture) have increased from 13 percent to 27 percent over this 43-year period (Section 3.2).

Data limitations

- All data in this study were generated from aerial imagery in GIS; field checking should be used when accuracy of data is imperative, such as when site-specific decisions are made.
- Only riparian areas within known potential salmon habitat were examined; if additional riparian land cover data are needed for any reason, those data would have to be newly generated.

How this study may be used

- Data generated in this study may be used to identify locations for restoration, including removal of invasive species and planting of native plants.
- Riparian land cover based on 2015 aerial imagery may be used as a baseline and compared to future land cover data to detect change in forest, impervious surface, and other land cover types over time.

5.0 RECOMMENDATIONS

The following recommendations were generated after conducting the assessment of Bear Creek watershed riparian areas. Any or all of the following recommendations could be conducted/implemented to improve and enhance our knowledge of the riparian area in the Bear Creek watershed and therefore contribute to any protection and restoration plans.

Improved study corridor extent. Future work may include generating an updated corridor file based on the following changes/improvements:

- Correct stream channel locations and study corridor extent where current streams are mapped incorrectly. Only the stream channel at Leota Lake was corrected for this analysis, but other inaccuracies in the stream data exist. Updating the streams and the study corridor extent would provide more accurate information about land cover in the riparian area.
- Expand study corridor so it is based on ordinary high water mark (OHWM) of the streams. The current study corridor extent is based on the stream center line, but because streams vary in width, an updated stream extent based on OHWM would provide more accurate information about land cover in the riparian area.

Field Checking. Field verification of some of the land cover types can increase the veracity and reliability of the data:

- It is recommended that a subsample of the land cover areas attributed as having invasive species are field checked to ensure that those locations appearing through aerial imagery to be Himalayan blackberry or reed canarygrass were interpreted correctly.
- A subsample of the Non-forested Wetland land cover should be field checked in the same manner that wetland data checking is recommended in the wetland study (King County 2017) prepared for the Bear Creek Watershed-Scale Stormwater Management Plan. The work for this riparian assessment and the data gathered as part of King County (2017) should be analyzed in combination to improve both datasets.

Beaver activity. Beavers are known to be present in much of the watershed. Beaver activity may contribute to the health of the watershed at the same time it causes problems for land owners and land managers.

- Some large beaver dams were identified during the land cover mapping; however, the majority of beaver activity in the Bear Creek watershed would not be readily visible using aerial imagery. Because dam building by beavers has the capacity to impact riparian areas, groundwater, stream water temperatures, salmon habitat, and infrastructure, an examination of beaver impacts in the Bear Creek watershed is recommended.

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7.0 APPENDICES

Appendix A: Area of Land Cover in the Riparian Study Extent, By Catchment.

Appendix B: Area of Invasive Species Coverage in the Riparian Study Extent, By Catchment.

Appendix C: Stream Miles Per Catchment and Stream Miles with No Shade By Catchment.

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Appendix A: Area (in acres) of Land Cover in the Riparian Study Extent, By Catchment.

This table includes the 103 catchments (out of 140) that contained riparian study extent. If acreage shows as 0.0, the area was smaller than 0.04 acres.

Catchment ID	Impervious	Trees	Shrub	Non-forested Wetland	Other	Pasture	Beaver Dam	Water	Acres in:	
									Catchment	Riparian area
BEA010	4.7	2.0	4.5		4.5	1.5		1.9	44.2	19.0
BEA020	0.6	0.9	1.7		3.1	1.0		1.7	10.6	9.1
BEA030	2.5	10.7	5.6		2.2	14.3		0.0	135.3	35.5
BEA040	0.2	1.6	0.8		0.3	0.1			106.0	3.1
BEA050	2.3	7.0	2.2		3.6	1.4		1.0	147.7	17.5
BEA060	1.4	6.9	12.8		1.7	2.2		1.5	172.1	26.5
BEA070	2.9	0.5	0.1		3.3				45.6	6.9
BEA080	1.3	0.2	0.1		0.6				69.0	2.2
BEA100	2.3	3.4	7.1		2.6	4.0		1.1	62.9	20.5
BEA120	2.5	25.5	11.5		4.6	16.8		0.2	255.6	61.0
BEA130	0.7	0.8	0.2		1.6	0.0			147.2	3.2
BEA140	1.1	13.9	3.2		4.6	1.7			187.7	24.6
BEA150	0.9	33.1	8.0		3.1	1.4	0.0	0.4	258.5	47.0
BEA160	0.0	0.1						0.0	30.3	0.1
BEA180	0.2	14.4	1.9		2.5		0.0	1.9	138.3	21.0
BEA190	2.3	4.1	4.4		1.7	0.0		0.2	169.5	12.7
BEA200	8.1	13.9	13.3		9.3	6.2		2.1	321.0	52.8
BEA210	0.3	0.6	0.1		0.2			0.1	59.3	1.2
BEA220	5.1	20.0	5.5		7.4	2.0		0.1	196.5	40.1
BEA230	3.9	3.3	2.8		1.8	5.9		0.7	43.9	18.5
BEA240	0.1	0.3	0.1		0.2	1.5		0.4	99.8	2.5
BEA245	3.6	12.8	8.4	2.0	5.9	7.0		1.8	117.4	41.6
BEA250	0.1	0.0			0.1				493.3	0.2
BEA260	2.1	14.5	11.4		3.9	2.4		0.9	68.3	35.1
BEA270	2.4	25.9	3.4		4.5	0.1		0.5	115.5	36.7
BEA275	1.3	9.2	1.0		3.0			0.4	225.3	14.9
BEA280	4.8	11.5	7.8		6.9	2.1		0.3	125.5	33.3
BEA290	3.7	22.1	6.0		5.8	0.5		0.0	163.1	38.2
BEA300	1.2	12.0	8.6	2.0	2.1			0.7	62.7	26.5
BEA310	2.5	27.3	5.5		6.6	0.6		0.2	131.0	42.7

Catchment ID	Impervious	Trees	Shrub	Non-forested Wetland	Other	Pasture	Beaver Dam	Water	Acres in:	
									Catchment	Riparian area
BEA315	1.1	21.1	4.4	2.6	2.2	0.7	0.1	4.7	175.6	37.0
BEA320	0.1	35.4	6.6	8.4	1.2		0.1	1.4	212.0	53.2
BEA325		26.4	3.1		1.0			0.3	195.4	30.8
BEA330	0.0	0.1	0.0		0.0				99.7	0.1
BEA350	1.9	15.2	15.9		3.3	18.1		2.4	543.1	56.9
BEA360	0.4	3.4	1.5		2.6	0.6		0.0	184.1	8.5
BEA370	1.9	21.7	9.0	2.4	6.3	1.3		0.9	213.9	43.5
BEA380	0.0	0.4	0.1	0.0	0.0				99.9	0.6
BEA390	4.5	23.5	7.8	0.2	5.6	2.0		0.0	140.8	43.6
BEA400	0.5	2.1	0.5		0.5				86.1	3.6
BEA410	0.5	10.0	2.4		3.0	0.5		0.1	21.7	16.5
BEA420	1.0	30.1	8.1		2.8			0.1	155.0	42.1
BEA430	1.7	16.6	5.2	0.4	2.8			15.2	653.5	41.9
BEA450	1.9	34.7	2.5		2.3			0.3	363.6	41.7
BEA480	1.6	18.8	3.1		3.2	1.5			130.5	28.1
BEA490	1.3	27.3	6.0	5.2	2.9	0.9	0.1	1.8	355.7	45.4
BEA500	4.4	31.5	9.1	8.7	9.7	0.7		1.0	251.2	65.2
BEA510	0.0	0.4	0.0		0.3				145.1	0.8
BEA525	0.5	15.4	3.5	0.3	1.6	0.2		0.2	132.8	22.6
BEA530	3.3	22.4	2.3		6.3			0.2	366.1	34.3
BEA540	0.0	0.3	0.1		0.0				124.1	0.4
BEA570	1.1	20.7	13.7	3.9	1.1	2.5		1.2	178.9	44.1
BEA580		0.8	0.3					0.0	175.3	1.1
BEA590	1.5	21.8	26.4		1.3	0.4		3.1	223.0	54.5
BEA600		2.2	2.7						202.9	4.8
BEA610	0.2	8.0	4.5	3.1	0.0	0.3		15.5	212.9	31.6
BEA620	0.1	2.3	0.7						46.1	3.1
BEA625	0.2	15.3	1.1		1.0	0.6			103.5	18.2
BEA630	0.2	0.4	0.1		0.6				168.3	1.2
BEA640		4.6	1.8	10.1	0.0			1.2	55.2	17.8
BEA650	0.6	11.1	3.5	0.2	1.4	0.0			50.3	16.7
BEA660	4.2	81.1	13.8	47.3	12.3	7.6	0.2	7.8	1168.3	174.3
BEA665	2.7	23.1	4.7	1.6	7.8	0.8		0.2	184.8	40.8
BEA670	0.3	0.2	0.0	0.4	1.0			3.9	185.1	5.8
BEA690	0.7	5.3	1.1		0.0				175.6	7.1
BEA700	2.3	9.9	8.5		5.1	3.3		0.5	236.9	29.5
BEA710	1.2	10.7	8.2		3.1	1.3		0.0	187.3	24.6
BEA720	6.7	12.7	4.0		12.5	0.9		0.1	83.3	37.0

Catchment ID	Impervious	Trees	Shrub	Non-forested Wetland	Other	Pasture	Beaver Dam	Water	Acres in:	
									Catchment	Riparian area
BEA725	3.8	14.4	4.5		7.2			0.1	62.3	30.0
BEA730	3.4	24.4	9.0	0.3	7.7	1.5		0.0	342.0	46.4
BEA740	0.2	0.3	0.0		0.6				160.5	1.1
BEA760	6.2	8.8	7.3		15.1	0.5		0.1	242.0	37.9
BEA770	0.1	0.1	0.0		0.1				217.8	0.3
BEA780	0.9	4.5	4.4	2.3	0.6	7.2		0.3	130.8	20.2
BEA800	1.4	19.2	11.2	12.8	3.0	1.5		2.0	352.5	51.2
BEA830	2.4	15.9	11.7	1.5	4.0	0.0		0.0	253.0	35.6
BEA840	2.6	4.3	0.8		1.9	0.2			255.1	9.8
BEA850	2.0	5.1	0.4		5.8			10.6	246.7	23.9
BEA860	5.5	14.8	3.7		10.1	1.2		0.4	242.0	35.7
MON001	0.0	0.1	0.0		0.1	0.4			23.4	0.7
MON004	0.6	0.0	0.0		0.2				7.3	0.8
MON007	1.4	0.0	0.2		0.7			0.1	14.9	2.4
MON009	0.0	0.0			0.0	0.0			1.0	0.1
MON013	0.0	2.9	4.2		0.3	0.0			14.7	7.4
MON014	0.2	0.0	0.1		0.2	0.0		0.0	2.4	0.7
MON018	0.3	0.5	0.9		0.1				3.3	1.9
MON019	0.0	0.4	0.4		0.0	3.0			13.8	3.8
MON022	0.1		0.0		0.0				2.0	0.1
MON025	0.1	2.3	1.0		1.1			0.2	6.6	4.7
MON026	0.0	0.8	0.5		0.0				3.3	1.3
MON027	0.3	1.4	1.9		0.3	1.2			5.4	5.1
MON029	0.4	1.1	1.1		0.4				6.4	3.0
MON030	1.2	1.0	1.3		0.6			0.1	6.1	4.2
MON032	0.5	2.9	1.3		0.4	0.0			7.1	5.0
MON033	0.2	3.5	2.5		0.9	0.8		0.1	10.6	8.0
MON039	0.1	0.3	0.8		0.3				1.5	1.5
MON046	0.2	0.0	0.0		0.1			0.0	1.0	0.4
MON047	0.8	0.0	0.0		0.3	0.0		0.1	1.2	1.2
MON048	0.4	0.0	0.0		0.3				1.7	0.7
MON049	0.0	0.0	0.0		0.0	0.0			0.8	0.1
MON110	0.0	0.2	0.2			0.3		0.2	1.2	0.9
MON139	0.8	0.4	0.1		0.2	1.5			8.9	3.0
MON147	0.0		0.3						0.6	0.3
Total	149.3	1015.2	394.5	115.8	265.3	136.3	0.6	94.7	15140.8	2172.7

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Appendix B: Area (in Acres) of Invasive Species Coverage in the Riparian Study Extent, By Catchment.

This table includes the 73 catchments in the study extent with invasive species coverage. If acreage shows as 0.0, the area was smaller than 0.04 acres.

Catchment	Invasive	Acres in:	
		Catchment	Riparian area
BEA010	1.6	44.2	19.0
BEA020	0.1	10.6	9.1
BEA030	3.1	135.3	35.5
BEA040	0.5	106.0	3.1
BEA050	0.4	147.7	17.5
BEA060	2.6	172.1	26.5
BEA100	6.4	62.9	20.5
BEA120	5.5	255.6	61.0
BEA140	1.9	187.7	24.6
BEA150	0.8	258.5	47.0
BEA180	1.9	138.3	21.0
BEA190	3.5	169.5	12.7
BEA200	7.0	321.0	52.8
BEA210	0.1	59.3	1.2
BEA220	1.6	196.5	40.1
BEA230	2.4	43.9	18.5
BEA240	0.1	99.8	2.5
BEA245	5.9	117.4	41.6
BEA260	6.8	68.3	35.1
BEA270	0.4	115.5	36.7
BEA275	0.1	225.3	14.9
BEA280	3.8	125.5	33.3
BEA290	0.3	163.1	38.2
BEA300	7.8	62.7	26.5
BEA310	0.3	131.0	42.7
BEA315	2.0	175.6	37.0
BEA320	6.5	212.0	53.2
BEA350	26.4	543.1	56.9

Catchment	Invasive	Acres in:	
		Catchment	Riparian area
BEA370	6.7	213.9	43.5
BEA380	0.0	99.9	0.6
BEA390	3.2	140.8	43.6
BEA410	1.4	21.7	16.5
BEA420	2.2	155.0	42.1
BEA430	1.1	653.5	41.9
BEA450	0.1	363.6	41.7
BEA480	1.4	130.5	28.1
BEA490	1.8	355.7	45.4
BEA500	13.9	251.2	65.2
BEA510	0.0	145.1	0.8
BEA525	0.9	132.8	22.6
BEA530	0.4	366.1	34.3
BEA570	13.0	178.9	44.1
BEA580	0.2	175.3	1.1
BEA590	15.7	223.0	54.5
BEA610	4.4	212.9	31.6
BEA620	0.3	46.1	3.1
BEA640	10.2	55.2	17.8
BEA650	2.3	50.3	16.7
BEA660	55.7	1168.3	174.3
BEA665	1.5	184.8	40.8
BEA670	0.4	185.1	5.8
BEA700	1.4	236.9	29.5
BEA710	0.8	187.3	24.6
BEA720	0.1	83.3	37.0
BEA725	2.1	62.3	30.0
BEA730	1.2	342.0	46.4
BEA760	1.5	242.0	37.9
BEA780	8.2	130.8	20.2
BEA800	12.3	352.5	51.2
BEA830	8.6	253.0	35.6
BEA840	0.5	255.1	9.8
BEA860	0.4	242.0	35.7
MON007	0.0	14.9	2.4
MON009	0.0	1.0	0.1
MON019	0.4	13.8	3.8
MON025	0.0	6.6	4.7

Catchment	Invasive	Acres in:	
		Catchment	Riparian area
MON026	0.4	3.3	1.3
MON029	0.1	6.4	3.0
MON032	0.3	7.1	5.0
MON033	0.1	10.6	8.0
MON049	0.0	0.8	0.1
MON110	0.3	1.2	0.9
MON139	1.4	8.9	3.0
Total	276.7	15,140.8	2,172.7

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Appendix C: Stream Miles Per Catchment and Stream Miles with No Shade By Catchment.

The total stream miles for the 79 catchments that contain stream reaches within the riparian study extent are shown in the left column. The total stream miles for the 70 catchments with stream reaches lacking shade are shown in the right column.

Catchment ID	Stream miles	
	Total per catchment	No shade
BEA010	0.73	0.59
BEA020	0.37	0.03
BEA030	0.89	0.18
BEA040	0.03	0.00
BEA050	0.37	0.16
BEA060	0.75	0.57
BEA070	0.00	
BEA100	0.51	0.49
BEA120	1.30	0.38
BEA140	0.47	0.11
BEA150	1.06	0.10
BEA180	0.42	0.13
BEA190	0.35	0.12
BEA200	1.16	0.91
BEA220	0.77	0.10
BEA230	0.44	0.40
BEA240	0.01	0.01
BEA245	0.86	0.41
BEA260	0.96	0.55
BEA270	0.70	0.02
BEA275	0.30	0.06
BEA280	0.76	0.37
BEA290	0.79	0.08
BEA300	0.66	0.46
BEA310	0.86	0.09
BEA315	0.88	0.28
BEA320	1.06	0.34
BEA325	0.67	0.02
BEA350	1.24	1.13

Catchment ID	Stream miles	
	Total per catchment	No shade
BEA360	0.15	0.08
BEA370	0.86	0.57
BEA390	0.94	0.27
BEA400	0.05	
BEA410	0.52	0.05
BEA420	0.91	0.10
BEA430	0.78	0.03
BEA450	0.96	0.02
BEA480	0.61	0.11
BEA490	0.92	0.17
BEA500	1.45	1.04
BEA525	0.47	0.14
BEA530	0.70	0.10
BEA570	0.94	0.60
BEA590	1.12	0.63
BEA600	0.08	
BEA610	0.67	0.02
BEA620	0.08	0.00
BEA625	0.41	0.02
BEA640	0.45	0.45
BEA650	0.36	0.10
BEA660	3.71	2.02
BEA665	0.89	0.27
BEA670	0.08	0.00
BEA690	0.13	
BEA700	0.59	0.28
BEA710	0.50	0.07
BEA720	0.70	0.06
BEA725	0.84	0.15
BEA730	0.94	0.14
BEA760	0.80	0.37
BEA780	0.43	0.29
BEA800	1.05	0.52
BEA830	0.82	0.45
BEA840	0.22	0.02
BEA850	0.49	0.11
BEA860	0.72	0.19
MON007	0.02	

Catchment ID	Stream miles	
	Total per catchment	No shade
MON013	0.14	
MON018	0.00	
MON025	0.09	0.03
MON026	0.02	0.01
MON027	0.13	
MON029	0.10	0.01
MON030	0.15	0.02
MON032	0.12	0.02
MON033	0.26	0.00
MON039	0.04	
MON047	0.09	
MON110	0.01	0.01
MON139	0.08	0.06
Total	46.91	17.68