Knotweed Treatment in the Cedar River Municipal Watershed 2016 – 2018

Annual Report for Seattle City Council
Civil Rights, Utilities, Economic Development and Arts Committee

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EXECUTIVE SUMMARY

Seattle Public Utilities (SPU) has been treating Bohemian knotweed (*Polygonum* x *bohemicum)* in the Cedar River Municipal Watershed (CRMW) with the herbicide imazapyr annually since 2010. Bohemian knotweed poses threats to both water quality and habitat within the CRMW (Appendix A). Three city ordinances have authorized imazapyr treatment (2010 through 2012, 2013 through 2015, and 2016 through 2018). This report summarizes work conducted during the 2016 through 2018 ordinance period.

All ordinances have limited the herbicide use to imazapyr only, with ongoing monitoring, water quality testing after each treatment, and annual reports to City Council. Over the past nine years, knotweed has been treated with imazapyr across an estimated 28 acres annually; most acres have been treated eight or nine times, but some areas have received only six treatments. It often takes many years of consecutive annual treatments to eradicate large knotweed patches.

Herbicide use closely aligns with the total knotweed leaf biomass, because the herbicide is applied to all leaves on each plant. The maximum legally allowed application rate for imazapyr is 96 ounces per acre. The maximum amount used in the watershed was 26.9 ounces per acre (a total of 678 ounces) in 2011, and has been as low as 0.4 ounces per acre (in 2018). The annual decrease in knotweed foliage has led to a corresponding annual decrease in total imazapyr quantities, as well as a decrease in the amount of herbicide applied per acre.

From 2010 through 2016, SPU staff surveyed over 1,100 acres of off-road habitat for knotweed. No additional off-road habitat was surveyed in 2017 or 2018 due to staffing shortages and transitions. In 2013, several more acres of knotweed, mostly at Taylor Townsite, were found and treated for the first time. No other patches were found 2014 through 2016. In addition to the 1,100 acres, staff also survey approximately 475 acres of off-road habitat and over 300 miles of road annually.

Water quality testing has yielded only a few imazapyr detections since 2010. However, there were a few instances of unexpected positive detections over the years, and it was determined that these results were likely due to self-contamination. Because of these positive sample results, water sample collection methods were improved in 2018 to minimize the potential for false positive results.

Two of the largest knotweed sites (Cedar River Watershed Education Center and Taylor Townsite) have had extensive restoration efforts with removal of invasive species and planting of native trees and shrubs, starting in 2013 and continuing through 2017. No additional work was done in 2018. Additional site restoration information is available in Appendix B.

INTRODUCTION

BACKGROUND

The highly invasive species Bohemian knotweed poses an extreme ecological threat, especially to riparian areas (Appendix A). Many years of experience by multiple agencies in the Pacific Northwest have found that herbicide is the only way to successfully treat large patches of knotweed. Consequently, since 2010, SPU has been treating knotweed within the CRMW under special ordinances that allow the limited application of the herbicide imazapyr.

To date, a total of three ordinances have been passed by Seattle City Council allowing knotweed treatment with imazapyr, each for a three-year period. This limited authority allows oversight and feedback from City Council and interested stakeholders on the knotweed program. The first two ordinances were for treatment from 2010 through 2012 (Number 123365) and from 2013 through 2015 (Number 124191). The most recent ordinance (Number 124852) was passed on September 8, 2015, and allowed treatment through 2018. All ordinances have limited the herbicide use to imazapyr only, with water quality testing after each treatment, ongoing monitoring, and annual reports to City Council.

DRIVERS FOR CONTROL

Knotweed on the Cedar River and its tributaries is regulated by the King County Noxious Weed Control Board (KCNWCB) and is legally required to be controlled. Legal control is defined as preventing the dispersal of all propagating parts capable of forming a new plant (King County 2018). Because knotweed can propagate from small plant fragments, complete removal of knotweed along the Cedar River and its tributaries is necessary to fulfill this obligation. In addition to legal requirements, SPU is obligated as the upstream steward of the Cedar River to control knotweed along its streambanks and tributaries. Downstream of Landsburg Dam, SPU, Forterra, and King County have received grant funding to remove knotweed and restore riparian areas along the Cedar River. Failing to control knotweed upstream of Landsburg could render these efforts useless, as fragments can float downstream and create new plant colonies.

SPU focuses on being effective stewards of the municipal watershed lands and resources it owns. Restoring and maintaining healthy forests, wetlands, streams, and lakes in the municipal watersheds that supply Seattle-area residents with drinking water is a priority for SPU. These healthy ecosystems provide the abundant and high-quality drinking water on which the citizens of this region depend. Protecting water quality for human use also protects resources used by other species. Lands of the CRMW are managed under the 50-year Habitat Conservation Plan (HCP), which requires that SPU promote and protect native diversity of plants and animals.

Knotweed is a costly and destructive plant, due to its rapid growth, its tendency to quickly displace native vegetation, and its ability to alter soil and water chemistry. A summary of the risks posed by knotweed to the CRMW is presented in Appendix A.

METHODS

KNOTWEED SURVEYS

In 2013, following recommendations from interested stakeholders, SPU identified over 1,500 acres of off-road habitat that potentially could contain knotweed, based on the location of known knotweed patches, streams and other water bodies, and the extent of deciduous forest canopy. None of these sites had previously been surveyed for knotweed. These areas were sorted into high (1,219 acres) and medium (388 acres) priority based on their proximity to existing knotweed and flowing water. These off-road surveys were initially successful in finding more knotweed patches. In 2013, SPU found a total of 2.15 additional acres of knotweed (most in Taylor Townsite), all of which were treated for the first time that year. By the end of 2016, less than 100 acres classified as high priority remained to be surveyed, and no further large knotweed patches had been found (Figure 1). Unfortunately, due to staffing shortages and transitions, no additional surveys were conducted in 2017 or 2018. Surveys are scheduled to recommence in 2019.

In addition to these prioritized areas, SPU also annually surveys approximately 475 acres of off-road habitat. This includes all known off-road knotweed patches and areas routinely surveyed for other projects (e.g., wetlands surveyed for amphibian egg masses). These surveys were completed in 2016, 2017, and 2018, and SPU anticipates this level of survey to continue. SPU will include additional priority acres as funding and staffing allow. SPU also conducts annual comprehensive invasive species surveys of more than 300 miles of road and 13 gravel pits (8 of which are active) as part of the Early Detection/Rapid Response protocol used by the Major Watersheds Invasive Species Program. This level of road survey is expected to continue. To date, knotweed dispersal appears to be spreading by plant fragments along travel corridors (streams, roads, wildlife paths). No new knotweed plants that appear to have been spread via seed have been found.

TREATMENT AREAS

In 2016 and 2017, SPU surveyed all areas previously treated with herbicide and treated the small scattered individual plants (Figure 2). High priority locations were surveyed and treated in 2018, but not all locations were visited due to time constraints. Fewer acres contained plants in 2017 and 2018 than in previous years (Table 1). Most sites have now received eight or nine annual treatments, with a small number of patches receiving a total of six or seven treatments by the end of 2018.

Maps in previous reports have shown knotweed at the Rock Creek Complex, Cedar River, and road patches on map figures, but these patches were not included in the total acreages (Table 1). The 2018 report has included all acreage and, as a result, acreages in this report are larger than in previous reports. All knotweed patches have been mapped as polygons using a handheld Global Positioning System (GPS). In this report and all previous reports, knotweed acreage has been derived from estimating the percent cover of knotweed throughout these polygons, and therefore all reported acreage is approximate.

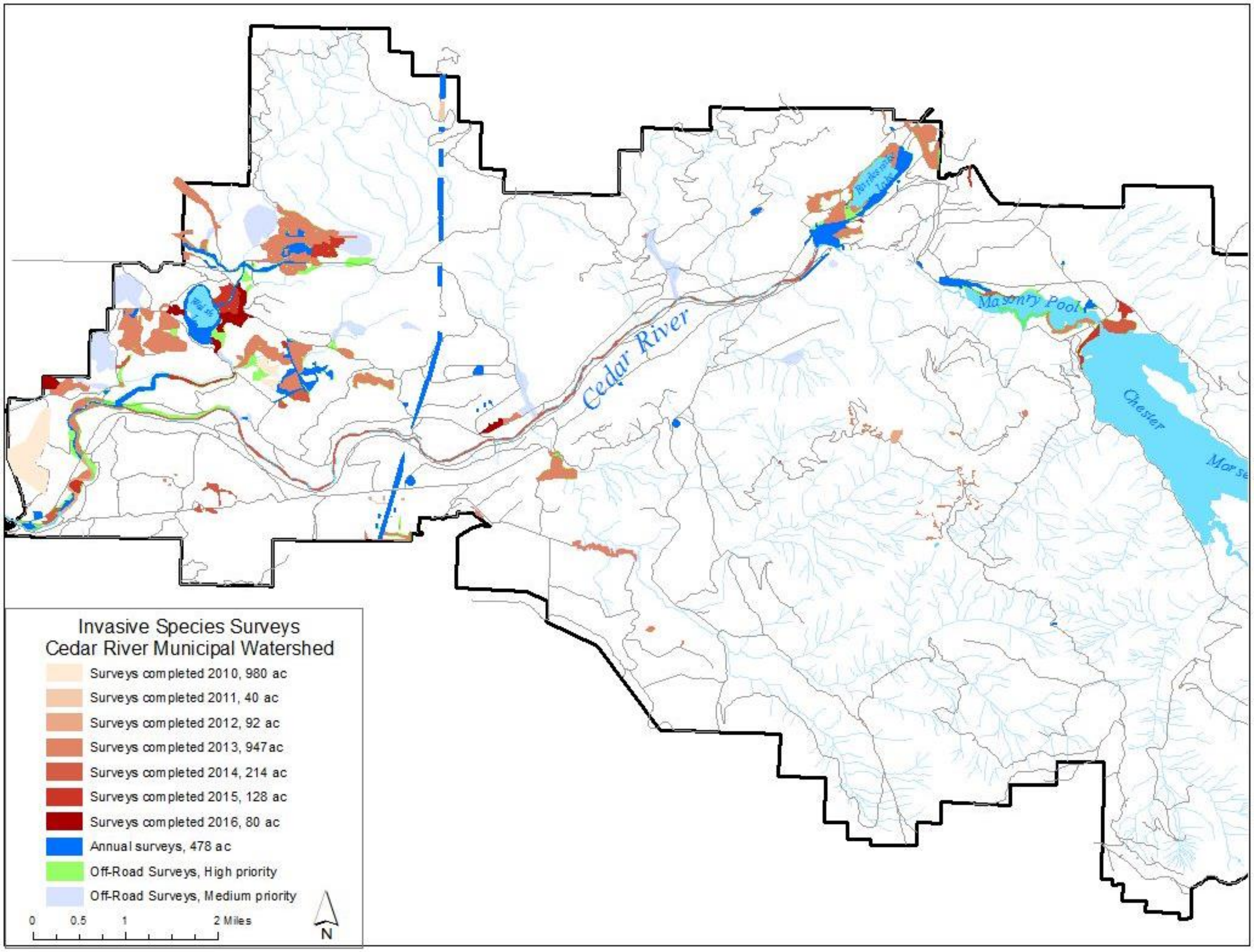

Figure 1. Off-road areas of high and medium priority to survey for invasive species, plus annual surveys and areas surveyed in 2010 through 2016. No further off-road surveys were conducted in 2017 or 2018.

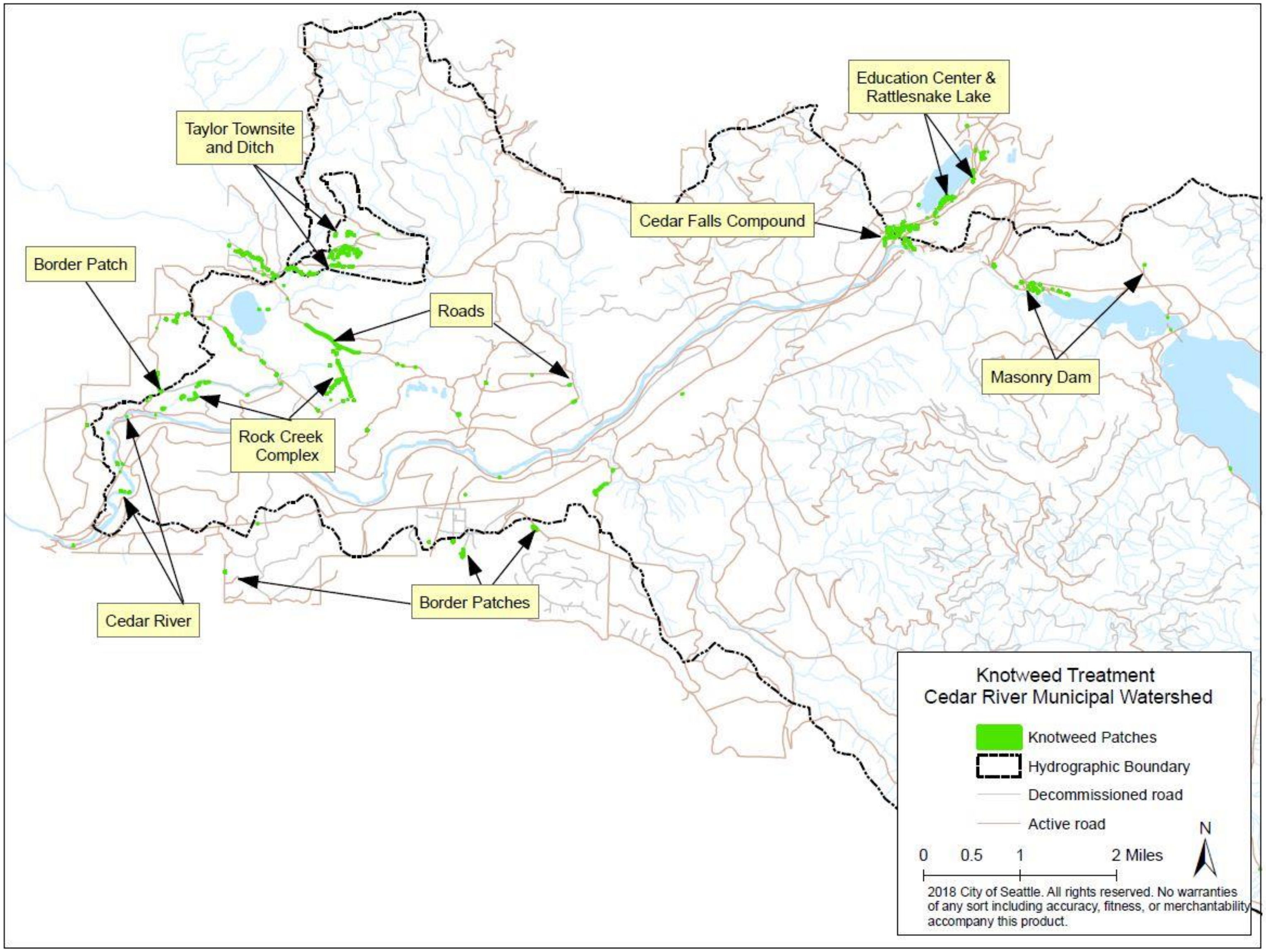

Figure 2. All previously treated knotweed patches in the Cedar River Municipal Watershed. Most patches have been treated eight or nine times, with some being treated as few as six times.

Table 1. Estimated Acres of Knotweed Treated by Site and Year.						
Hydrographic Boundary	Site	2010	2011	2012	2013-2016[1]	2017-2018[1]
Inside Hydrographic Boundary	Masonry Dam	0.3	0.4	0.6	0.7	0.3
	Cedar Falls In	1.6	1.6	1.6	1.6	1.5
	Rock Creek Complex	4.4	4.4	4.4	4.4	4.4
	Road Patches	4.2	4.2	4.2	4.2	4.2
	Cedar River	1.0	1.0	0.8	0.7	0.1
Outside Hydrographic Boundary	Cedar Falls Out	1.7	1.8	1.8	1.8	1.5
	Ed Center/ Rattlesnake Lake	3.0	3.1	3.2	3.3	1.7
	Border[2]	1.1	1.1	1.1	1.4	1.0
	Taylor	0	7.6	7.7	9.3	8.8
Total Inside Hydro Boundary		11.5	11.6	11.6	11.6	10.5
Total Outside Hydro Boundary		5.8	13.6	13.8	15.8	13.0
Grand Total		**17.3**	**25.2**	**25.4**	**27.4**	**23.5**

[1] Years are grouped because knotweed acreage did not change substantially during these timeframes.

[2] Border patches are all patches outside of the hydrographic boundary that are not at Cedar Falls, the Education Center, Rattlesnake Lake, or Taylor Townsite.

TREATMENT LOGISTICS

From 2016 through 2018, SPU used the same application method and herbicide concentration as in 2010 through 2015, i.e., a targeted backpack foliar spray of 1 percent aquatic formulation imazapyr mixed with 0.5 to 2 percent modified vegetable oil surfactant and a small amount of non-toxic blue dye in water. It was applied strictly according to label instructions, including restrictions such as not applying during rain, wind, or temperature inversion. All the same safety procedures were followed, with certified herbicide applicators on site performing the mixing of the tank solutions. No spills, injuries, or any adverse effects were incurred by SPU staff conducting the applications.

From 2016 through 2018, knotweed plants were small and difficult to see amongst the thick understory of shrubs and tall grass. In addition, plants had a large variation in timing of growth, with small newly emerged growth found as early as May and as late as October. To get as much herbicide into the root system as possible, SPU schedules the herbicide application for when the plants have put on maximum leaf growth, but before the leaves start to senesce. SPU also aims to treat knotweed before the plant starts to flower to avoid pollinators. This timing varies depending on elevation and site-specific conditions. For untreated knotweed at elevations in the CRMW, flowering generally occurs in early September, so the target timing is mid to late August. The other primary consideration on timing of application is the weather. August is generally the driest month, with September weather being less predictable. For these reasons, SPU began treatment during August 2016 through 2018. Treatments in 2017 and 2018 took longer than in previous years because contractors were not used, and a single staff person did nearly all the treatment.

To ensure that SPU treated all knotweed plants, SPU surveyed and treated each large site twice, four to six weeks apart in 2016 and 2017. Plants treated with imazapyr show signs of decline within that time and are easily identifiable. During the second survey, SPU treated any newly emerged or previously missed plants. This technique follows King County’s best management practices (King County 2015). Time constraints prevented staff from conducting a second round of treatments in 2018.

RESULTS

AMOUNT OF IMAZAPYR APPLIED

In all treatment sites combined, the average application rate in 2018 was 0.4 ounces imazapyr per acre. The maximum allowable application rate of imazapyr is 96 ounces per acre per year. The total amount of imazapyr applied in 2018 was 10 ounces spread over approximately 23.5 acres. The total amount of herbicide applied has declined since 2011, from from a total of 678 ounces applied in 2011, to 10 ounces applied in 2018. Herbicide is applied using hand-held sprayers, and each leaf is sprayed with imazapyr. The annual decrease in knotweed foliage has led to a corresponding annual decrease in total imazapyr quantities, as well as a decrease in the amount of herbicide applied per acre (Table 2).

Table 2. Total Amount of Imazapyr Applied and Application Rate by Year.

Year	Amount Imazapyr (oz)	Approximate Area Treated (ac)	Approximate Application Rate (oz/ac)
2010	334	17.3	19.3
2011	678	25.2	26.9
2012	244	25.4	9.6
2013	169	27.5	6.1
2014	121	27.5	4.4
2015	61	27.5	2.2
2016	50	27.5	1.8
2017	34	23.5	1.4
2018	10	23.5	0.4

IMAZAPYR TREATMENT RESULTS

From 2016 through 2018, most of the knotweed sites have shown a continued decline in foliage. Above ground knotweed leaf biomass in 2017 had declined by 20 times from 2011 levels, indicated by the decrease in total imazapyr used. Because SPU attempts to evenly coat every leaf on each plant, the total annual application amount is used to estimate changes in leaf biomass and demonstrates the success SPU has had in decreasing knotweed in the municipal watershed.

Many of the smaller knotweed patches had either no or very few small stems. Most of the larger sites that have received six to nine previous treatments still had small to medium knotweed plants scattered throughout the site, indicating that the large root mass, although clearly damaged, was not yet dead. Knotweed rhizomes (roots that can sprout) can be up to 65 feet long and seven feet deep (Soll 2004). It is important to wait until all root segments send up shoots so enough herbicide can be applied to each segment of the root system to kill it. Because roots can remain dormant for up to 20 years without sending up shoots, this process can take decades (Parkinson and Mangold 2010). A few very large plants were found at Taylor Townsite and Rock Creek Complex in 2018, indicating that they had not been treated in several years. Due to the complex nature of these sites, it is not surprising that patches can go undiscovered for several years at a time. Because these plants were in flower at the time of discovery, they were not treated to avoid disrupting pollinators. These plants were flagged in the field and their locations were recorded on a GPS for treatment in 2019. See Appendix A for a complete discussion of knotweed treatment, flowering, and potential effect on pollinators.

WATER QUALITY TEST RESULTS

In each year, 2010 through 2018, water samples were taken both before (baseline) and after (post-treatment) the herbicide application. Samples were taken from two locations on the Cedar River (one at the point closest to a knotweed patch, approximately 250 feet away; and the other at the Landsburg water supply intake facility), one location at Rattlesnake Lake, and one location on a small creek running through Taylor Townsite. All water samples were analyzed for imazapyr at Pacific Agricultural Laboratory (PAL) near Portland, Oregon.

Sampling protocol from 2010 through 2017 involved water sample collection on the same day that herbicide application was taking place in other areas of the watershed. Staff who collected water samples were often wearing clothing or boots that were worn while applying herbicide. Disposable gloves that were used to collect water samples were stored with herbicide equipment and came from the same box as gloves that were used to apply herbicide. During this time, there were several water quality test results that were unexpected and have been attributed to self-contamination. A test in 2011 that detected imazapyr prior to application at Taylor Townsite is believed to have been self-contaminated. In 2015, a detection of 0.099 parts per billion (ppb) was found at the Landsburg intake facility. SPU worked with PAL and determined the sample was likely contaminated during collection. Additional unexpected detections came from the Cedar River and Landsburg in 2016, and from one sample in 2017.

Other detections have come from Taylor Townsite, which is located outside of the drainage area of the municipal water supply, but within SPU's administrative boundary of the CRMW. This site contains more knotweed than any other site treated by SPU, resulting in more herbicide applied in that area than any other. A small ditch, Taylor Overflow Ditch, runs through Taylor Townsite, and then flows into Issaquah Creek. Taylor Overflow Ditch does not flow into the Cedar River and is thus unlikely to affect the water quality at Landsburg. The water samples from Taylor Townsite were taken from Taylor Overflow Ditch, and it is likely that most of these samples were detecting imazapyr that entered the ditch after application due to the higher rate of application in this area, and because knotweed grows directly along Taylor Overflow Ditch. It is also possible that imazapyr could have been inadvertently introduced to samples during collection due to the sampling protocols described above. A summary of all herbicide detections is in Table 3.

Table 3. Summary of Herbicide Detections During Imazapyr Treatment, 2010 – 2018.				
Ordinance Number	**Year**	**Date**	**Location (Sample Number)**	**Amount Detected (µg/L or ppb)**
123365	2010	7 samples collected 8/30/10 – 9/15/10 from throughout the watershed yielded no detections.		
	2011	8/1/2011	Taylor (Baseline)	0.07
		8/3/2011	Taylor (Post #1)	0.12
		8/17/2011	Taylor (Post #2)	0.02
		7 additional samples collected 8/1/11 – 8/30/11 from throughout the watershed yielded no detections.		
	2012	9/5/2012	Taylor (Post #1)	0.12
		8 additional samples collected 9/4/12 – 10/8/12 from throughout the watershed yielded no detections.		
124191	2013	9/11/2013	Taylor (Post #1)	0.042
		10/8/2013	Taylor (Post #2)	0.46
		11/5/2013	Taylor (Post #3)	0.021
		5 additional samples collected 9/9/13 – 11/5/13 from throughout the watershed yielded no detections.		
	2014	8 samples collected 8/25/14 – 8/27/14 from throughout the watershed yielded no detections in the field. One sample was determined to be contaminated in the lab, and lab records were subsequently corrected.		
	2015	8/11/2015	Landsburg (Post #1)	0.099
		7 additional samples collected 8/10/15 – 8/24/15 from throughout the watershed yielded no detections.		
124852	2016	8/17/2016	Cedar (Post #1)	0.47
		8/17/2016	Taylor (Post #1)	0.027
		8/17/2016	Landsburg (Post #1)	0.036
		5 additional samples collected 8/8/16 – 8/17/16 from throughout the watershed yielded no detections.		
	2017	8/16/2017	Taylor (Post #1)	0.056
		7 additional samples collected 7/24/17 – 8/16/17 from throughout the watershed yielded no detections.		
	2018	15 samples collected 8/27/18 – 10/9/18 from throughout the watershed yielded no detections.		

Due to the likelihood of self-contamination in samples, water sample collection methods were improved in 2018 to minimize the potential for false positive results. All baseline samples were collected prior to any herbicide being applied in the CRMW. After application, samples were collected wearing boots not worn during herbicide application and with disposable gloves that were not stored near herbicide. Post-samples were also collected on days when no herbicide application was taking place, to reduce the chance of cross-contamination. Imazapyr is mobile in soil but unlikely to move through the environment until a rain event occurs, unless imazapyr directly enters waterways through dripping or drift. Imazapyr also has a half-life of two to five days (Mangels and Ritter 2000), so detection rates can diminish after that period. With this in mind, 2018 post-samples were collected in accordance with the following criteria:

- If spraying was conducted within 10 feet of a water body, samples were collected 24 hours later;
- If spraying was conducted further than 10 feet from a water body, samples were collected after a rain event; or
- If no rain event occurred, samples were collected within 5 days of application.

Several quality control samples were collected from Masonry Pool throughout the application period, far upstream from any herbicide application within the watershed. Water quality was tested more extensively in 2018, with 15 water samples collected from August 27 through October 9 at five separate locations (Figure 3). There were no detections of imazapyr in any of the 2018 water samples. Appendix A includes a detailed risk assessment and literature review of the latest available science on the environmental and human health effects of imazapyr.

COSTS

The cumulative total cost (including staff and contractor labor and materials) to treat knotweed with herbicide over approximately 28 acres annually from 2010 through 2018 was nearly $124,000. Approximate annual cost per acre to treat the knotweed with imazapyr has declined from a high of $1,270/acre in 2010 to a low of $243/acre in 2017. Treatment in 2018 was approximately $297/acre. This compares with a cumulative cost of nearly $200,000 ($44,000/acre) to treat approximately 4.5 acres of small scattered patches by covering knotweed with geotextile fabric, a treatment SPU tried experimentally from 2004 to 2012. Covering was only marginally successful on very small patches. The larger patches were still alive after more than eight years of continual covering. Fabric along active roads will be left down indefinitely. Fabric was removed from isolated patches away from active roads and are now spot-treated with herbicide annually.

The total annual cost to treat knotweed with herbicide has decreased from a high of about $32,000 in 2011 to a low of around $5,700 in 2017. Costs increased slightly to nearly $7,000 in 2018 due to increased water quality testing, and those additional costs will continue in the future. The annual costs will likely average $7,000 because staff will need to continue to survey and monitor all mapped knotweed populations for several years until the knotweed is eradicated. The time and cost to continue to control knotweed using imazapyr will be covered by the existing watershed Invasive Species Management Program budget and staff. Appendix A includes an evaluation of the long-term financial and environmental implications for knotweed control.

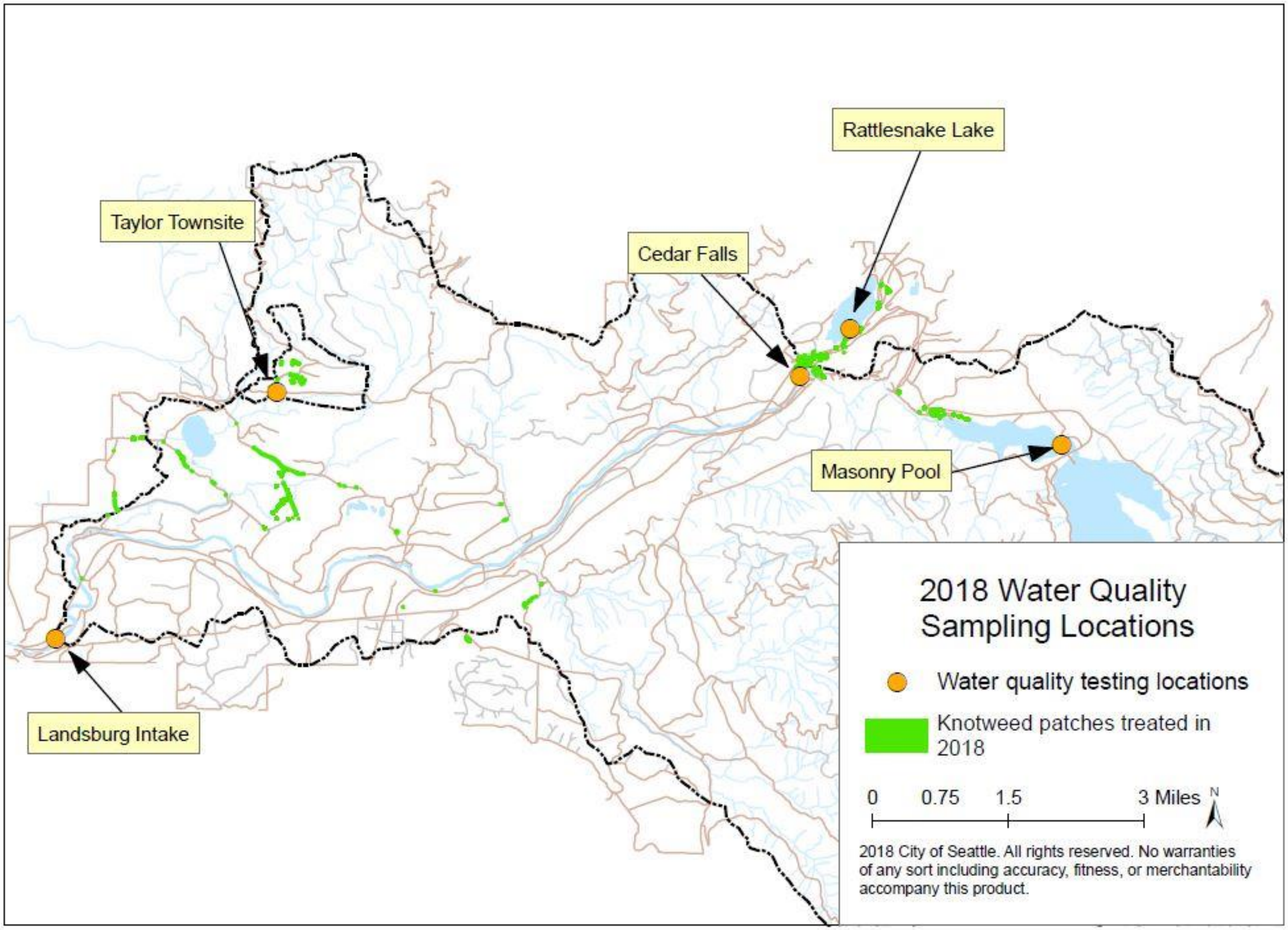

Figure 3. 2018 water quality sample locations and knotweed survey and treatment areas.

CONCLUSION

LONG-TERM IMPLICATIONS FOR KNOTWEED CONTROL

While knotweed biomass in the CRMW has decreased significantly since treatment began in 2010, there is still work to be done. Some knotweed patches appear to be eradicated, while others still have small plants that persist year to year. In large sites such as the Rock Creek Complex, Education Center, and Taylor Townsite, plants can go unnoticed for several years in a row due to the shrubby understory and the size of the patches. Because of this, SPU anticipates that knotweed control in the CRMW will be a long-term management effort, although the sites will continue to require less herbicide each year.

If left untreated, there is evidence that a small amount of live knotweed present at treatment sites can return to the original infestation level in as little as three seasons, eventually surpassing the infestation level that was present before any investments in knotweed control. This regrowth would result in the loss of progress toward long-term knotweed control, increased future control costs, degradation of environmental quality, and the alteration of the sustainable ecological services of invaded sites. In addition, it could jeopardize the extensive ongoing restoration projects along the Cedar River downstream of Landsburg. As mentioned above, long-term maintenance and control costs of knotweed in the CRMW should be minimal. However, an ongoing monitoring program is essential to ensure that all known knotweed is eradicated, water quality is protected and any newly discovered patches are treated with imazapyr before they have a chance to spread. Controlling knotweed without imazapyr would raise the costs to control knotweed substantially.

ADDITIONAL INFORMATION

Reports detailing the 2010 through 2012 and 2013 through 2015 treatments are available in the project plans and reports section on City of Seattle's Watershed Habitat Conservation Plan page:
http://www.seattle.gov/util/EnvironmentConservation/OurWatersheds/Habitat_Conservation_Plan/ManagingtheWatershed/StreamRiparianHabitatRestoration/Metrics/index.htm

For more information about the Watershed Invasive Species Program, see the Major Watersheds Invasive Species Management Plan, available online:
http://www.seattle.gov/util/cs/groups/public/@spu/@ssw/documents/webcontent/01_029017.pdf

REFERENCES

King County. 2015. Best Management Practices Invasive Knotweeds. King County Noxious Weed Control Program. Available online: http://your.kingcounty.gov/dnrp/library/water-and-land/weeds/BMPs/Knotweed-Control.pdf.

King County. 2018. Noxious Weeds Lists and Laws. King County. Last updated February 4, 2018. Available online: https://www.kingcounty.gov/services/environment/animals-and-plants/noxious-weeds/laws.aspx.

Mangels, G. and A. Ritter. 2000. Estimated environmental concentration of imazapyr resulting from aquatic uses of Arsenal herbicide. Pesticide Registration Report # EXA 00-008, American Cyanamid Co.; Report Archived at Waterborne Environmental Inc., Leesburg, VA.

Parkinson, H. and J. Mangold. 2010. Biology, Ecology, and Management of the Knotweed Complex. Montana State University Extension. EB0196. December 2010.

Soll, J. 2004. Controlling knotweed (*Polygonum cuspidatum, P. sachalinense, P. polystachyum* and hybrids) in the Pacific Northwest. The Nature Conservancy. Available online: http://www.invasive.org/gist/moredocs/polspp01.pdf.

APPENDIX A: RISK ASSESSMENT LITERATURE REVIEW

KNOTWEED RISKS AND CONTROL

Bohemian knotweed (*Polygonum* x *bohemicum*) poses a large threat to the health of both habitat and water quality in the Cedar River Municipal Watershed (CRMW). The primary goals of Seattle Public Utilities (SPU) in the CRMW are to protect the public's high quality drinking water supply and maintain and enhance habitat for fish and wildlife, particularly salmon. Studies have shown that knotweed has many negative impacts on native ecosystems. Removal is difficult, and although SPU has tried multiple methods, the application of the herbicide imazapyr has been found to be the most effective.

Risks Posed by Knotweed

Non-native invasive species are organisms introduced deliberately or unintentionally outside their natural habitats, where they can dominate their new environments and locally eliminate native species. They pose serious challenges to the conservation of native biodiversity, with significant negative impacts on the functions, goods, and services provided by ecosystems. These ecosystem services include the production of clean water and the maintenance of habitat for salmon and other native fish, and wildlife including birds, mammals, amphibians, and insects. The management costs of invasive species include not only prevention, control, and mitigation, but also the direct and indirect costs associated with the adverse impacts on these ecosystem services.

As is often the case with hybrids, the hybrid Bohemian knotweed has been found to be more competitive and invasive than either of the parent species, Japanese knotweed (*P. cuspidatum*) and giant knotweed (*P. sachalinense*) (Parepa et al. 2013). This hybrid is widespread throughout the Pacific Northwest, and is the species found in the municipal watershed. Among the numerous invasive plant species present in the CRMW, knotweed is one of the most threatening to native ecosystem functioning. Once knotweed becomes established, it forms large monotypic stands that eliminate all native vegetation and are extremely difficult to eradicate. It can reproduce from tiny root or stem fragments, which are readily transported by water, wildlife, and humans. If unchecked, stands continue to expand and provide propagules that exacerbate infestations downstream and via other transportation routes.

Specifically, knotweed is known to:

- reduce the amount and diversity of native streamside vegetation through competition for light and nutrients (Urgenson et al. 2012);
- eliminate native vegetation through secreted chemicals that are toxic to other plants, also known as allelopathy (Murrell et al. 2011);
- change the soil nutrients and alter soil nutrient cycling, affecting the growth and development of native plant species and insects living in the soil (Urgenson et al. 2009);
- decrease the abundance and richness of both native plants and native invertebrates (Gerber et al. 2008);

alter the quality, quantity, timing, and chemistry of leaf inputs into riparian areas and streams (Claeson et al. 2013, Claeson and Bisson 2013, Urgenson et al. 2009, Urgenson 2006);

- destabilize stream banks, changing the patterns and amounts of streamside erosion and sediment input into streams, decreasing habitat quality for fish and other aquatic animals (Parkinson and Mangold 2010, King County 2015);
- provide little or no food or nesting habitat for native birds and mammals (Parkinson and Mangold 2010, King County 2015); and
- modify the microclimate, making the area inhospitable to many native wildlife species, including reducing amphibian foraging success (Maerz et al. 2005).

Because knotweed inhibits native tree seedling establishment in riparian zones (Urgenson et al. 2012), it can also affect future large woody debris recruitment into streams, significantly affecting channel dynamics and fish habitat, potentially negatively affecting state and federally listed fish species (NMFS 2010).

Claeson et al. (2013) compared knotweed litter with native red alder (*Alnus rubra*) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*). They found that although senesced knotweed leaves were lower in nitrogen and phosphorus, and higher in cellulose, fiber, and lignin content than alder leaves, they had many similarities to cottonwood leaves. Fungal biomass differed among all three species and changed over time. Macroinvertebrate shredders collected from experimental leaf packs after 31 days were proportionately more abundant on alder leaves than knotweed and cottonwood. Decay rates were not significantly different among leaf species, but during the first 31 days alder broke down faster than knotweed. After 56 days, all the leaf packs were mostly decomposed. Overall, the major discrepancies between leaf species were those related to the initial structural and chemical quality of leaf litter. However, changes in the timing and quantity of litter inputs are important factors to be considered in understanding the impact of invasive knotweed on stream ecosystem processes. Bohemian knotweed drops all its leaves in a three to four week period with the first hard frosts of late fall, whereas native deciduous shrubs and trees in the Pacific Northwest drop the majority of their leaves in the fall over a two to three month period, and coniferous trees shed litter over even longer time periods. Studies in England and France also found that aquatic hyphomycete and invertebrate assemblages that breakdown organic matter differed between stream sites with and without knotweed (Lecerf et al. 2007).

Maerz et al. (2005) studied the effects of knotweed on green frogs (*Rana clamitans*) in terrestrial fields near wetlands. Frogs were allowed to forage in feeding buckets along transects that traversed ground from knotweed-free to knotweed-dominated areas. They found that change in frog mass declined significantly along transects, with most frogs in knotweed-free plots gaining body mass and no frogs in knotweed-invaded plots gaining mass. It was noted in the discussion that many factors would have been involved in the foraging activity of the frogs, but their results led them to hypothesize that knotweed invasions indirectly degrade terrestrial habitat quality for frogs by reducing arthropod abundance. Their study of vegetation structure and composition on the test sites showed that diverse assemblages of native plants that covered non-invaded plots were absent from areas invaded by knotweed.

Knotweed Control Options

Due to the scale of spread of knotweed and the extreme difficulty of control by physical means, The Nature Conservancy (2002) has recognized that herbicides will often need to be the primary means of control. Most cities and counties in western Washington are using herbicide to control knotweed, including both upland and riparian areas. Scientists from the Washington State Extension Program and the King County Noxious Weed program have found that imazapyr is the safest and most effective herbicide for treating knotweed, resulting in the highest mortality and using the smallest amount of chemical (King County 2015; Dr. T. Miller, pers. comm. 2014). Most land managers throughout western Washington are now using targeted foliar spray of 1 percent imazapyr on knotweed, as it is currently the least toxic and most effective option.

Imazapyr is a non-selective herbicide used for the control of a broad range of invasive plants including terrestrial annual and perennial grasses, broadleaved herbs, woody species, and riparian and emergent aquatic species. It can only be applied as a foliar spray (not stem injection). Only glyphosate, which has higher toxicity than imazapyr, is certified for use with stem injection. Experience has shown that the stem injection method typically uses about five times more herbicide than foliar spraying, with no greater knotweed mortality rates. The advantage of using stem injection can be lower mortality to adjacent native plants. However, when foliar spray is correctly applied, there is minimal damage to adjacent plants.

Knotweed Control in the Cedar River Municipal Watershed

SPU focuses on being effective stewards of the municipal watershed lands and resources it owns or controls. Restoring and maintaining healthy forests, wetlands, streams, and lakes in the municipal watersheds that supply Seattle-area residents with drinking water is a priority for SPU. It is these healthy ecosystems that provide the abundant and high-quality drinking water on which the citizens of this region depend. Protecting water quality for human use also protects resources used by other species. Lands of the CRMW are managed under the 50-year Habitat Conservation Plan (HCP), which requires that SPU promote and protect native diversity of plants and animals.

SPU’s Secondary Use Policies, adopted by Ordinance 114632 and enacted in 1989, prohibits the use herbicides (i.e., pesticides designed specifically to be toxic to plants) in the CRMW. The intent was to stop the broadcast spraying of herbicide to control vegetation along forest roads, a typical forest management technique at that time. This was prior to the widespread recognition of the damage that certain non-native invasive plants can have on ecosystems and water quality.

SPU attempted to control a total of 4.5 acres in the CRMW by continual covering with geotextile fabric for eight years (2004 through 2012). This expensive (greater than $200,000) attempt was successful only on the smallest patches. Since 2008, SPU, King County, and Forterra have received over $1,30,000 in grants for programs to control this destructive plant and restore riparian areas along the Cedar River below Landsburg. They have worked along a total of 19 river miles, using herbicides to treat knotweed scattered over 105 acres of riparian habitat. They have planted over 20,000 native plants, worked with 368 landowners and engaged over 900 volunteers (Stewardship-In-Action 2014). Continued upstream control in the CRMW is essential to the success of these extensive efforts to control knotweed downstream and restore critical habitat used by salmon and numerous other wildlife species.

IMAZAPYR TOXICITY AND RISKS

Imazapyr inhibits an enzyme and amino acid synthesis found only in plants, and is thus classified as a Category III (low toxicity) herbicide by the US Environmental Protection Agency (EPA) (2006). Imazapyr has relatively low toxicity to mammals, showing low toxicity if individuals get residues on their skin, and very low toxicity if it is eaten or inhaled. It is classified as “practically non-toxic” to “slightly toxic” to fish and “practically non-toxic” to birds (EPA 2006).

Most of the toxicology studies are unpublished reports submitted to the EPA as part of the registration and re-registration process. This can potentially be a concern of bias. But, as stated in Durkin (2011), this concern is largely without foundation because there are strict guidelines developed by the EPA for conduct and reporting of studies. In addition, these types of studies are conducted under Good Laboratory Practices, an elaborate set of procedures involving documentation and independent quality control and quality assurance that typically exceeds that required of open literature peer-reviewed publications. Finally, the EPA reviews each study for adherence to their guidelines and practices.

Imazapyr Risks to Human Health

Human health risk is evaluated in relation to toxicity testing on mammals. As reported by EPA (2006) and reviewed in Durkin (2011) and AMEC (2009), the acute oral LD_{50} (lethal dose at which 50 percent of the test subjects die) is greater than 5,000 mg/kg for mammals. This is the highest dose tested, but that dose still did not achieve a 50 percent mortality in laboratory animals. So, a definitive mammal LD_{50} was not able to be determined. The chronic dietary No Observed Adverse Effect Level (NOAEL) is 10,000 parts per million (ppm) in dogs, rats, and mice.

Several multi-generation reproductive and developmental studies were conducted, and none indicated any adverse effects on reproductive capacity or normal development. Results of assays for carcinogenicity and mutagenicity are consistently negative, so the EPA categorizes imazapyr as Class E: evidence of non-carcinogenicity (EPA 2006). The EPA human health risk assessment for imazapyr finds no endpoints of concern associated with systemic toxic effects for either acute or chronic exposures (Durkin 2011). Available data indicate that orally administered imazapyr is well absorbed, and the majority of the dose is rapidly excreted unchanged in urine and feces (Durkin 2011). No endocrine or immune system effects were observed. Only one study of very high intravenous doses showed any signs of neurotoxicity (AMEC 2009). No other studies showed any neurotoxic effects.

Some clinical case reports of human intentional (attempted suicide) or accidental ingestion of large amounts of the formulation Arsenal are reported in the open literature. The reported signs and symptoms of imazapyr poisoning included vomiting, impaired consciousness, and respiratory distress requiring intubation (Lee et al. 1999). The respiratory distress was likely due to aspiration from vomiting and not from the imazapyr. There are no reports of human fatality due to large amounts of imazapyr ingestion. (Durkin 2011).

Studies on effects of acute dermal exposure, up to 2,000 mg/kg, were not associated with any signs of systemic toxicity (AMEC 2009). When risk characterization for workers was computed, even at the highest application rate modeled, the upper range of hazard quotients was below the level of concern by a factor of 8.5 (AMEC 2009). Imazapyr is reported as a mild skin irritant and mild eye irritant. Two studies of 99.3 percent imazapyr powder (acid) administered directly into the eye found severe and irreversible eye damage (Durkin and Follansby 2004). Because only dilute liquid and not concentrated powder is used in general herbicide application, this finding was not considered relevant to the risk assessments (Durkin 2011).

Dr. Allan Felsot, a well-known and respected toxicologist and professor of environmental toxicology at Washington State University, prepared a worst-case scenario for this project in which the entire maximum annual amount of herbicide used on all the knotweed in 2015 in the CRMW (not just that within the hydrographic boundary) was put directly into Lake Youngs, the municipal water storage lake. That would result in a concentration of 26.6 parts per trillion of imazapyr. He assumed no breakdown of the chemical and evaluated the human health risk of this concentration in the drinking water. His data showed that this concentration was at least 60,000,000 times lower than the dose found to cause no adverse effects on a human child.

Imazapyr Risks to Wildlife

In both 2005 and 2011 risk assessments, the US Forest Service (USFS) found that no adverse effects are likely to occur for a variety of mammals and birds with spraying at a typical application rate (Durkin 2011, Bautista 2005). Studies evaluated both acute (single) and chronic (extending over the average species lifetime) exposures. Test animals included small mammals such as mice, small insectivorous mammals, both large and small herbivorous mammals, medium carnivorous mammals, fish-eating birds, herbivorous birds, predatory birds, and insectivorous birds. Studies indicate that imazapyr is rapidly excreted in urine and feces by mammalian systems, with no bioaccumulation in the liver, kidney, muscle, fat, or blood (Soll 2004, Miller et al. 1991). Although herbicides contain inert ingredients that are considered proprietary, these toxicity tests were performed on the entire formulation, not just the active ingredient, indicating that the inert ingredients likely have low toxicity as well.

A peer-reviewed field study found that there were no adverse effects on benthic macroinvertebrates (including invertebrate biomass, community composition, and deformities) at rates as high as 100 times that of normal applications (Fowlkes et al. 2003). Another peer-reviewed study tested the embryos of zebra fish (*Danio rerio*) in an extremely sensitive in vivo test for the effects of endocrine system dysfunction (Stehr et al. 2009). They found an “absence of toxicity at relatively high exposure concentrations”.

Trumbo and Waligora (2009) in an acute toxicity study of bullfrog tadpoles (*Rana catesbeiana*), a surrogate for native amphibians, found the LC^{50} (lethal concentration in water in which 50 percent of the subjects die) for imazapyr was 1,739 mg/L. Any concentration over 100 mg/L is considered practically non-toxic. This extremely high concentration required to achieve 50 percent mortality indicates that imazapyr has very low toxicity to the tadpoles.

In a toxicity study directed at the Oregon spotted frog (*Rana pretiosa*), listed as federally threatened, Yahnke et al. (2013) exposed juvenile spotted frogs to tank mixes of imazapyr (aquatic formulation), surfactant (Agri-Dex), and dye for 96 hours at concentrations associated with an application rate of up to 96 oz/ac. Following exposure, the frogs were reared for two months. No mortalities or changes in feeding behavior, growth, or body and liver conditions were found. The tank mix used in the study (aquatic formulation and Agri-Dex) is the same one used in the CRMW, except that SPU's application rate is far lower and SPU never applies imazapyr directly to water.

In another amphibian toxicity study, Hurley and Shanaman (2007) conducted a risk assessment of imazapyr to the California red-legged frog (*Rana aurora draytonii*), also federally listed as threatened. They found that no direct adverse effects were expected for either the aquatic or terrestrial phase of the frog. They also found no indirect adverse effects through food sources.

A recent study compared the relative sensitivity of amphibians and fish to over 50 different chemicals (Weltje et al. 2013). They found that for both acute and chronic sensitivity, amphibians and fish had very similar responses. So recent concern that amphibians may be more sensitive to various chemicals than fish may be unjustified.

Imazapyr Risks to Pollinators

European honey bee (*Apis mellifera*) Colony Collapse Disorder (CCD) is a major concern in western Washington, as well as throughout the country and world. Since the disorder was first named in 2007, population declines in European honey bees, native bees, and other pollinators have continued. Native bumble bees in particular have suffered significant range restrictions and reduced abundance (Hatfield et al. 2012). These pollinator declines have a significant negative effect not only on agricultural crop production, but also on native plant reproduction and native biodiversity.

Recently, neonicotinoid insecticides (insecticides are pesticides specifically designed to be toxic to insects) have been identified as likely contributors to the population declines (Hopwood et al. 2012). Unlike earlier insecticides, they are long-lasting compounds that can be systemic within the plant (including pollen and nectar) and are now extensively used both in agriculture and by homeowners. Several of these types of insecticides, including imidacloprid, the most widely used neonicotinoid product, are toxic at high doses to both honey bees and bumble bees (Schmuck et al. 2001). Data for chronic low dose exposures are less clear. It may or may not cause mortality, depending on specific factors and conditions. However, it still may cause sublethal alterations in navigation, learning, and foraging activity (Han et al. 2010, Decourtye et al. 2003).

Although no direct link has been demonstrated between neonicotinoids and CCD, it is likely one of several major contributors and stressors. Other contributors likely include disease, parasitic bee mites (including *Varroa* mite) and miticides used to control them in the hives, fungus and fungicides, nutrition, and synergistic effects between the stressors (Sanchez-Bayo and Goka 2014, Johnson et al. 2010). In their risk assessment of pesticide residues and bees, Sanchez-Bayo and Goka (2014) reported that a total of 161 pesticides have been found in bee hives, of which 83 were insecticides, 40 fungicides, 27 herbicides and 10 acaricides. Of the 49 most common compounds, six were herbicides, and none included imazapyr. Johnson et al. (2010) listed 121 pesticides found in apiary samples of wax, pollen, bees, and honey, and imazapyr was not among them. Likewise, Wu et al. (2011) found 39 pesticides in brood combs, of which only two were herbicides and neither were imazapyr.

The primary cause of bee poisoning is highly toxic insecticides with residual toxicity longer than 8 hours. Hooven et al. (2013) notes that “the mode of action of herbicides affects plants, not insects, and herbicides are unlikely to cause bee poisoning incidents under field conditions”. Imazapyr is not included in the 150 active ingredients most likely to cause bee toxicity (Hooven et al. 2013).

Imazapyr toxicity to humans and animals discussed above also applies to insects. Because imazapyr inhibits enzymes found only in plants, it has very low bee toxicity. The honey bee was tested for toxicity during the initial toxicity studies (Atkins 1984, Atkins and Kellum 1983, cited in Durkin 2011), where the LD_{50} for both oral and contact toxicity studies was greater than 0.1mg/bee (or greater than 1,000 mg/kg of body weight). This is similar to the NOAEL values reported for mammals and birds. As with mammals and birds, they were unable to reach an LD_{50} level at the highest doses tested (i.e., less than 50 percent of the test subjects died).

Stark et al. (2012) conducted a study on the effects of three herbicides on Behr’s metalmark butterfly (*Apodemia virgulti*), one of which was imazapyr. They used the terrestrial formulation (which includes surfactant) and the maximum legal allowable dose (96 oz/ac, compared to SPU’s highest application rate of 26.9 oz/ac in the CRMW) and sprayed butterfly instars (larval stages between molts) while they were on buckwheat. In addition, they sprayed only the buckwheat, then fed it to the larvae. All three herbicides reduced the number of individuals reaching the pupal stage by 24 to 36 percent. Because each herbicide had a different mode of action, the authors stated that the effects were likely due either to inert ingredients or indirect effects on food plant quality, rather than direct toxicity from the herbicides. Stark (2015 pers. comm.) stated he knew of no ongoing or planned studies looking at the effects of imazapyr on bees or other pollinators. In 2015, the Pesticide Program Director for the Xerces Society for Invertebrate Conservation (A. Code pers. comm.) also knew of no research looking at toxicity of imazapyr on pollinators. There are no published data to indicate that dermal contact or ingestion of imazapyr by bees or other pollinators causes any toxic effects, lethal or sublethal. Because past research has not found any significant toxicity of the herbicide imazapyr to bees, researchers are focusing on insecticides, many of which are highly toxic to pollinators, as discussed above.

Herbicides can indirectly affect pollinators if they remove a significant portion of their food sources. This can be a concern with knotweed, as large flowering patches can be used extensively by bees. In the municipal watershed, SPU bends large canes prior to the first herbicide treatment, then treats the regrowth which has no flowers. SPU’s experience in the CRMW is that after the first herbicide treatment, the knotweed above-ground biomass is greatly reduced, and only an occasional isolated plant might produce a few flowers. But most plants do not flower in subsequent treatment years. This was confirmed by several other land managers in western Washington at knotweed working group meetings in 2015. If pollinators are observed on knotweed before spraying, spraying is delayed to a time of day where pollinators are not present, or after the flowers have gone to seed. This method is consistent with the King County Noxious Weed Control Program, which in 2015 clarified its already existing practices for treating knotweed with herbicide and potential effects on pollinators. In their updated Best Management Practices for Knotweeds brochure (King County 2015), they state that they avoid spraying knotweed when bees or other pollinators are present whenever feasible.

SPU shares the concern about pollinator population declines. Consequently, SPU is planting a range of native flowering plants whenever appropriate during CRMW restoration projects, including restoration of sites formerly dominated by knotweed. SPU chooses a variety of native plants that have different flower colors and shapes, with flowering periods that vary throughout the growing season, providing nectar and pollen to many pollinator species, focusing especially on native bumble bees (Hatfield et al. 2012). This diversity of native species should provide better native pollinator habitat than the invasive knotweed, which flowers for a single short period during late summer or early fall, depending on weather, elevation, and site-specific factors such as soil type and moisture**.**

IMAZAPYR CHEMISTRY

Imazapyr is the common name for the chemical 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5oxo-1*H*-31 imidazol-2-yl]-3-pyridinecarboxylic acid. It is sold under numerous trade names and has both terrestrial and aquatic formulations. The aquatic formulation does not include surfactant. Several studies have found that the surfactant in terrestrial glyphosate formulations may be more toxic to amphibians than the main ingredient itself (King and Wagner 2010, Relyea and Jones 2009, Cauble and Wagner 2005). There is concern that this may also be true for imazapyr formulations. For this reason, SPU always uses the aquatic formulation of imazapyr and mixes with the least toxic surfactant available.

Imazapyr Mode of Action

Imazapyr is absorbed quickly through plant foliage and can also be taken up by roots. It is moved readily within the plant to the growing meristematic tissues, where it inhibits the enzyme acetolactate synthase (ALS) (Tu et al. 2004). ALS is required for the synthesis of three essential amino acids required for protein synthesis and cell growth in the plant (valine, leucine, and isoleucine). Only plants have ALS and produce these three amino acids; animals must obtain them from their diet. Because animals do not synthesize these amino acids, imazapyr is specifically toxic to plants and has low toxicity to humans and other animals (including mammals, birds, fish, and insects) (Massachusetts Department of Environmental Protection 2012, Durkin 2011, Bautista 2005, Durkin and Follansbee 2004). The rate of plant death is usually slow (several weeks) and is likely related to the amount of stored amino acids available to the plant.

Imazapyr Breakdown Process and Byproducts

The half-life of imazapyr in soils in the field have been has been reported to be as short as 10 days to as long as 17 months in humid temperate climates, depending on soil type and particle size, pH, temperature, moisture content, and organic material content. Because imazapyr is water-soluble, it can move in soil and can potentially enter the ground water. However, the amount of imazapyr movement depends on the soil pH. Below pH 5, the adsorption capacity of imazapyr increases and its movement in soils is limited (Soll 2004). Most forest soils in western Washington are acidic, with soils under Douglas-fir generally below pH 6, and soils under red alder (common in riparian areas) below pH 5 (pers comm. Darlene Zabowski, soil science professor, University of Washington).

Imazapyr is degraded slowly in soils primarily by microbial metabolism. It will undergo rapid photodegradation (breakdown by sunlight) in water, but there is little to no photodegradation of imazapyr in soil, and it is not readily degraded by other chemical processes. Imazapyr does not bind strongly with soil particles and, depending on soil pH, can be neutral or negatively charged. When negatively charged, imazapyr remains available in the environment for continued uptake by the target species until it is degraded by soil microbes.

Imazapyr is water soluble and is broken down by sunlight in water, with a reported half-life in water as short as two days (Soll 2004), but no longer than five days (EPA 2006). A study of the persistence of imazapyr associated with smooth cordgrass control in an estuary in Willapa Bay, Washington, found half-lives were less than 0.5 day in water and 1.6 days in sediment (Patten 2003, Pless 2005).

In water, imazapyr initially photodegrades rapidly to two primary byproducts, “CL 119060”, and “CL9140” (7-hydorxyfurol[3,4-b]pyridine-5(7H) and 2,3-pyridinedicarboxylic acid). According to the manufacturers, CL119060 is biologically oxidized to CL 9140, and eventually mineralizes to carbon dioxide (CO_2) following the cleavage of the pyridine ring structure. Both imazapyr degradation byproducts rapidly degrade, with half lives of two to five days (Mangels and Ritter 2000, Wisconsin Department of Natural Resources 2012).

Dr. Felsot, referenced above in the Imazapyr Risks to Human Health section, was asked about the potential toxicity of breakdown byproducts. He said that all these byproducts are biodegradable. When the formulation is given to test animals in high doses, they result in similar breakdown byproducts within the animals as would occur in the environment. Indeed, these breakdown byproducts are even more bioavailable than any that would occur in the environment because they are already in systemic circulation within the animal. In the environment, bioavailability is limited by interactions with solid surfaces, such as soil, sediment, plant waxes, etc. Thus, these breakdown byproducts, if toxic in and of themselves, would have affected the physiology of the test animals. Yet, all the listed byproducts do not cause acute toxicity at environmental levels of exposure. In fact, none of the byproducts even cause chronic or sub-chronic toxicity at levels of environmental exposure.

IMAZAPYR ADJUVENTS

Adjuvants are compounds added to the formulation or the spray mix to improve its performance. They can enhance the activity of an herbicide's active ingredient (activator adjuvant, including surfactants) or offset any problems associated with its application (special purpose or utility modifiers such as defoamers). On the label, these compounds are often called "inert" or "other ingredients". Surfactants are one type of adjuvant that makes the herbicide more effective by increasing absorption into the plant by lowering the surface tension between the liquid herbicide formulation and the solid leaf surface. Adjuvants can make a significant difference in how well the herbicide treatment works. Adjuvants present in terrestrial formulations generally include both inert ingredients and surfactants (discussed separately below). Those in aquatic formulations include inert ingredients, but not surfactants.

Inert Ingredients

Formulations of herbicides often contain proprietary carriers and other so-called "inert" ingredients that are usually not identified on herbicide labels. The EPA now uses the term "other ingredients" rather than "inert" to describe these compounds that are intentionally added to a formulation but have no inherent herbicidal activity. Inert ingredients (inerts) are most often added to the formulation to facilitate its handling, stability, or mixing.

Inerts and surfactants are not under the same registration guidelines as the active ingredients in pesticides. The EPA classifies these compounds into four lists based on the available toxicity information:

- List 1: "inerts of toxicological concern"
- List 2: "potentially toxic inerts, high priority for testing"
- List 3: "inerts of unknown toxicity"
- List 4: "minimal risk inerts" or "inerts for which EPA has sufficient information to conclude that their current use patterns will not adversely affect public health or the environment."

If the compounds are not classified as toxic, then all information on them is considered proprietary and the manufacturer need not disclose their identity.

The identity of inert compounds used in imazapyr formulations is generally confidential, but Syracuse Environmental Research Associates reviewed them, using the Freedom of Information Act, for preparation of risk assessments conducted for the USFS (Durkin 2011, Bautista 2005, Durkin and Follansbee 2004). They conducted very comprehensive searches of the literature and used peer-reviewed articles from public scientific literature, current EPA documents available to the public, and Confidential Business Information to evaluate toxicity and risk from the herbicides analyzed. No apparently hazardous materials were identified in the review of the inerts used in either the terrestrial or aquatic formulations of imazapyr.

The Northwest Coalition for Alternative to Pesticides obtained information on inert ingredients in the formulation Arsenal (aquatic formulation) under the Freedom of Information Act and posted it on their website. The only inert listed other than water is glacial acetic acid (defined as anhydrous or water-free acetic acid, i.e., undiluted). Dilute acetic acid, the major component in vinegar, is an approved food additive and is classified as a Generally Regarded as Safe compound (AMEC 2009).

Surfactants

There are several types of surfactants, including non-ionic which form stable emulsions, oil-based or methylated seed oil concentrates, organosilicon, and nitrogen containing compounds. They are usually proprietary blends of heavy-range paraffin-based petroleum oil, polyol fatty acid esters, and/or polyethoxylated derivatives thereof. They improve pesticide application by modifying the wetting and deposition characteristics of the spray solution, resulting in a more even and uniform spray deposit on the leaves of the target species.

In toxicity tests on rainbow trout performed by the Washington Cooperative Fish and Wildlife Unit at the University of Washington, Agri-Dex was found to be by far the least toxic surfactant tested (Smith et al. 2004). In their laboratory tests it took 271 ppm, or a concentration of greater than 1000 mg/L, for an LC50 dose (the concentration at which 50 percent of the test subjects died). This compares to only 6 ppm for R-11, 17 ppm for LI700, and 74 ppm for Hasten. They also studied the relative concentrations of the surfactants in relation to water depths expected in the field. Even at the maximum allowed concentration of Agri-Dex of 5 percent (more than 5 times that used in knotweed control), a trout stream would have to be sprayed directly and be less than 5 mm (or about ¼ inch) deep in order to reach the LC50 concentration for trout. Clearly trout could never survive in such shallow water, so in practice no mortality would occur.

The 2008 Material Safety Data Sheet for Agri-Dex reports that it is expected to be adsorbed to soil and should be biodegradable. Bioaccumulation is unlikely due to the low water solubility of the product. Animal toxicity data for similar products required very large doses (greater than 2,000 mg/kg) to cause mortality, showed low inhalation toxicity, and were practically non-irritating to skin and eye in tests on rabbits.

The Washington State Department of Agriculture requires aquatic toxicity tests if a surfactant is labeled for aquatic use in that state. In 2012 they summarized the aquatic acute toxicity data for adjuvants allowed for use on aquatic sites (WSDA 2012). Of the 25 products reviewed, Agri-Dex had by far the least toxicity to rainbow trout and daphnids (LC50 of greater than 1000 mg/L). Consequently, SPU uses Agri-Dex (0.5 to 2 percent) as the surfactant mixed with the aquatic formulation of imazapyr to treat knotweed in the Cedar River Municipal Watershed. All available data continues to indicate that this combination is the least toxic option.

REFERENCES

AMEC. 2009. Human health and ecological effects risk assessment, imazapyr. AMEC Geomatrix Inc. For Washington State Department of Agriculture. Available online: https://agr.wa.gov/PlantsInsects/Weeds/NPDESPermits/docs/2009AMECHumanHealthEcologicalEffectsRiskAssessmentImazapyr.pdf.

Atkins, E. and X. Kellum. 1983. Bee adult toxicity dusting test summary: test no. 389. MRID No. 00133554 (as cited by Durkin and Follansbee 2004).

Atkins, E. 1984. Bee adult toxicity dusting test summary (and test data using arsenal herbicide): unpublished study prepared by University of California Department of Entomology, Riverside, BADTD No 414, Summary sheet No 766, MRID No 00153780, 11 pp. (as cited by Durkin and Follansbee 2004).

Bautista, S. 2005. Summary of herbicide effects to wildlife. Appendix in Preventing and managing invasive plants final environmental impact statement. USDA Forest Service. April 2005.

Cauble, K. and R. Wagner. 2005. Sublethal effects of the herbicide glyphosate on amphibian metamorphosis and development. Bulletin of Environmental Contamination and Toxicology 75:429-435.

Claeson, S. and P. Bisson. 2013. Passive reestablishment of riparian vegetation following removal of invasive knotweed (*Polygonum*). Invasive Plant Science and Management 6:208-218.

Claeson, S., C. LeRoy, J. Barry, and K. Kuehn. 2013. Impacts of invasive riparian knotweed on litter decomposition, aquatic fungi, and macroinvertebrates. Biological Invasions DOI 10.1007/s10530-013-0589-6. Available online: http://www.fs.fed.us/pnw/lwm/aem/docs/claeson/2013_claeson_et_al_knotweed_impacts_onlinefirst_112513.pdf.

Decourtye, A., E. Lacassie, and M. Pham-Delegue. 2003. Learning performances of honeybees (*Apis mellifera*) are differentially affected by imidacloprid according to the season. Pest Management Science 69:269-278.

Durkin, P. and M. Follansbee. 2004. Imazapyr – human health and ecological risk assessment final report to USDA, Forest Service. Available online: http://www.fs.fed.us/foresthealth/pesticide/pdfs/121804_Imazapyr.pdf.

Durkin, P. 2011. Imazapyr – human health and ecological risk assessment final report to USDA Forest Service. Available online: http://www.fs.fed.us/foresthealth/pesticide/pdfs/Imazapyr_TR-052-29-03a.pdf.

EPA. 2006. Reregistration eligibility decision for imazapyr. Environmental Protection Agency. EPA 738-R-06-007.

Fowlkes, M., J. Michael, T. Crisman, and J. Prenger. 2003. Effects of the herbicide imazapyr on benthic macroinvertebrates in a logged pond cypress dome. Environmental Toxicology and Chemistry 22(4):900-907.

Gerber, E., C. Kerbs, C. Murrell, M. Moretti, R. Rocklin, and U. Schaffner. 2008. Exotic invasive knotweed (*Fallopia* spp.) negatively affects native plant and invertebrate assemblages in European riparian habitats. Biological Conservation 141: 646-654.

Han, P, C. Niu, C. Lei, J. Cui, and N. Desneux. 2010. Use of an innovative T-tube maze assay and the proboscis extension response assay to assess sublethal effects of GM products and pesticides on learning capacity of the honey bee *Apis mellifera*. Ecotoxicology 19:1612-1619.

Hatfield, R., S. Jepsen, E. Mader, S. Hoffman Black, and M. Shepherd. 2012. Conserving bumble bees. Guidelines for creating and managing habitat for America's declining pollinators. 32 pp. Portland OR. The Xerces Society for Invertebrate Conservation. Available online: http://www.xerces.org/bumblebees/guidelines/.

Hopwood, J., M. Vaughan, M. Shepherd, D. Biddinger, E. Mader, S. Hoffman Black, and C. Mazzacano. 2012. Are neonicotinoids killing bees? The Xerces Society for Invertebrate Conservation. Available online: http://www.xerces.org/neonicotinoids-and-bees/.

Hooven, L., R. Sagili, and E. Johansen. 2013. How to reduce bee poisoning from pesticides. Pacific Northwest extension publication PNW591. Available online: https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/pnw591.pdf.

Hurley, P. and L. Shanaman. 2007. Risks of imazapyr use to the federally listed California red legged frog. Pesticides Effects Determination. Environmental Fate and Effects Division, Office of Pesticide Programs, USEPA. Available online: http://www3.epa.gov/pesticides/endanger/litstatus/effects/redleg-frog/imazapyr/analysis.pdf.

Johnson, R., M. Ellis, C. Mullin, and M. Frazier. 2010. Pesticides and honey bee toxicity – USA. Apidologie 41:312-331.

King County. 2015. Best Management Practices Invasive Knotweeds. King County Noxious Weed Control Program. Available online: http://your.kingcounty.gov/dnrp/library/water-and-land/weeds/BMPs/Knotweed-Control.pdf.

King, J. and R. Wagner. 2010. Toxic effects of the herbicide Roundup regular on Pacific Northwestern amphibians. Northwest Naturalist 91:318-324.

Lecerf A, C. Patfield, A. Boiche, M. Riipinen, E. Chauvet, and M. Dobson. 2007. Stream ecosystems respond to riparian invasion by Japanese knotweed (*Fallopia japonica*). Canadian Journal of Fisheries and Aquatic Science 64(9):1273–1283.

Lee, H., K. Chen, and M. Wu. 1999. Acute poisoning with an herbicide containing imazapyr (Arsenal) – a report of six cases. Clinical Toxicology 37:83-89.

Maerz, J., B. Blossey, and V. Nuzzo. 2005. Green frogs show reduced foraging success in habitats invaded by Japanese knotweed. Biodiversity and Conservation 14:2901-2911.

Mangels, G. and A. Ritter. 2000. Estimated environmental concentration of imazapyr resulting from aquatic uses of Arsenal herbicide. Pesticide Registration Report # EXA 00-008, American Cyanamid Co.; Report Archived at Waterborne Environmental Inc., Leesburg, VA.

Massachusetts Department of Environmental Protection. 2012. Imazapyr: review for use in lakes and ponds in Massachusetts. Available online: http://www.mass.gov/eea/docs/agr/pesticides/aquatic/imazapyr.pdf.

Miller, P., C. Fung, and B. Ginger. 1991. Animal metabolism, p. 171. In: Shaner, D. and S. O'Connor, eds. 1991. The Imidazolinone Herbicides. CRC Press, Boca Raton, FL. 290 p.

Murrell, C., E. Gerber, C. Krebs, M. Parepa, U. Schaffner, and O. Bossdorf. 2011. Invasive knotweed affects native plants through allelopathy. American Journal of Botany 98(1):38-43.

NMFS. 2010. Consultation letter and programmatic biological opinion for vegetation treatments using herbicides on BLM lands across nine BLM districts in Oregon. National Marine Fisheries Service. Available online: http://www.blm.gov/or/plans/vegtreatmentseis/files/Veg_Treatments_ROD_Oct2010_AttachD.pdf.

Parepa, M., M. Fischer, C. Krebs, and O. Bossdorf. 2013. Hybridization increases invasive knotweed success. Evolutionary Applications 7(3): 413-420. ISN 1752-4571. DOI 10.1111/eva.12139.

Parkinson, H. and J. Mangold. 2010. Biology, Ecology, and Management of the Knotweed Complex. Montana State University Extension. EB0196. December 2010.

Patten, K. 2003. Persistence and non-target impact of imazapyr associated with smooth cordgrass control in an estuary. Journal of Aquatic Plant Management 41:1-6.

Pless, P. 2005. Use of imazapyr herbicide to control invasive cordgrass (*Spartina spp*.) in the San Francisco estuary: water quality, biological resources, and human health and safety. Prepared for San Francisco Estuary Invasive Spartina Project. Prepared by Petra Pless, D. Env. Leson & Associates, Berkeley, CA.

Relyea, R. and D. Jones. 2009. Toe toxicity of Roundup Original Max to 13 species of larval amphibians. Environmental Toxicology and Chemistry. 28:2004-2008.

Sanchez-Bayo, F. and K. Goka. 2014. Pesticide residues and bees – a risk assessment. PLOS ONE. Vol 9, issue 4. E94482.

Schmuck, R., R. Schoning, A. Stork, and O. Schramel. 2001. Risk posed to honeybees (*Apis mellifera*) by an imidacloprid seed dressing of sunflowers. Pest Management Science 57:225-238.

Smith, B., C. Curran, K. Brown, J. Cabarrus, J. Gown, J. McIntyre, E. Moreland, V. Wong, J. Grassley, and C. Grue. 2004. Toxicity of four surfactants to juvenile rainbow trout: implications for use over water. Bulletin of Environmental Contamination and Toxicology 72:647-654.

Soll, J. 2004. Controlling knotweed (*Polygonum cuspidatum, P. sachalinense, P. polystachyum* and hybrids) in the Pacific Northwest. The Nature Conservancy. Available online: http://www.invasive.org/gist/moredocs/polspp01.pdf.

Stark, J., X. Chen, and C. Johnson. 2012. Effects of herbicides on Behr's metalmark butterfly, a surrogate species for the endangered butterfly, Lange's metalmark. Environmental Pollution. Vol 1643: 24-27.

Stehr, C., T. Linbo, D. Baldwin, N. Scholz, and J. Incardona. 2009. Evaluating the effects of forestry herbicides on fish development using rapid phenotypic screens. North American Journal of Fisheries Management 29: 975-984.

Stewardship-In-Action. 2014. 2014 Progress Report. Available online: http://www.seattle.gov/util/cs/groups/public/@spu/@ssw/documents/webcontent/01_031848.pdf.

The Nature Conservancy. 2002. Controlling knotweed in the Pacific Northwest. Available online: http://www.invasive.org/gist/moredocs/polspp01.pdf.

Trumbo, J. and D. Waligora. 2009. The impact of the herbicides imazapyr and triclopyr trimethylamine on bullfrog tadpoles. California Fish and Game 95(3): 122-127.

Tu, M., C. Hurd, and J. Randall. 2004. The Nature Conservancy Weed Control Methods Handbook: tools and techniques for use in natural areas, imazapyr. Available online: http://www.invasive.org/gist/handbook.html.

Urgenson. L. 2006. The ecological consequences of knotweed invasion into riparian forests. Master's thesis, University of Washington, College of Forest Resources, Seattle, WA.

Urgenson, L., S. Reichard, and C. Halpern. 2009. Community and ecosystem consequences of giant knotweed (*Polygonum sachalinense*) invasion into riparian forests of western Washington, USA. Biological Conservation 142(7):1536-1541.

Urgenson, L., S. Reichard, and C. Halpern. 2012. Multiple competitive mechanisms underlie the effects of a strong invader on early to late-seral tree seedlings. Journal of Ecology 100: 1204-1215.

WSDA. 2012. Summary of aquatic acute toxicity data for spray adjuvants allowed for use on aquatic sites in Washington (rev. 7/20/12). Washington State Department of Agriculture. Available online: http://www.clallam.net/WeedControl/assets/applets/Toxicity_of_Surfactants.pdf.

Weltje, L., P. Simpson, M. Gross, M. Crane, and J. Wheeler. 2013. Comparative acute and chronic sensitivity of fish and amphibians: a critical review of data. Environmental Toxicology and Chemistry 32(5): 984-994.

Wisconsin Department of Natural Resources. 2012. Imazapyr Chemical Fact Sheet. Available online: https://dnr.wi.gov/lakes/plants/factsheets/ImazapyrFactsheet.pdf.

Wu, J., C. Anelli, and W. Sheppard. 2011. Sub-lethal effects of pesticide residues in brood comb on worker honey bee (*Apis mellif*era) development and longevity. PLOS ONE. Vol 6(2) e14720.

Yahnke, A., C. Grue, M. Hayes, and A. Troiano. 2013. Effects of the herbicide imazapyr on juvenile Oregon spotted frogs. Environmental Toxicology and Chemistry 32(1): 228-235.

APPENDIX B: SITE RESTORATION

Ensuring knotweed treatment sites are repopulated with native plants following treatment is the most effective method for preventing re-infestation of knotweed and other invasive plants. SPU's goal is to restore areas formerly occupied by knotweed to naturally functioning ecosystems dominated by a variety of native trees and shrubs. This restoration will both increase resistance to future invasions by non-native species and provide high quality habitat for native wildlife, including birds, mammals, amphibians, and insects. Most large sites formerly occupied by knotweed became infested with other non-native invasive species after treatment. Consequently, these sites need continued restoration work, including removal of other invasive species and planting native trees and shrubs. The two largest knotweed sites, the Education Center and Taylor Townsite, have been actively restored since 2013.

EDUCATION CENTER RESTORATION

In 2013, the non-profit group Friends of the Cedar River Watershed (FCRW), in conjunction with SPU, received a 5-year King Conservation District (KCD) grant totaling $46,000 to restore the formerly knotweed-infested area near the Education Center to native trees and shrubs. The grant funded several volunteer events and six weeks of Washington Conservation Crew (WCC) time spread over the five years, from 2013 through 2017. It also funded the purchase of approximately 2,800 native plants. In 2015, FCRW dissolved and Forterra assumed management of the grant.

From 2013 through 2017, SPU and FCRW staff, volunteers, and WCC crews cleared the Education Center site of invasive Himalayan and evergreen blackberry (*Rubus armeniacus* and *Rubus laciniatus*), English ivy (*Hedera helix*), black locust (*Robinia pseudoacacia*), foxglove (*Digitalis purpurea*), mullein (*Verbascum thapsus*), Scots broom (*Cytisus scoparius*), and birdsfoot trefoil (*Lotus corniculatus*) that had invaded the area formerly dominated by knotweed. SPU staff designed seven planting zones, each with different long-term goals and specific planting plans (Figure B1). A total of 204 native overstory trees (seven species), 3,397 small trees and shrubs (31 species), and 486 forbs (five species) were planted during these years (Table B1). In addition, volunteers and contractors moved several hundred yards of mulch, surrounding each native planting with mulch to help suppress non-native weeds and provide more growing space for the plantings. SPU will continue planting native species, as needed, both from purchased stock and from transplanting appropriate species from nearby sites in the municipal watershed. A visual record of Education Center knotweed response to treatment and site restoration from 2010 through 2017 is found in Figures B2 through B17.

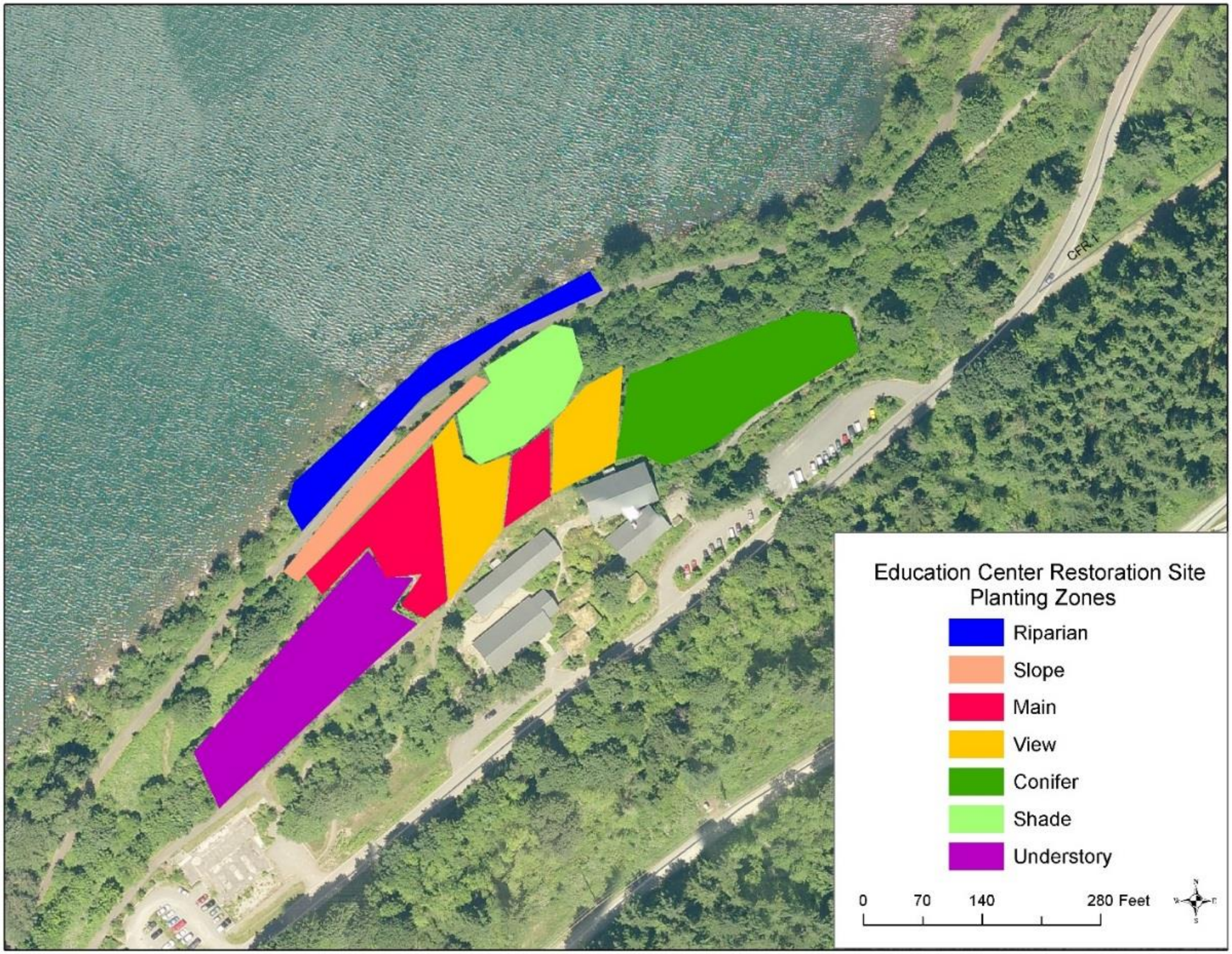

Figure B1. Location of the seven planting zones near the Education Center

Table B1. Species and Number of Native Trees and Shrubs Planted at the Education Center, 2013 – 2017.			
Overstory Trees			
Big-leaf maple (*Acer macrophyllum*)	15	Sitka spruce (*Picea sitchensis*)	40
Black cottonwood (*Populus balsamifera* ssp. *trichocarpa*)	15	Western hemlock (*Tsuga heterophylla*)	29
		Western redcedar (*Thuja plicata*)	50
Douglas-fir (*Pseudotsuga menziesii*)	30	Western white pine (*Pinus monticola*)	25
Total trees planted			**204**
Small Trees and Shrubs			
Baldhip rose (*Rosa gymnocarpa*)	155	Red osier dogwood (*Cornus sericea*)	200
Beaked hazelnut (*Corylus cornuta*)	70	Red-flowering currant (*Ribes sanguineum*)	135
Bitter cherry (*Prunus emarginata*)	50	Redstem ceanothus (*Ceanothus sanguineus*)	50
Black hawthorn (*Crataegus douglasii*)	50	Salal (*Gaultheria shallon*)	5
Cascara (*Frangula purshiana*)	125	Salmonberry (*Rubus spectabilis*)	60
Indian plum (*Oemleria cerasiformis*)	80	Serviceberry (*Amelanchier alnifolia*)	75
Kinnikinnick (*Arctostaphylos uva-ursi*)	54	Snowberry (*Symphoricarpos albus*)	135
Mock orange (*Philadelphus lewisii*)	25	Spirea (*Spiraea douglasii*)	65
Nootka rose (*Rosa nutkana*)	145	Sweet gale (*Myrica gale*)	20
Oceanspray (*Holodiscus discolor*)	186	Tall Oregon grape (*Mahonia aquifolium*)	180
Pacific crabapple (*Malus fusca*)	25	Thimbleberry (*Rubus parviflorus*)	120
Pacific ninebark (*Physocarpus capitatus*)	125	Twinberry (*Lonicera involucrata*)	150
Pacific rhododendron (*Rhododendron macrophyllum*)	50	Vine maple (*Acer circinatum*)	235
		Willow, Hooker's (*Salix hookeriana*)	100
Peafruit rose (*Rosa pisocarpa*)	120	Willow, Pacific (*Salix lucida* ssp. *lasiandra*)	230
Red elderberry (*Sambucus racemosa*)	57	Willow, Sitka (*Salix sitchensis*)	320
Total small trees and shrubs planted			**3397**
Forbs			
Fern, deer (*Blechnum spicant*)	75	Goat's beard (*Aruncus dioicus*)	165
Fern, oak (*Gymnocarpium dryopteris*)	75	Spreading dogbane (*Apocynum androsaemifolium*)	6
Fern, sword (*Polystichum munitum*)	165		
Total forbs planted			**486**

Figure B2. Knotweed before initial 2010 treatment. 12-foot tall knotweed covered the entire site.

Figure B3. May 2011. Spring after the first treatment, showing the dead canes from the first treatment. Canes had been bent prior to treatment to facilitate access for the applicators.

Figure B4. August 2011. One year after first treatment, showing dead canes, knotweed regrowth, and initial invasion by Himalayan blackberry.

Figure B5. August 2011. Large patches of Himalayan blackberry began to encroach the site one year after the first treatment.

Figure B6. September 2012. One year after the second treatment, there were scattered medium sized knotweed plants. Dead canes had been hand-cleared from the site to make finding re-growth easier.

Figure B7. September 2012. Invasive black locust took over a portion of the site one year after second treatment. Mullein, foxglove, and other non-native plants also started to invade.

Figure B8. September 2013. One year after third treatment and initial KCD grant restoration work (invasive species removal and planting native trees and shrubs).

Figure B9. October 2014. One year after fourth treatment, with continued KCD grant restoration work (spreading mulch, planting).

Figure B10. August 2015. One year after fifth treatment, there were small scattered knotweed plants amongst the planted native trees and shrubs.

Figure B11. September 2016. One year after sixth treatment, there were small scattered knotweed plants still growing amongst the planted native trees and shrubs.

Figures B12 and B13. September 2016. Trees and shrubs planted on the site had high survival and grew vigorously.

Figure B14. September 2016, continued. Trees and shrubs planted on the site had high survival and grew vigorously.

Figure B15. September 2016, continued. Trees and shrubs planted on the site had high survival and grew vigorously.

Figure B16. July 2017. One year after seventh treatment. There was a dramatic drop in number and size of knotweed plants in 2017. Planted native trees and shrubs continue to grow vigorously and are beginning to shade major portions of the site, which should help suppress future knotweed and other non-native invasive plants.

Figure B17. July 2017, continued. Planted native trees and shrubs continue to grow vigorously and are beginning to shade major portions of the site.

TAYLOR TOWNSITE RESTORATION

From 2014 through 2017 at Taylor Townsite and the Taylor overflow ditch, contract crews cleared 12.4 acres of invasive species, including blackberry, foxglove, mullein, and non-native thistle species (*Cirsium* spp.). This area included the 9.3 knotweed-infested acres, plus adjacent wetlands and blackberry patches. SPU planted a total of 2,545 native overstory trees that will eventually provide long-term shade to suppress future invasive plants. In addition, SPU planted 7,197 native small trees and shrubs, and 800 emergent species to restore native habitat and ecological functions (Table B2). SPU split the area into 21 different planting sites, and developed specific prescriptions and species mixes for each site, depending on the amount of soil moisture and sun exposure (Figure B18).

Table B2. Species and Number of Native Trees and Shrubs Planted at Taylor Townsite, 2013 – 2017.

Overstory Trees			
Big-leaf maple (*Acer macrophyllum*)	380	Sitka spruce (*Picea sitchensis*)	604
Black cottonwood (*Populus balsamifera* ssp. *trichocarpa*)	325	Western hemlock (*Tsuga heterophylla*)	220
		Western redcedar (*Thuja plicata*)	494
Noble fir (*Abies procera*)	135	Western white pine (*Pinus monticola*)	305
Shore pine (*Pinus contorta* ssp. *contorta*)	82		
Total trees planted			**2,545**
Small Trees and Shrubs			
Beaked hazelnut (*Corylus cornuta*)	7	Red-flowering currant (*Ribes sanguineum*)	350
Bitter cherry (Prunus emarginata)	345	Redstem ceanothus (*Ceanothus sanguineus*)	300
Cascara (Frangula purshiana)	475	Serviceberry (*Amelanchier alnifolia*)	300
Choke cherry (Prunus virginiana)	25	Snowberry (*Symphoricarpos albus*)	300
Indian plum (Oemleria cerasiformis)	310	Snowbrush (*Ceanothus velutinus*)	300
Mock orange (Philadelphus lewisii)	320	Spirea (*Spiraea douglasii*)	50
Nootka rose (Rosa nutkana)	350	Sweet gale (*Myrica gale*)	200
Oceanspray (Holodiscus discolor)	120	Thimbleberry (*Rubus parviflorus*)	200
Pacific crabapple (Malus fusca)	320	Twinberry (*Lonicera involucrata*)	300
Pacific dogwood (Cornus nuttallii)	20	Vine maple (*Acer circinatum*)	200
Pacific ninebark (Physocarpus capitatus)	350	Willow, hooker (*Salix hookeriana*)	350
Paper birch (Betula papyrifera)	80	Willow, Pacific (*Salix lucida* ssp. *lasiandra*)	550
Peafruit rose (Rosa pisocarpa)	150	Willow, Scouler's (*Salix scouleriana*)	300
Red osier dogwood (Cornus sericea)	325	Willow, Sitka (*Salix sitchensis*)	300
Total small trees and shrubs planted			**7,197**
Emergent Species			
Sedge, Dewey's (*Carex deweyana*)	400	Sedge, thick-headed (*Carex pachystachya*)	200
Sedge, slough (*Carex obnupta*)	200		
Total emergent species planted			**800**

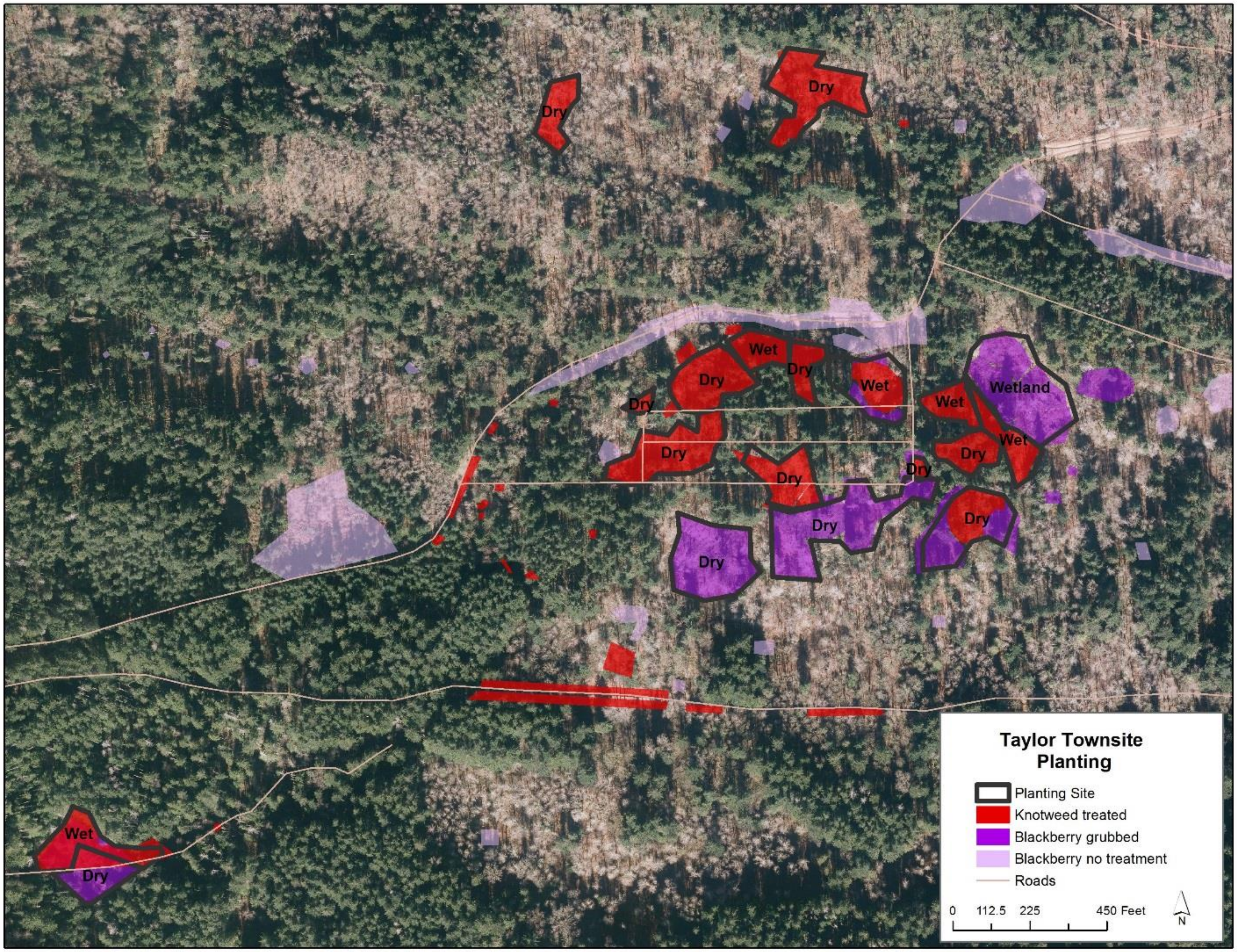

Figure B18. Planting sites at Taylor Townsite, categorized as wet or dry

In both the Education Center and Taylor Townsite restoration projects, the variety of native trees and shrubs was designed not only to restore ecological functioning, but also to provide a diversity of flowering plants to enhance pollinator habitat. Pollinators in the watershed include bees, butterflies, moths, flies, beetles, birds, and bats. The trees and shrubs SPU plants have a variety of different flower colors and shapes, with flowering periods that vary throughout the growing season, providing nectar and pollen to many pollinator species. Numerous bee species, especially the native western bumblebee (*Bombus occidentalis*), have suffered population declines in recent years and are of particular concern. Bumblebees are often the first bees active in spring and the last bees active in fall, so flowers at these times of year are especially important. Plants such as Indian plum (*Oemleria cerasiformis*), red-flowering current (*Ribes sanguineum*), vine maple (*Acer circinatum*), and tall Oregon grape (*Mahonia aquifolium*) provide early spring flowers; Pacific ninebark (*Physocarpus capitatus*), red osier dogwood (*Cornus sericea*), and oceanspray (*Holodiscus discolor*) provide late spring and early summer flowers; and goat's beard (*Aruncus dioicus*)and the native rose species (*Rosa* spp.) flower during summer. Late flowering plants are primarily forbs, including Canada goldenrod (*Solidago canadensis*), pearly everlasting (*Anaphalis margaritacea*), yarrow (*achillea millefolium*), and aster species (*Aster* spp.), but also include western flowering dogwood (*Cornus nuttallii*). SPU plans to add forbs where appropriate in open sunny areas. This diversity of native species provides better pollinator habitat than non-native invasive plants, which flower for single short periods, often during the middle of the growing season.