Ecological Restoration Project Planning In the Union Bay Natural Area;

A synthesis of restoration techniques for varying site goals

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EXECUTIVE SUMMARY

Ecological restoration is a rapidly growing field in applied ecology that tests new ideas and methodologies in the process of repairing damaged ecosystems. Goals of ecological restoration projects have evolved from a primary focus on restoring historical conditions to consider a variety of criteria in the planning process. This project assessed a 3-acre study site within the Union Bay Natural Area (UBNA) in Seattle, WA, to develop three separate restoration project plans that vary in their project goal. The purpose of this project was to research the ecological restoration planning process, outline guiding steps, and exemplify how a diverse set of objectives can be applied to a single site. The deliverables of this project include three project plans with restoration goals focused on (I) enhancement of wetland habitat, (II) bioremediation of contaminated soils and groundwater, and (III) creation of year-round pollinator habitat. The three restoration project plans display how restoration can take multiple trajectories and result in different functions and benefits depending on the project goal. The conditions of the site dictate limitations of each project plan including: soil condition, topography, hydrology, and competition of invasive species. While each project plan focused on one primary goal, they share some of the functions and benefits provided by another. It is important to note that each project plan could be altered in strategies used, including the plant palette and planting designs, to change the functions and benefits provided, as well as the costs and labor required. This paper outlines the planning process, presents the three separate project plans, compares project benefits and constraints, and provides guidelines for developing ecological restoration project goals.

HISTORY OF THE UNION BAY NATURAL AREA

The Union Bay Natural Area (UBNA) is a 73.5-acre parcel of land located on the north shore of Lake Washington adjacent to the University of Washington campus (Ewing, 2010). UBNA has a layered history of a landscape transformed and degraded through human disturbance. In the late 1800s and early 1900s, the area now known as UBNA was under the water of Lake Washington (Chrzastowski, M. 1983) (Figure 1). With the construction of the Montlake Cut and the Ballard Lock System in 1916, the lake was consequently lowered by about nine feet, exposing open mudflats on the lake shore (Chrzastowski, M. 1983). Marshland previously confined to a small area at the northern end of Union Bay then expanded out into this newly available substrate and reached as far south as today's Husky Stadium (Caldbick, 2013). The area also held the largest and deepest peat repository in the state of Washington (Caldbick, 2013).

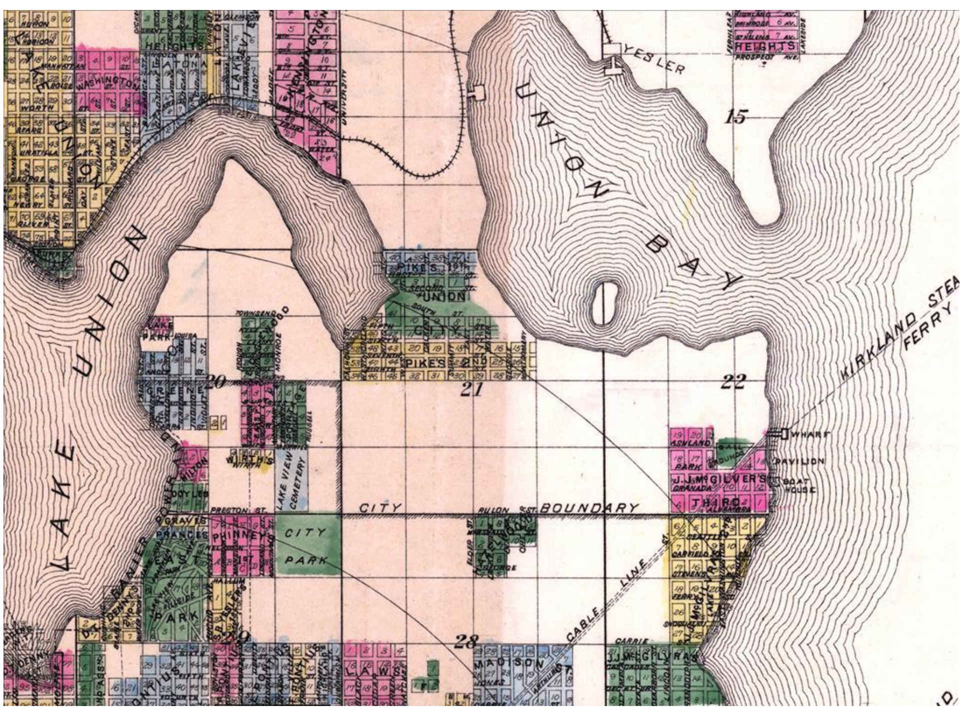

Figure 1: Map of Union Bay and Lake Union before construction of the Montlake Cut circa 1890. Note the town of Yesler located where Yesler Swamp, a part of UBNA, now resides. Source: https://www.historylink.org/File/10182

Despite the wildlife habitat and ecosystem functions provided by the marsh, the area was seen as unutilized space. In 1926 the area was designated as the Montlake dump, with city-contracted waste haulers unloading up to 100 truckloads of waste each day (Caldbick, 2013). After several decades of contracted dumping, the waste haulers were joined by residents that also disposed of their household waste, making it the largest dump in the city of Seattle and the repository for up to 60% of the city's waste (Caldbick, 2013) (Figure 2). The Montlake dump was in service for an unusually long duration of over 40 years (UWEHS, 2017). Figure 3 shows the full extent of the Montlake Dump on which UBNA and several sports fields now reside on top of. In the late 1960s pressure from local citizens concerned about the toxic gases, including methane, that were being released from the decaying waste finally caused the impetus for the landfill to cease dumping (Caldbick, 2013).

Figure 2: Aerial view of UBNA and the growing Montlake Dump in 1952, outlined in red. Source: https://www.historylink.org/File/10182

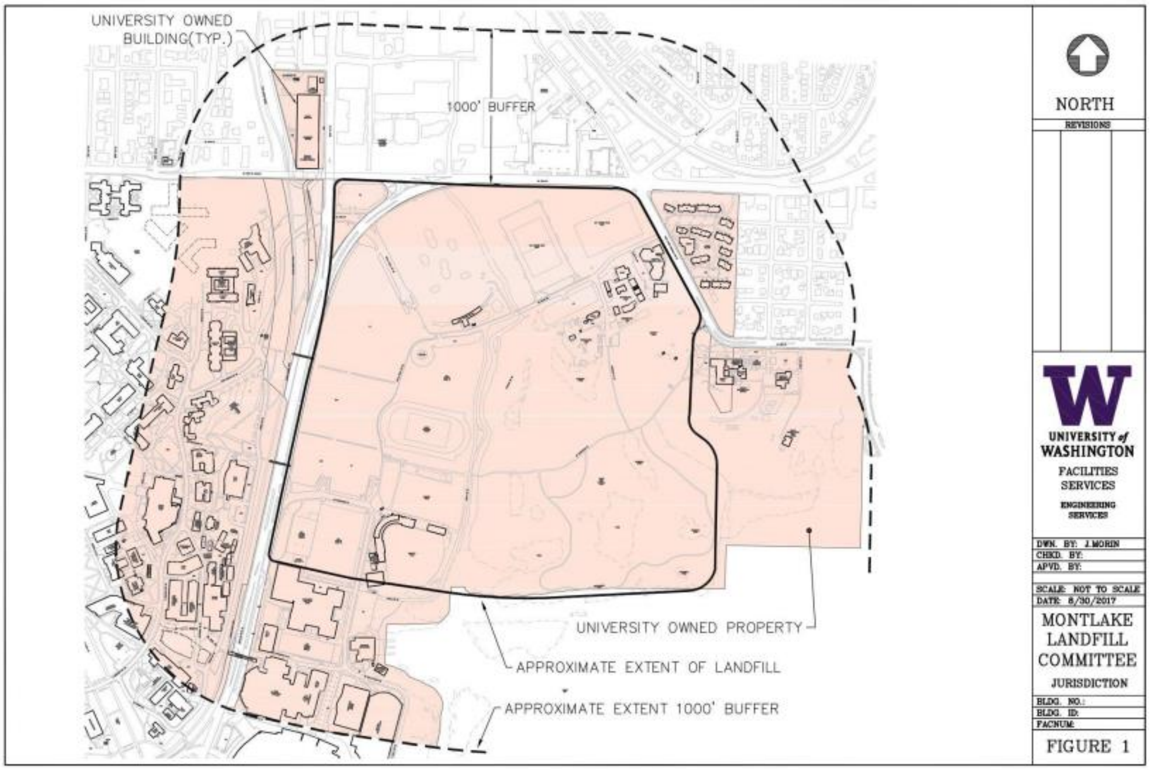

Figure 3: Approximate boundaries and 1,000-foot buffer zone of the Montlake landfill.
Source: University of Washington Environmental Health and Safety Department (UWEHS). (2017). *Montlake Landfill Project Guide.* University of Washington.

The common practice of capping the landfill was employed after the dump closed in 1966. The cap, consisting of mainly heavy clay, was placed over the landfill measuring approximately two feet deep, with landscaped areas receiving an additional six inches of topsoil (UWEHS, 2017). Unsuitable for development, the University Arboretum Committee proposed turning the area into a "living laboratory" for research (Ewing, 2010). In 1974 the idea gained traction with the support of the dean of the College of Forestry, and a $35,000 grant provided by the Northwest Ornamental Horticultural Society to create a master plan for the "Union Bay Teaching and Research Arboretum" (Caldbick, 2013). Aside from seeding with non-native European grasses, the majority of the land was left to fallow for over a decade (Ewing, 2010). As waste began to decompose and settle underneath the cap, certain areas of UBNA started to subside, creating depressions with poor drainage that formed permanent ponds fed by rainwater (UWEHS, 2017) (Figure 4). Starting in the early 1990s University of Washington faculty member, Kern Ewing, began leading student ecological restoration projects to create a series of habitat types on the now weed dominated landfill cap (Figure 5).

Figure 4: A depression forming Shoveler's pond in 1998. Source: http://hallsc.blogspot.com/p/self-guided-tour.html

Today UBNA is the second largest natural area on the shores of Lake Washington and is composed of a riparian corridor, wetlands, open grasslands, woodlands, and shoreline of Lake Washington (Ewing, 2010). More recently, in 2016 the Washington Department of Transportation (WSDOT) partnered with the University of Washington to restore portions of UBNA for mitigation required for the expansion of the SR-520 bridge. The 23.26-acre WSDOT mitigation project includes the establishment of 1.19 acres of wetland habitat, the enhancement of 9.31 acres of existing wetland habitat, and enhancement of 12.76 acres of wetland and shoreline buffer vegetation in UBNA (Togher et al., 2011).

Figure 5: A forest restoration project underway in 2007. Source: http://hallsc.blogspot.com/p/self-guided-tour.html

While UBNA has seen enormous progress, there are still areas that without the aid of ecological restoration, will remain degraded habitat on the former landfill. These areas are currently dominated by the non-native grasses seeded on the landfill cap, and by invasive species such as Himalayan blackberry (*Rubus armeniacus*) English ivy (*Hedera helix*), and reed canary grass (*Phalaris arundinacea*) that colonized the available space before native species could establish. Active management is needed to control populations of invasive species and restore native plant communities to provide essential ecosystem functions and wildlife habitat in this unique refuge surrounded by urban development.

RESTORATION PROJECT PLANNING

Background

The goals of ecological restoration projects have evolved to include a variety of criteria that may deviate from historical ecosystems of a particular site. The original approach to ecological restoration focused on returning a degraded, damaged or destroyed ecosystem to the structure and species composition it contained at a previous point in time. Today many ecological restoration project goals target restoring impaired ecosystem functions such as for erosion control, nutrient cycling, water filtration, flood mitigation, pollination services, recreation, and many others. These projects may not return a historical ecosystem, but may create another type of habitat to provide the ecosystem functions desired, such as the creation of wetlands for mitigation projects. Restoration may also focus on providing a specific natural good like a wild crop for social benefit (SER, 2003). The goals of an ecological restoration project can also focus on restoring habitat for a particular key species, such as salmon in the Pacific Northwest, or increasing the extent of endangered habitats such as the Puget Sound Lowland Prairie ecosystem. More recently, goals of ecological restoration projects focus on ameliorating impacts of climate change, such as the restoration of brackish marsh in shoreline communities or the creation of habitats for carbon sequestration. A range of criteria exist, but what remains constant is transforming a disturbed landscape back into a healthy, functioning ecosystem.

Design Process

A successful ecological restoration project recognizes the importance of the design process. It is essential to allocate adequate time and resources to assess the project site, brainstorm and set attainable goals, and determine monitoring strategies (Lake, 2001). One of the most challenging aspects of an ecological restoration project is defining the project goals and objectives (Rieger et al., 2014). Even "self-evident" project goals may need careful deliberation depending on project constraints. A specific goal accompanied by measurable objectives within a given timeframe are key elements of project planning. Clarifying and enumerating objectives provides criteria that can be directly measured during monitoring to determine if project objectives and overall goals are met (Rieger et al., 2014). Clear goals and objectives also facilitate direct communication of the project to all stakeholders, as well as replicable. The goal and objectives determine the basis for design strategies, including restoration actions, plant palette, site design, and timeline.

Identifying key constraints such as site conditions, funding, and ongoing impacts and disturbances to the site is the first step in designing restoration project plans. Many projects ultimately come to a compromise of project priorities based on project constraints. The condition of the project site itself is one constraint to potential project goals. The speed of ecosystem degradation often exceeds the rate to which they can be restored, even with active intervention. Hectares of a forest can be logged with heavy machinery in a single day, but require decades for recovery (Lake, 2001). A site assessment is necessary to determine the current state of the site, the causes and severity of disturbances, and the likelihood of whether restoration actions will allow recovery (Rieger et al., 2014; Lake, 2001). In extreme cases of degradation, such as former mines and hazardous waste sites, the project site may not be amenable to specific project goals. Determining the severity of the disturbance to the site will help guide in developing feasible restoration goals. Observation and evaluation of the site's current topography, hydrology, soils, and vegetation can give indications to the level of disturbance to the area.

Examining the site's topography and hydrology and comparing it to historical records may indicate significant disturbances to the site. Sediment may have been removed or added, and hydrology may have been rerouted, buried beneath the ground, or channelized. Altered topography disturbs the original soil structure and may create conditions that necessitate heavy machinery to restore the site's elevation, gradients, or landscape formations. Altered hydrology will affect the plant community and may limit restoration project goals such as levees blocking floodplains for wetland restoration. Without heavy machinery to remove levees and allow natural flow, the area may not be amenable to restoration into a wetland habitat. Hydrology is especially important for wetland and riparian restoration, but affects all habitat types with each plant community uniquely adapted to certain hydrological conditions.

The soil composition and structure can play a large role in determining what plant communities it can support. For example, heavy clay soils will retain more water and therefore do not support vegetation communities adapted to well-drained soils such as dry prairies. In comparison, sandy soils will rapidly drain and will not support plants with high water requirements. Soils with a very low or high pH or lacking macronutrients may require amendments before planting to encourage survival. Alternatively, the plant palette can be designed to address soil quality issues such as installing plants associated with nitrogen-fixing bacteria. Soil can be tested for its texture, moisture content, macronutrients, and pH to determine suitable plant communities for the site.

The existing vegetation composition can also reflect levels of disturbance to the site. Invasive plant species tend to dominate degraded sites where disturbance to the soils have allowed rapid colonization of exotic species and the exclusion of natural succession. The presence of a mix of species both native and non-native may demonstrate a site less disturbed, or a site rebounding from disturbance. The type of vegetation can also signify growing conditions. Areas primarily dominated by grass species unmanaged through mowing or burning, often do not have enough moisture to allow woody species to establish. The presence of wetland species may indicate areas saturated for a portion of the growing season. The dominance of plant species associated with nitrogen-fixing bacteria may indicate the soils contain low amounts of macronutrients such as nitrogen. Vegetation can, therefore, give indications to the levels of disturbance, the site and soil conditions, and the potential for restoration.

Project planning should also consider aspects beyond the site itself and consider limitations due to ongoing or potential future natural and anthropogenic disturbances. Restoration projects in areas requiring active management such as mowing in parks may be an essential aspect to consider if trying to establish scrub-shrub or forest habitats. External natural disturbances to the site also may alter project goals and design. For example, river and stream restoration projects need to consider the meandering of the channel and peak flows that can dramatically change the landscape. Restoration should allow and support the natural succession of the site when possible. Sometimes this works against the project goal, such as the removal of woody species, naturally recruited in prairie restoration. However, working with the natural succession of a project site requires less labor and maintenance and ultimately has a higher likelihood of attaining project goals. Overall, a restoration project cannot force the restoration of a particular ecosystem if the abiotic conditions do not match.

The availability of resources is another major constraint in developing project goals and objectives. Budgets dictate planning based on capital to pay for labor and materials, and often limit a project’s scale. A project ultimately wants to maximize benefits while working within available resources. Limited funds may alter methodologies used, such as manual versus chemical control of invasive species, or deciding the stock type. With more ecological restoration needed than resources available, priorities of project investors influence decision making. Special interest groups may provide funding for specific purposes such as restoring habitat for salmon, a highly prioritized market in the Pacific Northwest.

After addressing project constraints, the next step in project planning is to consider the site's potential. The Society for Ecological Restoration (SER) recommends using a SWOT-C protocol. The SWOT-C protocol looks at the strengths, weaknesses, opportunities, threats, and constraints of the project. The site assessment helps determine the criteria for the SWOT-C protocol. SER uses a Suitability and Feasibility Analysis wheel to improve planning considerations (Figure4). At this stage, various goals can be considered and potential ecosystem functions identified.

Figure 6: SER's suitability and feasibility analysis wheel to help guide considerations for the SWOT-C analysis. Source: Rieger et al., 2014.

Every proposed goal should consider both short and long term implications, as well as current or potential cultural and social values (Rieger et al., 2014). This initial brainstorming phase may benefit from a smaller group of people who know the project site and conditions (Rieger et al., 2014). However, after proposing the initial goals and objectives, it is crucial to include all stakeholders of the project. It is common for projects that do not include all stakeholders in the planning process to encounter unexpected issues due to limited feedback on the plan, implementation, and potential effects on various user groups. Stakeholders should include the project managers, landowners and land managers, volunteers, or work crews implementing the project, community members, and any other interest groups affiliated with the site.

Comparing the benefits of project goals may be difficult when addressing separate criteria that are measured in different ways. One method would be to rank project goals according to the severity of the issues addressed through the project. For example, a goal of conserving a rare or endemic habitat type may outweigh goals focused on certain ecosystem functions such as reducing storm water runoff or sequestering carbon. While constraints create a framework, a project must work within, specific goals and objectives are often decided based on subjective prioritization.

Project Planning for UBNA Restoration Site

Identifying the restoration goals and constraints for the project began with a site assessment of the three-acre area of degraded habitat within UBNA. A significant limitation to restoring this site to historical conditions is the large scale alteration of the former topography and hydrology. As previously mentioned, UBNA was under the water of Lake Washington before the construction of the Ballard locks and Montlake cut. Unless the hydrology of the lake is allowed to reach its previous levels, UBNA will never return to lake habitat due to its elevation alone. However, with some areas subsiding and forming depressions and ponds, restoration of the historical marsh habitat that developed from the lowering of Lake Washington in 1916 is feasible in some areas. The potential to restore a historical ecosystem is one criterion for developing Project Plan I: enhancing wetland habitat.

Examination of the soils and current vegetation composition gave further insight into the disturbance of the project site. A soil texture test revealed a sandy-clay loam, suitable for a variety of species. Sandy-clay loam soils often have a balance of drainage and water retention. Low concentrations of heavy metals and petroleum aromatic hydrocarbons (PAHs) detected in the soil chemical analysis are not at levels that should affect plant growth on site, but their presence created criteria for Project Plan II: bioremediation of contaminated soils and groundwater. Variations in color, depth of horizons, and course materials indicate certain areas may be more suited to wetland habitats and some more suitable to prairie habitats, influencing criteria again for Project Plan I, as well as Project Plan III: creating year-round pollinator habitat.

An assessment of the vegetation demonstrated dominance of non-native and invasive species, with some native species occurring in small populations either intentionally planted or self-established. The presence of native emergent vegetation indicated conditions of wetland habitat in the northeastern portion of the site. Due to the site's manageable size, and the density of invasive species cover, restoration through student efforts is feasible. The occurrence of native species growing on site also suggests the area has suitable growing conditions if management were to occur. Constraints due to ongoing disturbances were not severe enough to limit project goals, but do have implications for management, discussed within each restoration project plan.

The following project plans were created at a conceptual level, and therefore are not limited by a specific budget. The scale of the project was dictated by project boundaries of other restoration sites and the Loop Trail at the southern edge. All three plans develop actions for restoring the full three acres to connect the various restoration projects on the north, east and west sides of the project site for a continuous area of restored habitat. However, implementation of this project may require dividing the site into multiple sub-sections depending on the budget and labor available. Restoration projects in UBNA are mainly driven through student efforts and volunteers and therefore do not have costs for permitting, labor, or high overhead that need to be included in budgeting. The budgets for the following project plans were determined by the quantity and cost of plants required for the planting plans. Previous restoration projects have been funded through the University of Washington via classes, student projects, and research. The Campus Sustainability Fund is also an opportunity for funding as well as sponsorship from other organizations.

Assessing project conditions set the foundation for brainstorming potential restoration project goals within a framework. Multiple criteria led to the creation of Project Plan I: enhancing wetland habitat. First, the site assessment discovered the northeast portion of the site appears to be slowly subsiding and creating conditions for wetland habitat. Wetland habitat was further evidenced through obligate emergent vegetation, gleyed soils, and presence of surface water over two weeks into the growing season. Project Plan I works with this process and enhances the formation of wetland habitat by planting a diversity of obligate and facultative wetland species. If this area continues to subside and hold more surface water, these emergent plants will be better adapted to colonize the wet environment. The surrounding urban landscape and the value of limited habitat for shorebirds were other influential criteria. A matrix of development exists on the north, east, and west sides of UBNA, making this limited habitat extremely valuable to wildlife. UBNA is also the second largest natural area on Lake Washington, a rare landscape of this scale.

The site's location along the shoreline of Lake Washington also makes it prime habitat for shorebirds and waterfowl. In addition to the ecological benefits, Project Plan I also supports the cultural and social values of the Audubon Society and bird watchers who express concern over limited shorebird habitat. UBNA is a renowned area for its biodiversity of birds and therefore attracts a high number of bird watchers and Audubon members. In an interview with prominent bird watcher, Constance Sidles, she expressed deep concern for maintaining open habitat for shorebirds. Restoration work through the WSDOT SR-520 mitigation project increased the amount of scrub-shrub and forested wetland habitat, which ultimately reduces open pond and wetland habitats. Shorebirds rely on these open habitats to have a clear line of sight to avoid predation. Audubon members want to maintain open habitat areas including wetlands, ponds, mudflats and prairies, and avoid planting woody species.

Limitations to this project plan include a suitable substrate throughout the site for planting wetland species. While the northeast portion of the site has soils with lower drainage, other portions of the site have better drainage and are therefore too dry to support wetland species. The compromise was made to plant prairie species in drier areas which would still provide open habitat compared to scrub-shrub and forest habitats. The natural succession of black cottonwoods and willow species colonizing the site is another challenge, as ongoing active management would be needed to prevent the area from becoming scrub-shrub or forested habitat. Project Plan I, therefore, prioritizes working with the current and future conditions of subsiding terrain, enhancing limited habitat for shorebirds, and supporting cultural values of birdwatching while working with limitations of soil substrate.

Project Plan II, bioremediation of contaminated soils and groundwater, primarily focuses on the previous land use of the area. Under the varying depths of the landfill cap, is refuse slowly decomposing and potentially leaching contaminants into the soil and water. Previous soil tests, as well as chemical analyses of two soil samples from the site, indicated low levels of heavy metals, petroleum hydrocarbons (PAHs) and high phosphorus. Bioremediation is a viable solution to help remediate these contaminants. The connection of UBNA and underlying waste to Lake Washington make contamination of ground and surface water a high concern and criteria for developing Project Plan II. This project goal also considers the cultural and social values of clean water for recreation. Project plan II also allows for a natural succession of the site, specifically, colonization of black cottonwood and willow species. These species are not only pioneers in natural succession, but are also hyperaccumulator species often used in bioremediation projects. The installation and natural recruitment of these species also increases structural diversity, provides additional scrub-shrub and forest habitat, and provides perches for large raptors.

Project Plan II is limited in the extent of possible treatment, as bioremediation on the 3-acre project site will only accomplish a fraction of the total remediation needed to address the potential leaching occurring throughout UBNA. It is also a project plan more limited in resources required for adequate monitoring, as soil tests are often expensive and outside student budgets. Project Plan II, therefore, prioritizes treating and containing contaminants within the soil and groundwater, working with the natural succession of black cottonwoods and willows colonizing the site, and addressing social values of clean water standards, while recognizing the limitations of the project extent and available resources for adequate monitoring.

Project Plan III, creation of year-round habitat, restores a portion of rare habitat, the Puget Sound Lowland Prairie, to provide year-round habitat for pollinators. Project Plan III is suitable for the site conditions, as evidenced by the soils and existing plant species. While an ephemeral wetland exists in the northeast section of the project site, a majority of the site currently has drier soils with higher levels of drainage. Depressions on the site without standing water into the growing season are also likely to support prairie species. The project plan will therefore include restoration of the ephemeral wetland, but have a greater focus on restoring prairie habitat for a majority of the site. It is difficult to predict the levels of subsidence of the landfill materials; as a result, a restoration plan focused on potential subsidence (Project Plan I) as well as a plan focused on the current topography (Project Plan III) were developed.

Project Plan III also addresses the low diversity of native flowering plants on site as observed through the site assessment. During a subsequent site visit, a high number of bees were found utilizing the few native flowers available, including the field lupine and a handful of common camas. These observations demonstrate the need for a higher diversity of flowering plants to support pollinator populations. Project Plan III also supports the social and cultural values of the UW Farm, located about a quarter mile north from the restoration project site. Food production on the farm would benefit from a higher diversity of pollinator species supported by the floral resources and habitat provided through the restoration project. Project Plan III has the same challenge as Project Plan I of required maintenance of woody species necessary to maintain the prairie habitat. Project Plan III may also be limited by future conditions of the site as areas continue to subside and create more saturated conditions.

The following sections review the site assessment and then outline each project plan and its implementation. Each project plan describes the background information on the project plan goal, an explanation of the design, plant palette, planting plan, budget, and map.

SITE ASSESSMENT

Project Site Location and Boundaries

The restoration project site is within the Union Bay Natural Area (UBNA) located on the north side of Union Bay on Lake Washington, in Seattle, Washington (Figure 8). The 3-acre restoration project site is centrally located in UBNA between several areas undergoing ecological restoration (Figure 9). On both the west and eastern sides of the project site is work being done by the Washington Department of Transportation (WSDOT) to create wetland buffers for their SR520 Mitigation project. On the northern edge is a prairie restoration project implemented by students of the University of Washington. The site extends south to the waterfront trail (Figure 7). Restoration of the 3-acre project site would connect existing restoration efforts, for a continuous stretch of restored habitat.

Figure 7: View of the project site looking down from a small hill on the Loop Trail, facing south towards the shoreline of Union Bay.

Surrounding Landscape

Beyond the boundaries of the restoration site within UBNA is a mix of restored wetland, open prairie, woodland, and riparian habitats as well as unmanaged areas currently dominated by non-native and invasive species. Key features in the surrounding landscape include Ravenna creek, a riparian corridor, a prairie restoration site, and the UW farm (Figure 9).

Figure 8: Project site is located within the Union Bay Natural Area (UBNA) highlighted in red, on the north side of the Union Bay.

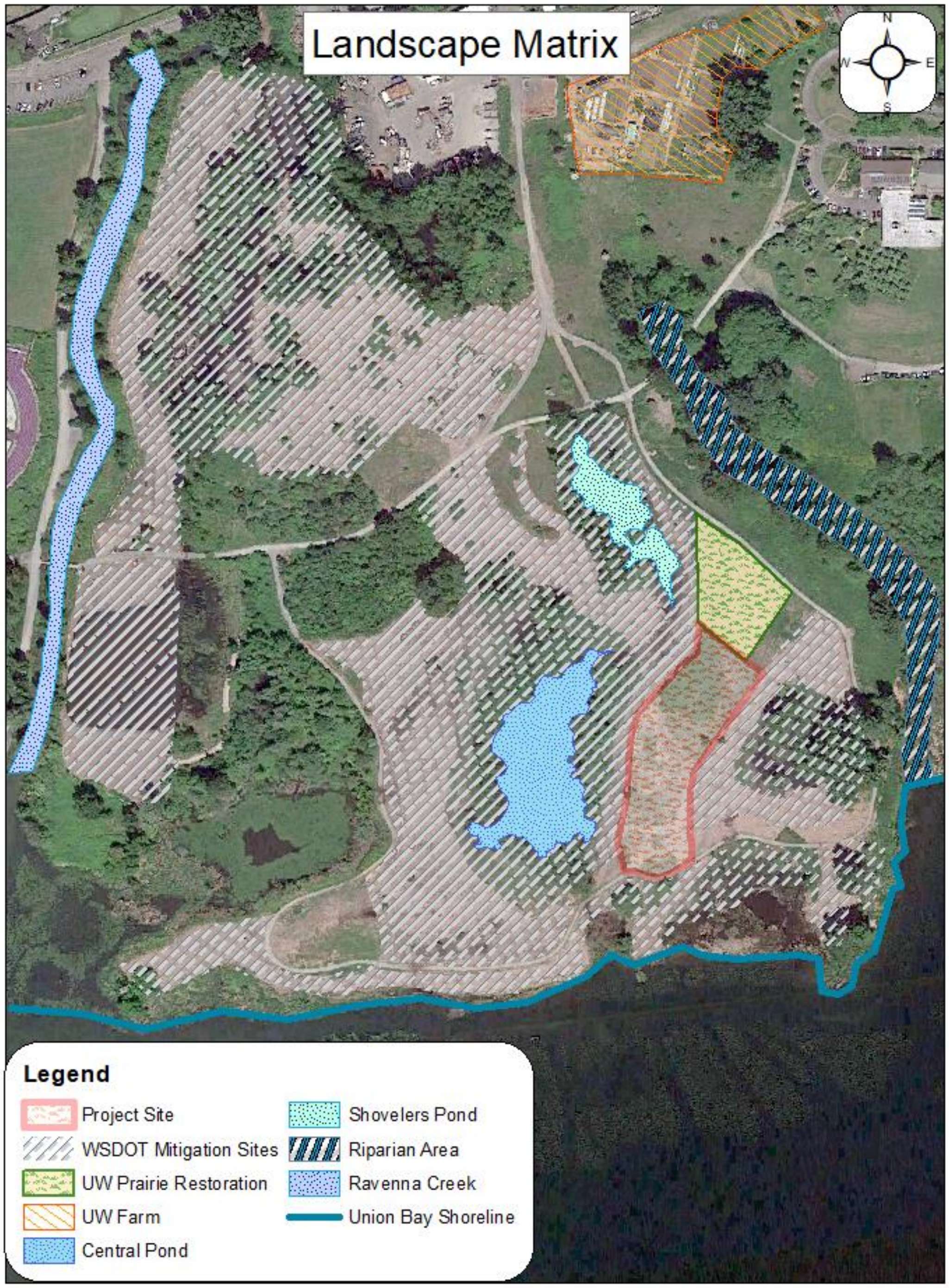

Figure 9: Landscape matric highlighting key features around the project site.

Pond and wetland habitats in UBNA formed through the subsidence of landfill materials, and occur on both the east and west sides of the project site. This includes Central Pond, on the western side of the project site, which holds water year round (Figure 10), and an ephemeral forested wetland on the eastern side of the project site dominated by black cottonwood (*Populus trichocarpa*) (Figure 11). Both Central Pond and the forested wetland are lined by a wetland buffer created by the WSDOT mitigation project. The buffer is a mix of scrub-shrub habitat dominated by a mix of native shrubs including red osier dogwood (*Cornus sericea*), Pacific crabapple (*Malus fusca*), tall Oregon grape (*Mahonia aquifolium*), *spreading* gooseberry (*Ribes divaricatum*), black gooseberry (*Ribes lacustre*), nootka rose (*Rosa nutkana*), snowberry (*Symphoricarpos albus*), and lady fern (A*thyrium filix-femina*) (Figure 11). The western buffer is a narrow strip about 30 feet wide following the edge of Central pond. The eastern buffer is about 75 feet wide around the forested wetland habitat.

Figure 10: Central pond is located on the eastern side of the project site, separated by a scrub-shrub buffer installed by the WSDOT mitigation project.

Figure 11: Forested wetland and scrub-shrub buffer installed through the WSDOT mitigation project east of the project site.

Open prairies in UBNA consist of both restored and unrestored areas and are managed through mowing, including the student restoration site on the northern boundary of the project site. With only a small percentage of these prairie habitats restored, the majority are dominated by non-native European grasses, Queen Anne's lace (*Daucus carota*), and chicory (*Cichorium intybus*), with patches of Himalayan blackberry. However, restoration efforts have increased the abundance of various native Puget lowland prairie species, including Roemer's fescue (*Festuca idahoensis* var. *roemeri*), common yarrow (*Achillea millefolium*), and common camas (*Camassia quamash*).

Figure 12: Prairie restoration project north of the project site.

Woodland habitat in UBNA is the result of initial restoration efforts and mainly consists of black cottonwood and red alder (*Alnus rubra*). The WSDOT mitigation work includes further restoration of forested woodland habitat in UBNA contributing to species diversity by increasing the abundance of deciduous species including red alder, Oregon Ash (*Fraxinus latifolia*), and Garry oak (*Quercus garryana*) and evergreen conifers including: western red cedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), Sitka Spruce (*Picea sitchensis*) and Shore pine (*Pinus contorta* var. *contorta*). While there are a few mature conifers within UBNA, most of these individuals are young saplings installed within the last two years.

Riparian habitats exist along Ravenna creek which becomes University Slough to the west, as well as drainage from depressions in the northeast which create an ephemeral rivulet that flows to Lake Washington on the eastern side of the site. These areas have large established black cottonwood and various deciduous and evergreen species. A majority of the understory vegetation within riparian areas in UBNA are dominated by invasive English ivy and Himalayan

Figure 13: Riparian habitat east of the project site. Dominant species include black cottonwoods and red alder.

blackberry. Recent student projects have restored a portion of the riparian habitat along the rivulet draining to Lake Washington on the eastern side of UBNA (Figure 9).

The shoreline of Union Bay is approximately 150 feet from the southern edge of the restoration site, on the opposite side of the loop trail which marks the southern boundary of the project site. The shoreline is dominated by native cattail (*Typha latifolia*) as well as invasive reed canary grass (*Phalaris arundinacea*). Additionally, the University of Washington farm is roughly a quarter mile north of the project site and is also a part of UBNA.

Outside the boundaries of UBNA, the surrounding area to the north, east and west is highly urbanized (Figure 8). In the northern portion of UBNA, Ravenna Creek flows through a small corridor between a golf driving range and sports fields. However, further upstream Ravenna creek is diverted underground below the development of University Village. This development unfortunately reduces connectivity between the habitat of UBNA and Ravenna Park further north. South of UBNA, across Union Bay, is the Washington Park Arboretum and Interlaken Park, but there are no direct corridors that connect these two areas. Further west is the University of Washington's main campus and further east is the Center for Urban Horticulture and Laurelhurst neighborhood. Minimal native vegetation exists in these urban areas as most landscaping consist of ornamental plants.

Lake Washington is a part of the Lake Washington-Cedar/Sammamish Watershed connecting UBNA to the Cedar and Sammamish Rivers, Lake Sammamish, Lake Union, and

Puget Sound. More broadly, the city of Seattle itself is within the Puget lowlands, which extend west of the Cascade Range to the Olympic Mountains and from the San Juan Islands in the north to past the southern tip of the Puget Sound.

Environmental Functions

UBNA provides crucial habitat for wildlife within dense urban development. UBNA is the second largest natural area on the shores of Lake Washington and as previously mentioned, provides a diversity of habitat types. Over 240 species of birds have been observed in UBNA (Sidles, 2013). Typical bird species that may use terrestrial upland habitat of UBNA include warblers (*Dendroica* spp.), hairy woodpeckers (*Leuconotopicus villosus*), red-tailed hawks (*Buteo jamaicensis*), Cooper's hawks (*Accipiter cooperii*), and band-tailed pigeons (*Patagioenas fasciata*) (Sidles, 2013; Togher et al., 2011). In addition to terrestrial prairie, forest and scrub-shrub species, UBNA provides especially important refugia for migrating waterfowl. Typical bird species that may use the wetland and shoreline habitat include: sandpipers (*Actitis* spp.), least terns (*Sternula antillarum*), dowitchers (*Limnodromus* spp.), Canada geese (*Branta canadensis*), wood ducks (*Aix sponsa*), hooded mergansers (*Lophodytes cucullatus*), wigeons (*Mareca* spp.), Northern shovelers (*Anas clypeata*), red-winged blackbirds (*Agelaius phoeniceus*), marsh wrens (*Cistothorus palustris*), great blue herons (*Ardea herodias*), and belted kingfishers (*Megaceryle alcyon*) (Sidles, 2013; Togher et al., 2011).

Figure 14: A long-billed Dowitcher, one of 29 species of shorebirds who visit UBNA. Source: Doug Parrot

Other wildlife observed in UBNA include American beavers (*Castor canadensis*), coyotes (*Canis latrans*), black-tailed jack rabbits (*Lepus californicus*), Eastern cottontails (*Sylvilagus floridanus*), mink (*Mustela vison*), big brown bats (*Eptesicus fuscus*), little brown bats (*Myotis lucifugus*), Pacific tree frogs (*Pseudacris regilla*), common garter snakes (*Thamnophis sirtalis*) and long-toed salamanders (*Ambystoma macrodactylum*) (Togher et al., 2011).

Figure 15: UBNA provides habitat to a variety of mammal species including coyotes. This coyote was sighted and photographed in UBNA in 2017. Source: Larry Hubbell

In addition to providing habitat for hundreds of species, UBNA supports several ecosystem functions. Wetland areas either formed from the settling of the landfill cap, or created through the WSDOT mitigation project, slow runoff and provide filtration of surface water through wetland vegetation. UBNA is also important habitat for invertebrates including pollinator species. Native pollinators are not only key components to functioning ecosystems, they are vital to crop production. UBNA is valuable habitat for native pollinators that can support food production at the nearby University of Washington farm. Restoration of native plant communities can also reduce erosion, and storm water run-off from adjacent hardscapes. Restoration of native habitats within UBNA will enhance these ecosystem functions and have the potential to provide others.

Topography

UBNA lies at 26 feet above sea level. The entire area of UBNA forms a shallow basin with slightly increasing slopes on the north, west and east sides (Figure 16). The project site consists of low sloped (5.5-10%) undulating depressions caused by the settling of the landfill. Three large depressions were most notable at the project site (Figure 17). The depression with the highest slope (10%) has formed an ephemeral wetland indicated by the gleyed soil, vegetation and presence of surface water two weeks into the growing season in the north east section of the site (Figure 17). The area has a southeast orientation and receives ample amount of sunlight unobstructed by large trees or shrubs to the south.

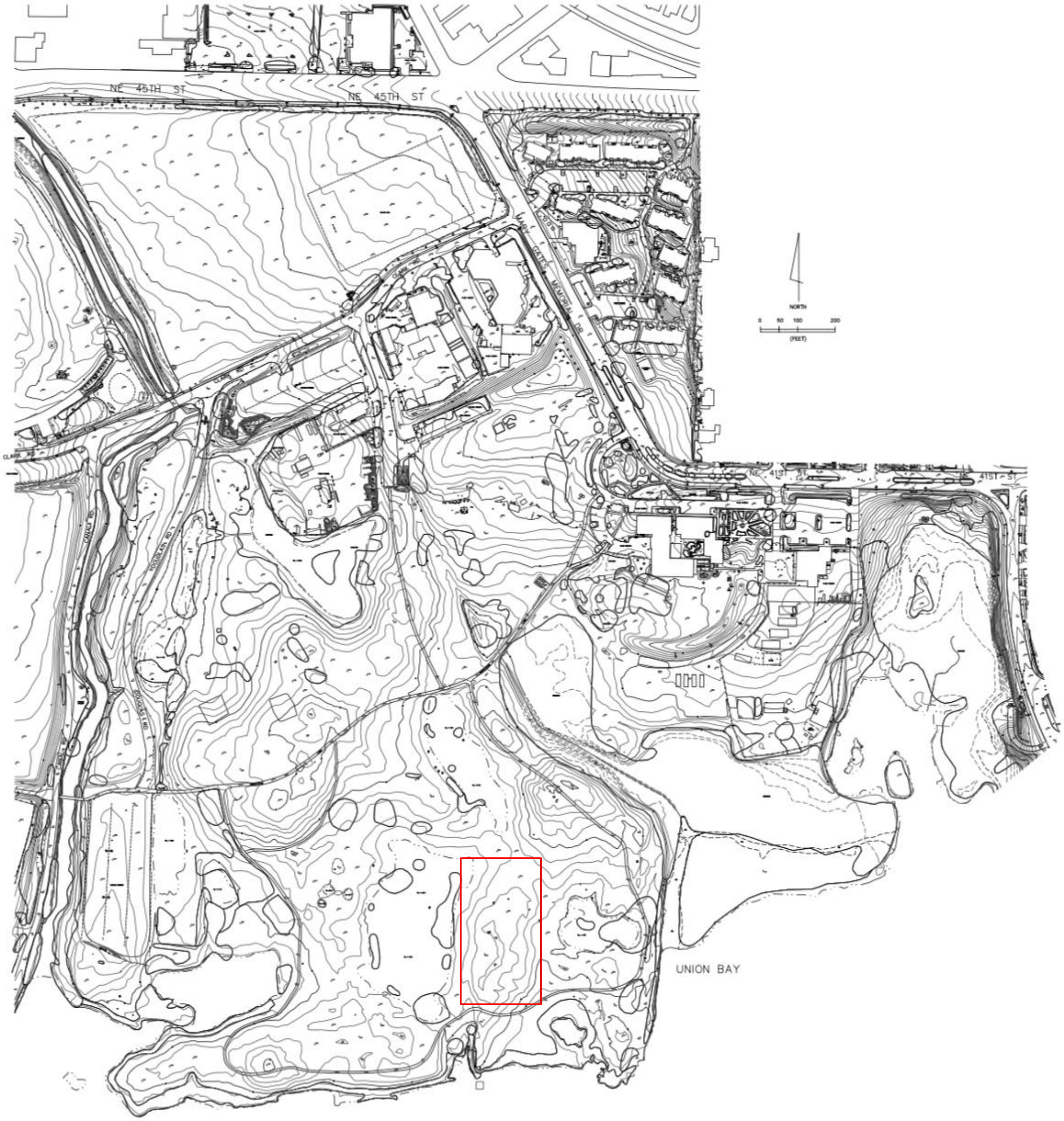

Figure 16: Topography of UBNA. As landfill materials decompose, portions of UBNA subside forming depressions throughout the landscape. The restoration project area is outlined in red. Source: Ewing, K. (2010) *Union Bay Natural Area and Shoreline Management Guidelines*. University of Washington Botanic Gardens

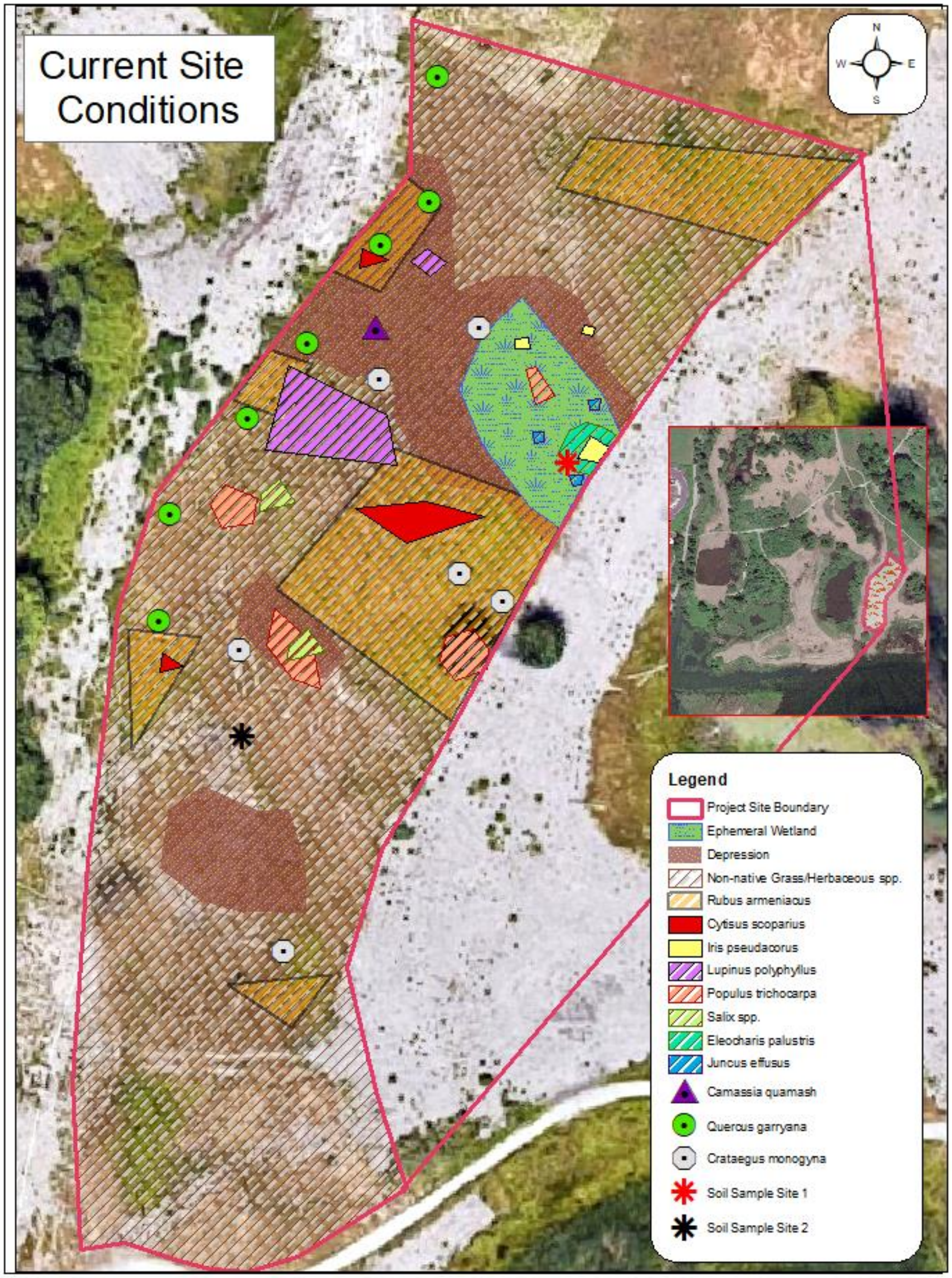

Figure 17: Map of current site conditions. Three large depressions have formed on site with one holding standing water to qualify as an ephemeral wetland. While non-native and invasive species dominate the site, some native species exist. Soil sample site 1 is located within the ephemeral wetland area and soil sample site 2 within a slightly higher elevation, drier area.

Hydrology and Surface Water Features

The topography of UBNA is slowly changing with several areas forming depressions as materials of the landfill and cap continue to settle. Depressions with poor drainage have either become year-round ponds or ephemeral pools filling up with water that persist into early spring. Three depressions exist on the project site. One depression with a slope of 10% was observed to hold surface water into the growing season, qualifying it as an ephemeral wetland area (Figure 18). This area measures approximately 3,000 square feet and is located on the northeastern portion of the site adjacent to the WSDOT wetland buffer (Figure 17). Several small ruts of unknown origin also create ephemeral rivulets filling with water during times of high precipitation. The western edge of the restoration site is Central Pond, a year-round pond fed by rainwater that formed over a decade ago by the settling of fill material. Central Pond is forming a connection with Union Bay just beyond the southern boundary of the restoration site, draining over the Loop Trail.

Figure 18: Ephemeral wetland in the northeast section of the site. Surface water was observed in this area two weeks into the growing season.

Vegetation

The project site is currently dominated by non-native and invasive species, but contains small populations of a few hardy Washington native species. Dominant non-native species include European grasses (*Agrostis* spp., *Elymus repens,* and *Poa annua*), Queen Anne's lace (*Daucus carota*), chicory (*Cichorium intybus*), Canada and bull thistle (*Cirsium arvense* and *Cirsium vulgare*), curly dock (*Rumex crispus)* and large patches of Himalayan blackberry (Figure 19). A population of Scotch broom (*Cytisus scoparius*) also exists on site, with individuals scattered within patches of Himalayan blackberry (Figure 22). Two well established common hawthorn (*Crataegus monogyna*) and multiple seedlings also exist scattered on the site (Figure 22).

Figure 19: Patches of Himalayan blackberry among non-native grass and herbaceous species comprise a majority of the project site

A few native species have been deliberately planted within the site boundaries, while others have managed to establish within the invasive species. A previous student project involved planting Garry oaks (*Quercus garryana*) in the student prairie restoration site located on the northern boundary of the project site. The plantings extend beyond the northern site boundary into the project site in the northwestern corner (Figure 23). Two native emergent species are also growing on site. One small population of creeping spike rush (*Eleocharis palustris*) (Figure 20) and several clumps of common rush (*Juncus effusus*) are growing in the ephemeral wetland in the northeast portion of the site (Figure 23). Creeping spike rush is an

Figure 20: Creeping spike rush, an obligate wetland plant, growing in the ephemeral

obligate wetland plant, meaning it only grows in wetland conditions. The occurrence of this species further substantiates wetland habitat forming in the northeast section of the site. There is also a well-established population of large-leaved lupine (*Lupinus polyphyllus*) with individuals growing within Himalayan blackberry (Figure 23). Post site assessment, a handful of undetected common camas (*Camasia squamish*) were found blooming during a site visit (Figure 23). It is unknown whether these species naturally established in this area or were purposely planted. The appearance of the camas, was a good reminder to revisit the site throughout the planning process to observe how the landscape changes over time and with the seasons.

Native species that likely established on their own include black cottonwood (*Populus trichocarpa*), Pacific willow (*Salix lasiandra*), and Scouler's willow (*Salix scouleriana*) (Figure 21). One large established black cottonwood exists on the eastern edge of the site as well as several small patches of seedlings (Figure 23). Several seedlings of Pacific and Scouler's willow also occur with the black cottonwoods. While native, seedlings of black cottonwood and willow species may need to be managed in the restoration of open prairie or wetland habitats. Common yarrow (*Achillea millefolium*) was also observed growing within the non-native graminoid and herbaceous species throughout the site. The occurrence of these native species on the project site are encouraging signs for potential restoration. A full species list is located in Appendix III, Table 25.

Figure 21: Natural recruitment of black cottonwood seedlings on the project site.

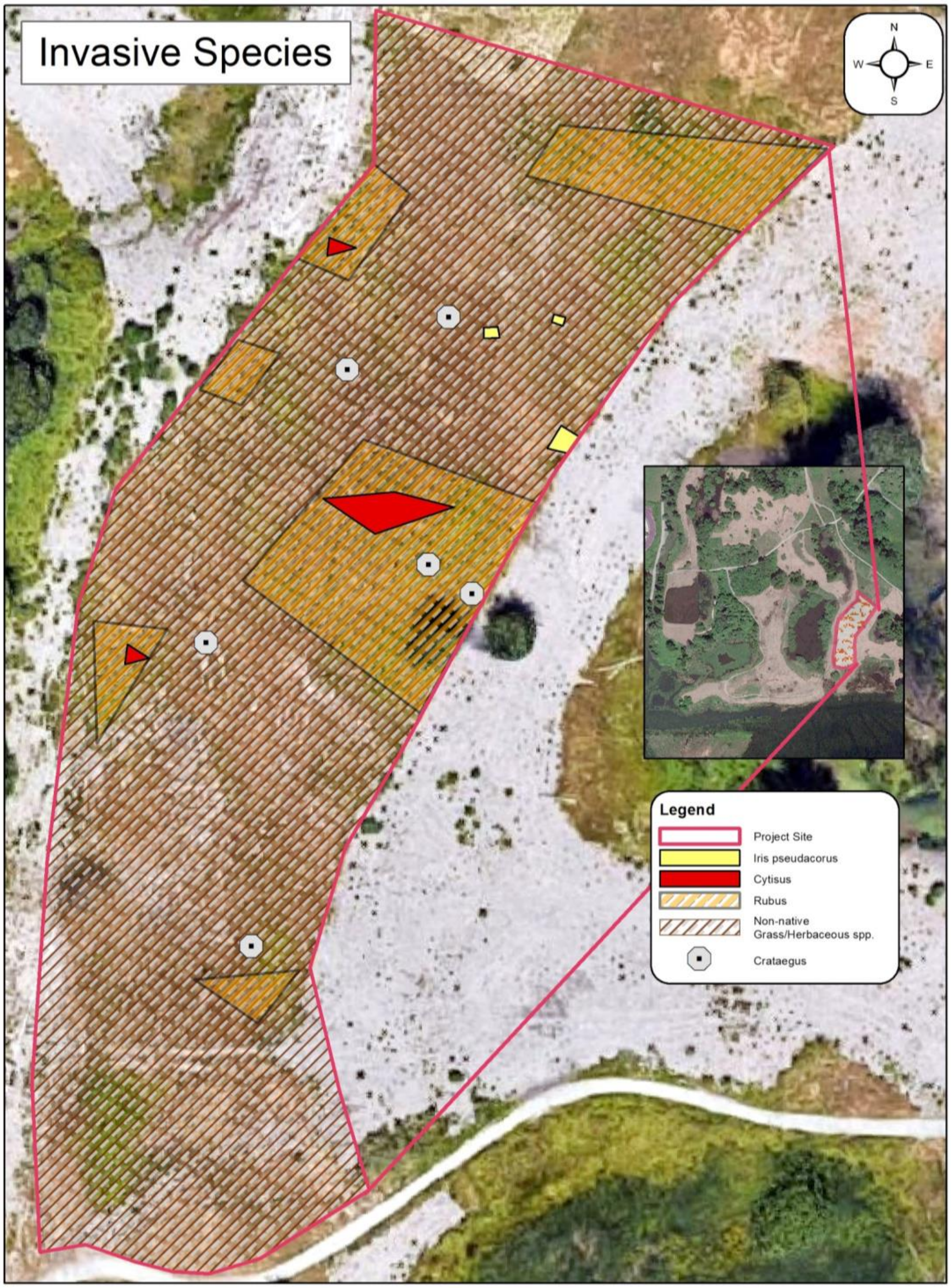

Figure 22: Map of non-native and invasive species at project site. Dominant invasive species include Himalayan blackberry (*Rubus armeniacus*), Scotch broom (*Cytisus scoparius*), English hawthorn (*Crataegus monogyna*) and non-native grass and herbaceous species.

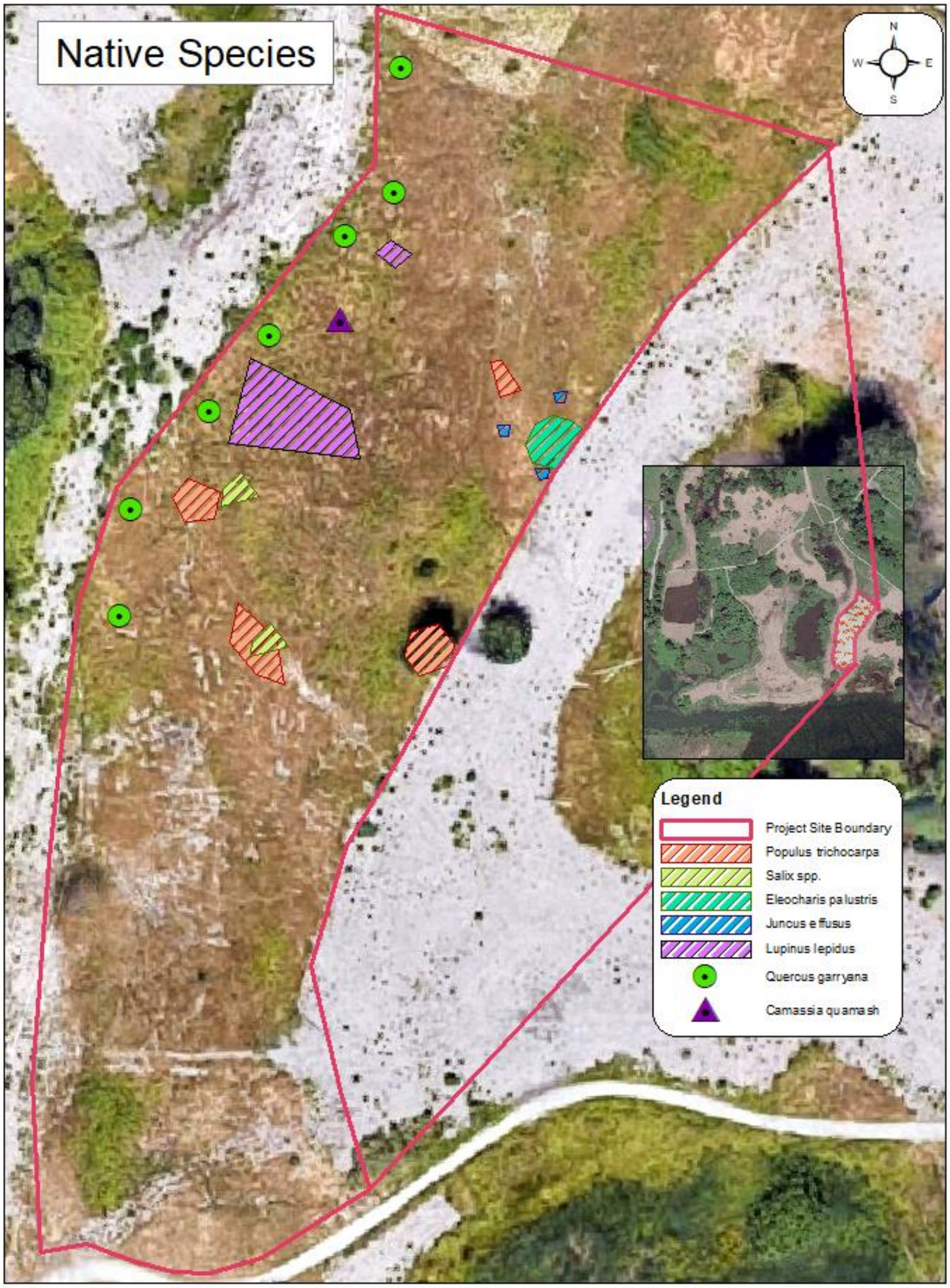

Figure 23: Map of native species at project site. Species include wetland emergents: creeping spike rush (*Eleocharis palustris*), and common rush (*Juncus effusus*), scrub-shrub species: Pacific willow (*Salix lasiandra*), and Scouler's willow (*Salix scouleriana*), broadleaf deciduous black cottonwoods (*Populus trichocarpa*), and prairie species: common yarrow (*Achillea millefolium*) and Garry oaks (*Quercus garryana*).

Soil Condition

Two sampling points were chosen, one located in the ephemeral wetland area, and one from a slightly higher elevation, drier area. (Figure 17). At each sampling location a hole measuring two feet deep was excavated (Figure 24). At each sampling site the depth of the O and A horizons were measured in centimeters (Table 1). The soil color was measured using the Munsell Color Charts (Appendix II; Figure 57 & 58, Table 1). Texture was measured using methodologies from Thien's *A flow diagram for teaching texture by feel analysis* (1979) (Table 1). Soil samples were weighed and dried to determine the moisture content (Table 1). Qualitative observations included: above ground vegetation, invertebrates encountered, course materials (pebbles/cobbles) present, and noticeable compaction and/or erosion (Table 2) which were adopted from Hillard (2018) site assessment.

Figure 24: Left: Image of soil pits dug for soil sampling. Pits measured 26 inches deep at two locations. Middle: Soil sample site #1 in the ephemeral wetland area. While surface water was not present at the time of sampling, the pit filled with surface water after reaching the desired depth. The soil in this sample consisted of a heavy clay loam, with a developing O horizon (2.54 cm), no course materials, and gleyed soils starting at 6 cm deep. Soil sample #2 in a drier, higher elevation area had a higher sand content, making it a sandy clay loam, with a very shallow O horizon of 0.64 cm, pebbles and cobbles present, and a higher degree of observed compaction.

Table 1: Results of soil sampling in soil pit 1 located within the ephemeral wetland area and soil pit 2 within a slightly higher elevated portion of the site. Results indicate the depth of the O and A soil horizons, the soil color, texture and percent moisture content.

Sample	**O Horizon (cm)**	**A Horizon (cm)**	**Color**	**Texture**	**Moisture**
1 Wetland	2.54 cm	3.81 cm	Gley 1 5/5GY	Clay Loam	11.52 %
2 Prairie	0.64 cm	21.59 cm	5Y 4/2	Sandy Clay Loam	8.34 %

Table 2: Qualitative observations of soil samples including: vegetative cover of the pit, invertebrates encountered, coarse materials present, and detection of compaction and erosion.

Sample	**Vegetation**	**Invertebrates**	**Coarse Minerals**	**Compaction**	**Erosion**
1 Wetland	*P. trichocarpa* (seedlings), *E. palustris*, *A. odoratum*	None	None	None	None
2 Prairie	*R. armeniacus*, *P. lanceolata*, *A. millefolium*, *A. odoratum*	None	Pebbles, cobbles	11.43 cm	None

Soil sample one shows characteristics of wetland/hydric soils. The presence of standing water occurred two weeks into the growing season (April 6-20, 2019), but subsequently dried. The soil sample was taken after standing water dried in late April, 2019. There was a fair amount of humus at the surface (2.54 cm), and gleyed soils appeared after a shallow A horizon (about 6 cm deep) (Table 1). Groundwater began to fill the pit after reaching the desired depth and rose to 11.5 cm down. The gleyed soils demonstrate standing water has created anaerobic conditions.

Soil sample two shows some characteristics that could support a Puget lowland prairie habitat. Puget Sound lowland prairies formed on soils made of glacial outwash, a sandy rocky soil. Glacial outwash soils characteristically rapidly drain, are fairly shallow, and have low organic matter content. Soil sample two has a high amount of pebbles and cobble, and a very shallow O horizon (0.64 cm) (Table 1). The soil texture has a higher amount of clay than glacial outwash being a sandy clay loam, but contains a fair amount of sand that induces drainage (Table 1). At the time of soil testing, soil sample two demonstrated a moisture content of about 8%, however, the area is likely to dry with ceased precipitation and increasing summer temperatures.

Soil Chemical Analysis

The University of Washington Environmental Health and Safety Office conducted soil testing for the expansion of the UW farm in January 2017, located about a quarter mile north of the project site. A composite soil sample was taken from six soil borings at 1, 1.5, and 2 feet deep by GeoEngineers for testing (GeoEngineers, 2017). Chemical analysis included diesel-range and heavy oil-range hydrocarbon, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and metals (arsenic, cadmium, chromium, lead, and mercury) (GeoEngineers, 2017). These analyses were selected based on criteria for the Montlake Landfill Project guide and the paper "Contaminated Soil in Gardens-How to Avoid Harmful Effects" (GeoEngineers, 2017). Results indicated concentrations of carcinogenic PAHs in the 1-2-foot soil interval at a concentration of 0.1 milligrams per kilogram, equal to the MTCA Method a cleanup level for Unrestricted Land Use (0.1mg/kg) (GeoEngineers, 2017). Arsenic, chromium, and lead were also detected, but are well below Washington State Model Toxics Control Act for soil cleanup levels (GeoEngineers, 2017).

Soil testing was also performed in 2012 by AMEC Environment & Infrastructure, Inc. for the construction of athletic fields about a quarter mile west of the project site, also located on the former Montlake Dump. Their soil tests also found concentrations of petroleum hydrocarbons, arsenic, chromium and lead.

Soil samples for the restoration site were collected on May 3, 2019 at two locations, one in the ephemeral wetland habitat and one in a drier, upland portion within the site (Figure 17). These two areas were chosen to compare contaminants within differing saturation and habitat type. To collect samples, a two-foot hole was dug with a shovel. A measuring tape was placed into the hole to measure depths for collection. Samples were taken at 6, 12, 18, and 24 inches deep to create a composite sample for the sample site. Most herbaceous species have maximum root depths of two feet, therefore two feet was the maximum depth for sampling. At each interval, a sample measuring approximately two square inches was taken with a hori-hori and placed into a clean plastic bag. The samples were then mixed together by shaking the bag, thoroughly mixing the substrates. The composite sample was then placed in a labeled, sanitized glass jar. The jar was placed in a cooler with an ice pack, to preserve the sample as it was transported to the lab. While ideal soil sampling would take separate samples from each depth, limited funding only allowed for two samples total, therefore a composite sample was utilized.

Results of the soil tests demonstrate low levels of carcinogenic poly-aromatic hydrocarbons (cPAHs), specifically pyrene and benzo-a-pyrene (Fremont Analytical, 2019). The level of phosphorus is the only contaminant exceeding cleanup levels according to the UW Health and Safety Office. Soil sample 1 located in the ephemeral wetland area had 252 mg of phosphorus per Kg of dry soil, and soil sample 2 in the slightly higher elevation prairie habitat had 254 mg of phosphorus per Kg of dry soil (Fremont Analytical, 2019). Heavy metals were detected in both soil samples in low concentrations including arsenic, chromium, copper, iron, lead and zinc. All are below any required levels for cleanup. Nitrogen was very low in both soil samples.

Habitat Features

Currently, only limited small pieces of woody debris exist on site. No snags, rock piles, or brush piles exist on site. Additionally, no man made habitat structures such as perches, bird houses or bat boxes exist on the project site.

Ongoing Disturbances/ Threats to Site

Ongoing disturbances are primarily the reintroduction of invasive species to the project site and disturbance from users of the natural area. The southern border of the restoration site is a frequently used trail by dog walkers, runners, and bicyclists. These activities may disturb or scare wildlife within the site. While it is fairly uncommon, people may also wander off trail, disturbing vegetation and wildlife further within the site. Another ongoing disturbance are pets that are allowed by their owners to run off of a leash. While this violates local governance, it commonly occurs in UBNA. Unrestored portions of UBNA are mowed by the University of Washington Botanical Garden's (UWBG) maintenance staff to control invasive species. However, this will not be required if the project successfully removes the invasive species and vegetates the area with native species.

Post restoration efforts, an ongoing threat to the site will be the continued introduction of seed and propagules from invasive plant species in surrounding unmanaged areas. Himalayan blackberry, a prevalent species within the Union Natural Area, is dispersed by wildlife including many bird species that eat the berries and spread seed to surrounding areas. Seeds of other invasive species such as Canadian thistle, which is also prevalent in the area, can spread onto the site via wind. Users of UBNA also pose risk of spreading seeds of invasive species on their clothes and shoes, and have the potential to introduce new non-native species to the area. Additionally, the only known population of Scotch broom within UBNA also exists on site (Figure 22). Scotch broom is likely to be an ongoing threat to the site as each seed can remain viable in the soil for over 30 years (with higher estimates ranging up to 80 years) (Washington State Noxious Weed Control Board, 2007). Finally, the high number of herbivores, including eastern cottontails, will be a threat to new vegetation planted. Preventing damage and mortality requires protection of any plants installed, such as tree tubes or chicken wire, to ensure survival during the establishment phase.

Figure 25: Eastern cottontails can decimate young vegetation installed in restoration efforts in UBNA. Preventing this herbivory requires herbivore protection to better ensure survival during the establishment phase.

Current Human Use/Impact

UBNA is a popular spot for public recreation. As previously mentioned, many people use the trail system to run, walk their dogs, and ride their bikes. UBNA is also a well-known birding area with many devoted birders. This human use can have impacts on the site such as compaction of soils, trampling of plants (if users walk off the paths), seed dispersal of non-native and invasive plants, disturbance to wildlife, and potential litter being discarded on site.

Partnerships and Collaborations

All restoration projects in UBNA work with the Center for Urban Horticulture, a part of the University of Washington, who own and manage the property. Some student restoration projects are in collaboration with the University of Washington's Society for Ecological

Restoration (SERUW) student chapter. The SERUW helps with publicity of work party events and has the potential to provide some funding for plant and material costs.

Project Constraints

Projects within UBNA are limited due to resources and time. Aside from the WSDOT mitigation project, ecological restoration projects in UBNA are carried out by students and faculty of the University of Washington with volunteer support. These projects are limited in funding dictated by available budgets and potential fundraising. Student projects are also limited by time as students typically have one or two years to plan and implement projects. This unfortunately often comes with the consequence of little to no maintenance of the site or subsequent monitoring. While labor can be provided through volunteers, it can fluctuate according to the season and the weather, as well as the outreach and publicity for the work parties. Volunteers also lack specialized skills and knowledge of best management practices, which can impede specific planting plans or site designs, or result in poor quality of work performed. A project within UBNA may also be constrained by local availability of desired plant species. Most plants sourced for restoration projects within UBNA are supplied by the UW native plant nursery which is limited in selection due to space and time constraints.

PROJECT PLANS

Restoration Project Plan I: Wetland enhancement

Figure 26: A created wetland established through the WSDOT mitigation project within UBNA in 2016. Source: https://www.wsdot.wa.gov/Projects/SR520Bridge/About/UBNA.htm

Background

By the 1980s approximately 53% of the wetland habitat had been lost in the contiguous United States due to draining and filling for agriculture and development (National Research Council Committee on Mitigating Wetland Losses, 2001). Not only do wetlands support a high biodiversity of microorganisms, invertebrates, and wildlife, they provide important ecosystem functions of natural flood control, recharge of groundwater aquifers, stabilization of shorelines, and improvement of water quality through filtration and treatment of ground and surface waters (National Research Council Committee on Mitigating Wetland Losses, 2001). Concern over the loss of wetlands in the United States has led to efforts by the federal government to protect wetlands on both public and private lands, as well as the restoration of wetland habitat.

The long term success of a wetland restoration project depends on the appropriate hydrology (Hammer, 1996). Wetland hydrology, including depth, period, and duration, determine the presence of surface water, nutrient availability, aerobic/anaerobic soil conditions, and soil structure (Hammer, 1996). Hydrology also determines the structure and function of the plant community. In turn, the vegetation can affect the hydrologic inputs and outputs through interception of precipitation and evapotranspiration, and alter the depth, velocity and circulation patterns of water moving through the system (Hammer, 1996). The inflow of water into wetlands is through surface or subsurface flows and/or directly added through precipitation (Mitsch & Gosselink, 1993). The outflows are through evapotranspiration and surface outflows of streams and rivers (Mitsch & Gosselink, 1993). Subsurface losses are generally less significant because most wetlands have impermeable substrates that cause standing water to occur. In order for the site to support a wetland ecosystem, the inputs must equal or exceed the outputs at least on an annual basis (Mitsch & Gosselink, 1993). The hydroperiod, which includes the time of year, spatial distribution, and depth of flooding, varies among types of wetlands (Hammer, 1996). Some wetland communities are adapted to permanent flooding, while others are adapted to seasonal flooding and some to only a few days of inundation. Therefore, the water balance must be considered when restoring or creating specific wetland habitats (Hammer, 1996). Land managers can control surface water inflows and outflows do a certain degree through excavation and levees, but not subsurface flows, precipitation, and evapotranspiration, which can significantly alter the hydrology and therefore soils and vegetation of the site.

Wetland soils are generally considered to be hydric because they develop under anaerobic conditions caused by saturation or inundation (Hammer, 1996; Mitsch & Gosselink, 1993). In well-developed wetlands, the upper layers are often organic or histosols created by the slow decomposition of organic matter in anaerobic conditions, while lower layers consist of mineral soils (Hurt et al., 1998). Hydric soils are often dark in color because of the buildup of organic matter, but they may also display gleying, which is when the waterlogged clay soils become grey color, or mottling, which refers to orange, yellow or red-brown patches, spots, or streaks also caused by saturation (Hurt et al., 1998). These hydric soils may also have a rotten egg odor to them (Hurt et al., 1998).

The vegetation of wetlands is unique in that the plants must have adaptations for them to survive in oxygen poor, anaerobic conditions for more than ten days during the growing season (Hammer, 1996). In order to be considered a wetland by legal terms, the specific hydrology, hydric soils, and wetland vegetation must be present and measured by standards developed by the Army Corps of Engineers. The Washington Department of Ecology values the conservation of wetlands of any size, but most jurisdictions have minimum size requirements (Hruby, 2014). Wetlands that meet the legal definition are called "jurisdictional" wetlands. The specific wetland hydrology requires that soils be saturated within 12 inches of the soil surface over a two week (14 days) period during the growing season (U.S. Army Corps of Engineers Environmental Laboratory, 1987). This measurement determines that the hydric soils promote establishment of vegetation adapted to saturated soils. Most wetland reports rely on indicators such as high water marks, driftlines, or watermarks on the bark of woody plants to determine duration of saturation (Hruby, 2014).

The National Wetland Plant List (Lichvar et al., 2016) compiled by the US Fish and Wildlife Service categorizes plants according to the likelihood they occur in a wetland. *Obligate wetland* (OBL) plant species grow in wetland habitats 99% of the time, occurring almost nowhere else (Lichvar et al., 2016). *Facultative* (FAC) plants either occur in wetlands or in other environments. *Facultative wetland* (FACW) plant species have a high probability of occurring in wetlands ranging from 67–99% of the time, but can also occur elsewhere (Lichvar et al., 2016). *Facultative upland* (FACU) plant species sometimes occur in wetlands (estimated 1% to <33%), but more often occur in non-wetlands (Lichvar et al., 2016). The wetland vegetation criterion for the Army Corps of Engineers is satisfied when more than 50% of the plant species present are at least *Facultative* (Lichvar et al., 2016).

Wetland delineation is the process of determining the location and physical limits of a wetland. This involves examining the hydrology, soils and vegetation by reviewing existing wetland inventory maps, physically walking the site, surveying the vegetation, and digging soil sample pits (Lichvar et al., 2016); U.S. Army Corps of Engineers Environmental Laboratory, 1987). Wetlands in Washington are then rated on a score from one to four based on sensitivity to disturbance, rarity, our ability to replace them, and the functions they provide (Hruby, 2014).

Restoration Goals, Objectives and Actions

Restoration Goal: Enhance wetland habitat

Objective 1: Decrease cover of high priority dominant invasive species, *Rubus armeniacus, Cytisus scoparius, Iris pseudacorus,* and Cirsium spp. to below 10% cover by year one.

- ➢ **Action:** Mow the site in both the early and late summer, optimally over multiple growing seasons prior to restoration work.
- ➢ **Action:** Manually remove all *Rubus armeniacus, Cytisus scoparius,* and *Cirsium* spp. on site by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** UWBG personnel treat *Iris pseudacorus* with Glyphosate (Aquamaster®)

Objective 2: Increase diversity and cover of native emergent vegetation in the ephemeral wetland and depressions by establishing at least five species with 60% combined cover by year two.

- **Action:** Mow the site in both the early and late summer, optimally over multiple growing seasons prior to restoration work.
- **Action:** Identify and mark the perimeter of the ephemeral wetland, depressions, and transition zones with pin flags or stakes.
- **Action:** Use flagging tape and/or pin flags to mark native species
- **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.
- **Action:** Manually clear dense patches of non-native grasses and forbs within the depressions and transition zone by scraping the soil surface with Mcleods and removing non-native vegetation.
- **Action:** Install native emergent species according to planting plan

Objective 3: Objective 3: Provide a minimum of 50% cover of native grass and forb species on site in areas surrounding depressions by year two.

- **Action:** Mow the site in both the early and late summer, optimally over multiple growing seasons prior to restoration work.
- **Action:** Identify and mark the perimeter of prairie plots according to project design.
- **Action:** Use flagging tape, pin flags, or other marker to identify native species in each plot.

- ➢ **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** Manually clear dense patches of non-native grasses and forbs within the depressions and transition zone by scraping the soil surface with Mcleods and removing non-native vegetation.
- ➢ **Action:** Install native herbaceous and grass species within patches according to planting plan

Objective 4: Manage native woody species to prevent site from becoming scrub-shrub or forested wetland habitat.

- ➢ **Action:** Remove *Salix* spp. and *Populus trichocarpa* manually, or cut back and apply Glyphosate herbicide on stems during the growing season.

Project Site Design

The subsidence of the cap that has created several ponds and wetland habitats within UBNA is predicted to continue to occur. A 2012 technical report by AMEC Environment & Infrastructure, Inc., estimates settlement to range from 0.5-1 inch per year, based on monitoring results that measured settlements of six inches within five years. The report predicts a maximum subsidence of 1.5 feet over 20 years (AMEC Environment & Infrastructure, Inc. 2012). The formation of these depressions and ponds changes the hydrology of surface water by causing it to collect in the areas with a slightly lower elevation, especially in areas with poor drainage.

At the restoration project site, a depression in the northeast section is forming an ephemeral wetland habitat. This area was detected to hold surface water for two weeks into the growing season (April 6- April 20, 2019) which qualifies it for the designation as wetland habitat. This ephemeral wetland and extended saturated soils measure approximately 3,000 square feet (Figure 30). The inflows to this area are assumed to be primarily from precipitation, though some subsurface flow may occur. There is no surface outflow from the area, suggesting evapotranspiration is the only outflow. The occurrence of standing water, in addition to an obligate wetland plant species, creeping spike rush (*Eleocharis palustris*), and gleyed soils observed in the soil sample pits indicate this area as an ephemeral wetland habitat with the potential to increase in size over time.

The planting palette for Project Plan I consists of both obligate and facultative wetland plants for the ephemeral wetland and other depressions on the project site. This project aids succession of the site from non-native and invasive terrestrial species, to native wetland emergent species better adapted to future conditions as the area continues to subside and withhold surface water for longer durations. The implementation of this project would also provide a seed source of native emergent species to adjacent wetland areas, as well as to potential future wetland areas that develop.

The site assessment demonstrated there are large portions of the site with a slightly higher elevation and better drainage which is unsuitable to wetland vegetation. While the primary goal of Project Plan I is to enhance wetland habitat, the project has to work within the conditions of the site. As a result, areas with a slightly higher elevation and better drainage will be planted with 10 x 10 ft. plots of native Puget lowland prairie species. The area will be selectively planted in 10 x 10 ft. plots because planting the entire site on dense, one-foot spacing, would require over 130,000 plants which is infeasible for the budgets and labor required for the project to be implemented. Alternatively, these densely planted plots will provide vegetative propagules and a seed source capable of spreading between the plots to hopefully provide a continuous cover over time.

While prairies are not shorebird habitat, they still provide open habitat with clear line of site for shorebirds utilizing depression and ephemeral wetland habitat. The wetland areas also have the potential to grow in size as the topography changes and rhizomatous emergent species colonize saturated conditions. Plants in each area including the ephemeral wetland, depressions, transition and prairie plots, will all be planted on a dense one-foot spacing in between plants (Figure 27, 28, 29). Dense planting will help curb competition from invasive species by obtaining space and resources at a faster rate. Each planting area will have its own planting design that will repeat in all areas except for 10x10 foot plots. Plants will be sourced from Fourth Corner Nursery as bare root transplants (Tables 3-6).

Project implementation will be divided into multiple phases. Phase 1 (Year 1) will focus on two periods of invasive control. Larger invasive herbaceous and woody species will be removed by digging, uprooting, and disposing of individual plants. Dense patches of non-native grasses and forbs will be removed through scraping the soil surface with Mcleods to remove vegetation and as much of their root systems as possible. The site will be treated once in the early spring (March-April) when the ground is soft and plants are just beginning to emerge, and once again in mid-summer (July-August), before non-native and invasive species have set seed. UWBG personnel will treat *Iris pseudacorus* with Glyphosate (Aquamaster®) in the initial invasive control efforts and should apply a secondary treatment if needed. Site preparation is crucial for survivorship of plants installed. Phase 2 (Year 2) will continue invasive species control and plant bare root plants in late fall (October-November). Phase 3 (Year 3) will be continued maintenance to control invasive species and provide supplemental planting as needed. Phase 4 (Year 4-10) will be vegetation monitoring of the site in late summer (August-September) and any maintenance determined needed from monitoring results.

Project Timeline

Table 3: The project will be divided into multiple phases, with initial efforts focused on invasive removal for at least two seasons before plant installation in the late fall of Year 2. Following plant installation will be continued maintenance to control invasive species and provide supplemental planting as needed. The final phase focuses on annual monitoring until Year 10 of the project.

Phase 1- Year 1											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Initial Invasive species control				Initial Invasive species control					
Phase 2- Year 2											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Secondary Invasive species control				Secondary Invasive species control			Native Species Installation		
Phase 3- Year 3											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Site maintenance				Site maintenance			Supplemental planting		
Phase 4-Year 4-10											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
							Vegetation Monitoring				

Plant Palette

Table 4: Species plant palette and procurement plan for the ephemeral wetland portion of the site.

Ephemeral Wetland Species						
Species	**Common Name**	**Indicator Status**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Scirpus microcarpus	Small-fruited bulrush	OBL	1,869	Bare root	$0.33	Fourth Corner
Carex stipata	Sawbeak sedge	OBL	670	Bare root	$0.33	Fourth Corner
Oenanthe sarmentosa	Water parsley	OBL	251	Bare root	$0.40	Fourth Corner

Table 5: Species plant palette and procurement plan to vegetate depressions on site.

Depression Species						
Species	**Common Name**	**Indicator Status**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Juncus ensifolius	Dagger leaf rush	FACW	1,722	Bare root	$0.33	Fourth Corner
Juncus effusus	Common rush	FACW	6,410	Bare root	$0.33	Fourth Corner
Deschampsia cespitosa	Tufted hairgrass	FACW	1,435	Bare root	$0.33	Fourth Corner

Table 6: Species plant palette and procurement plan for transition habitat between the depressions and prairie plots.

Transition Species						
Species	**Common Name**	**Indicator Status**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Juncus tenuis	Slender rush	FAC	4,396	Bare root	$0.33	Fourth Corner

Table 7: Species plant palette and procurement plan for prairie plots.

Prairie Species						
Species	**Common Name**	**Indicator Status**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Festuca idahoensis var. *roemeri*	Roemer's Fescue	FACU	5,734	Bare root	$0.33	Fourth Corner
Achillea millefolium	Common Yarrow	FACU	846	Bare root	$0.35	Fourth Corner
Eriophyllum lanatum var. leucophyllum	Common Woolly Sunflower	Not Listed	1,410	Bare root	$0.40	Fourth Corner

Deschampsia cespitosa	Tufted hairgrass	FACW	1,410	Bare root	$0.33	Fourth Corner
Camassia quamash	Common Camas	FACW	1,410	Bulbs	$0.40	Fourth Corner

Budget

Table 8: The plant budget lists quantities of each species on a dense one-foot spacing as the plan is designed, and an alternative spacing of two feet. Prices were sourced from Fourth Corner Nursery catalogue.

Plants	**Quantity 1' Spacing**	**Unit Price**	**Cost**	**Quantity 2' Spacing**	**Unit Price**	**Cost**
Scirpus microcarpus	1,869	$0.33	$616.77	542	$0.33	$178.86
Carex stipata	670	$0.33	$221.10	194	$0.33	$64.12
Oenanthe sarmentosa	251	$0.40	$100.40	73	$0.40	$29.12
Juncus ensifolius	1,722	$0.33	$568.26	499	$0.33	$164.80
Juncus effusus	6,410	$0.33	$2,115.30	1,859	$0.33	$613.44
Deschampsia cespitosa	1,435	$0.33	$473.55	416	$0.33	$137.33
Juncus tenuis	4,396	$0.33	$1,450.68	1,275	$0.33	$420.70
Festuca idahoensis var. roemeri	5,734	$0.33	$1,892.22	1,663	$0.33	$548.74
Achillea millefolium	846	$0.35	$296.10	245	$0.35	$85.87
Eriophyllum lanatum var. leucophyllum	1,410	$0.40	$564.00	409	$0.40	$163.56
Deschampsia cespitosa	1,410	$0.33	$465.30	409	$0.33	$134.94
Camassia quamash	1,410	$0.40	$564.00	409	$0.40	$163.56
TOTAL	**27,563**		**$9,327.68**	**7,993**		**$2,705.03**

Planting plans

Ephemeral Wetland Planting Plan

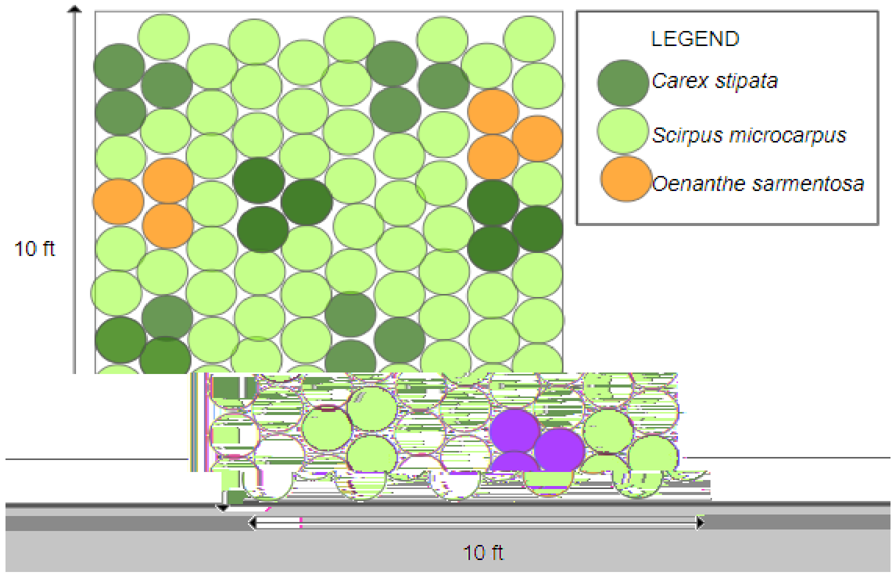

Figure 27: Planting design for a given 100 square feet of the ephemeral wetland. Clusters of three individuals of sawbeak sedge (*Carex stipata*) and water parsley (*Oenanthe sarmentosa*) will be interspersed between small-fruited bulrush (*Scirpus microcarpus*) on a dense one-foot spacing. This pattern will be repeated to fill in the entire area of the ephemeral wetland.

Depression Planting Plan

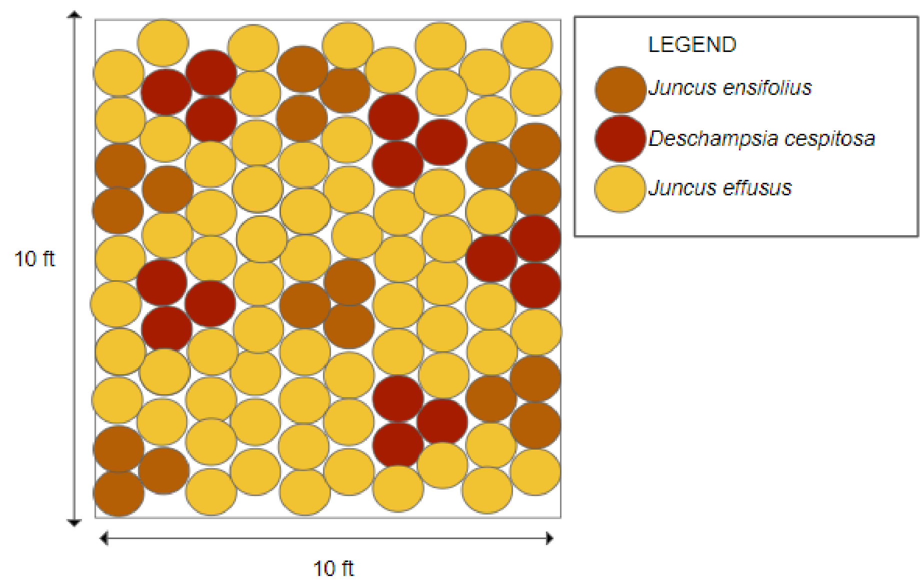

Figure 28: Planting design for a given 100 square feet of depressions on site. Clusters of three individuals of dagger leaf rush (*Juncus ensifolius*) and tufted hairgrass (*Deschampsia cespitosa*) will be interspersed between common rush (*Juncus effusus*) on a dense one-foot spacing. This pattern will be repeated to fill in the entire area of the depressions.

Prairie Plot Planting Plan

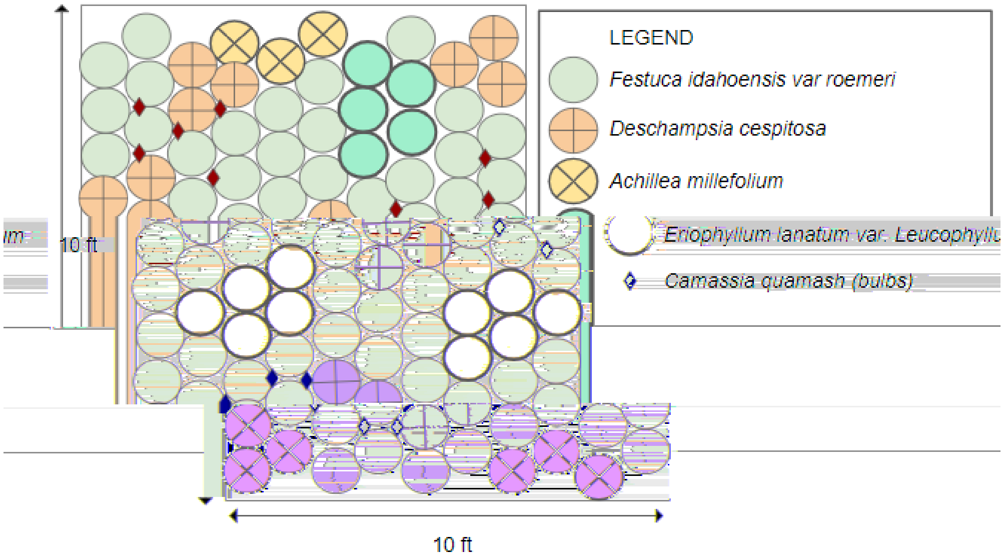

Figure 29: Planting design for prairie plots measuring 10’x10’. Clusters of species will be grouped by three to five individuals of common yarrow (*Achillea millefolium*), common woolly sunflower (*Eriophyllum lanatum* var. *leucophyllum*), and tufted hairgrass (*Deschampsia cespitosa*) interspersed between Roemer's fescue (*Festuca idahoensis var. roemeri*) on a dense one-foot spacing between plants. Bulbs of common camas (*Camassia quamash*) will be planted in spaces between graminoid species. Common yarrow will be purposely planted on the edge of the plot boundary as it can be an aggressive rhizomatous species which can compete with non-native species between plots.

Project Map

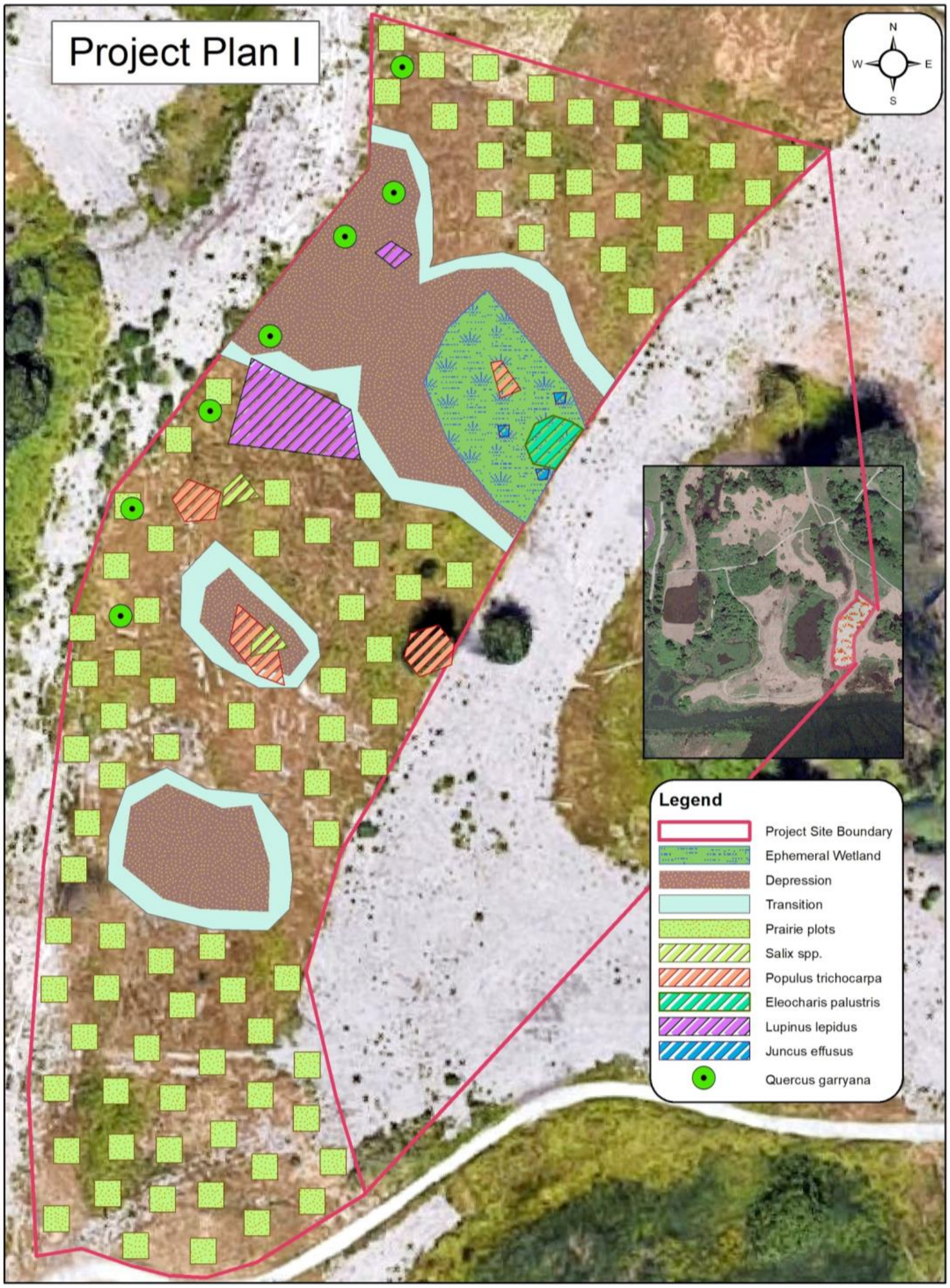

Figure 30: Map of Project Plan I including planting areas, and native vegetation. Depressions will be planted with facultative wetland plants and surrounded by a narrow transition zone to prairie plots scattered across areas with higher elevation and better drainage. As depressions continue to subside, emergent species can spread vegetatively as well as through seed to occupy forming wetland areas.

Restoration Project Design II: *Bioremediation of contaminated soil and groundwater*

Figure 31: Oro Loma Horizontal Levee Project in San Lorenzo, CA, where restoration of native vegetation is utilized for treating incoming wastewater at a local sanitary district. Source: https://oroloma.org/horizontal-levee-is-thriving/

Background

Bioremediation can be conducted through plants, fungi, and/or their associated microorganisms. Phytotechnology is an overarching type of bioremediation focused on the specific application of plants to remediate or contain contaminants in soil and groundwater (Kennen & Kirkwood, 2015). More specifically, phytoremediation refers to the degradation and/or removal of a particular contaminant at a polluted site by a specific plant species or group of plants (Darwish, L. 2013). Phytotechnology also includes other techniques used for remediation including stabilization of pollutants through plant roots within the soil, in order to prevent spread and contain the pollutant to one area (Darwish, L. 2013). Methods of phytotechnology vary for different types of contaminants.

For man-made organic contaminants comprised of carbon, nitrogen, and oxygen compounds, which include: petroleum aromatic hydrocarbons (PAHs), chlorinated solvents (like trichloroethylene), pesticides, explosives, and persistent organic pollutants (POP) including DDT, Chlordane, and PCBs, the compounds can be broken down into smaller, less toxic components (Darwish, L. 2013; Kennen & Kirkwood, 2015). This can occur though phytodegradation where the plant uptakes the contaminant and breaks it down into non-toxic metabolites used for photosynthesis (Kennen & Kirkwood, 2015). Organic contaminants may also be taken up and phytometabolized to become bound in the plant tissue, or taken up and released into the atmosphere through phytovolatilization (Darwish, L. 2013; Kennen & Kirkwood, 2015). Organic contaminants are also often broken down in the soil through microbial activity within the plant's rhizosphere known as rhizodegradation (Darwish, L. 2013). Through photosynthesis, plants produce sugar exudates that leach out through plant roots. These sugars, as well as organic acids, amino acids, enzymes, and oxygen, released through root respiration, create favorable conditions for microorganisms to feed and reproduce (Kennen & Kirkwood, 2015). These microorganisms feed on the carbon of the organic compounds breaking down the compounds of the contaminant (Kennen & Kirkwood, 2015).

Inorganic contaminants cannot be broken down, as they are already natural elements, but can be remediated in several ways. Inorganic contaminants include plant macronutrients including nitrogen and phosphorus, and metals such as arsenic, nickel, selenium, cadmium, zinc, boron, cobalt, copper, chromium, iron, manganese, molybdenum, lead, fluorine, mercury, and aluminum (Darwish, L. 2013; Kennen & Kirkwood, 2015). Some of these elements may be extracted from the soil and groundwater (phytoextraction), but require subsequent removal to prevent the vegetative matter from decomposing back into the soil (Kennen & Kirkwood, 2015). If unable to extract the inorganic contaminants, plants and microbes can sometimes stabilize the contaminant within the soil (phytostabilization) or change its state (Kennen & Kirkwood, 2015). Phytohydraulics is a method of phytotechnology to utilize the uptake of water through plant roots to limit the spread of a contaminant within the groundwater from spreading (Kennen & Kirkwood, 2015).

With UBNA's history as a former landfill, the soils and groundwater have a high potential of being contaminated with organic and inorganic pollutants. There is also the possibility of leachate from the landfill entering nearby water bodies including the wetlands within UBNA, Ravenna Creek, and Lake Washington. The Montlake landfill was built well before regulations that now mandate lining to prevent leaching of waste materials. The cap of Montlake Fill also ranges in depth, with some areas only covered by two feet of fill soil (UWEHS, 2017). Waste in landfills can contribute the following contaminants: petroleum compounds including MTBE, MTEX, gasoline, diesel fuel, petroleum hydrocarbons including Polycyclic aromatic hydrocarbons (PAHs) from coal, tar, crude oil, heating oil and creosote, chlorinated solvents including trichloroethylene the most common pollutant of groundwater, persistent organic pollutants (POPs) including DDT, Chlordane, and PCBs, pesticides, metals, and plant macronutrients including phosphorus and nitrogen (Kennen & Kirkwood, 2015). The most often leached pollutants from landfills include nitrogen in the form of ammonia, salts (sodium, chloride, other additives), and metals (Kennen & Kirkwood, 2015).

In data collected from the University of Washington's Health and Safety Office, soil test samples from UBNA demonstrated low, but detectable, levels of petroleum hydrocarbons, PAHs, PCBs, and metals including Arsenic, Lead and Chromium (AMEC Environment & Infrastructure, Inc. 2012; GeoEngineers, 2017). While the levels of these contaminants do not warrant legal action for cleanup, bioremediation can help to break down and stabilize these contaminants within the restoration project site. While concrete evidence is lacking, varying concentrations of pollutants may be hindering the establishment and succession of native plants and be favoring non-native invasive species. Remediating the soils and water may therefore improve native plant communities in UBNA. Addressing contaminants in the groundwater is also important, considering the former landfill is on marshland connected through groundwater to several surface waters including Ravenna Creek and Lake Washington. A drawback of Project Plan II includes increasing the amount of woody shrubs and trees which as previously mentioned, decreases the amount of open wetland and prairie habitat needed for waterfowl, shore birds, and prairie species. Another major consideration of Project Plan II is that the project area is only a small portion of UBNA and it is unknown whether higher concentrations of pollutants exist elsewhere.

Restoration Goals, Objectives and Actions

Restoration Goal: Bioremediation of contaminated soil and groundwater

Objective 1: Decrease cover of high priority dominant invasive species, *Rubus armeniacus, Cytisus scoparius, Iris pseudacorus* and Cirsium spp. to below 10% cover by year one.

- ➢ **Action:** Mow the site in both the early and late summer, optimally over multiple growing seasons prior to restoration work.
- ➢ **Action:** Manually remove all *Rubus armeniacus, Cytisus scoparius,* and *Cirsium* spp. on site by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** UWBG personnel treat *Iris pseudacorus* with Glyphosate (Aquamaster®)

Objective 2: Decrease the levels of polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyl (PCBs) detected in soil samples through rhizodegradation.

- ➢ **Action:** Mow the site in both the early and late summer, optimally over multiple growing seasons prior to restoration work.
- ➢ **Action:** Identify and mark the perimeter of plots of prairie degradation mats according to project design.
- ➢ **Action:** Use flagging tape, pin flags, or other marker to identify native species in each plot.
- ➢ **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** Manually clear dense patches of non-native grasses and forbs within the depressions and transition zone by scraping the soil surface with Mcleods and removing non-native vegetation.
- ➢ **Action:** Install native grass species with extensive fibrous root systems including, Roemer's fescue (*Festuca idahoensis var. roemeri*) and blue wild rye (*Elymus glaucus*) capable of rhizodegradation of PAHs and PCBs within the soil

Objective 3: Stabilize heavy metals detected in soil sample and prevent spread into Central Pond through phytostabilization and phytohydraulics of a groundwater migration tree stand.

- ➢ **Action:** Identify and mark the perimeter of the groundwater migration tree stand.
- ➢ **Action:** Use flagging tape, pin flags, or other marker to identify native species
- ➢ **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.

- ➢ **Action:** Manually clear dense patches of non-native grasses and forbs within the depressions and transition zone by scraping the soil surface with Mcleods and removing non-native vegetation.
- ➢ **Action:** Install black cottonwood (*Populus trichocarpa*) and quaking aspen (*Populus tremuloides*) according to the planting plan.

Objective 4: Decrease the level of phosphorus in the soils.

- ➢ **Action:** Identify and mark the perimeter of areas designated for hyperaccumulator species within the project design in the field.
- ➢ **Action:** Use flagging tape, pin flags, or other marker to identify native species.
- ➢ **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** Manually clear dense patches of non-native grasses and forbs within the depressions and transition zone by scraping the soil surface with Mcleods and removing non-native vegetation.
- ➢ **Action:** Install native hyperaccumulator species, including Pacific willow (*Salix lasiandra*) and Scouler's willow (*Salix scouleriana*) for phytometabolization of excess phosphorus.

Project Site Design

In order to utilize phytotechnologies to break down and stabilize contaminants, the restoration project plan will utilize several phytoremediation planting typologies, which are strategies employed based on the specific process of remediation. This will create a patchwork of native scrub-shrub willow (*Salix* spp.), emergent vegetation, and open prairie habitats to create degradation cover and stabilization mats, and a groundwater migration tree stand of black cottonwood and quaking aspen (Figure 36).

Degradation cover is a phytotechnology used where thick deep rooted herbaceous species are used to create hospitable conditions for their associated microbial communities to treat contaminants up to 5 feet deep. This will be employed to remediate PAHs, as well as excess phosphorus within the soil (Kennen & Kirkwood, 2015). The degradation cover utilizes rhizodegradation of contaminants through microbial associations with soil microbes. Degradation cover mats will be divided into two designs based on the soil condition. For drier, higher elevation areas, 10’ x10’ plots of degradation cover will consist of native prairie species including Blue wild rye (*Elymus glaucus*), Roemer's fescue, and Canada Goldenrod (*Solidago canadensis*) (Figure 32). These species have been proven in multiple studies to help degrade PAHs within the soil (Kennen & Kirkwood, 2015). The area will be selectively planted in 10 x 10 ft. plots because planting the entire site on dense, one-foot spacing, would require over 130,000 plants which is infeasible for the budgets and labor required for the project to be implemented. Alternatively, these densely planted plots will provide vegetative propagules and a seed source capable of spreading between the plots to hopefully provide a continuous cover over time.

Graminoids are more commonly used for remediation of PAHs because of their fast growth and dense fibrous root systems, which also help to sequester excess nutrients (Kennen & Kirkwood, 2015). Prairie lupine (*Lupinus lepidus*) will also be planted for its association with nitrogen fixing bacteria. The degradation rate of hydrocarbons can be increased with the availability of nitrogen within the system because hydrocarbons contain excessive carbon content that upsets the ratio of nitrogen and phosphorus necessary for proper plant and microbial growth (Kennen & Kirkwood, 2015). Lighter fractions of TPH can be degraded within a five-year time frame, while heavy fractions including PAHs may range from 5-20+ years for remediation depending on concentrations and environmental conditions (Kennen & Kirkwood, 2015). Within the depressions on the project site, degradation cover will be installed with common rush, small-fruited bulrush, and wool grass (*Scirpus cyperinus*), all of which have demonstrated the ability to help degrade TPH and PAHs (Kennen & Kirkwood, 2015) (Figure 33). Plants will be installed on a dense one-foot spacing, with the planting plan replicated to fully vegetate several depressions within the project site (Figure 36). Vegetation used in the degradation mats do not need to be harvested or removed from the project site. Rhizodegradation helps to break down these contaminants within the soil, therefore, plants are not extracting PAHs into their tissue.

Since inorganic contaminants including metals cannot be degraded, they will be stabilized within the soil. Stabilization mats will consist of Pacific willow (*Salix lasiandra*) and Scouler's willow (*Salix scouleriana*) to prevent metals including detected arsenic, lead and chromium from moving within the soils (Figure 34). The live willow stakes will be installed on larger three foot centers to allocate enough space for plant's size at maturity. The stabilization mats will occur in areas where natural recruitment of willows and black cottonwood are already occurring and in areas that protect depressions and ephemeral wetland (Figure 36). The stabilization mats will also act as degradation cover as *Salix* spp. are hyperaccumulators capable of removing excess macronutrients as well as breaking down other organic pollutants (Kennen & Kirkwood, 2015). Vegetation used for stabilization mats do not need to be harvested or removed from the site as the contaminants are stabilized within the soil. In the southwestern portion of the site, black cottonwood and quaking aspen (*Populus tremuloides*) will be planted to create a groundwater migration tree stand. The groundwater migration tree stand will stabilize heavy metals detected in soil sample and prevent spread into Central Pond and Lake Washington through phytohydraulics which utilizes the drawing force of plant roots to control subsurface flow. The live stakes and bare root transplants will be planted on ten foot centers to provide adequate space for growth.

Project implementation will be divided into multiple phases. Phase 1 (Year 1) will focus on two periods of invasive control. Larger invasive herbaceous and woody species will be removed by digging, uprooting, and disposing of individual plants. Dense patches of non-native grasses and forbs will be removed through scraping the soil surface with Mcleods to remove vegetation and as much of their root systems as possible. The site will be treated once in the early spring (March-April) when the ground is soft and plants are just beginning to emerge, and once again in mid-summer (July-August), before non-native and invasive species have set seed. Site preparation is crucial for survivorship of plants installed. Live stakes will be planted in the late fall (October-November) of Year 1. Live stakes will be installed before bare root plants because they are easier to identify and weed around, having larger spacing and less delicate structures compared to herbaceous vegetation. This will also give these species a head start in the establishment phase, while invasive removal is still occurring. Phase 2 (Year 2) will continue invasive species removal and plant bare root plants and any additional live stakes in the late fall (October-November). Phase 3 (Year 3) will be continued maintenance to control invasive species and provide supplemental planting as needed. Phase 4 (Year 4-10) will be vegetation monitoring of the site in late summer (August-September) and any maintenance determined needed from monitoring results.

Project Timeline

Table 8: The project will be divided into multiple phases. Phase one will focus on two periods of invasive control in the spring and summer and installation of live stakes in the fall. Phase 2 will continue invasive removal and plant container and bare root plants in the late fall. Phase 3 will be continued maintenance to control invasive species and provide supplemental planting as needed. Phase 4 focuses on annual monitoring until Year 10 of the project.

Phase 1 - Year 1											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Initial Invasive species control				Initial Invasive species control			Live stake installation		
Phase 2 -Year 2											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Secondary Invasive species control				Secondary Invasive species control			Bare root/ Container plant Installation		
Phase 3 - Year 3											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Site maintenance				Site maintenance			Supplemental planting		
Phase 4 - Year 4-10											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
							Vegetation and Soil Monitoring				

Plant Palette

Table 9: Species plant palette and procurement plan for prairie degradation mats. If limited by budget, cuttings of willows and black cottonwoods can be sourced within UBNA.

Species for Prairie Degradation Mats						
Species	**Common Name**	**Contaminant Addressed**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Elymus glaucus	Blue wild rye	TPH, PAH	1,971	Bare root	$0.33	Fourth Corner
Festuca idahoensis var. roemeri	Roemer's Fescue	TPH, PAH	4,453	Bare root	$0.33	Fourth Corner
Solidago canadensis	Canada Goldenrod	TPH, PAH	657	Bare root	$0.40	Fourth Corner
Lupinus lepidus	Prairie Lupine	*N.A. for nitrogen fixation*	73	Plug	$1	Fourth Corner

Table 10: Species plant palette and procurement plan for wetland degradation mats.

Species for Wetland Degradation Mats						
Species	**Common Name**	**Contaminant Addressed**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Juncus effusus	Common rush	PAH	7,489	Bare root	$0.33	Fourth Corner
Scirpus microcarpus	Small-fruited bulrush	TPH, PAH	2,106	Bare root	$0.33	Fourth Corner
Scirpus cyperinus	Wool Grass	TPH, PAH	2,106	10 in Plug	$1.00	Sound Native Plants

Table 11: Species plant palette and procurement plan for prairie stabilization mats.

Hyperaccumulator Species						
Species	**Common Name**	**Contaminant Addressed**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Salix lasiandra	Pacific willow	Macronutrients N, P Metals- As, Pb, Cr	651	Cuttings	$0.60 Or $0.00	Fourth Corner Nursery OR UBNA Cuttings
Salix scouleriana	Scouler’s willow	Macronutrients N, P Metals- As, Pb, Cr	521	Cuttings	$0.60 Or $0.00	Fourth Corner Nursery OR UBNA Cuttings

Table 12: Species plant palette and procurement plan for groundwater migration tree stand.

Species for groundwater migration tree stand						
Species	**Common Name**	**Contaminant Addressed**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Populus trichocarpa	Black cottonwood	Macronutrients -N, P Metals, PCBs, TPH and PAHs	252	Cuttings	$0.60 Or $0.00	Fourth Corner Nursery OR Cuttings sourced from UBNA
Populus tremuloides	Quaking aspen	Macronutrients -N, P Metals, PCBs, TPH and PAHs	315	Bare root	$0.91	Fourth Corner Nursery

Budget

Table 13: The plant budget lists quantities of herbaceous species on a dense one-foot spacing as the plan is designed, and an alternative spacing of two feet. Prices were sourced from Fourth Corner Nursery catalogue.

Plants	**Quantity**	**Unit Price**	**Cost**	**Quantity 2' Spacing**	**Unit Price**	**Cost**
Elymus glaucus	1,971	$0.33	$650.43	572	$0.33	$188.76
Festuca idahoensis var. roemeri	4,453	$0.33	$1,469.49	1,291	$0.33	$426.03
Solidago canadensis	657	$0.40	$262.80	191	$0.40	$76.40
Lupinus lepidus	219	$1.00	$219.00	63	$1.00	$63.00
Juncus effusus	7,489	$0.33	$2,471.37	2,172	$0.33	$716.76
Scirpus microcarpus	2,106	$0.33	$694.98	611	$0.33	$201.63
Scirpus cyperinus	2,106	$1.00	$2,106.00	611	$1.00	$611.00
Salix lasiandra	651	$0.60	$390.60	189	$0.60	$113.4
Salix scouleriana	521	$0.60	$312.60	151	$0.60	$90.60
Populus trichocarpa	252	$0.60	$151.20	73	$0.60	$43.80
Populus tremuloides	315	$0.91	$286.65	91	$0.91	$82.81
TOTAL	20,740		$9,015.12	8,035		$2,697.00

While the soil test is not required in order to implement the project plan, it is necessary for observing changes of contaminants within the soil and whether the project is meeting objectives of bioremediation. Prices listed in Table 13 are sourced from Fremont Analytical Lab. It is important to note prices reflect a 50-60% discount for the tests being a part of a student project.

Table 14: Budget for soil tests.

Soil Test	**Price/Sample**	**Cost**
Diesel & Heavy Oil Range Organics	**$26.00**	**$52.00**
PAHs (EPA 8270-SIM)	$95.00	$190.00
First Metal (As)	$10.00	$20.00
Metal: Each Additional (Cd, Cr, Cu, Fe, Hg, Pb, Zn)	$42.00	$84.00
Ammonia (SM 4500 NH3)	$12.50	$25.00
Total Phosphorus	$17.50	$35.00
	TOTAL	$406.00

Planting plans

Prairie Degradation Mat Planting Plan

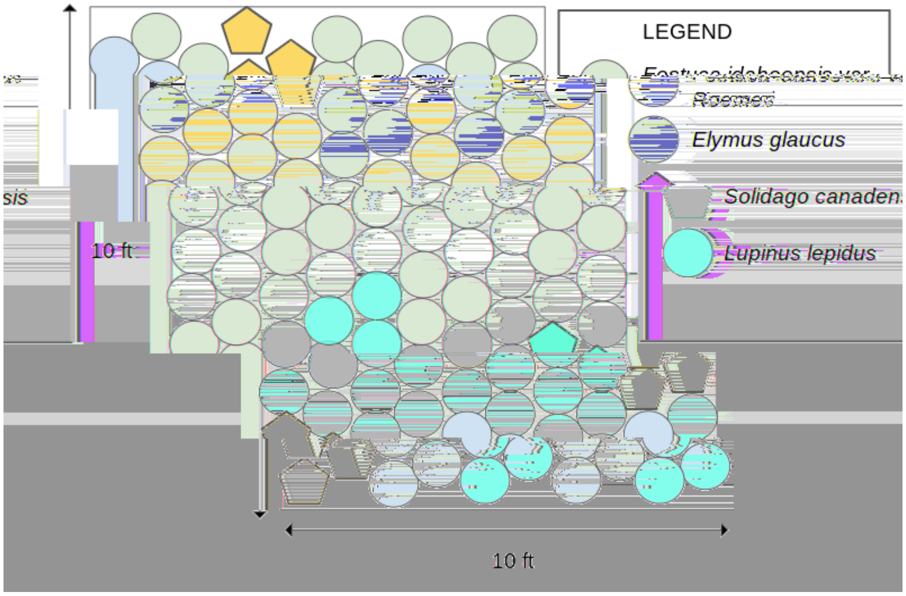

Figure 32: Planting design for prairie degradation mat plots measuring 10’x10’. Clusters of three individuals of blue wild rye (*Elymus glaucus*), Canada goldenrod (*Solidago canadensis*), and field lupine (*Lupinus lepidus*) will be interspersed between Roemer's fescue (*Festuca idahoensis var. roemeri*), on a dense one-foot spacing. Canada goldenrod will be purposely planted on the edge of plots as it can be an aggressive rhizomatous species which can compete with non-native species between plots.

Wetland Degradation Mat Planting Plan

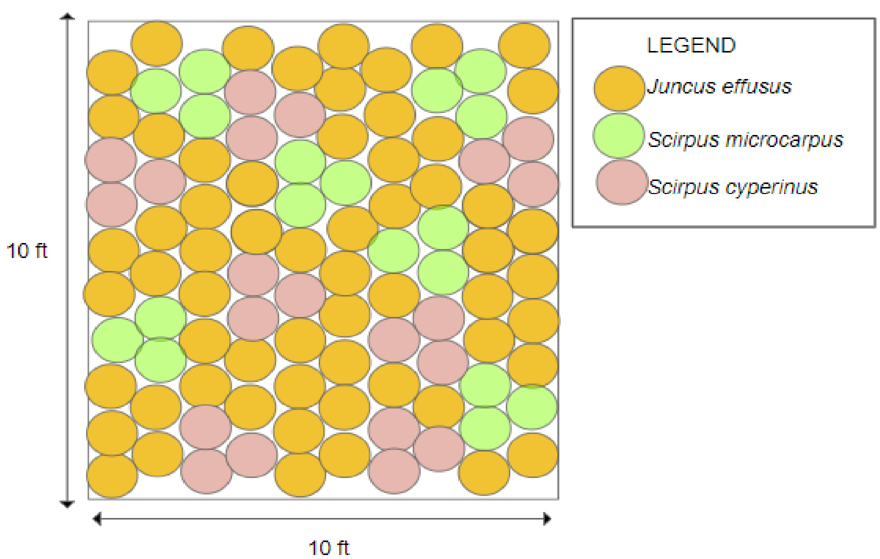

Figure 33: Planting design for a given 100 square feet of the wetland degradation mat that will be located in two depressions on the project site (Figure 36). Clusters of three individuals of small-fruited bulrush (*Scirpus microcarpus*) and wooly grass (*Scirpus cyperinus*) will be interspersed between common rush (*Juncus effusus*) on a dense one-foot spacing. This pattern will be repeated to fill in the entire area of the wetland degradation mats.

Hyperaccumulator Planting Plan

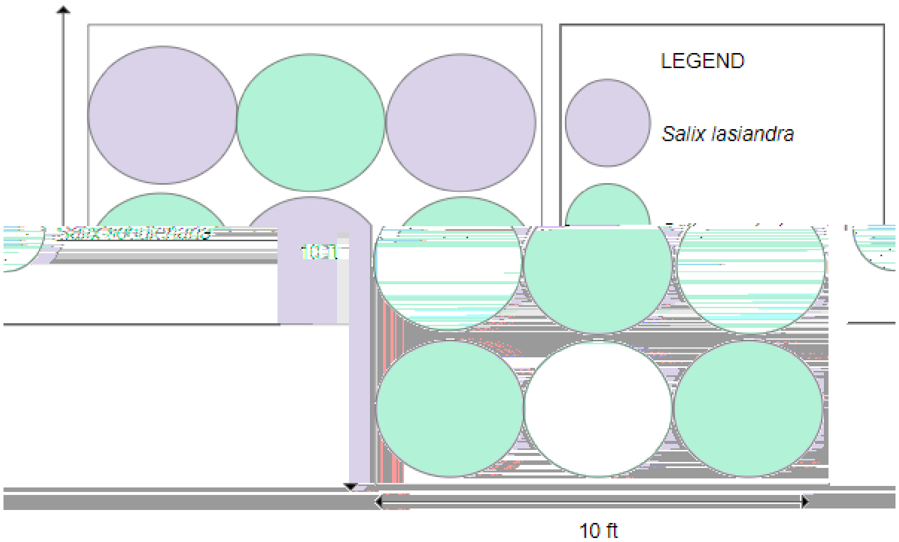

Figure 34: Planting design for areas designated for hyperaccumulator species. Cuttings will be planted on roughly three foot centers. Species will alternate between Pacific willow (*Salix lasiandra*) and Scouler's willow (*Salix scouleriana*). This pattern will be repeated to fill in the entire area designated for hyperaccumulator species.

Groundwater Migration Tree Stand Planting Plan

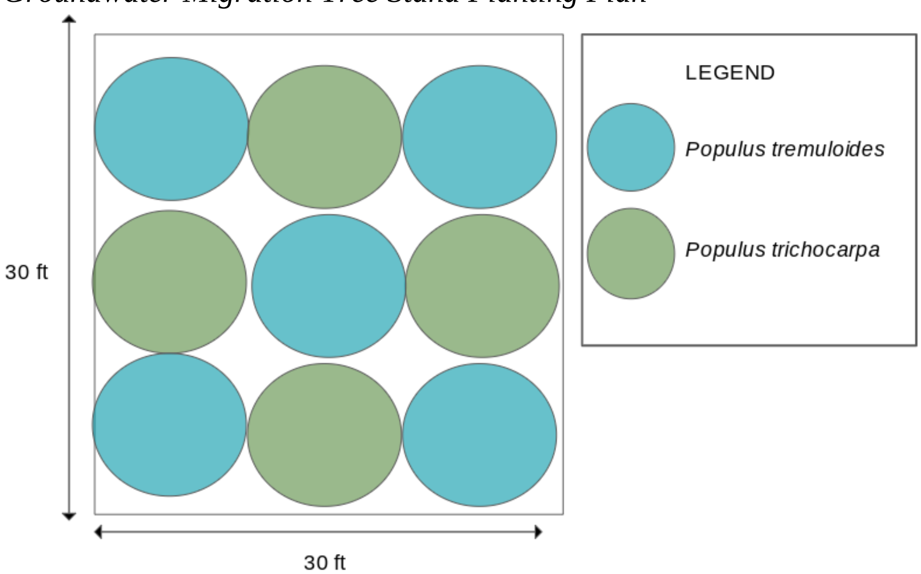

Figure 35: Planting design for the groundwater migration tree stand. Cuttings and bare root transplants will be planted on roughly ten foot centers given the size of these trees upon maturity. Species will alternate between black cottonwood (*Populus trichocarpa*) and quaking aspen (*Populus tremuloides*). This pattern will be repeated to fill in the entire area of the groundwater migration tree stand.

Project Map

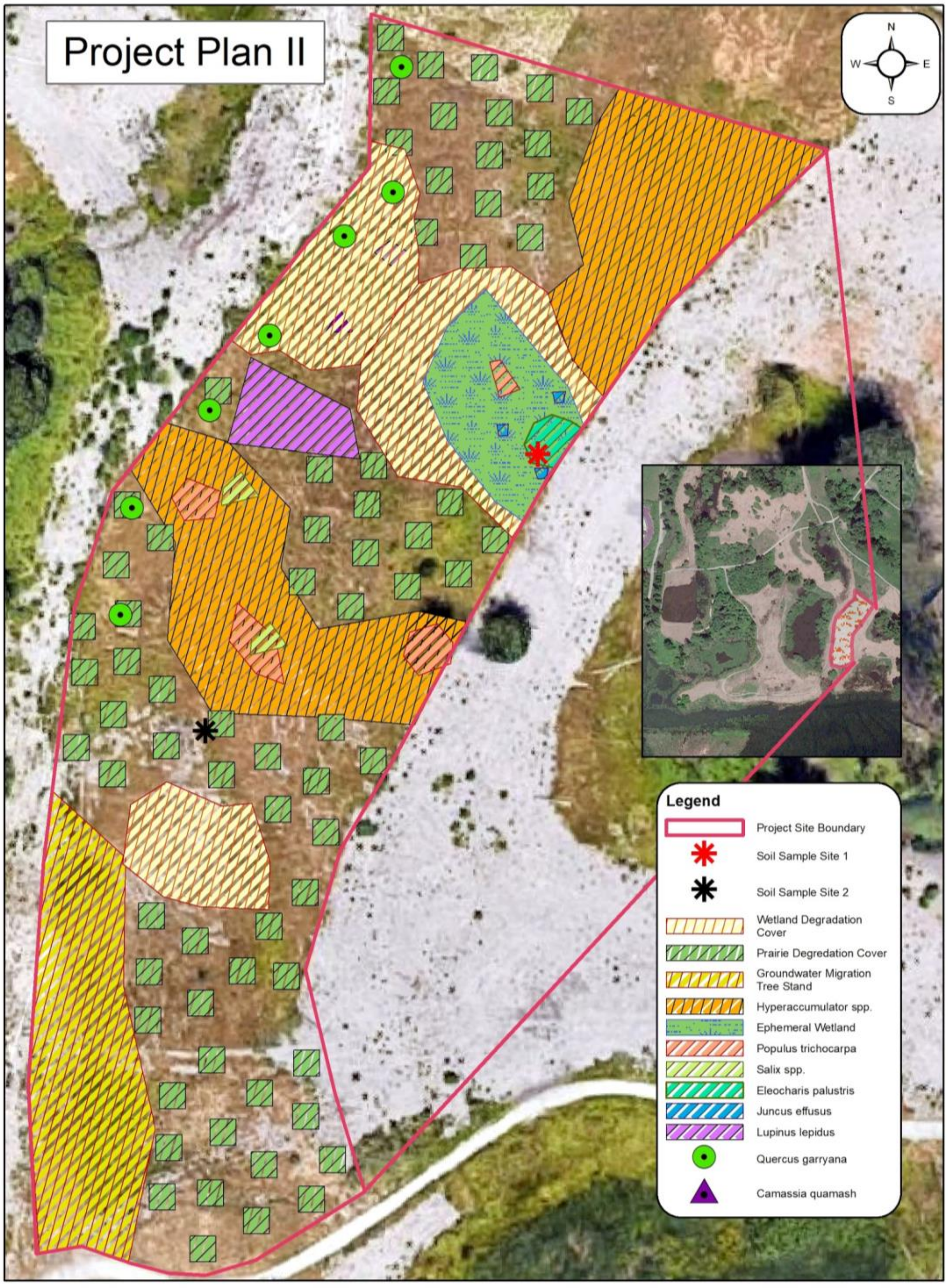

Figure 36: Map of Project Plan II including planting areas, and native vegetation. Wetland degradation mats will be planted in two depressions. Hyperaccumulator species will be planted in two sections with natural recruitment of willow species already occurring. The migration tree stand will be planted in the lower southwest portion of the site, adjacent to Central Pond. Prairie degradation mat plots measuring 10’x10’ will be installed scattered across areas with higher elevation and better drainage.

Restoration Project Design III: *Creation of year-round pollinator habitat*

Figure 37: A restoration project by Earthcorps on the Burke Gilman trail in Seattle, WA. The primary goal of this restoration project was to focus on creating year-round pollinator habitat. Source: https://www.earthcorps.org/our-story/key-initiatives/pollinator-corridors/

Background

Declining populations of pollinators, especially native bee species, is in part due to vast habitat loss coupled with managed landscapes that are inhospitable to pollinators (Cane & Tepedino, 2001). Urban and agricultural landscapes are often sprayed with pesticides that poison pollinators meant to control plant pests, weeds and fungi (Cane & Tepedino, 2001). Pesticides are suspected to be a leading cause for declines of bee species in particular (Lee-Mäder & Xerces Society, 2011). Managed landscapes also often lack native species that provide food and forage as well as nesting sites. Urban parks and home gardens tend to be dominated by easy-to-maintain lawns and ornamental plants chosen for aesthetics rather than their flower resources and habitat (Lee-Mäder & Xerces Society, 2011).

To adequately restore or create pollinator habitat, it is vital to know the lifespan and habitat needs of each life stage of pollinator species. To provide habitat for a variety of species, there must be a diversity of flowering native plants available throughout the active months from spring through fall, as well as nesting and egg laying sites, sheltered/undisturbed places, and a landscape free of pesticides (Lee-Mäder & Xerces Society, 2011). 70% of all bee species in the United States are solitary ground nesters (Lee-Mäder & Xerces Society, 2011), and research by Gathmann & Tscharntke (2002) demonstrated solitary bees having a small foraging range, suggesting local habitat structure is more important than large-scale landscape structure. Native bee species of the Pacific Northwest include bumble bees (*Bombus* spp.), mason bees (*Osmia* spp.), sweat bees (*Lasioglossum* and *Halictus* spp.), mining bees (*Andrena* spp.), leafcutter bees (*Megachile* spp.), and cuckoo bees (*Sphecodes, Nomada*, *Triepeolus and Coelioxys* spp.) (Sardiñas, 2016).

When foraging, most bee species search for both nectars for energy and pollen to feed their brood. Some species also collect specific flower oils as a food source for both adults and larvae. It is important to provide flowering species that bloom in various stages to provide food resources throughout the months pollinators are active, from early spring until fall. During the winter time, the males and worker bees of naive species die while larvae hibernate until spring (Lee-Mäder & Xerces Society, 2011). The queen bees of *Bombus* species will also hibernate underground over winter (Lee-Mäder & Xerces Society, 2011). It is especially important to plant species that bloom in early spring to provide food resources for early emerging species, such as mining bees (*Andrena* spp.) mason bees (*Osmia* spp.), and bumblebee queens (*Bombus* spp.) (Lee-Mäder & Xerces Society, 2011). Early forage may also encourage bumble bee queens that are emerging from hibernation to start their nests nearby or increase the success rate of nearby nests. Species that bloom mid-season provide the bulk of food resources during the most active months, and late flowering species ensure queen bumble bees are strong and numerous going into winter hibernation (Lee-Mäder & Xerces Society, 2011).

In addition to floral resources for food, certain substrates and vegetation are needed for nesting. Tunnel nesting bees including native *Osmia* spp. require substrates to carve their tunnels within such as snags or pithy stems of woody shrubs and trees (Lee-Mäder & Xerces Society, 2011). Varying bee species also forage for nest building materials such as mason bees (*Osmia* spp.) which search for damp clay for their tunnel nests, and leafcutter bees (*Megachile* spp.) which search for leaves and occasionally flower petals to line their brooding cells (Sardiñas 2016). Ground nesting bees, including native mining bees (*Andrena* spp.), require barren or sparsely vegetated patches of soil in well-drained areas, which are often on slopes (Lee-Mäder & Xerces Society, 2011). Bumble bees nest in old rodent burrows or under tussocks of grass. Other pollinators, including some native fly and beetle species, require decaying wood for egg laying and the nutritional needs of their larvae. Butterflies lay their eggs directly on or near the caterpillar's food source, which is often a particular host plant. Eggs are laid on or near the host plant to ensure caterpillars don't have to crawl far for nourishment. Considering each of the requirements for all life stages is vital for restoring habitat for native pollinators.

Restoration Goals, Objectives and Actions

Restoration Goal: Creation of year-round pollinator habitat

Objective 1: Decrease cover of dominant invasive species: *Rubus armeniacus, Cytisus scoparius, Iris pseudacorus* and *Cirsium* spp. to below 10% cover of site by year one.

- ➢ **Action:** Manually remove all *Rubus armeniacus, Cytisus scoparius,* and *Cirsium* spp. on site by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** UWBG personnel treat *Iris pseudacorus* with Glyphosate (Aquamaster®)

Objective 2: Establish a diversity of native species for each flowering window: early, mid, and late, to provide food and habitat for pollinators in active months by year two.

- **Action:** Mow the site in both the early and late summer, optimally over multiple growing seasons prior to restoration work.
- **Action:** Identify and mark the perimeter of prairie plots according to project design. Colored pin flags should be used to designate each planting design. Design 1: red, Design 2: Green, Design 3: Yellow.
- **Action:** Use flagging tape, pin flags, or other marker to identify native species in each plot.
- **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.
- **Action:** Manually clear dense patches of non-native grasses and forbs within the depressions and transition zone by scraping the soil surface with Mcleods and removing non-native vegetation.
- **Action:** Install a diversity of plant species for each flowering window- early, mid, and late according to the planting plan and specific plot design.
- **Action:** Monitor for plant survivorship and pollinator visitation
- **Action:** Amend species composition as needed and replant for mortality to ensure diversity in each flowering phase is provided

Objective 3: Manage native woody species to prevent site from becoming scrub-shrub or forested wetland habitat.

- **Action:** Remove *Salix* spp. and *Populus trichocarpa* manually, or cut back and apply Glyphosate herbicide on stems during the growing season.

Objective 4: Create potential habitat for tunnel nesting mason bees (*Osmia* spp.)

- ➢ **Action:** Construct and install three nesting blocks placed according to project design.

Objective 5: Create potential habitat for ground nesting mining bees (*Andrena* spp.)

- ➢ **Action:** Locate and mark the area designated for bare ground according to the project plan.
- ➢ **Action:** Manually remove larger invasive herbaceous and woody species by digging, uprooting, and disposing of individual plants.
- ➢ **Action:** Expose bare soil by removing all grass and herbaceous species using a McLeod.
- ➢ **Action:** Maintain bare ground in these areas through routine maintenance.

Objective 6: Create potential habitat for native bumble bees (*Bombus* spp.) and native fly and beetle species.

- ➢ *Actions for this objective accomplished through plot design 3 which includes native grass species and woody debris to provide habitat.*

Objective 7: Create overwintering sites for butterfly species

- ➢ **Action:** Source and assemble a log pile by crisscrossing logs with gaps of 3-4 inches and plant Orange Trumpet Honeysuckle (*Lonicera ciliosa*) for cover.

Project Site Design

Typically, optimal habitat for pollinator species is in open areas including meadows, prairies, scrubland, or the shrubby edges between grasslands and forests. The restoration design for this project will seek to emulate the vegetation structure and function of a Puget lowland prairie ecosystem, with certain habitat features aimed to target native pollinator species. This restoration project will extend restoration efforts adjacent to the project site, expanding prairie habitat restored north of the site, as well as create a matrix of habitat in between the scrub-shrub wetland buffers installed by WSDOT.

To provide continuous food supplies, a high diversity of flowering plants will be planted on site (Table 16). Research suggests that pollinators are more attracted to groups of plants (clumps at least 3 feet in diameter) than to widely and randomly dispersed plants (Lee-Mäder & Xerces Society, 2011). Large patches are also easier for pollinators to find within the landscape, especially small habitats within urban setting (Lee-Mäder & Xerces Society, 2011). The restoration design will include a dense network of 10’x10’ plots consisting of three designs with varying flowering species to support wild bee diversity and their ecological function as pollinators (Figure 42). The entire site will not be vegetated as planting herbaceous and grass species on dense one-foot spacing would require over 130,000 plants which is infeasible for the budgets and labor required for the project to be implemented. Alternatively, these densely planted plots will provide vegetative propagules and a seed source capable of spreading between the plots to hopefully provide a continuous cover over time.

Without snags available on site, tunnel nesting bees including (*Osmia* spp.) will be provided with three nesting blocks (see *Tunnel nesting bee block* section for construction) installed on site in various locations (Figure 42). For bumble bee habitat, native grass species including Roemer's Fescue, and tufted hairgrass will be installed in patches amongst the herbaceous species. Roemer’s fescue will comprise a majority of the cover of grass species as this species comprises 30-70% of overall cover in remaining Puget Sound lowland prairies (Chappell & Crawford, 1997). The Garry oaks already planted within the site also contribute to the lowland Puget Sound prairie habitat, as it is a typical tree species found in this habitat type. While around three quarters of the restoration site will be vegetated with prairie species, the ephemeral wetland area will be planted with native emergents including small-fruited bulrush (*Scirpus microcarpus*) and sawbeak sedge (*Carex stipata*), as well as the native perennial wetland herb water parsley (*Oenanthe sarmentosa*) (Figure 42). The project needs to work with the conditions of this portion of the site, which is not conducive to prairie plants, as surface water extends into the growing season, favoring plants adapted to hydric soils.

For ground nesting bees (*Andrena* spp.), an area of the southwestern portion of the site with dry gravelly soil will be maintained for bare ground by removing any growing vegetation. This area already has a low cover of vegetation as well as a course soil texture. The goal of this area is to be free of vegetation so *Andrena* spp. will have easy access to barren soil to nest. Maintenance of this area is critical to maintain it as barren ground. For butterfly overwintering habitat, a log pile will be constructed on site by layering woody debris including sticks and logs, leaving gaps of at least 3-4 inches. To provide cover, a native vine, Orange Trumpet Honeysuckle (*Lonicera ciliosa*) will be planted around the pile base. Additional woody debris will also be placed on site as habitat for fly, beetle, butterfly and bee species as well as other wildlife within the Prairie Plot Design #3 (Figure#).

In addition to the restoration project site, the wetland buffer installed for the WSDOT mitigation project also host beneficial pollinator plants including tall Oregon grape, Nootka rose, spreading gooseberry, black gooseberry, red osier dogwood, and common snowberry. This provides a greater diversity of plants within a few hundred feet away from potential nesting sites, which is crucial for smaller species that may only fly up to 500 feet away from their nests (Lee-Mäder & Xerces Society, 2011).

Project implementation will be divided into multiple phases. Phase 1 (Year 1) will focus on two periods of invasive control. Larger invasive herbaceous and woody species will be removed by digging, uprooting, and disposing of individual plants. Dense patches of non-native grasses and forbs will be removed through with Mcleods to remove vegetation and as much of their root systems as possible. The site will be treated once in the early spring (March-April) when the ground is soft and plants are just beginning to emerge, and once again in mid-summer (July-August) before non-native and invasive species have set seed. UWBG personnel will treat *Iris pseudacorus* with Glyphosate (Aquamaster®) in the initial invasive control efforts and should apply a secondary treatment if needed. Site preparation is crucial for survivorship of plants installed. Phase 1 will also create and maintain areas of bare ground for ground nesting species (*Andrena* spp.). Phase 2 (Year 2) will continue invasive species removal, install woody debris, including the log pile, and plant bare root plants in late fall (October-November). Phase 3 (Year 3) will be continued maintenance to control invasive species, installation of tunnel nesting bee boxes, and supplemental planting as needed. Phase 4 (Year 4-10) will be vegetation monitoring of the site in late summer (August-September) and any maintenance determined needed from monitoring results.

Project Timeline

Table 15: The project will be divided into multiple phases. Phase one will focus on two periods of invasive control in the spring and summer in addition to clearing and maintaining the bare ground area for ground nesting bees. Phase 2 will continue invasive removal and maintenance of bare ground as well as add woody debris and plant installation in the late fall. Phase 3 will be continued maintenance as well as installation of the tunnel nest bee blocks. In the fall, any supplemental planting will be installed as needed. Phase 4 focuses on annual monitoring until Year 10 of the project.

Phase 1- Year 1											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Phase 1 Invasive species control Clear area for ground nesting bees				Phase 1 Invasive species control Maintenance of bare ground area					
Phase 2-Year 2											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Phase 2 Invasive species control Maintenance of bare ground area				Phase 2 Invasive species control Woody debris installation			Native Species Installation		
Phase 3-Year 3											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		Site maintenance Install tunnel nest bee boxes				Site maintenance			Supplemental planting		
Phase 4-Year 4-10											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
							Vegetation/ Pollinator Monitoring				

Plant Palette

Table 16: Herbaceous species plant palette and procurement plan for prairie plots.

Herbaceous Prairie Species						
Species	**Common Name**	**Blooming Months**	**Quantity 1' spacing**	**Stock Type**	**Unit Price**	**Source**
Dodecatheon hendersonii	Broad-leaved Shooting Star	February - May	470	Bare root	$0.50	Fourth Corner
Lomatium utriculatum	Pomocelery lomatium	February - June	235	Bare root	$0.45	Fourth Corner
Ranunculus occidentalis var. occidentalis	Western Buttercup	March - June	564	Bare root	$0.45	Fourth Corner
Balsamorhiza deltoidea	Deltoid Balsamroot	March - July	141	Bare root	$0.60	Fourth Corner
Camassia quamash	Common Camas	April - June	1,175	Bulbs	$0.40	Fourth Corner
Fragaria virginiana	Wild Strawberry	April- June	282	Bare root	$0.40	Fourth Corner
Fritillaria affinis var. *affinis*	Chocolate Lily	April - July	282	Bulbs	$1.50	Fourth Corner
Viola adunca	Western Blue Violet	April - August	235	Bare root	$0.40	Fourth Corner
Microseris laciniata	Cut-leaf Microseris	April - August	188	Plug	$1.50	UW SER
Eriophyllum lanatum var. leucophyllum	Common Woolly Sunflower	May- August	235	Bare root	$0.40	Fourth Corner
Achillea millefolium	Common Yarrow	May - July	423	Bare root	$0.35	Fourth Corner
Lupinus lepidus	Prairie Lupine	June - August	94	Bare root	$0.40	Fourth Corner
Hieracium cynoglossoides	Houndstongue hawkweed	June - August	141	Plug	$1.50	UW SER
Potentilla gracilis	Slender cinquefoil	July - August	235	Bare root	$0.35	Fourth Corner
Solidago canadensis	Canada Goldenrod	September - November	611	Bare root	$0.40	Fourth Corner
Erigeron	Showy Fleabane	June -	235	Bare root	$0.35	Fourth

speciosus		October				Corner

Table 17: Graminoid species plant palette and procurement plan for prairie plots.

Graminoid Prairie Species					
Species	**Common Name**	**Quantity 1' spacing**	**Stock Type**	**Unit Price**	**Source**
Festuca idahoensis var. *roemeri*	Roemer's Fescue	7,849	Bare root	$0.33	Fourth Corner
Deschampsia cespitosa	Tufted hairgrass	1,269	Bare root	$0.33	Fourth Corner

Table 18: Species plant palette and procurement plan for ephemeral wetland.

Ephemeral Wetland Species						
Species	**Common Name**	**Blooming Months**	**Quantity 1' spacing**	**Stock Type**	**Unit Price**	**Source**
Scirpus microcarpus	Small-fruited bulrush	NA	1,869	Bare root	$0.33	Fourth Corner
Carex stipata	Sawbeak sedge	NA	670	Bare root	$0.33	Fourth Corner
Oenanthe sarmentosa	Water parsley	June- October	251	Bare root	$0.40	Fourth Corner

Table 19: Species installed for cover of overwintering log habitat.

Vine Species						
Species	**Common Name**	**Blooming Months**	**Quantity**	**Stock Type**	**Unit Price**	**Source**
Lonicera ciliosa	Orange Trumpet Honeysuckle	May-July	16	Plug		UW SER

Budget

Table 20: The plant budget lists quantities of each species on a dense one-foot spacing as the plan is designed, and an alternative spacing of two feet. Prices were sourced from Fourth Corner Nursery catalogue.

Plants	**Quantity**	**Unit Price**	**Cost**	**Quantity 2' Spacing**	**Unit Price**	**Cost**
Dodecatheon hendersonii	470	$0.50	$235.00	136	$0.50	$68.15
Lomatium utriculatum	235	$0.45	$105.75	68	$0.45	$30.67
Ranunculus occidentalis var. occidentalis	564	$0.45	$253.80	164	$0.45	$73.60
Balsamorhiza deltoidea	141	$0.60	$84.60	41	$0.60	$24.53
Camassia quamash	1,175	$0.40	$470.00	341	$0.40	$136.30
Fragaria virginiana	282	$0.40	$112.80	82	$0.40	$32.71
Fritillaria affinis var. affinis	282	$1.50	$423.00	82	$1.50	$122.67
Viola adunca	235	$0.40	$94.00	68	$0.40	$27.26
Microseris laciniata	188	$1.50	$282.00	55	$1.50	$81.78
Eriophyllum lanatum var. leucophyllum	235	$0.40	$94.00	68	$0.40	$27.26
Achillea millefolium	423	$0.35	$148.05	123	$0.35	$42.93
Lupinus lepidus	94	$0.40	$37.60	27	$0.40	$10.90
Hieracium cynoglossoides	141	$1.50	$211.50	41	$1.50	$61.34
Potentilla gracilis	235	$0.35	$82.25	68	$0.35	$23.85
Solidago canadensis	611	$0.40	$244.40	177	$0.40	$70.88
Erigeron speciosus	235	$0.35	$82.25	68	$0.35	$23.85
Festuca idahoensis var. roemeri	7,849	$0.33	$2,590.17	2276	$0.33	$751.15
Deschampsia cespitosa	1,269	$0.33	$418.77	368	$0.33	$121.44
Scirpus microcarpus	1,869	$0.33	$616.77	542	$0.33	$178.86
Carex stipata	670	$0.33	$221.10	194	$0.33	$64.12
Oenanthe sarmentosa	251	$0.40	$100.40	73	$0.40	$29.12
Lonicera ciliosa	16	$1.50		5	$1.50	$6.96
TOTAL	17,470		$6,908.21	7,993		$1,385.41

Planting plans

Prairie Plot Design #1

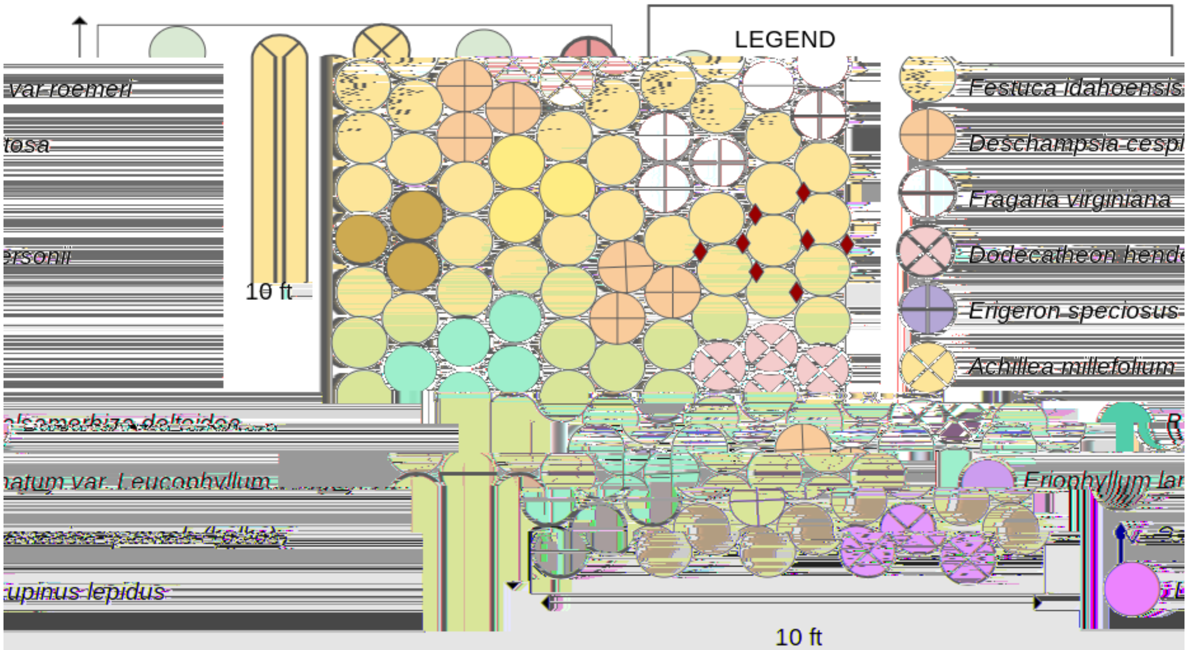

Figure 38: Planting design #1 for prairie plots measuring 10'x10'. Clusters of flowering species will be grouped by three to five individuals on dense one-foot spacing in between Roemer's fescue (*Festuca idahoensis var. roemeri*) and tufted hairgrass (*Deschampsia cespitosa*). Early flowering species include broad-leaved shooting star (*Dodecatheon hendersonii*) and deltoid balsamroot (*Balsamorhiza deltoidea*), mid-flowering species include: wild strawberry (*Fragaria virginiana*), common yarrow (*Achillea millefolium*), common woolly sunflower (*Eriophyllum lanatum* var. *leucophyllum*), and field lupine (*Lupinus lepidus*), and late flowering species include showy fleabane (*Erigeron speciosus*). Bulbs of common camas (*Camassia quamash*) will be planted in spaces between graminoid species. Common yarrow will be purposely planted on the edge of plots as it can be an aggressive rhizomatous species which can compete with non-native species between plots.

Prairie Plot Design #2

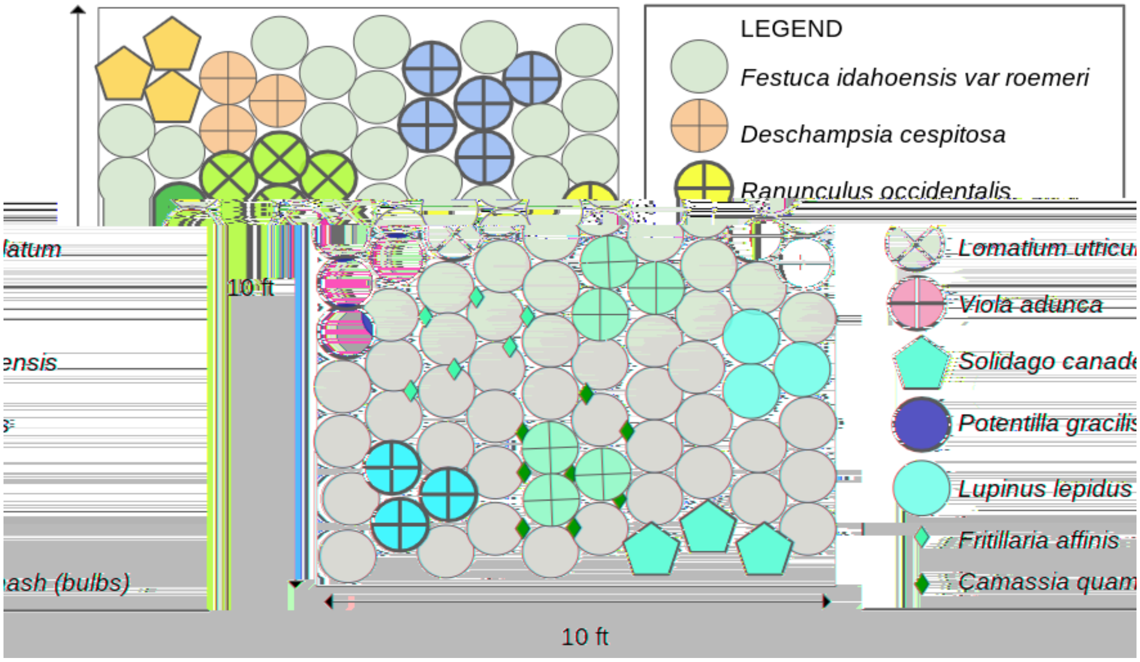

Figure 39: Planting design #2 for prairie plots measuring 10’x10’. Clusters of flowering species will be grouped by three to five individuals on dense one-foot spacing in between Roemer's fescue (*Festuca idahoensis var. roemeri*) and tufted hairgrass (*Deschampsia cespitosa*). Early flowering species include western buttercup (*Ranunculus occidentalis var. occidentalis*) and pomocelery lomatium (*Lomatium utriculatum*), mid-flowering species include Western blue violet (*Viola adunca*) and field lupine (*Lupinus lepidus*), and late flowering species include Canada goldenrod *(Solidago canadensis)* and slender cinquefoil (*Potentilla gracilis*). Bulbs of common camas (*Camassia quamash*) and chocolate lily (*Fritillaria affinis var. affinis*) will be planted in spaces between graminoid species. Canada goldenrod will be purposely planted on the edge of plots as it can be an aggressive rhizomatous species which can compete with non-native species between plots.

Prairie Plot Design #3

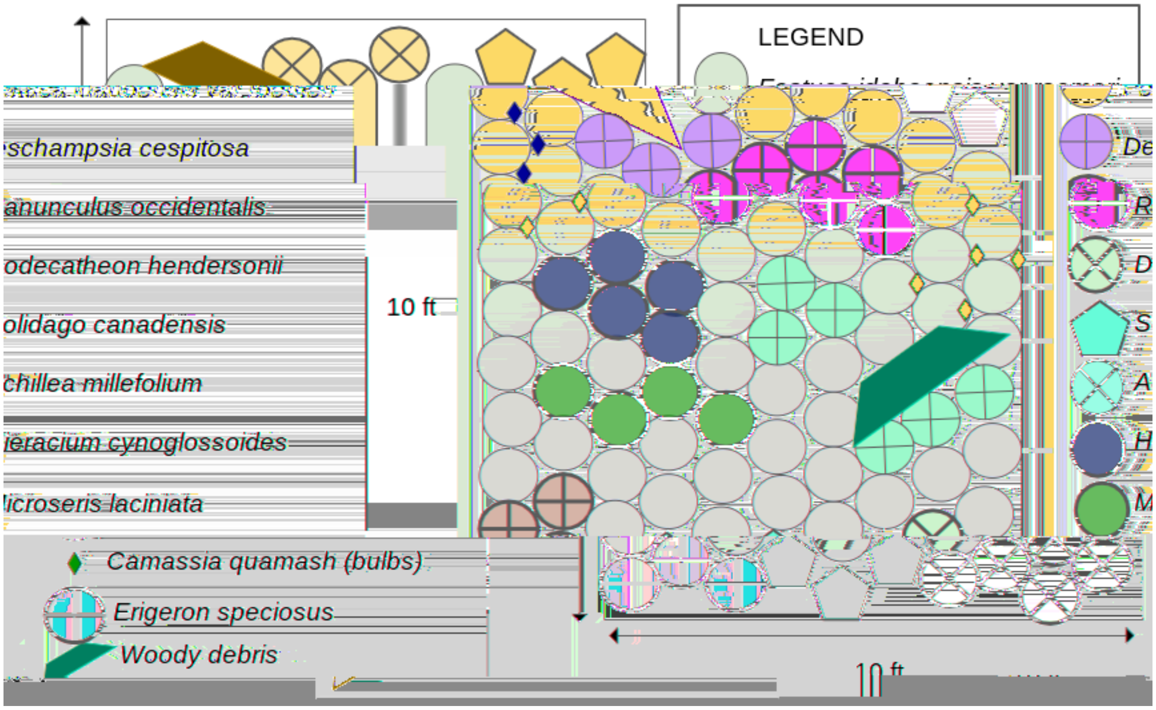

Figure 40: Planting design #3 for prairie plots measuring 10’x10’. Clusters of flowering species will be grouped by three to five individuals on dense one-foot spacing in between Roemer's fescue (*Festuca idahoensis var. roemeri*) and tufted hairgrass (*Deschampsia cespitosa*). Early flowering species include broad-leaved shooting star (*Dodecatheon hendersonii*) and western buttercup (*Ranunculus occidentalis var. occidentalis*), mid-flowering species include: cut-leaf microseris (*Microseris laciniata*), houndstongue hawkweed (*Hieracium cynoglossoides*), and common yarrow (*Achillea millefolium*), and late flowering species include showy fleabane (*Erigeron speciosus*) and Canada goldenrod *(Solidago canadensis).* Bulbs of common camas (*Camassia quamash*) will be planted in spaces between graminoid species. Canada goldenrod will be purposely planted on the edge of plots as it can be an aggressive rhizomatous species which can compete with non-native species between plots.

Ephemeral Wetland Planting Plan

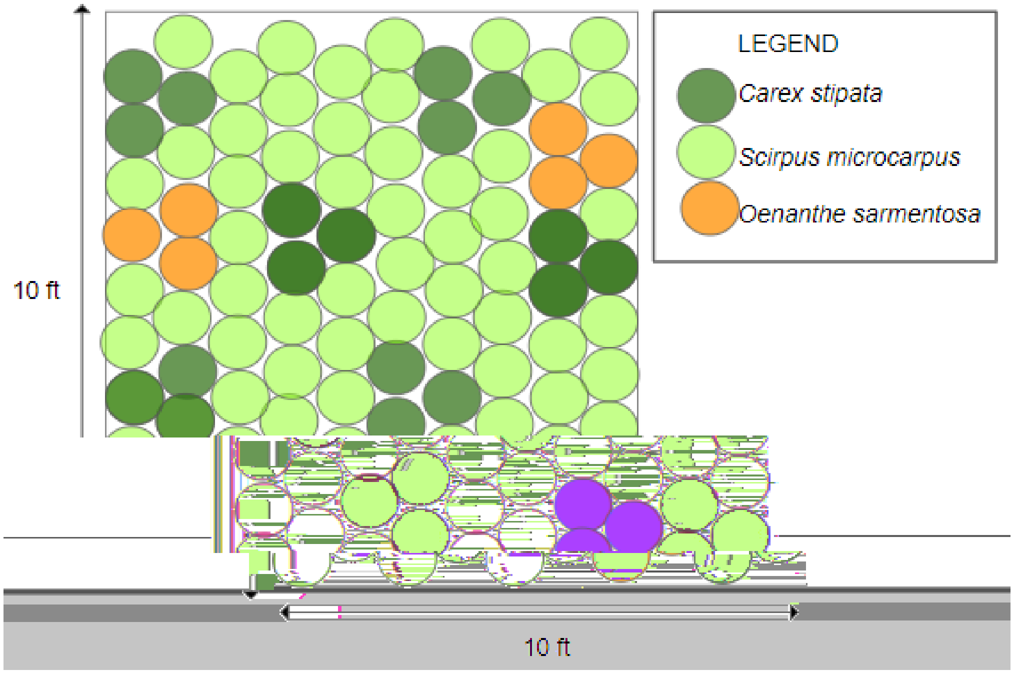

Figure 41: Planting design for a given 100 square feet of the ephemeral wetland. Clusters of three individuals of sawbeak sedge (*Carex stipata*) and water parsley (*Oenanthe sarmentosa*) will be interspersed between small-fruited bulrush (*Scirpus microcarpus*) on a dense one-foot spacing. This pattern will be repeated to fill in the entire area of the ephemeral wetland.

Project Map

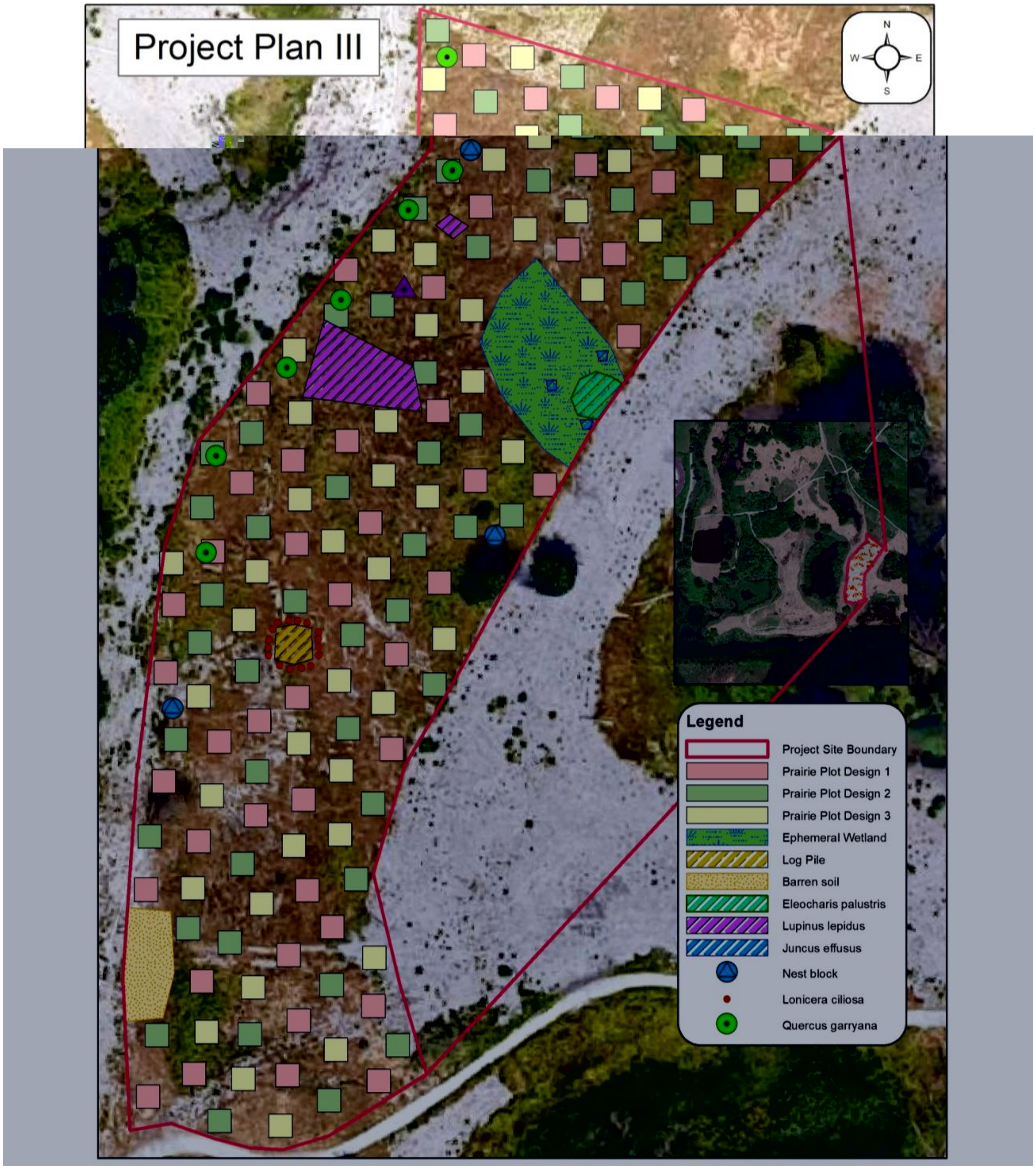

Figure 42: Map of Project Plan III including the layout of three separate prairie plot designs, current native vegetation, and locations of habitat structures to be installed. With proper management of non-native species, the densely planted prairie plots have the potential to spread vegetatively and via seed to occupy space between the plots.

ALTERNATIVES

As mentioned in the project constraints, implementation of a project plan may be limited by funding and available labor. All restoration project plans follow best management practices to ensure the highest possibility of successful implementation. Plant spacing is a critical element that dictates budgets and required labor for planting. Best management practices suggest using a dense plant spacing, especially for emergent, graminoid, and herbaceous species. Dense planting creates higher competition against non-native and invasive species, taking up the physical space as well as available resources. Larger gaps in between plantings allow easier access for non-native and invasive species to establish. However, dense planting plans require a vastly higher amount of plants and therefore money and labor for installation. In the 100 sq. ft. plots designed in the project plans, planting on 1 ft. centers requires a total of 115 plants (Figure 43). On 2 ft. centers the number of plants dramatically decreases to 29 plants total (Figure 43). While planting less densely saves on the cost of plants and labor for planting, there may be a tradeoff of more maintenance needed to control non-native and invasive species, and potentially more plants and labor required for supplemental planting.

Each project plan may consider dividing the project site into separate sections to implement in phases considering labor and time constraints for project implementation. Breaking down the project site into smaller sub-sites makes them more manageable for the level of a student project. Dividing the site in half or in thirds may be a more realistic approach to restoration of this site. An entirely different approach would be to hire a professional crew to restore the site and not rely on volunteer labor. Professional restoration ecologists and technicians will be more efficient in the implementation process, capable of removing a higher amount of non-native species and installing a higher number of plants per hour than an average volunteer. A professional crew would be the optimal method for implementation if funding and resources are available. A combination of work crews and student/volunteer efforts is also a possibility.

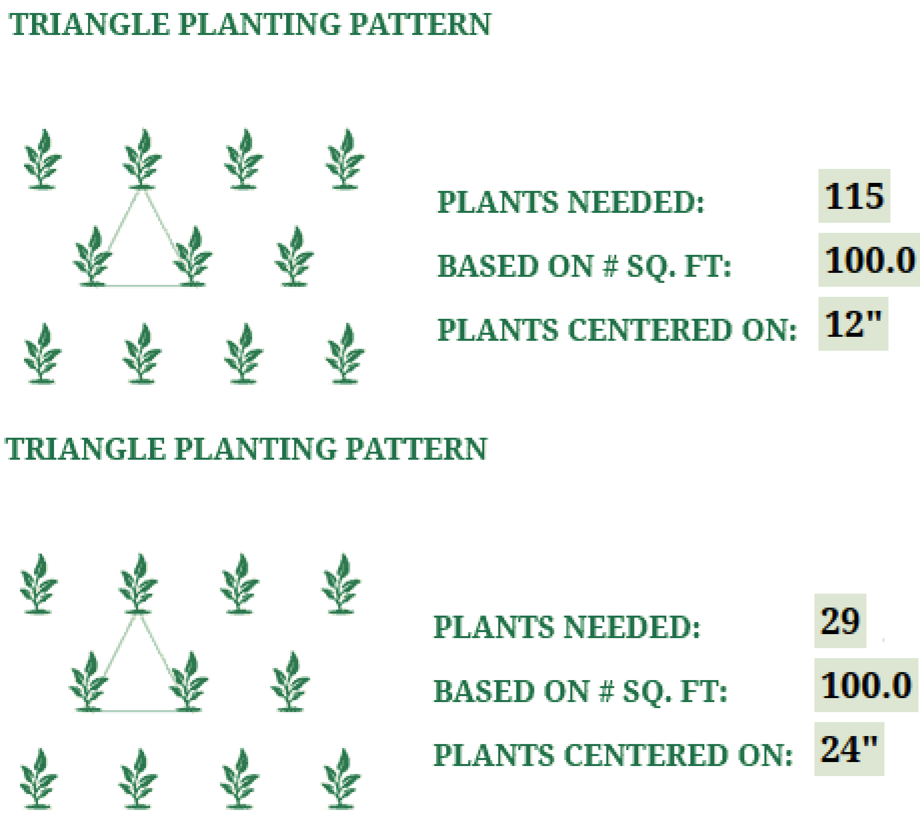

Figure 43: Comparison of planting designs based on one foot centers versus two foot centers. As demonstrated through the figure, dense one-foot spacing requires nearly four times the number of plants required for two-foot spacing. If projects are limited by funding and available labor, alternatives including larger plant spacing may be utilized. Source: https://www.midwestgroundcovers.com/Plant-Calculator

PROJECT COMPARISON

The three restoration project plans display how restoration can take multiple trajectories and result in different functions and benefits depending on the project goal. Table 21 compares the physical, ecological, and economical specifications of each project plan. It is important to note that these metrics are based on the methodologies used in each plan and could be adjusted by using alternative strategies. For instance, the total area planted or the number of plants and corresponding costs could be adjusted based on the density of the plant spacing and whether the areas are fully planted or installed in select plots. Project Plan II: bioremediation of contaminated soil and groundwater, vegetates the most extensive total area encompassing 38,317 sq. ft. (Table

21). Project Plan II vegetates the most extensive area with less plants and a smaller budget than Project Plan I: enhancement of wetland habitat, because of the larger plant spacing of willows, black cottonwoods, and quaking aspen used in the design.

Project Plan I and Project Plan III: Creation of year-round pollinator habitat, installs vegetation of two different habitat types including prairie and wetland, while Project Plan II establishes a total of four habitat types with the addition of scrub-shrub and forested habitats (Table 21). However, these habitats are intentionally avoided in the other two project plans and are therefore not considered beneficial to the other project plans. This demonstrates how the specific project goal influences the functions and benefits both intentionally and unintentionally created. Project Plan I requires the highest number of plants with 27,563 total (Table 21). This is roughly 10,000 more plants than Project Plan III, but results from the planting plan strategy. The number of plants could be decreased for both Project Plan I and II by increasing plant spacing or by planting in select plots. Project Plan III has the highest plant diversity of 22 species, double the number of plant species in Project Plans I and II (Table 21). Project Plan III has a higher species diversity because of the high number of flowering plants required to support native pollinator species throughout their active months. Project Plan I has the highest costs for plants based on the quantity alone at $9,327.68 (Table 21). However, considering additional costs of monitoring, Project Plan II is estimated at a similar overall cost. Project Plan III has the lowest costs because it requires less plants to vegetate select plots, and has limited additional costs aside from materials needed for nesting blocks.

Table 21: Project Figures Comparison. Projects compared by their physical, ecological and economic impacts.

Criteria	**Project Plan I:** Enhance Wetland Habitat	**Plan II:** Bioremediation of Contaminated Soil and Groundwater	**Project Plan III:** Create Year-round Pollinator Habitat
Physical			
Total Area Planted (sq. ft.)	26, 153	38,317	16,889
Total Area Prairie Habitat (sq. ft.)	9,400	7,300	14,100
Total Area Wetland Habitat (sq. ft.)	16, 753	11,703	2,789
Total Area Scrub-shrub Habitat (sq. ft.)	0	13,018	0
Total Area Forest Habitat (sq. ft.)	0	6,296	0
Ecological			
Total Number of Plants	27,563	20,594	17,470
Total Number of Species	12	11	22
Total Number of Beneficial Pollinator Species	4	2	18
Total Number of Bioremediation Species	4	11	4
Economical			
Total Plant Costs	$9,327.68	$8,869.12	$6,908.21
Additional Costs	$0.00	$400-1,000 for soil tests	$50-100 for nest block materials

In deciding the goal of an ecological restoration project, it is important to consider the benefits as well as potential drawbacks of implementing the project plan. While each project focused on their own primary goal, each project plan supports the goals of another to some extent. Table 22 compares each project plan based on a ranking system invented to demonstrate the ability of the project plan to produce specific functions and benefits. Each project plan was given a score of 0, 1, or 3 for each function/benefit, with 0 signifying the project does not provide the function/benefit, 1 signifying the project provides the function/benefit to a minimal extent, and 3 signifying the project plan fully provides the function/benefit.

Table: 22 Comparison of Project Benefits. Table comparing project functions/benefits based on a scoring system. Scoring is based on a range of 0,1,3, with 0 meaning the project does not provide the function/benefit, 1 meaning the project provides a portion of the function/benefit, and 3 fully provides function/benefit

Function/Benefit Provided	Project Plan I: Enhance Wetland Habitat	Project Plan II: Bioremediation of Contaminated Soil and Groundwater	Project Plan III: Create Year-round Pollinator Habitat
Project returns site to a historical reference point	1	0	0
Provides a diversity of habitat types	1	3	1
Project provides open habitat for shorebirds	3	0	1
Project provides forested habitat with perches for raptors	0	3	0
Project provides scrub shrub habitat for wildlife	0	3	0
Project provides a limited habitat type in UBNA	3	0	3
Project increases species diversity in UBNA	1	1	3
Project reduces or stabilizes contaminants	1	3	1
Project supports natural vegetation succession occurring on site	0	3	0
Project is prepared for changes in topography and hydrology as landfill materials settle	3	1	1
Project provides species diversity that support year-round pollinator habitat	0	0	3
Project supports Audubon stakeholders	3	0	1
Project supports UW Farm stakeholders	0	0	3
TOTAL SCORE	16	17	17

Overall, each project provides the intended project goal as well as other functions and benefits. Through this ranking system, it appears that each project offers a similar amount of functions and benefits, with each project having roughly the same total score (Table 22). Again, it is important to note that each project plan could be altered in strategies employed to change the functions and benefits provided. For example, prairie plots in Project Plan I could be vegetated with a higher species diversity that could potentially benefit pollinators. However, with the focus being on enhancing wetland habitat, the prairie plots were kept to a simple design to reduce the labor of implementing more complicated designs like in Project Plan III.

The main functions/benefits Project Plan I fully provide include: enhancing limited wetland habitat within UBNA, providing open habitat for shorebirds, preparing for potential future site conditions and supporting Audubon stakeholders (Table 22). Project Plan III has some overlap with Project Plan I by providing another type of limited habitat, open prairie, within UBNA. Project Plan III also partially provides the function of creating suitable habitat for shorebirds through the restoration of the ephemeral wetland and the clear line of sight maintained with prairie vegetation. Restoration of open habitats also support the values of Audubon stakeholders by excluding the installation of woody species. Project Plan III also partially prepares for future conditions of the site, again through the restoration of the ephemeral wetland, and with some prairie species adapted to wetter conditions such as the western blue violet. Project Plan II has less overlap with Project Plan I mainly due to the installation of woody species for bioremediation purposes (Table 22). Project Plan I only has three species that overlap with species utilized in Project Plan II, including Roemer's fescue, common rush, and small-fruited bulrush, though in fewer quantities. Project Plan III has a higher number of species in common with Project Plan I (seven total) including common yarrow, camas, sawbeak sedge, tufted hairgrass, water parsley, woolly sunflower, and small-fruited bulrush (Table 23). Drawbacks of Project Plan I include a lack of structural diversity and the maintenance required to prevent the natural recruitment of woody species to maintain an open habitat.

The main functions/benefits Project Plan II fully provide include: addressing concerns of contamination of soil and groundwater from the former landfill, offering a diversity of habitat types including scrub-shrub and forested habitats, and supporting natural vegetation succession occurring on site as black cottonwoods and willows are key species used in bioremediation (Table 22). Project Plan II is the only plan that incorporates woody species into the design which provide the function of perches for raptors, but directly conflicts with creating shorebird habitat. Project Plan II does not overlap with either plan in any functions/benefits the project fully provides. Project Plans I and II do not provide the same diversity of habitats, though all project plans include at least two habitat types including the small ephemeral wetland and prairie habitat. Project Plans I and III provide four species utilized in bioremediation (Table 22), but are not likely to remediate contaminants to the same extent as Project Plan II. A drawback of Project Plan II is that it doesn't focus on providing a specific type of limited habitat. The plan also decreases the amount of open habitat for shorebirds and does not support the cultural/social value of Audubon. However, if bioremediation proves successful, it would provide the social benefit of clean water for recreation and healthier soils for vegetation to grow.

The main functions/benefits Project Plan III fully provide include: increasing a limited habitat type in UBNA (prairie habitat), increasing species diversity in UBNA, creation of year-round pollinator habitat, and support of social values of the UW farm (Table 22). Project Plan III is unique from the other project plans in the high diversity of flowering plants installed to support native pollinators. While Project Plan III provides 18 beneficial pollinator plants, Project Plan II only provides two species that would benefit native pollinators, including Canada goldenrod, and field lupine (Table 22 & 23). Project Plan I provides four species beneficial to native pollinators, including those used in Project Plan II, as well as yarrow and camas (Table 22 & 23). Project Plan I and II minimally increase species diversity in UBNA in comparison to Project Plan III.

Project Plan III is the only project plan that provides a diversity of floral resources and habitat to support native pollinators, which also may benefit the UW farm if it attracts and supports native pollinators as intended. Project Plan III may be able to help remediate the soils through the extensive root systems of native grasses installed, but without hyperaccumulator species such as black cottonwoods, quaking aspen, and willows, excess nutrients, as well as PAHs and heavy metals, may continue to persist and spread on site. One drawback of Project Plan III is with the potential of the site to continue to subside and accumulate surface water, creating hydric soils and conditions unfavorable to terrestrial prairie species. The project plan also doesn't provide a diversity of habitats, nor support the natural succession of the site, requiring maintenance of native woody species recruits.

Table 23: Comparison of Number of Plant Species. This table lists the number of each species in each project. Two graminoid species occur in each plan, Roemer's Fescue (*Festuca idahoensis var. roemeri*), and small-fruited bulrush (*Scirpus microcarpus*). Nine species occurred in two project plans, namely prairie species, and 19 in only one project plan that are utilized to provide a specific function according to their project goal.

Species		Project Plan I	Project Plan II	Project Plan III
Achillea millefolium	Common Yarrow	846		423
Balsamorhiza deltoidea	Deltoid Balsamroot			141
Camassia quamash	Common Camas	1,410		1,175
Carex stipata	Sawbeak sedge	670		670
Deschampsia cespitosa	Tufted hairgrass	2,845		1,269
Dodecatheon hendersonii	Broad-leaved Shooting Star			470
Elymus glaucus	Blue wild rye		1,971	
Erigeron speciosus	Showy Fleabane			235
Eriophyllum lanatum var. leucophyllum	Common Woolly Sunflower	1,410		235
Festuca idahoensis var. roemeri	Roemer's Fescue	5,734	4,453	7,849
Fragaria virginiana	Wild Strawberry			282
Fritillaria affinis var. affinis	Chocolate Lily			282
Hieracium cynoglossoides	Houndstongue hawkweed			141
Juncus effusus	Common rush	6,410	7,489	

Juncus ensifolius	Dagger leaf rush	1,722		
Juncus tenuis	Slender rush	4,396		
Lomatium utriculatum	Pomocelery lomatium			235
Lonicera ciliosa	Orange Trumpet Honeysuckle			16
Lupinus lepidus	Prairie Lupine		73	94
Microseris laciniata	Cut-leaf Microseris			188
Oenanthe sarmentosa	Water parsley	251		251
Populus tremuloides	Quaking aspen		252	
Populus trichocarpa	Black cottonwood		315	
Potentilla gracilis	Slender cinquefoil			235
Ranunculus occidentalis var. occidentalis	Western Buttercup			564
Salix lasiandra	Pacific willow		651	
Salix scouleriana	Scouler's willow		521	
Scirpus cyperinus	Wool Grass		2,106	
Scirpus microcarpus	Small-fruited bulrush	1,869	2,106	1,869
Solidago canadensis	Canada Goldenrod		657	611
Viola adunca	Western Blue Violet			235

GUIDELINES FOR PROJECT DEVELOPMENT

The following is a general outline for the process of developing ecological restoration goals. It was developed through the process of creating the three restoration project goals and draws from experience and many sources listed in the references.

1. Define project site location and boundaries
2. Research history of the site and how land use has affected the area
3. Conduct a site assessment including:
    a. Topography
    b. Hydrology/surface water
    c. Soil condition
    d. Existing vegetation
    e. Habitat features
    f. Landscape matrix, connectivity, surface waters, etc.
    g. Wildlife
4. Determine severity of disturbance based on site assessment
5. Identify ongoing disturbances/threats to site
6. Identify current human use/impact
7. Meet and hear from project stakeholders and local community members
8. Identify constraints to the project including budget, site condition, and ongoing threats
9. Brainstorm possible restoration goals
10. Prioritize potential goals, potentially through a ranking system
11. Determine costs of project with the ideal number of plants, materials, and labor. Ensure more time is allocated then what may seem necessary to allocate for unforeseen obstacles.
12. If multiple goals are prioritized, determine if multiple goals can be accomplished at the site
13. If deciding between several options, compare top choices by benefits provided, budget, and labor required, and decide which project will have the maximum benefits for the lowest amount of required resources.
14. Review project constraints, budgets, and any issues from stakeholders in the process of implementing the proposed goal
15. Propose project goal to stakeholders, review feedback and adjust as needed. Issues with any stakeholders should be addressed before project planning proceeds
16. Apply and obtain any permits necessary
17. Revisit site on multiple occasions through the planning process to ensure as project planning occurs, it fits the conditions of the site and to observe how the site may change throughout the year.

PROJECT IMPLEMENTATION

Invasive species removal

Himalayan blackberry (*Rubus armeniacus*)

Figure 43: Himalayan blackberry leaves and fruit. Identifying traits include: arching canes, with large sharp, often red thorns, palmately compound leaves with 3 to 5 (typically 5) leaflets with toothed margins, and flat topped clusters of 5-20 five-petaled flowers. Source: https://www.nwcb.wa.gov/weeds/himalayan-blackberry

The widespread occurrence of Himalayan blackberry qualifies it as a Class C noxious weed that does not require control in King County (King County, 2018). This non-native and highly invasive species is native to Armenia and Northern Iran and readily invades a variety of habitats including riparian areas, forest edges, oak woodlands, meadows, roadsides, and other disturbed open areas (King County, 2018). Himalayan blackberry is rhizomatous and forms large root balls that are most often found within the first 18 inches of the soil surface, though the roots can grow down several feet (Boersma, 2006). The species is agamospermic and can produce seed without pollination (Boersma, 2006). It can also spread vegetatively through layering. The berries of Himalayan blackberry are dispersed by wildlife, especially birds which can spread the seed over long distances. Infestations of Himalayan blackberry alter ecosystems by forming dense thickets that shade out other native species and hinder the reestablishment of the native species on disturbed sites. Dense infestations can also block the passage of mammals. Patches of Himalayan blackberry can spread rapidly, widening by ten feet or more each year depending on conditions, and produce copious amounts of seed with ten square feet (1 sq. m) producing an estimated 10,000 seeds (Boersma, 2006).

Control

Seedlings can be hand pulled, but larger plants must be dug out. A practical method of removal is to first cut back the stems to roughly one to two feet in height to better access the roots. It is essential to remove the root ball, and as much of the roots as possible, as it can easily resprout. Areas with large infestations can be mowed to prevent spread and make removal more manageable, but subsequent pulling and mulching is necessary to eradicate the population. If removal is limited to once a year, the optimal time frame is when the plant begins to flower as food reserves within the roots have been allocated to producing flowers. Another tactic is to mow the plants before the plants fruit and then subsequently pull the cut canes in the late fall or winter when the ground is soft from precipitation. After removal, a thick layer (6-8 inches) of mulch should be applied to suppress the plant from resprouting and potential germination of seeds within the soil.

Required tools for manual removal:

- Pants and long sleeve shirt to protect skin
- Thick leather gloves
- Hand pruners or loppers
- Shovels or spading forks

Scotch broom (*Cytisus scoparius*)

Scotch broom (*Cytisus scoparius*) is classified as a class B noxious weed in Washington, with populations widespread in some areas and limited in distribution in others (King County, 2018). Class B noxious weeds require control in regions where they are not yet widespread, as preventing new infestations is a primary goal (King County, 2018). Scotch broom is also on the Washington state quarantine list, which means it is prohibited to sell or distribute the species within the state (King County, 2018). In areas where populations exist, control is decided at a local level, with containment being the top priority (King County, 2018). Scotch broom is a fast-growing evergreen shrub native to Western Europe and the British Isles (Boersma, 2006). It can grow three feet in height within the first year and live for 15-20 years (Boersma, 2006). It does not tolerate cold temperatures and generally restricted to lower elevations. It commonly establishes on coastlines where there is a more moderate climate (Boersma, 2006).

Scotch broom tends to aggressively spread, forming dense monocultures that outcompete and shade native species. It is especially problematic in grassland and open forest habitats. As a legume, Scotch broom can colonize infertile areas through symbiotic associations with nitrogen-fixing bacteria. Scotch broom is commonly found on roadsides, dunes, grasslands and other disturbed areas (Boersma, 2006). The increase in nitrogen caused by populations of Scotch broom can alter plant communities adapted to low nitrogen soils, and favor other invasive species adapted to more fertile conditions (Boersma, 2006).

stems, three parted lower leaves, and simple upper leaves, and bright yellow, pea-shaped flowers. Source: https://www.kingcounty.gov/services/environment/animals-and-plants/noxious-weeds/weed-identification/scotch-

Control

Similar to Himalayan blackberry, Scotch broom seedlings can be removed by hand, but mature plants require digging or the use of a weed wrench. This is best done in late fall or early spring when the ground is moist. For larger infestations, repeated mowing can be utilized for suppression. However, without proper removal of the roots, cut stems may re-sprout. Therefore, if the control tactic is mowing, it should be done twice a year, once in early summer as the plants begin to flower, and at least once more in late summer, before any flowers that do bloom, set seed. This process most likely needs to be repeated over multiple years to remove established stands. After removal, the area should be applied with a thick layer of mulch or sheet mulched to prevent new seedlings from emerging. With each mature plant capable of producing 10,000 seeds per year, vast amounts of seeds can accumulate in the soil under mother plants and remain viable as a seed bank for 30-70 years (Boersma, 2006). Subsequent planting of fast growing native species will help increase competition and cover, reducing the possibility of future infestations.

Required tools for manual removal:

- Gloves
- Shovels
- Weed wrench for larger plants

Canada Thistle (*Cirsium arvense*) and Bull Thistle (*Cirsium vulgare*)

Figure 45: Canada thistle is identified by: spiny alternating lance shaped leaves and clusters of purple flower heads at the end of branched stems. Canada thistle is rhizomatous and may form dense stands. Source:https://blogs.reading.ac.uk/whiteknightsbiodiversity/2012/08/13/which-vanessa/dscn4281/

Canada thistle and bull thistle are both classified as class C noxious weeds in Washington (King County, 2018). Despite its common name, Canada thistle is native to Europe and northern Asia (Boersma, 2006). Bull thistle is native to Europe, Western Asia, and northwestern Africa (Boersma, 2006). They are both widely distributed in the Pacific Northwest and can form dense patches of several hundred individuals in ten square feet (1 sq. m) (Boersma, 2006). Both species are common in grasslands, riparian, areas and disturbed sites. Canada thistle is also known by the common name creeping thistle because of its ability to spread vegetatively through rhizomes that can grow 15 feet laterally and up to three feet deep each year (Boersma, 2006). Canada thistle is considered one of the world's worst weeds because of its ability to invade all agricultural areas, pasturelands, and any areas with disturbed open soil, and persist through vegetative reproduction (Boersma, 2006). Canada and bull thistle are also problematic because their thistles make them less palatable to wildlife and grazing animals, making them increasingly competitive to native species. Established populations of Canada and bull thistle can produce hundreds of thousands of seeds per year that readily spread via wind and quickly germinate on barren soil (Boersma, 2006).

Control

Mechanical control should focus on preventing either species from setting seed. For small populations, individuals may be cut back before flowering or dug out using a mattock. Larger infestations can be mowed and should be timed according to flowering. If plants are cut or mowed without removal of the roots too early before flowering, plants may resprout and flower again that season, so careful timing is key. Any plants removed with flowers should be disposed of offsite. Cleared areas should be covered in a thick (6-8 inches) of mulch to prevent plants from resprouting or further seed germination.

Required tools for manual removal:

- Thick leather gloves
- Hand pruners
- Mattocks

Yellow flag iris (*Iris pseudacorus*)

Yellow flag iris (*Iris pseudacorus*) is a widespread invasive species, classified as a class C noxious weed in Washington that does not require control in King County (King County, 2018). Yellow flag iris most likely escaped cultivation from garden ponds where it was planted for its bright yellow flowers. Yellow flag iris spreads by both seed and vegetatively through rhizomes. Vegetative reproduction allows yellow flag iris to quickly colonize large areas and form dense monotypic stands that outcompete native species. It is native to Europe, North Africa, Western Asia, and Siberia (Boersma, 2006). Seeds of yellow flag iris can float and have a 48-62% germination rate even after being in salt water for 31 days (Boersma, 2006). Yellow flag iris can tolerate a range of conditions including shade or full sun, high soil acidity, brackish water, and drought, making it a strong competitor against native species (Boersma, 2006). Excavated rhizomes are able to germinate even after several months without any water (Boersma, 2006).

Figure 47: Yellow flag iris can be identified by: growing in shallow water, with broad, flat, lanceolate leaves overlapping at the base, and bright yellow iris flowers with brownish purple mottled markings. Source: https://bcinvasives.ca/invasive-species/identify/invasive-plants/yellow-flag-iris

Control

Yellow flag iris can be extremely hard to remove once an infestation is fully established. Flowers can be cut to limit seed production, but subsequent control with herbicide is recommended (Boersma, 2006). If hand pulling, extra care should be taken as the leaves can be sharp and resins within the leaves can cause skin irritation (Boersma, 2006). Hand pulling is only recommended for smaller populations, as it is nearly impossible to remove all of the rhizomes that readily resprout. In UBNA yellow flag iris may be treated with spot spraying with glyphosate (Aquamaster®) by UWBG maintenance staff as part of their Integrative Pest Management (IPM). **Note chemical control needs to be performed by trained UWBG staff*

Required tools for manual removal:

- Gloves
- Hand pruners
- Mattocks

Non-native grasses and forbs

Prevalent non-native grasses and forbs on the project site include: bentgrass (*Agrostis* spp.), common velvet grass (*Holcus lanatus*), quackgrass (*Elymus repens*), purplestem beggarticks (*Bidens connata*), chicory, Queen Anne's lace (*Daucus carota*), hairy cat's ear (*Hypochaeris radicata*), wild lettuce (*Lactuca* spp.), plantain (*Plantago* spp.), curly dock (*Rumex crispus*), creeping buttercup (*Ranunculus repens*), and perennial sow thistle (*Sonchus arvensis*). All species, except Queen Anne's lace, are not listed as noxious weeds in the state of Washington (King County, 2018). Queen Anne's lace is listed as a class C noxious weed that does not require treatment, but is recognized as a widespread invasive species (King County, 2018). Non-native grasses including bentgrass, common velvet grass, and quackgrass are perennials, with bentgrass and quackgrass also capable of vegetative reproduction through rhizomes, making them strong competitors against native grass species. Perennial herbaceous species include chicory, hairy

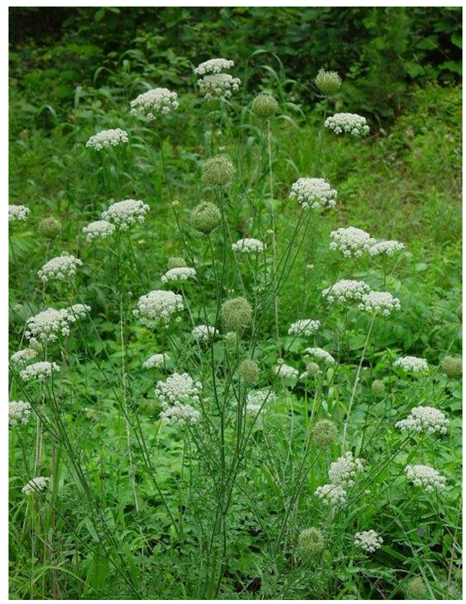

Figure 48: Queen Anne's lace, also known as wild carrot. One of over a dozen non-native herbaceous species growing at the project site. Source: http://www.missouriplants.com/whitealt/Daucus_carota_page.html

cat's ear, curly dock, and perennial sow thistle. Many of these species, both annuals and perennials, can produce copious amounts of seed that readily germinate, and create dense populations that crowd out native species. These non-native species are often the first to colonize disturbed soils, their seeds spreading by wind or animals, and quickly growing to occupy bare ground before the natural succession of native plants can occur.

Control

Control of these various non-native grass and herbaceous species can be managed through mowing to prevent the spread of seed and to exhaust the seed bank of annual species. Mowing twice a year, once in early summer as the plants begin to flower, and at least once more in late summer, before any flowers that do bloom set seed, will prevent new seedlings from establishing and producing more seed. Perennial plants need their roots physically dug out for proper removal. This is especially crucial for rhizomatous grasses and forbs whose growth may be stimulated by cutting. For large areas where hand pulling may be infeasible, mowing with subsequent tilling can help to uproot the invasive species for subsequent hand removal. However, tilling damages soil structure and can encourage new weed seeds to germinate. This process of mowing and tilling may also need to occur for several years to clear large infestations. Creating competition as well as shading out invasive plants with installed native plants is another tactic that can be employed. The use of herbicides such as Glyphosate may be necessary for infestations of some rhizomatous invasive species.

For manual removal, McLeod's are a good tool for clearing patches of these non-native species. By piercing the ground and pulling back on the McLeod, one can pull up the plants and their roots like a mat of sod. Care should be taken to limit removing too much of the topsoil. Proper technique should only be removing the vegetation and roughly one inch of topsoil.

Clearing patches within large areas and planting with native species will help create competition that can aid restoration of native vegetation communities. Cleared areas should be covered with a thick layer of 6-8 inches of mulch to prevent plants from resprouting or germination of seeds within the soil.

Required tools for manual removal:

- Gloves
- Mattocks or shovels

Marking the Site

An initial step in project implementation is marking the site boundaries, planting areas, and monitoring points. Wood or metal stakes or pin flags are often used in the field. Pin flags of varying color can help distinguish certain areas by using a color code. Designating locations for photo monitoring and soil testing will ensure the same locations are used every year. For monitoring points, wood or metal stakes should be used instead of pin flags for the sake of longevity.

Planting

Timing

The optimal planting time in the Pacific Northwest is in the fall when rains have returned or in early spring. During this time, plants are either entering dormancy or currently dormant and less vulnerable to water stress compared to the spring or summer (Whisenant, S. 1999). Planting in the fall allows the plants to receive adequate water while establishing without irrigation needed. Planting can continue through winter for hardy graminoid and herbaceous species, shrubs, and trees. Less hardy species susceptible to frost should be planted in the spring. If planting in the spring without adequate rain in the forecast, it is essential to water all plants after installation. Subsequent watering or irrigation will most likely be needed if planting later in the season.

Technique

Proper planting technique involves planting the plant at the correct depth. For container plants, holes should be dug to a depth equal or slightly shallower than the soil level in their pots (Figure 49). The correct depth can be measured by placing the plant removed from its container into the hole. More importantly, you want the root crown to be slightly higher than the surrounding soil (roughly 0.5 cm) so as the soil and plant settle, it will rest at ground level. Planting at the correct depth ensures roots receive adequate oxygen. It also ensures the stem is not buried which can rot or become infected when buried. The width of the hole should be twice as wide as the container to encourage outward root growth. It is important to avoid digging the hole too deep as loose soil at the bottom of the hole may sink upon settling. Conversely, plants should not be planted in a hole too shallow where roots are exposed to the air.

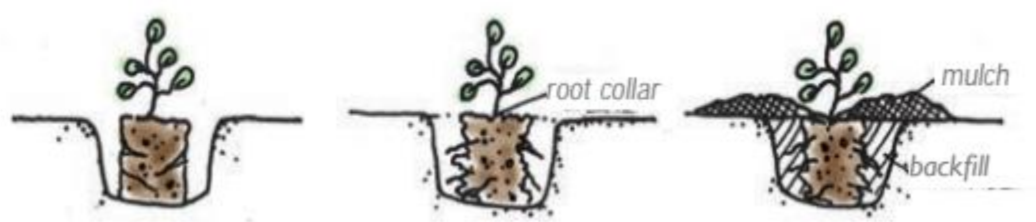

Figure 49: Proper planting technique for container plants ensures the root collar is level with the surrounding soil. Digging a hole slightly shallower than the plant root mass and container soil will help place the root collar even with the soil as the soil settles. A thick layer (roughly 6 inches deep) of mulch should be applied around the base of the plant with adequate space from the stem. Graphic sourced from Green Seattle’s Forest Steward Guide.

Care should be taken when removing the plant from its pot, limiting damage to the plant’s stem and foliage. Applying pressure to the sides of the container will help loosen the soil and roots. A good technique to remove the plant from the pot is to hold the plant on its side, parallel to the ground, and tap the edge of the container with a trowel until the plant and soil start to slip out from the container. Plant roots should be gently loosened by hand to encourage growth out of the potting media and into the native soils. Plants that have become root bound, with spiraling roots at the bottom of the container, should be teased apart or cut to encourage roots to grow outwards instead of continuing to spiral after installation. Once the roots are ready, hold the plant upright with one hand in the middle of the hole while filling soil back in around the plant. Gently apply pressure from the top to fill any air pockets.

Bare root

Bare root plantings are commonly used to establish woody plants. The planting strategy is similar for bare roots, where you want the hole to be just deep enough, so the root crown is slightly above the soil surface when the soil settles. Use the bare root plant to measure the correct depth of the hole, with the lowest roots touching the bottom of the hole and the root crown above the soil surface (Figure 50). One technique is to form a cone at the bottom of the hole to then place the roots over going in separate directions to encourage outward root growth. It is crucial to keep the roots of bare root plants covered and moist until they are planted in the ground by storing them in damp sawdust or soil until planting.

Figure 50: Proper planting technique for bare root plants. Forming a small mound at the bottom of the hole to spread roots helps encourage healthy growth. Graphic sourced from Green Seattle's Forest Steward Guide.

Cuttings

For non-rooted cuttings/live stakes, whips (slender, unbranched shoots) should be collected during late fall to early spring when plants are dormant (Dumroese et al., 2009). Dormant cuttings have the highest potential for new root formation. Whips should be between 0.4 to 0.75 inches (10 to 19 mm) in diameter, as thinner shoots are less likely to form new roots and survive (Dumroese et al., 2009). Whips are cut into individual cuttings between one to two feet in length (Dumroese et al., 2009). The bottom of each cutting should be cut at a 45° angle underneath a node and tops straight across just above a node. Cutting at different angles signifies the top and bottom to ensure proper flow of nutrients and water through the xylem and phloem. The 45° angle also makes it easier to drive the live stakes into the ground. Planting cuttings can either consist of pushing the cutting directly into softer substrates or the use of a planting bar to create a narrow, deep hole. A general rule is to plant cuttings with the majority of nodes below ground to encourage root growth, leaving about three to four nodes above ground. It is crucial to plant the cutting with the proper orientation.

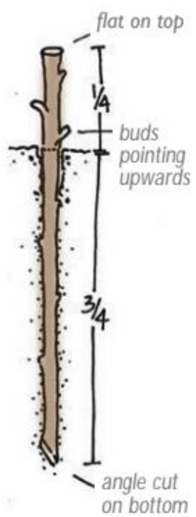

Figure 51: Graphic of a live stake cutting sourced from the Green Seattle Forest Steward Guide

Spacing

Sufficient planting density depends on the planting cost, plant size, growth rate, and management of the site. It can also vary with the species planted, climate and site quality. For this project spacing should be one foot between herbaceous species and grasses, a three-foot radius around shrubs, and ten feet around trees. Correct spacing ensures plants will have adequate access to space and resources. Densely planting with grass and herbaceous species, especially rhizomatous species, will provide competition against the high quantity of non-native and invasive species present on the project site. Plant spacing determines the number of plants required which has a large impact on budgets.

Staking

Avoid staking shrubs and trees as that will prevent them from developing strong roots and stems capable of holding themselves up without assistance. If necessary, loosely attach the plant to the stake at the lowest point possible to provide minimal assistance. Place stakes roughly one foot away from the plant. Remove supports when the plant can stand on its own.

Seeding

Before applying seed, it is crucial to prepare the site. Planting areas should be marked with wooden stakes or pin flags to designate boundaries. Within each planting area, any native species should be identified and also marked with pin flags or flagging tape to prevent removal. McLeod is a useful tool for clearing patches of non-native grasses and herbaceous species without natives present. More attention and care is needed when areas are intermixed with native and non-native species. Hand tools such as a mattock may be more appropriate to limit damage to native species when highly mixed. Multiple clearings, either numerous times in the growing season or optimally over multiple years, will have a higher likelihood or exhausting the non-native seed bank for proper eradication. Cleared areas should be covered with a layer of mulch (optimally 6-8 inches deep) until seeding takes place.

When the area is ready for seeding, the mulch should first be cleared with a hard stem rake or McLeod to expose soil. Mulch may hinder the germination of seeds, especially small seeds that can be easily buried. For broadcast hand seeding, it is recommended to mix the seed with sand for better dispersal. Seed should be tossed by hand first in one direction with careful attention to not step within the seeding area. The second round of seeding should then be done in the direction perpendicular to the first to ensure proper coverage. Scare tape mounted on bamboo stakes or strung from a line may be used to help lessen predation by birds. Interseeding can occur in areas with existing native herbaceous vegetation (Whisenant, S. 1999).

It is important to know the specific germination requirements of seed used. Species such as field lupine (*Lupinus lepidus*) require scarification, whereas other species require durations of stratification, such as common camas, to break dormancy. If a fridge is not available for artificial stratification, seeds should be directly seeded on the site in the fall, though this does risk seed predation by birds. It is important to seed a site after all other work on the site is finished in order to prevent trampling and movement of the seeds. Staggering seed application of different species over a series of years is another option to consider if a later successional species would benefit from a pioneer species first combatting against invasive species, jump starting nutrient cycling, or creating organic matter. Seeding should also take place when there is ample moisture to encourage germination, which is most often in early spring when temperatures are also increasing. For broadcast seeding, the soil should be lightly tilled to create various depressions and microsites. This will most likely occur during weeding and subsequent tilling may be unnecessary if the soil surface if already roughened.

Mulching

Adding mulch post weed removal and plant installation helps improve site conditions in several ways. Addition of mulch post weed removal will help to prevent weeds from re-sprouting from root or rhizome fragments or germination of seeds in the seed bank. It is important to apply a thick layer of mulch as any gaps or areas with a thin layer allow sprouts to reach the surface. Restoration practitioners suggest using an optimal depth of 6-8 inches. The thicker the layer of mulch, the harder for resprouts and seedlings to reach the surface.

Adding mulch around installed plants helps to reduce competition from encroaching weeds and retain moisture by shading the soil. Mulch has proven in to reduce weed counts by 50% or more (Cameron & Hitchmough, 2016). As the mulch slowly breaks down, it also releases nutrients back into the system. It is important to leave adequate space between the plant and surrounding mulch. Mulch applied too close to the plant can create lethal temperatures for the plant, create extra moisture retention and rot stems, or harbor fungi and pathogens that might harm the plant.

Herbivore Protection

Young plants provide tender shoots prime for herbivory. Restoration projects within UBNA have seen high rates of herbivory mainly from Eastern cottontails (*Sylvilagus floridanus*). While deer (*Odocoileus* spp.) tend to also be a major concern for revegetation projects, the lack of connectivity with UBNA prohibit deer from accessing the area. Northwestern crows (*Corvus caurinus*) have also been seen to pull newly installed plants out of the ground, exposing the plant roots to the sun to desiccate. No published studies have concluded why *C. caurinus* would be pulling out plants, as they normally eat marine invertebrates, fish, snakes, amphibians, seeds, garbage, and carrion, not vegetation. Regardless, in order to protect young plants until they are established, plants installed in restoration projects should be protected from herbivory in some manner. This can involve using chicken wire and fencing (though if large

Figure 52: Herbivore protection can include using blue tree tubes or chicken wire that physically block herbivores until the plant becomes established

enough gaps, *C. caurinus* may still be able to enter and remove plants), blue tree tubes, or other plant protectors. If burrowing rodents are an issue, the bottom of protection tubes can be buried a few inches below the surface to prevent wildlife from digging underneath the protector.

Commercial plant protectors are made of either solid or mesh plastic and are secured in place with bamboo or wood stakes. Solid walled plant protection tubes also help to create a mini greenhouse effect raising temperatures in the spring and fall and increasing moisture retention during dry summers. For sites with a hotter climate, open mesh tubes should be used in order to provide more air circulation. The bright blue color of the tree protection tubes also identifies locations of plants in the field, which limits accidental trampling, mowing or removal, especially in sites with high amounts of non-native species. Reflective tape may also be a way to help scare away wildlife interested in newly installed plantings. All plant protection should be removed after the plants become established and are able to withstand browsing. This is typically after one or two growing seasons. Without removal, plants may become constricted, or the plastic material may begin to photodegrade and become pollution at the restoration project site.

Habitat Structures

Woody Debris

Over one hundred species of birds, mammals, amphibians and reptiles use large logs for nest and den habitat, food, cover, resting and preening (Link, 1999). Different stages of decay offer habitat and food to different species. Early stages of decay provide lookouts for chipmunks and ground squirrels, sunning

Figure 53: Long-toed salamander found under woody debris placed in a restoration site in UBNA. Dead and down wood provide habitat for many different species from invertebrates to amphibians and small mammals.

spots for Western fence lizards, and dens for raccoons, skunks and foxes (Link, 1999). As the log begins to decompose, small animals such as deer mice nest and look for food within the log (Link, 1999). Crevices between loosened bark provide habitat for beetles and salamanders (Link, 1999). The area of the log in contact with the soil also creates a moist microclimate for tree frogs and voles (Link, 1999). When the log is further decomposed, burrowing animals such as shrews, deer mice and voles dig tunnels and burrows inside the soft decaying wood and toads, skinks, and gopher snakes may also hide underneath (Link, 1999). In the final stages of decomposition is when invertebrate populations increase the most, which attracts insect eating wildlife species (Link, 1999). Woodpeckers also eat insects from logs at all stages.

Woody debris for the project site can be sourced through the Washington Park Arboretum, who can deliver wood to the site. Wood should be placed on site according to the project plan in areas where it will receive the most shade. In each location, a shallow depression should be dug where a quarter of the width of the woody debris can be buried in the soil. This will provide more opportunities for wildlife habitat by increasing the surface area of the log in contact with the soil. Once woody debris is in place, it is best to let it remain undisturbed until monitoring occurs to limit disturbance to wildlife. Woody debris will also be stacked into a pile for pollinator overwintering habitat for Project Plan III (Figure 42). The pile should leave gaps 3-4 inches wide to provide access inside. The base of the pile will be planted with Orange Trumpet Honeysuckle (*Lonicera ciliosa*) for cover.

Figure 54: Log pile created for overwintering habitat for butterfly species.
Source:http://content.yardmap.org/learn/brushpiles/

Tunnel Nesting Bee Blocks

Wooden nest blocks will be constructed for native tunnel-nesting bees (*Osmia* spp.). Wooden nest blocks should be constructed out of non-treated lumber. The following information on wood block construction is from Lee-Mäder, E., & Xerces Society (2011) *Attracting native pollinators: Protecting North America's bees and butterflies.* A 4x6 inch block of wood or piece of firewood can be used as long as it measures at least 4x6 inches. On one side, drill holes of varying diameter measuring between 3/22 and 3/8 inch. A greater diversity of nesting tunnels attracts a wider variety of bees. Holes ¼ inch or less in diameter should be drilled 3-5 inches deep, and holes larger than ¼ an inch in diameter should be 5-6 inches deep to encourage more production of females. Holes should be located ¾ inch away from the edges of the blocks and from adjacent holes. To create a smooth interior, wax paper cut into varying sizes should be rolled and slipped into the drilled holes. Lining the tunnels will help control pests and disease. The outer edge of the rolled paper should be colored black to help attract bees. A small square of plywood measuring roughly 6x8 inches can be attached to the top to protect the nest from rain. The exterior can be charred with a propane torch or painted black, which anecdotal evidence has shown bees are attracted to. However, the box can also be left as is as long as it is hung in a good location. In the Project Plan III design, nesting blocks are placed where they are partly sheltered from the elements, such as near a tree or group of shrubs (Figure 42). During installation, blocks should be placed facing east or southeast to receive morning sun.

Figure 55: Tunnel nesting bee blocks created from 4x4 lumber pieces drilled with holes of varying depth and size. Nesting blocks should be put in a secure area, partially protected from the elements. Source: https://cms.ctahr.hawaii.edu/pollinators/Resources/Home-Gardeners/Bee-hotels

Signage

Installing signs during project implementation helps to inform the public of what is happening in the area. All signs installed onsite should follow the formatting requirements of the UWBG and approved by UWBG personnel before posting. Signs should be laminated to protect them from the elements. Signs should adequately describe what is happening at the site, and what the goals of the project are intended to accomplish. Signs can also discourage people and their pets from entering the site which will help minimize trampling of vegetation, the spread and introduction of non-native seed, and disturbance to wildlife.

Record Keeping

Record keeping is an important component of any restoration project. All activities should be recorded in detail, as well as any volunteer events that help with invasive removal and plant installation. Record keeping helps inform project progress, the amount of time and labor certain activities take, as well as a record to refer to if adaptive management is needed. Copies of project records can be found in Appendix II.

MONITORING PLAN

Vegetation Monitoring

All restoration project plans include vegetation monitoring. Vegetation monitoring should occur on an annual basis in mid to late summer (August - September) when the greatest representation of vegetation is present. The results of monitoring will demonstrate whether the project plan is meeting the objectives in terms of native species establishment and spread and control of non-native and invasive species. In addition to random plot sampling, a general walk through of the site should be conducted on an annual basis to observe each planting area, noting any observations on establishment, mortality, invasive species, or additional maintenance needed. This will help guide maintenance and adaptive management and ensures the entire site is observed regardless of the random sampling locations surveyed.

Vegetation monitoring will closely follow methods used in L.C. Lee & Associates' *Year 1 monitoring report for the University of Washington-Bothell, Cascadia Community College Campus North Creek Ecosystem Restoration Project* (2003). Random plot sampling will occur in 30 plots within the restoration project boundaries. The Generalized Random-Tessellation Stratified (GRTS) spatial sampling method, utilizing the *spsurvey* package in R, will be used to generate 40 random locations of plot centers within the project area mapped in ArcGIS. Ten extra plot locations should be generated to account for potential unsuitable plots, such as those that occur on the edge of the site boundaries.

Plot centers are located in the field using a Garmin GPS unit. Each monitoring point should be used as the center of both herbaceous and woody species plots. Two different sized plots will be used based on the vegetation stratum being sampled. For herbaceous and graminoid species, a 1/100-acre (radius 11.8 feet) circular plot will be used and for woody shrubs and trees, a 1/l0-acre (radius 37.3 feet) circular plot. The radius of the circular plots should be measured out from the plot center and marked with pin flags in the four cardinal directions. Additional points along the circular outline can be measured and marked for a clear boundary. Pin flags of both the smaller and larger plots should be marked with different colored flags to better distinguish between the two. Care should be taken to avoid stepping on vegetation within the plots, which is especially important for the herbaceous/graminoid plot.

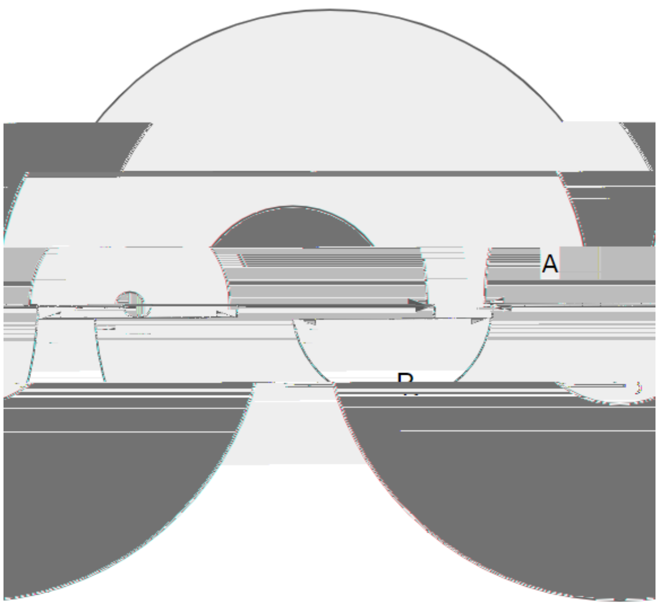

Figure 54: Vegetation monitoring plot design. For herbaceous and graminoid species, a 1/100-acre (radius 11.8 feet) circular plot will be used (B) and for woody shrubs and trees, a 1/10-acre (radius 37.3 feet) circular plot (A).

In each plot, all living plant species should be identified and recorded on the data sheet as well as any bare ground (code: BRGR) and litter (code: LTTR) which includes sticks, leaves, dead grass, etc. A four letter code using the first two initials of the genus and first two letters of the species epithet should be used to designate each species. For example, *Deschampsia cespitosa* should be recorded as DECE. All capital letters should be used for legibility. The general age of the plant: seedling, juvenile, mature, and maximum height of each species should also be recorded for each. The percent cover of each species should be estimated using a ‘bird’s eye view’ looking down over the plot. It is helpful to first establish the percent cover of bare ground and litter before plant species. Daubenmire (1959) cover classes should be used to simplify and accelerate data collection in the field (Table 24).

Table 24: Daubenmire percent cover classes and corresponding midpoints used to sum stratum and entire plot cover.

Percent Cover Range	Cover Class Midpoint
<1%	0.5
1-5%	3
5-15 %	10
15-25%	20
25-50%	38
50-75%	63
>75%	88

The midpoint of the cover classes is used to sum the total cover for each stratum: tree, shrub, and herbaceous, as well as total bare ground and litter cover. The total cover for each plant stratum is then summed to find a total vegetative cover for the plot. Overlapping species canopies, as well as stratum layers, allow for percent cover to exceed 100%. Individual plants outside of the plot, but with vegetative parts (branches, leaves, stems, etc.) extending into the plot, should be included in cover estimates, but it should be noted that the plant was not rooted within the plot in the notes section on the data sheet. It is important to ensure data sheets are filled out for every plot, especially noting plot number. Data sheets should be filled out using pencil, to neatly correct mistakes.

The species list (Appendix III, Table 25) included in this document should help to identify species in the field, however, if unknown plants are encountered and keying in the field does not yield a conclusive answer, the following steps should be taken:

1. Assign a unique code on the data sheet such as UNK_SP._1 (for unknown species number one)
2. Record the general characteristics and unique features of the plant (potential plant family, habit, leaf arrangement/shape/margin, flower structure and arrangement, existence of rhizomes or stolons, bark color and texture, etc.) Take pictures of the whole plant, leaves, flowers, or other key features and label the picture numbers on the data sheet. Placing a small whiteboard or scratch paper with the plant label in the picture taken for the sample will help with later reference.
3. Take a sample for reference. Specimens should be collected outside the plot, and if possible, include the root system. Specimens should be placed in a Ziploc bag, labeled with the species code, date, and collector, and subsequently pressed after returning from the field.

After all species are identified and measured for height and percent cover, a final step is to take pictures of the plot. A photo should be taken standing one meter from the southern edge of the plot facing north. Another picture should be taken at the southern edge looking down on the plot. A step stool may be useful to get a better vantage point.

Monitoring Equipment Needed:

- Data sheets (see Appendix II)
- Clipboard
- Pencil, sharpener, and eraser
- 50 ft. measuring tape
- Pin flags (2 colors)
- Collection bags
- Flora for plant identification
- Camera
- Previous years photo monitoring photos

Pollinator monitoring plan

Net sampling

For Restoration Project Design III; increasing year round pollinator habitat, monitoring of pollinator species is necessary to determine if the project goal and objectives are being met. Monitoring should occur on an annual basis to observe the diversity of species using the site. Monitoring should occur in mid-summer (July-August) when pollinators are most active. Sunny clear days are best, as pollinator activity decreases on overcast or cooler days.

Monitoring for invertebrates can occur in several ways, but aside from general observations, where identifying species is difficult, monitoring involves collecting and killing specimen for close inspection. One method of collection is to use a fine mesh net. Proper technique for netting involves holding the net with one hand below the head and the other towards the back or middle of the pole. When swinging the tip of the net should drop down first followed through with a sweeping motion. Bee species are often detected by their motion rather than their appearance (Droege, 2015). It is easier to catch a pollinator as it is leaving a flower rather when it is on a plant, as vegetation gets in the way. Netting pollinators as they leave vegetation will also prevent damage to flowers that support the pollinator populations.

Observe flower patches at a distance (4-8 feet) at first to limit disturbance (Droege, 2015). Pollinators often visit flowers in a pattern, and observing these patterns may help anticipate movements. When a specimen is spotted, the site should be carefully approached. Faster flying species should be prioritized for netting first, followed by slower moving species (Droege, 2015). Collection should also occur lower, within the vegetation, for lower flying pollinators. All herbaceous plots should be collected from as well as from the area designated for bare ground and around the constructed tunnel nesting bee blocks (Figure 42). Detailed records of observations should also be recorded, including a record of plants visited. Specimens collected within the net should be either transferred into a mason jar with soapy water, which will cause the specimen to drown, or placed in a Ziploc bag and frozen. Specimens from the soapy water jar can be strained using a paint strainer, coffee filter, sieve, or aquarium fish net, and then placed in a jar with 70% alcohol for preservation and identification (Droege, 2015). Frozen species will remain intact for identification or can be preserved in alcohol as well.

Monitoring Equipment Needed for Net sampling:

- Data sheets (see Appendix II)
- Clipboard
- Pencil, sharpener, and eraser
- Fine mesh net
- Mason jars or Tupperware
- 1-gallon water
- 1 Tb dish soap
- Paint strainer, coffee filter, aquarium net, or other filter
- 70% alcohol
- Identification guide

Bowl/Pan trap sampling

Another method of collection is to set up bowl traps. Bowl traps, also known as pan traps, involve using colored bowls filled with soapy water to attract insects that slip through the surface and drown, allowing subsequent identification. Disposable or reusable plastic bowls can be used, and if color is limited, the underside can be painted with spray paint. Bright yellow, blue or white have been used successfully to capture pollinators including bees, moths, butterflies, and flies as well as other invertebrates (Popic et al., 2013). Harris et al. (2017) tested 14 combinations of color, size, and placement height, and found yellow bowls placed on top of the soil substrate captured the greatest abundance and diversity of species. Approximately one tablespoon of unscented dish soap per gallon of water should be mixed to create soapy water to fill the bowls (Droege, 2015). The bowls should be placed in open areas where they are easily seen such as on top of mulched areas, or in between plantings. The goal is to locate them in areas where they are highly visible to the pollinators. Bowls should be placed approximately 50 feet apart and located in various locations around the site (Popic et al., 2013). Prioritization should be placed on areas with any observed activity. Traps should be checked, emptied of specimens, and refilled every 24 hours. The duration of how long the bowl traps remain on the site can vary based on the collection. Multiple days will allow for a greater chance of collecting a higher diversity of species. Specimens from the traps can be strained using a paint strainer, coffee filter, sieve, or aquarium fish net, and then placed in a jar with 70% alcohol, or frozen for preservation and identification.

After collection in the field, specimens should be identified and recorded. A local guide by Washington State University student, Elias H. Bloom, entitled *A Field Guide to Common Puget Sound Native Bees: Southern Region* as well as other guide books will aid in species identification. While either method is suitable for the project monitoring, research by Popic et al. (2013) found that net sampling yielded 30% higher abundance and 22% more species than pan traps. Their results suggest net sampling better reflects the spatial and temporal variation of floral resources at a site (Popic et al., 2013).

Monitoring Equipment Needed for Net sampling:

- Data sheets (see Appendix II) & clipboard
- Pencil, sharpener, and eraser
- 10 Colored bowls
- 2-5 gallons water (depending on # traps and water depth)
- 2-5 Tb dish soap (depending on water used)
- Paint strainer, coffee filter, aquarium net, or other filter
- 70% alcohol
- Mason jar or Tupperware
- Camera
- Identification guide

Nests

The area designated for bare ground (Figure 42) should also be monitored for any established nests by ground nesting (*Andrena* spp.). Any detected nests should be thoroughly documented with the location, number of individual specimens nearby or entering/exiting and a picture. Nests can be identified by the entrance to their burrows which are conical piles of dirt with a large hole in the middle. The tunnel nesting bee blocks should also be monitored for any activity or signs of use by *Osmia* spp. Lastly, woody debris and areas with cover from grass should be examined for bumble bee (*Bombus* spp.) nests.

Figure 57: Figure 54: Entrance to burrow of ground nesting Andrena spp. Source:https://www.123rf.com/photo_55255651_andrena-bee-at-the-entrance-to-its-nest-single-hymenoptera-.html

Soil testing

Soil testing will ultimately depend on funding, however, subsequent testing is necessary to determine if Restoration Plan II is reaching the project's objectives of bioremediation. Research suggests noticeable results will occur between 1-5 years for macronutrients nitrogen and phosphorus, and for total petroleum hydrocarbons (TPH) (Kennen & Kirkwood, 2015). Petroleum aromatic hydrocarbons (PAHs) may take between 5-20 years (Kennen & Kirkwood, 2015). While most metals will only be stabilized within the soil, testing can indicate whether the concentrations have increased, decreased or spread. Annual soil sampling is likely unfeasible due to lack of funding. At a minimum, soil sampling should occur once, five years after project implementation, as that is the average minimum amount of time needed for remediation of PAHs. Sampling should occur at the same sample sites (Figure 17) and follow the techniques outlined in the soil testing portion of this document. If additional funding is available, the site should be tested on a more regular basis and should sample from additional locations within the site. The optimal strategy to fully represent the site would consist of a sample taken every 400 square feet (Darwish, 2013). However, given the site it would be infeasible to test this extensively. Areas can be sampled by dividing the site into polygons of 400 square feet and creating a zigzagging pattern through them, sampling at intervals allowed by funding (Darwish, 2013).

Monitoring equipment needed for soil sampling:

- Data sheets (see appendix)
- Clipboard
- Pencil, sharpener, and eraser
- Measuring tape
- Shovel
- Hori-hori or trowel
- Ziploc bags
- Sanitized collection jars

- Small cooler with ice pack
- Camera

Photo documentation

Photo documentation is an easy way to visually record progress of the restoration site. The key to proper photo documentation is to align photo taking with a specific location, direction and angle each time. Photo points in the field should be marked with a wooden or metal stake placed during the beginning phase of the restoration project. To ensure proper framing, the photographer should stand behind the marker and face directly north. Visual cues such as objects in the distance including trees, buildings, mountains, etc. should be noted and compared to previous photos taken. The previous year's monitoring photos should be printed and taken into the field during monitoring for direct comparison. Photos should be taken during the same time every year, preferably later in the growing season, in the mid to late summer. Photos should be taken on a sunny day (if possible) with maximum light and minimal shadowing. Photo monitoring should start with photos before any activities are performed on the site, as the project is implemented, including key stages such as after invasive removal and after planting, and at least once every year post project implementation. Each photo should be labeled with the time and date and stored in an electronic database.

MAINTENANCE PLAN

Herbivore Deterrents

During routine checks of the site, blue tubes and any other herbivore protection should be observed. Herbivore deterrents may need to be adjusted or replaced if blown by the wind, removed by wildlife, or disturbed in other ways. Growth should also be monitored inside the blue tubes to ensure the plant is not becoming constricted within the protector. Herbivore protectors are most crucial in the winter and early spring when there is less vegetation for wildlife to eat. Plant protectors should be removed if plants become constricted during the growing season. However, it is best to leave herbivore deterrents for over the duration of the first growing season if possible. During the second growing season, protection can be removed and reused. Since blue tubes and other protectors help mark plants within the restoration site, flagging tape for shrubs and trees, and pin flags for herbaceous species, should be used to mark plantings in the field for future monitoring and maintenance.

Invasive Species Control

Invasive species control will be ongoing maintenance needed at the project site. Fragments of roots and rhizomes are likely to resprout and seeds within the existing seed bank are likely to continue to germinate after plant installation and initial control efforts. New invasive species may also be introduced to the site by wind, animals and people. With early detection, new infestations should be more easily eradicated. Subsequent weeding should be careful to avoid trampling or accidental removal of native vegetation. Herbicide application may be needed for certain persistent species such as Yellow Flag Iris (*Iris pseudacorus*). As mentioned, seed of Scotch broom (*Cytisus scoparius*), can remain in the soil seed bank for up to 80 years, therefore repeated control of this species is likely to occur over the course of several years.

Supplemental Plantings

Most restoration projects endure some plant mortality. This can be due to shock, drought, herbivory, pests, disease, fungi, or poor stock from the nursery. Vegetation monitoring will help to quantify which species are establishing and which are not. Species with high mortality or limited growth and vigor should be noted and avoided in any subsequent planting of the site. Any plant mortality should be replaced with other species successfully establishing or with new alternative species that would provide the same functions.

Mulching

Mulch on site most likely will be moved due to wind, rain, and animal movement, or broken down in decomposition. Routine checks as well as annual vegetation monitoring should assess whether plantings or weed control areas need additional mulch. An optimal depth for weed suppression is 6-8 inches.

Signage

Over time signs installed on site may need to be replaced as they become worn by the elements. Signs also have the potential to disappear from high winds or vandalism. During routine visits and monitoring, signs should be checked for replacement or fixing.

Adaptive Management

Adaptive management works to address any issues encountered or amend failed objectives. Adaptive management involves learning through the practice of management itself, with adjustments and different methods employed as understanding improves (Williams & Brown, 2014). For smaller scale restoration projects primarily focused on removing invasive species and revegetating with native species, problems often occur with plant survivorship and invasive species control.

There are many reasons why plants installed in a restoration project may not survive, including: poor nursery stock, environmental factors such as drought or unexpected harsh weather, improper plant installation, poor site prep, which can include failed suppression/control of competitive invasive species, or plants ill-suited to the site conditions. Adaptive management plans for revegetation projects often involve a separate planting palette with alternative species. Adaptive management can also focus on utilizing successes of the project, such as species that readily establish after installation. Certain species that fair well may be increased in abundance if other species fail to establish onsite. If species fail to establish, a further assessment of the site should be made and alternate strategies should be discussed and tried.

Planning for adaptive management should include contingency plans. These are often written in "If/then" statements. For example, in Project Plan I, "If more than 50% of obligate wetland plants do not survive in the ephemeral wetland by year 2, the area will be replanted with facultative wetland plants, better suited to the perhaps drier conditions." For Project Plan III an example could be, "If a species of a certain flowering window does not establish within the prairie plots, then another species from the same flowering window that is successfully establishing on site will replace it within the plots, to ensure temporal floral diversity"

Objectives focused on invasive species removal may be challenged by persistent species requiring more or ongoing maintenance, or alternative control strategies. Issues can include resprouts from root and rhizome fragments, germination of seeds in soils disturbed from removal, a persistent seed bank, the introduction of subsequent invasive species upon removal of another, or ineffective methods used. Adaptive management may also be necessary for specific site objectives, such as bioremediation of contaminants in Project Plan II. An example for Project Plan II may be “If rhizodegradation mats do not lower levels of PAHs within the soils, species with the ability of phytoextraction should be considered in areas with high contaminant levels.” Ultimately, adaptive management recognizes disturbed ecosystems, and their restoration, are only partially understood, and there is value in monitoring site conditions and using what is learned to improve management decisions (Williams & Brown, 2014).

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APPENDIX I: LIST OF ABBREVIATIONS

UBNA: Union Bay Natural Area
CUH: Center for Urban Horticulture
WSDOT: Washington Department of Transportation
SERUW: Society for Ecological Restoration University of Washington chapter
PAH: petroleum aromatic hydrocarbons
PCB: polychlorinated biphenyl

APPENDIX II: DOCUMENT TEMPLATES

Restoration Project Site Assessment

Project Site Name:

Date of Assessment:

Location:

Conducted by:

Client:

Site Photos Taken? Y /N

LANDSCAPE

	Measurement	Notes/Observations
Area		
Elevation		
Aspect		
Slope		
General Contour		

SOIL

Sample	O Horizon (cm)	A Horizon (cm)	Color	Texture	Moisture

Sample	Vegetation	Invertebrates	Coarse Minerals	Compaction	Erosion

DOMINANT VEGETATION

Species	Relative Cover	Nativity	Notes/Observations

HYDROLOGY

Surface Water Feature:
Size/Area: Location on site:

Water quality Indices	Measurement	Notes/Observations
Temperature		
pH		
Turbidity		
Nitrate / Total Phosphorus		
Invertebrate species observed		

Further testing needed?............................ Y/ N

WILDLIFE

Species	Common Name	Observed or Recorded	Location on site	Notes/Observations

HABITAT STRUCTURES
(Snags, dead and down wood, rock piles, brush piles, bare soil, tunnels/burrows, bird/bat houses)

ONGOING DISTURBANCES/THREATS TO SITE
(Introduction of invasive species propagules, land management actions- mowing, burning, pesticide use, potential contamination)

CURRENT HUMAN USE AND IMPACTS

SURROUNDING LANDSCAPE MATRIX
(Notes on adjacent ecosystems, urban development, connectivity, dominant vegetation, surface water features)

PROJECT SITE PRELIMINARY PLANNING

Does the site need:

Contouring……. …………………………..Y / N
Soil Amendments…………………………..Y / N
Invasive species control…..……...……......Y / N
Native Plant Installation…………………....Y / N
Mulch………………………………………Y / N
Herbivore Protection……………….…..…..Y / N
Habitat Structure Installation…………..…..Y / N

Vegetation Monitoring Data Sheet

Plot Number:______________________ Investigator(s): ____________________
Date:________________________

Tree Stratum Stratum % Cover: _______(Stratum Total/Plot Total)

Species	Maturity	Max Height	%Cover Class	Midpoint	Notes
			TOTAL		

Shrub Stratum Stratum % Cover: _______(Stratum Total/Plot Total)

Species	Maturity	Max Height	%Cover Class	Midpoint	Notes
			TOTAL		

Herb Stratum Stratum % Cover: _______(Stratum Total/Plot Total)

Species	Maturity	Max Height	%Cover Class	Midpoint	Notes
			TOTAL		

Absolute Total Vegetation Cover: ____________________________

Pollinator Monitoring Data Sheet

Date: Conducted by:

Species Abundance and Diversity- Net Sampling

Species	Quantity	Location on site	Flower Species Visited	Notes/Observations

Species Abundance and Diversity- Bowl/Pan Sampling

Species	Quantity	Bowl Location	Nearby Flower Species	Notes/Observations

Bee Nests

Type of Nest (ground, bumble, tunnel)	Location	# Bees Observed near nest	Notes/Observations

Soil Monitoring Data Sheet

Date: Conducted by:

Sample	O Horizon (cm)	A Horizon (cm)	Color	Texture	Moisture

Sample	Vegetation	Invertebrates	Coarse Minerals	Compaction	Erosion

APPENDIX III: ADDITIONAL TABLES and FIGURES

Species Inventory

Table 25: Species inventory of all species present on site. Species are listed in alphabetical order and include the common name, growing habit, and nativity. In total there are 10 native species and 25 non-native species on site.

Species	Common Name	Habit	Nativity
Agrostis capillaris	colonial bentgrass	Herb	Non-native
Agrostis gigantea	redtop	Herb	Non-native
Anthoxanthum odoratum	Sweet vernal grass	Herb	Non-native
Bidens cernua	nodding beggarticks	Herb	Native
Bidens connata	purplestem beggarticks	Herb	Non-native
Camassia quamash	Common camas	Herb	Native
Cichorium intybus	chicory	Herb	Non-native
Cirsium arvense	Canada thistle	Herb	Non-native
Cirsium vulgare	bull thistle	Herb	Non-native
Convolvulus arvensis	field bindweed	Herb	Non-native
Crataegus monogyna	Common hawthorn	Tree	Non-native
Cytisus scoparius	Scotch broom	Shrub	Non-native
Daucus carota	Queen Anne's lace	Herb	Non-native
Digitaria sanguinalis	hairy crabgrass	Herb	Non-native
Eleocharis palustris	Creeping spike rush	Herb	Native
Elymus repens	quackgrass	Herb	Non-native
Epilobium ciliatum	willow herb	Herb	Native
Holcus lanatus	common velvet grass	Herb	Non-native

Hypochaeris radicata	hairy cat's ear	Herb	Non-native
Iris pseudacorus	Yellow iris	Herb	Non-native
Juncus effusus	common rush	Herb	Native
Lactuca serriola	prickly lettuce	Herb	Non-native
Lotus corniculatus	bird's-foot trefoil	Herb	Non-native
Lupinus polyphyllus	large-leaved lupine	Herb	Native
Plantago lanceolata	narrow leaf plantain	Herb	Non-native
Plantago media	hoary plantain	Herb	Non-native
Populus trichocarpa	black cottonwood	Tree	Native
Quercus garryana	Garry oak	Tree	Native
Ranunculus repens	creeping buttercup	Herb	Non-native
Rubus armeniacus	Himalayan blackberry	Shrub	Non-native
Rumex crispus	curly dock	Herb	Non-native
Salix lasiandra	Pacific willow	Shrub	Native
Salix scouleriana	Scouler's willow	Shrub	Native
Sonchus arvensis	field sow thistle	Herb	Non-native
Sonchus asper	Prickly sow thistle	Herb	Non-native

Munsell Soil Color Charts

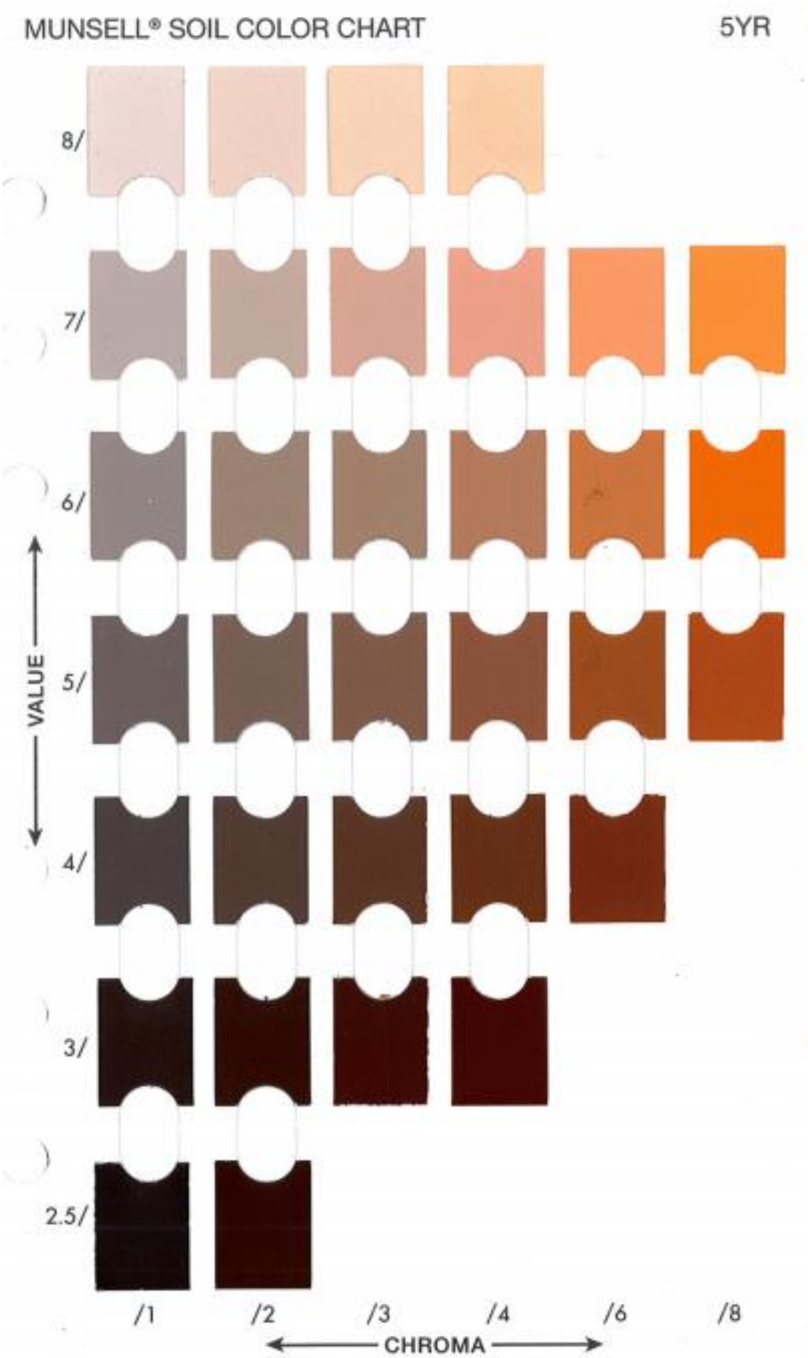

Figure 57: 5YR Munsell soil color chart used for determining soil sample 2 color. Soil sample 2 was observed to be a 5Y 4/2. This soil sample was collected in a slightly higher elevation prairie area with sandy, clay, loam soil. Source: Munsell, A. (1929). *Munsell book of color, defining, explaining and illustrating the fundamental characteristics of color.* Baltimore: Munsell Color.

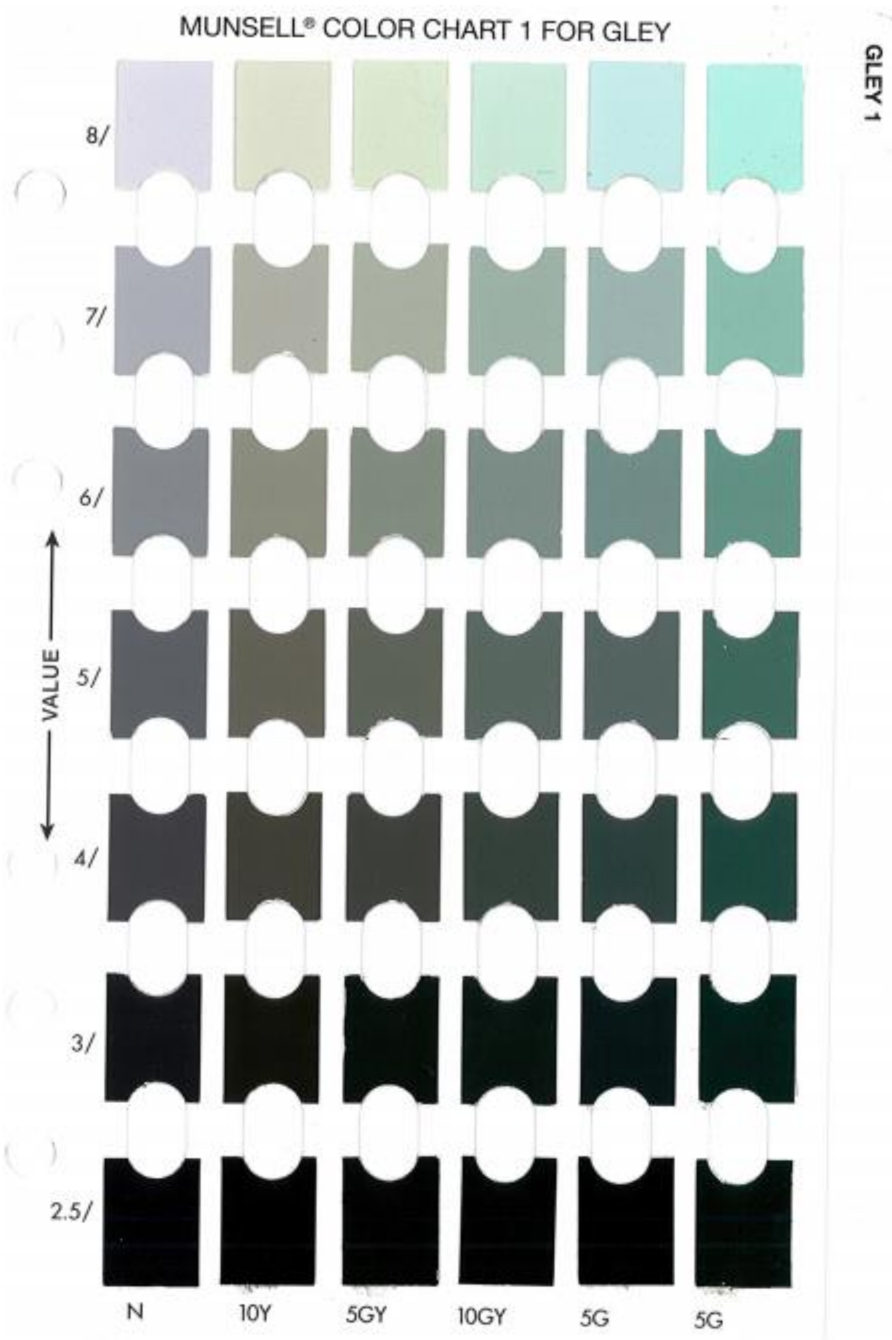

Figure 58: Gley 1 Munsell soil color chart used for deter mining soil sample 1 color. Soil sample 1 was collected in the ephemeral wetland area of the site. Gley soils are a sign of anaerobic environments, signifying the presence of surface water above. Source: Munsell, A. (1929). *Munsell book of color, defining, explaining and illustrating the fundamental characteristics of color.* Baltimore: Munsell Color.