# A Proposal for the Establishment of Permanent Sample Plots in the Cedar River Municipal Watershed


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# 1.0 INTRODUCTION

This document presents a proposal for the establishment of a set of Permanent Sample Plots (PSPs) as one component of an integrated data acquisition and analysis strategy to support the Cedar River Watershed (CRW) Habitat Conservation Plan (HCP). The proposal encompasses an evaluation of the advantages and limitations of PSPs, their contribution within the overall suite of data acquisition and analysis activities, and an implementation plan. Preparation of this proposal has included an assessment of the relative merits of available sampling designs, development of an explicit sampling design, specification of the sampling methods to be tested and used, and design of data management protocols to ensure consistency in data acquisition and facilitate data analysis and management.

The Cedar River Municipal Watershed is currently managed under a 50-year, multi-species HCP which was signed in April, 2000. The overall goal of the HCP is to implement conservation strategies designed to protect and restore habitats of all species of concern that may be affected by the facilities and operations of the City of Seattle on the Cedar River, while allowing the City to continue to provide high quality drinking water and reasonably priced electricity to the region. The watershed is being managed as an ecological reserve using an ecosystem approach, with the goals (among others) of protecting and restoring aquatic, riparian, late-successional, and old-growth habitats.

Restoration activities will be undertaken in areas of the CRW identified by selection and prioritization criteria presently under development. These criteria will be based, in part, upon the condition and extent of the various habitat types currently present in the CRW. The effects of restoration decisions will affect the condition of habitat and water quality within the CRW for decades and centuries to come. In the presence of uncertainty as to the ultimate outcome of these restoration activities, the HCP contains specific commitments to implement adaptive management approaches to restoration and to provide a mechanism to assess the degree of success and/or failure. These commitments speak to watershed management, monitoring of long-term trends in habitat condition, watershed characterization, use of best available science, adaptive management, and the application of sound data management practices. Specific commitments include but are not limited to:

- Tracking long-term trends in habitat and relevant aspects of key species ecology.
- Providing adequate ecological and environmental monitoring to ensure that the HCP is working as intended.
- Accurately characterizing terrestrial, aquatic and riparian habitats in the municipal watershed so that significant trends in habitat and broad-scale landscape changes over the 50-year term of the HCP can be documented.

We propose establishing and taking field measurements at a set of 300+ PSPs[1] as one component in an integrated program of monitoring to address these and other HCP commitments.

These PSPs will:

- Provide a long-term dataset that will allow us to monitor the trajectory of forest condition and processes through time using a system of geo-referenced plots.

[1] There are 310 PSPs that fall within the current ownership boundary of the CRW, based on the explicit sample design discussed in Section 4.0. The reason an approximate number is used reflects the fact that some sites may fall within waterbodies or otherwise be inappropriate for establishment of a PSP.

- Provide a framework of watershed-wide data, which will be compatible with, and complementary to, monitoring strategies for specific restoration projects.
- Utilize a systematic random sample (a grid system) that will provide good interspersion of sampling throughout the CRW and be statistically representative of broad categories of habitat in the watershed.
- Provide habitat data from fixed area plots that can be combined with various remote sensing data to establish extent and location of major habitat types in the CRW.

## 2.0 OVERVIEW OF PERMANENT SAMPLE PLOTS

Sample plots that are permanently monumented and from which data are repeatedly collected over long periods of time have been widely recognized as invaluable for monitoring and documenting natural processes and long-term changes in habitat composition and condition (Scott 1998, Dyrness and Acker 1999, 2000, Ahlstrand et al. 2001, Henderson and Lesher 2002, Smits et al. 2002). Permanent sample plots result in precise estimates of change (Scott 1998), giving much greater statistical power to detect change than would a series of temporary sampling units in the same habitats:

> "*The principal advantage of using permanent instead of temporary sampling units is that for many plant species the statistical tests for detecting change from one time period to the next in permanent sampling units are much more powerful than the tests used on temporary sampling units.*" (Elzinga et al. 1998).

A fundamental problem posed by the use of a PSPs is the selection of a strategy to choose plot locations. If PSPs are intended to document in a statistically valid manner the range of habitats and variability in a particular study area, their distribution needs to be designed to ensure no bias in the selection of locations. In the event that complete information is available regarding the distribution of habitat types of concern, PSPs may be pre-stratified in order to maintain statistical power in habitat types that occupy a small proportion of the study area. More commonly, however, complete information on which to base pre-stratification is lacking. Thus, based on analysis of the first suite of data, additional PSPs are subsequently established to improve the statistical power of the measurements in habitat types that occupy small areas (Fancy 2000). The initial effort of sample design and establishment is leveraged in subsequent repeated visits to the original and added PSPs. This preserves the original lack of bias in the selection of locations, thereby maintaining a statistically rigorous approach to sampling the study area.

Permanent Sample Plots have been used extensively to track processes and changes in forest habitat. In The Netherlands over 6,000 PSPs have been established since the 1930s, many in forested habitats (Smits et al. 2002). They are providing insight into vegetation succession, fluctuations within plant communities over time, and the effects of changes in the environment on the vegetation. Permanent Sample Plots have also been widely used in forests of the Pacific Northwest. The U.S. Forest Service (USFS) established 3,097 PSPs in western Washington during the 1980s and is continuing to monitor them (Henderson et al. 1989, Henderson and Lescher 2002). Thirty-eight PSPs were established in or near the H.J. Andrews Experimental Forest in the late 1970s, and have been re-visited at 5-6 year intervals (Dyrness and Acker 1999). Eighteen PSPs were established in Mount Rainier National Park in 1976-1997, which have been utilized in a number of research studies, including old-growth forest characterization, how forest characteristics change through time, and soil carbon and nitrogen in old-growth (Dyrness and Acker 2000). The National Park Service will soon be establishing PSPs in both the North Cascades and Olympic National Parks under their Long-term Ecological Monitoring Program (Freet 2001, Jenkins et al. 2002). Data from these PSPs will help document the distribution of vegetative assemblages, forest structure, and fuel loading, and monitor how these characteristics change through time.

Twenty-one PSPs were established in second-growth forest in the CRW in 1946-1979. They have been re-measured from one to ten times, most recently in 1986, and include some sites that have been thinned. Whenever possible, we will utilize data from these previously established plots in conjunction with data from the proposed grid-based PSPs. Unfortunately the previous PSPs are limited in number, located in spatially restricted areas, inconsistent in size, and used various sampling protocols, making many types of comparison difficult.

# 3.0 PERMANENT SAMPLE PLOTS IN THE CEDAR RIVER WATERSHED

## 3.1 General Objectives

Data collected at PSPs in the CRW are one component of an integrated effort to support the HCP. The data will be collected at geo-referenced and monumented locations, using specific protocols, and at regular time intervals. These data will contribute to several different aspects of the implementation and monitoring of restoration activities. The first data collection will be coupled with image analysis and forest inventory data to complete a characterization of the CRW. This characterization will support restoration site selection and prioritization, and establish a baseline of PSP data.

Subsequent data collections will be analyzed to establish long-term trends in a defined set of habitat conditions and ecological processes at a broad scale across the CRW. The following statements, excerpted from strategy documents developed by interdisciplinary (ID) teams working within the CRW, emphasize the importance of the monitoring effort:

> *"Long-term monitoring requires repeatable measures of habitat conditions such as structure, composition, species diversity, or abundance to allow comparison over a given time interval. Permanent plots or transects that can be re-sampled consistently, and combined with remote sensing data reliably acquired and analyzed over the monitoring time period are two approaches that will be used in long-term monitoring. The long-term monitoring component is coordinated closely with the Watershed Characterization program, under which baseline conditions (c. 2003) of the Watershed will be established." (Draft Monitoring Strategic Plan)*

> *"Because monitoring provides the thread of information that links our actions now to outcomes that may not be seen for hundreds of years, the importance of documenting our work takes on crucial importance." (Draft Restoration Philosophy for the Cedar River Habitat Conservation Plan, Section 3.4)*

The trends established by the multi-temporal data collection at PSPs may then be compared with the analysis of project-specific monitoring efforts to assess the success or failure of our restoration strategies. For example, establishing the trend of understory development within second-growth forest using data from PSPs will help establish a temporal baseline with which the outcomes of ecological thinning projects may be compared.

## 3.2 Specific Objectives

Specific objectives to be achieved by the establishment of PSPs and the compilation of a long-term dataset within the CRW include, but are not limited to:

- Providing field observations from fixed area plots (used in conjunction with forest inventory data from variable area plots) for integration with image analysis to establish a baseline characterization of the extent of different habitat types, to aid in restoration site selection and prioritization.

- Providing data for evaluating and understanding forest processes and functions at a broad scale.
- Capturing the current and future range of variation in a diverse suite of habitat conditions (see Section 5 and Appendix I for a complete description of conditions to be measured at PSPs).
- Establishing trends over time in habitat condition, species composition, complexity, and structure.
- Providing a framework of long-term watershed-wide data around which other data collection efforts can be planned and integrated
- Informing research and studies focused on the response of forested landscapes to the effects of climate change, environmental contaminants, and the invasion of exotic species (Jenkins et al. 2002).
- Providing a valuable data resource for other researchers, decision makers and policy makers in other institutions and agencies (e.g. University of Washington, Washington Department of Natural Resources, National Park Service, USFS).

In addition to the specific objectives stated above, PSPs will provide quantitative information that could also assist us in addressing regional issues of relevance to the HCP. Amongst these are:

- Support for a carbon sequestration model and potential future markets,
- Document the effects of regional changes in air quality (e.g., a potential correlation with cryptogam occurrence),
- Document the impacts of changing climate on vegetation
- Record changes in biodiversity.

### 3.3 The role of PSPs in characterizing the condition and extent of habitat in the CRW

The CRW Watershed Characterization project has a primary goal of producing a series of data from a wide variety of sources that will be used as tools to support restoration activities and as a baseline from which to monitor habitat trends. These data will provide consistency and transparency to the means of selection and prioritization of areas within the CRW that require management intervention. The baseline data will serve as a reference, to be used in conjunction with data collected in the future, as a means to evaluate the success of those management interventions that comprise the HCP. Permanent Sample Plots will provide one component of this Watershed Characterization effort by providing field data throughout the CRW that can be used in conjunction with other datasets.

The proposed PSPs are expected to characterize a suite of conditions in major upland habitat types at a set of mounmented locations. This first complete dataset will serve to capture the range of variability in conditions within the major habitat types. Data from PSPs will thus be a critical element in developing and testing methodologies to spatially extend these known conditions to the remainder of the CRW using remotely sensed data. This leveraging of the PSP data has been a key factor in the design of the plot and data protocols to be used to collect measurements (see Section 5.2). Current methodologies depend upon the use of a fixed radius plot that is sufficiently large to cover a set of image pixels and to accommodate the difficulties associated with accurately locating points on the ground within an image.

It is anticipated that a wide range of remotely sensed images may be used in conjunction with ground data to establish the extent and condition of major habitat types within the CRW. Knowing the condition and extent of various habitat types in the Watershed provides an important part of the information base on which to select and prioritize restoration areas. In addition, 40 of the proposed 310 PSPs fall in old-growth forest (see Section 4.2). Data collected from these PSPs will serve as a framework around which the old-growth characterization project, specified in the HCP, can be designed.

### 3.3.1 Field verification of aerial photography

The data from PSPs may be used as field-verification for interpretations of aerial photography. While clear boundaries, such as clear-cut/forest edges, can be consistently interpreted from aerial photographs (extent), interpreting habitat condition from aerial photographs contains inherent subjectivity. The PSPs will provide a means for un-biased sampling of certain habitat conditions that may be interpreted from aerial photographs.

### 3.3.2 Interpretation of pixel-based remotely sensed images

Pixel-based image data captured by airborne scanner instruments and satellite-borne sensors are currently available for the CRW. These images may be used in two distinct processes in conjunction with the data from PSPs to characterize the extent of habitat within the CRW. First, data from the PSPs will be used to establish linear regression relationships between variables measured at each PSP and image-derived estimates of the variable (Czaplewski and Catts 1992). Data from PSPs will be most useful for this procedure, though some variables from the forest inventory data may also be able to contribute to the process. The strength of these linear regression relationships will provide a basis for acceptance or rejection of the use of a remotely sensed data set as a tool for establishing the extent over which a specific habitat condition occurs.

Second, the data from the PSPs will be used to apply recently developed techniques for extrapolating from plot-based field measurements to pixel-based datasets, generally referred to as “k Nearest Neighbor” (kNN) (Weyermann and Fassnacht 2000) or “Gradient Nearest Neighbor” (GNN) estimation procedures (Ohmann and Gregory 2002). These procedures were developed in order to expand Forest Inventory Analysis (FIA) methods used by the USFS, and require ground data from fixed (PSP) rather than variable (forest inventory) plots. Thus far the procedures have not been evaluated with all categories of remotely sensed data, consequently there is a research need to apply them to the Modis/Aster Simulator (MASTER) data on-hand at the CRW. These data have a 5-meter pixel size and a total of 50 spectral bands.

### 3.3.3 Land-cover class mapping

The design of the proposed network of PSPs meets the criterion of random distribution required of sampling schema for accuracy assessment of land-cover class maps. In addition, the measurements to be made at each PSP (see Section 4) will allow definition of a series of criteria that define cover classes. For example, tree-species information can be aggregated with canopy closure information to create a class schema that is useful in making some restoration management decisions. The success of a specific remotely sensed dataset in discriminating these classes can be gauged by a comparison of cover-classes assigned to each PSP in the field and the value assigned by the land-cover classification analysis. This process will be similar to that used in the Northwest Forest Plan to characterize and monitor late-successional and old-growth forests, where data from a gridded system of PSPs is compared with remote sensing data (Hemstrom et al. 1998).

### 3.3.4 Validation of new remote sensing technologies

Remote sensing technology is increasingly diverse and is being used as a problem-solving tool in many different areas of habitat characterization. Each type of sensor that is available can be applied to a specific subset of the broad range of attributes required to characterize habitat in the CRW as a basis for answering specific key questions developed by staff. We are thus continually researching ways to add new tools. A good example of this is Light Detection and Ranging (LIDAR) sensors that record the height of a surface via rapidly pulsed laser systems. Establishing the PSPs provides a set of measurements throughout the Cedar River Watershed that can be used as one means to evaluate emerging remote sensing technologies such as LIDAR.

### 3.4 Using data from PSPs to monitor long-term trends

Multi-temporal data from PSPs will be one component of an environmental monitoring strategy documented in the CRW Strategic Monitoring Plan. Primary goals delineated in this Monitoring Plan include 1) increasing scientific knowledge about natural processes and functions, and 2) tracking habitat changes through time. Data from PSPs will allow us to begin to address both of these goals.

There are several basic forest processes we will monitor using PSPs (Table 1). We expect that all of these processes will be influenced, to some degree, by restoration activities. There is thus a key need to acquire data that will establish the direction and magnitude of changes in the occurrence of these processes across the CRW, such that we may compare the results of our interventions with general trends. For example, we anticipate that forest restoration activities will succeed in accelerating forests more quickly through the stem exclusion phase, resulting in greater heterogeneity and higher habitat quality for many wildlife species. Some processes such as soil development, however, could have the potential to be negatively affected by an acceleration of forest succession. Key questions that data from PSPs will help to answer include: "How does the development of epicormic branching or canopy differentiation compare in thinned and non-thinned forests?" and "How does soil development differ in thinned and non-thinned forests?"

Table 1. Forest processes to be monitored via data collection at PSPs

| Primary Forest Process | Associated Processes | Variables Measured to Monitor Process |
|---|---|---|
| Forest Succession | Tree Growth (diameter, height, crown depth, crown width, large branches) | Dbh, height, stratum, crown class, percent live crown, height to live crown, age and growth rates, epicormic branching, number of trees, tree species list |
| | Tree Mortality | Damage class, crown class, percent live crown, number of trees, mistletoe, |
| | Tree Regeneration | Dbh, height, crown class, number of trees, tree species list |
| | Species Dispersal | Plant species list, cryptogam species and abundance, insect species and abundance, mistletoe |
| | Bark Development | Cryptogam species and abundance, insect species and abundance |
| | Understory Development | Plant species list, percent cover by shrubs, percent cover by herbs, canopy closure |
| | Canopy Differentiation | Canopy closure, tree height, height to live crown, epicormic branching, height to lowest epicormic branch |
| | Development of Canopy Communities | Insects, cryptogams, other canopy community species and abundance |
| Forest Structural Development | Understory Tree Development | Tree species list, dbh, height, crown class, |
| | Tall Shrub Development | Plant species list, percent cover by shrubs, average shrub height, canopy closure |
| | Short Shrub Development | Plant species list, percent cover by shrubs, canopy closure |
| | Herb Development | Plant species list, percent cover by herbs, canopy closure |
| | Gap Development | Canopy closure, tree mortality processes |
| Dead Wood Processes | Snag development | Snag number, dbh, species, height |
| | Snag Decay | Snag decay class, fungal species and abundance |
| | CWD Decay | CWD species, number, diameter, length, decay class, suspended, fungal species and abundance |
| Nutrient Cycling | Decomposition, mineralization, nitrification, denitrification, immobilization | CWD decay class, number, diameter, length, fungal species and abundance, depth of duff, soil microbial community |
| Soil Development | Decomposition, weathering | Soil type, soil profile, soil microbial and invertebrate communities, depth of duff, plant species list, geology, slope aspect elevation |

We acknowledge that our desire to monitor ecological processes is to some extent dependent upon the use of surrogate measurements that will allow us to interpret the current status of a specific process. As noted in Jenkins et al. (2002):

> *"Vegetation is the great integrator of biological and physical environmental factors, and is the foundation of trophic webs and animal habitat (Gates 1993) as well as having a major role in geologic, geomorphologic and soil development processes (Schumm 1977, Jenny 1941). Consequently, results from monitoring vegetation and associated ecological processes are an essential tool for detecting changes occurring in ecosystems… Finally, monitoring vegetation in a statistically representative manner offers management the opportunity to extend plot data to a larger scale such as entire watersheds and perhaps the park as a whole. Changes in vegetation means changes in primary productivity and habitat quality and will be reflected throughout the ecosystem."*

We agree with this evaluation, and plan to focus the majority of data collected at the PSPs on vegetation. Data obtained at PSPs will be used in conjunction with other data to address key questions identified in the CRW Strategic Monitoring Plan, including tracking condition and extent of habitats, documenting the natural trajectory of ecosystems as they develop over time, increasing knowledge about natural processes and functions, assisting in clarifying the relationship of composition and structure to process and function, and developing and validating forest growth and species-habitat models.

### 3.5 Using data from PSPs in conjunction with data acquired to monitor restoration projects

Data from the proposed system of PSPs are not intended to substitute for restoration project-specific monitoring data. Rather, we propose that they enhance the value of these data by providing a means to assess the outcomes that may occur if no interventions were implemented. Knowledge about the trajectory of ecosystem development will aid in management by providing a reference with which areas undergoing restoration can be compared. Though many restoration projects will occur over the 50-year term of the HCP, large areas of the Watershed will not be treated. While control sites will be incorporated as a part of restoration project monitoring, documenting how the entire landscape develops through time will provide a much larger framework for comparison.

### 3.6 Limitations of PSPs

Because of the numerous uses and advantages of PSPs, the Watershed Characterization ID Team fully supports initiation of this project. The Team realizes, however, that there are limitations to what PSPs can provide. The density of PSPs will not be adequate to monitor individual restoration projects. In addition, investigation of some ecological processes may require specific research designs. The grid-based system of PSPs is not applicable to sampling riparian and aquatic habitat because streams occur as networks of linear features. Consequently, a different system of sampling plots is needed for characterizing and monitoring riparian and aquatic habitats. Permanent Sample Plots are not expected to adequately document localized stochastic events such as wildfires or debris flows. An alternative strategy is required to capture the distribution and effects of such events.

The grid-based system of PSPs (Section 4.0) and inventory points (Section 4.3) can be used as a starting point, however, to design sampling that will be compatible with, and contribute to, the overall effort of characterizing the Watershed, while addressing specific needs. Much can be gained by assuring that the establishment of PSPs and other sampling efforts inform each other. Similarly, it is advantageous to place all field data within a common data management framework, and where appropriate, utilize the same sampling protocols.

### 3.7 Relationship of PSPs to Riparian/Aquatic Sampling

As noted above, we recognize that the proposed grid system of PSPs will not serve to characterize riparian and aquatic habitats on a watershed scale, or to conduct long-term monitoring of these habitats. The location and distribution of sampling plots in these ecosystems will be established in relation to the stream network and will augment the currently proposed PSP grid system. Although some PSPs in the proposed grid system are located within riparian areas, they will not adequately represent the entire riparian system. Additionally, the study of riparian areas will have different objectives and will require a sampling design that accounts for the unique properties of riparian systems and their relationship to water courses. We anticipate that this design, when developed, will be integrated into the proposed grid-based system of PSPs.

Although some aspects of the specific sampling designs will differ between the proposed grid-based PSPs and those established in riparian systems, many of the variables measured will be the same or similar. For example, the suite of attributes to characterize forest structure, such as tree density, canopy closure, understory composition and cover, and abundance of downed logs (referred to in this document as coarse woody debris, CWD), will be measured in both. With prior consideration, these measurements will be comparable and serve to densify the grid-based PSPs. A complete proposal for long-term sampling of riparian and aquatic habitats will be presented in a separate document.

## 4.0 SAMPLING DESIGN

### 4.1 Overview

A sampling design should be structured to provide a valid statistical sample of the study population, which in our case consists of the land within the current ownership boundary of the City of Seattle CRW. Any such effort must meet two requirements with respect to sample distribution and the study population: 1) a random sampling method must be used, and 2) the positioning of sample locations must achieve a good interspersion throughout the population (Elzinga 1998).

There are a number of potential sampling designs that could be used to sample the CRW. The fact that the Watershed extends over 90,000 acres and spans over 5,000 feet in elevation raises issues of sample size and the spatial distribution of the plots. Options of sampling design are briefly discussed below.

#### *4.1.1 Random Sampling*

This approach is usually appropriate for small geographic areas with relatively little variation in physiographic variables such as elevation, and no consistent patterns across the landscape. The Watershed is characterized by a consistent increase in elevation from west to east. Similarly the logging history roughly follows this pattern with the western portion, or lower watershed, logged over a hundred years ago and areas in the upper watershed (eastern) logged more recently. Thus, there is a need for sample plots be more systematically located throughout the Watershed than would occur with a simple random sampling design.

#### *4.1.2 Stratified Sampling*

Stratified sampling is frequently used in ecological studies. To fully benefit from a stratified sampling design, however, one must know in advance the size and location of all strata that could potentially be of interest, both now and in the future. This is not, and can not, be known. In addition, stratum boundaries may change over time (e.g., forest succession), and we do not know all the places where management actions will be taken. So pre-stratification, especially if based on vegetation characteristics, is not generally recommended for PSPs that are intended to document a range of habitats and their variability (Fancy 2000).

A current challenge is to characterize the Watershed and the distribution of habitat types. We will be better able to do this after the PSPs are in place. One advantage of the PSPs is that the data will allow us to create strata of interest, which may change over time or with different studies. If analysis reveals that some strata of interest are inadequately represented, we can then densify the grid with additional PSPs, by using already identified inventory points (see Section 4.3) (Henderson et al. 1989, Fancy 2000).

#### *4.1.3 Systematic Random Sampling*

Systematic designs are appropriate for ecological studies in landscapes with a variety of habitats, as they achieve a good interspersion of sampling locations and sample evenly across a large area (Scott 1998, Fancy 2000). Random sampling is required for statistical validity and in order to generalize findings to broader areas. For these reasons we choose to use a systematic random design based on a grid that is randomly set upon the landscape and is at a density that provides the desired number of samples.

There are several requirements that the sampling design needs to meet:

- It should be statistically representative of the land base within the CRW.
- It should provide a set monumented, geo-referenced, and documented sample locations within the CRW, of which standard subsets will support specific studies that are statistically representative of the Watershed as a whole.
- It needs to provide a framework for densification and integration of other sampling efforts targeting special, or more spatially limited, habitats. This applies to sampling protocols, spatial location of samples, and data management practices.
- It should support post-sampling stratification by a variety of attributes, such as elevation, sites where intervention occurs, or forests of similar age or species composition.

#### *4.1.4 Potential Concerns*

One concern with systematic sampling designs is that they not be biased by existing environmental or culturally-imposed patterns. The most dominant pattern on the CRW landscape is the public land survey boundaries. These historic ownership boundaries reflect the timber harvest history in the CRW, particularly in the upper watershed, which has been logged more recently. These patterns approximate a spacing of one mile, reflecting section boundaries, though harvest boundaries and roads are mitigated by the fairly rugged topography. The choice of a grid interval that is not a multiple of one mile will locate the plots at a spacing that varies relative to the underlying pattern of historic ownership and harvest.

A second concern with this design may be our ability to post-sample stratify into specific areas of interest and retain adequate statistical power with the more limited sample size. One way to address this is with an initial sample design that provides a high likelihood that enough samples will exist in areas that we might subsequently use for stratification. While the location of future action is not known, the scope of this effort can be estimated. The HCP commits money for restoration thinning of, on average, 735 acres per year for each of 15 years for a total of 11,025 acres, or over 8% of the CRW. A systematic random sampling design is likely to provide adequate representation in these areas. In fact, an exploration of areas that have been restoration or pre-commercially thinned over the past 10 years indicates that 7.5% of the proposed 300+ PSPs fall within the 6.2% of the Watershed that has recently been thinned. Another method is to post-sample stratify, then add PSPs in areas where they are underrepresented (Fancy 2000). This is analogous to the unequal probability distribution suggested by Jenkins et al. (2002), where higher densities of PSPs would be located in certain areas (in our case, uncommon habitat types) when compared with other areas.

A third concern is the amount of resources necessary to monument and repeatedly sample over 300 PSPs. The choice of sample size is ultimately a balance between an adequate representative sample and the resources required. To address this concern, a subset of 103 plots was derived from the set of ~300 plots. This was done by first constructing a grid with a spacing that approximates the size that would place 100 samples within the Watershed and then choosing from the standard set of 300+ PSPs those falling closest to these 100. Thus, a systematic sampling design was used to identify a subset of 103 points to assure relatively equal spacing across the Watershed. This subset meets the conditions of good interspersion and randomness, and will support more limited research and data collection at a set of plots that is statistically representative of the entire CRW, although more limited in statistical power. For example, soil sampling may be time consuming in collection and analysis, so it may be done at the subset of 103 plots rather than all 300+. This would still express a range of soil types present in the Watershed. Likewise, smaller subsets of plots (e.g., 50 or 25) can be generated if smaller numbers of plots are appropriate for a specific study.

A fourth concern is the ease of access to PSPs. Access is presently not a significant issue, as the CRW has an extensive road system. As road decommissioning continues, however, access to some plots will become more difficult, and thus more time consuming.

Implementation of the monumenting and sampling will be staged based on the 103 points. This will assure that if the effort needs to be scaled back we will still have a statistically valid and useful data set. In addition, data from this subset can then be evaluated for statistical power, the range of variation expressed, and compared with the level of effort expended.

### 4.2 A Systematic Random Design for PSPs in the Cedar River Watershed

The broad parameters of our sampling design (approximate number of samples and random starting location) for the CRW PSPs were provided by Kim Iles, a forest biometrician under contract to SPU (Iles 2002). To identify sampling locations, a random coordinate or 'anchor point' was identified within the Watershed. Using this design a gridded set of points with a spacing of 3,600 feet, with every other row of the grid offset half this distance east or west, was distributed across the Watershed. This resulted in one sample point per 297 acres (0.46 sq mi) and a sample size of 310 plot locations falling within the current boundary of the CRW (Figure 1). At least three of these plots fall within open water and will not be formally sampled. Iles (2002) predicted that areas occupying from 2-5% of the Watershed would have some sample plots falling within them. In fact, this standard plot set has been shown to have at least one member fall in areas that occupy as little as 0.5% of the Watershed, based on current inventories. This is supported by initial analysis using this standard plot set and the best available classification of existing habitat (Table 2). Similarly, areas where restoration activities have been performed are represented, proportional to the size of the activity. The choice of sample density was ultimately based on experience and estimated available resources (Iles 2002). Further evidence of the systematic distribution of the plot locations is revealed by graphing the known elevation of each plot location, sorted in ascending order (Figure 2).

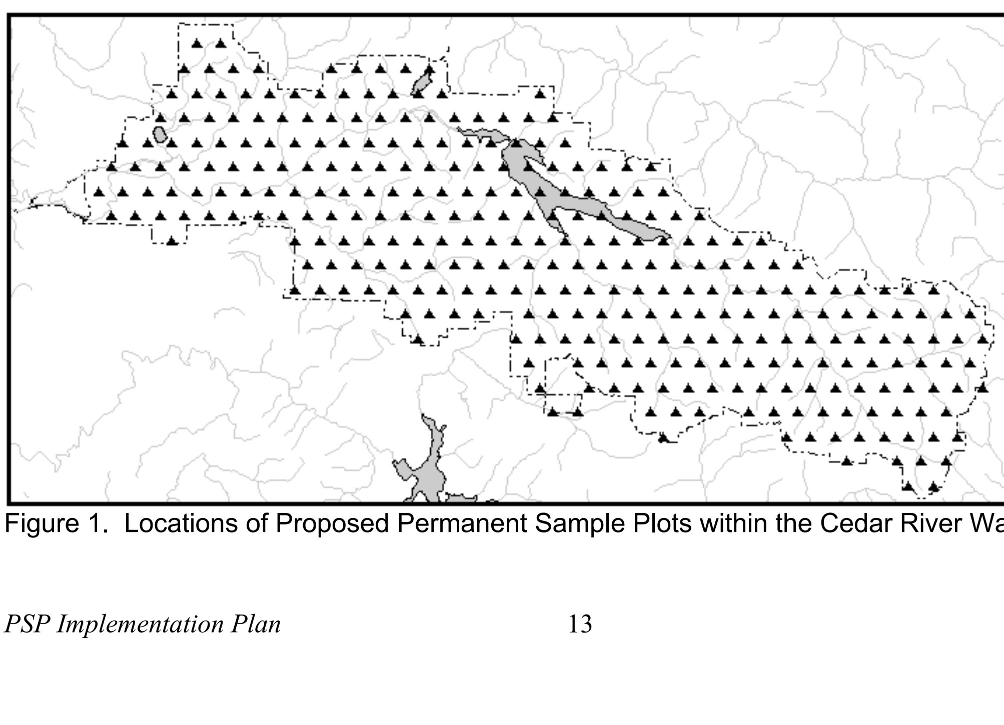

Figure 1. Locations of Proposed Permanent Sample Plots within the Cedar River Watershed.

Table 2. Comparison of current habitat type (estimated from best available data) at plot centers for 103 plots, 310 plots and the entire study area.

| Habitat/Land Cover | # of PSPs in set of 310 | % of PSPs in set of 310 | # of PSPs in set of 103 | % of PSPs in set of 103 | % of CRW |
|---|---|---|---|---|---|
| Old Growth | 40 | 12.9 | 17 | 16.5 | 14.3 |
| 2nd Growth > 30 yrs | 206 | 66.5 | 61 | 59.2 | 64.5 |
| 2nd Growth < 30 yrs | 42 | 13.5 | 10 | 9.7 | 11.8 |
| Open Water* | 5 | 1.6 | 3 | 2.9 | 2.5 |
| Wet Area | 6 | 1.9 | 4 | 3.9 | 2.2 |
| Rock | 6 | 1.9 | 4 | 3.9 | 2.6 |
| Other | 3 | 1.0 | 3 | 2.9 | 1 |
| Developed | 2 | 0.6 | 1 | 1.0 | 0.2 |
| Total | 310 | 100.0 | 103 | 100 | 99.1 |

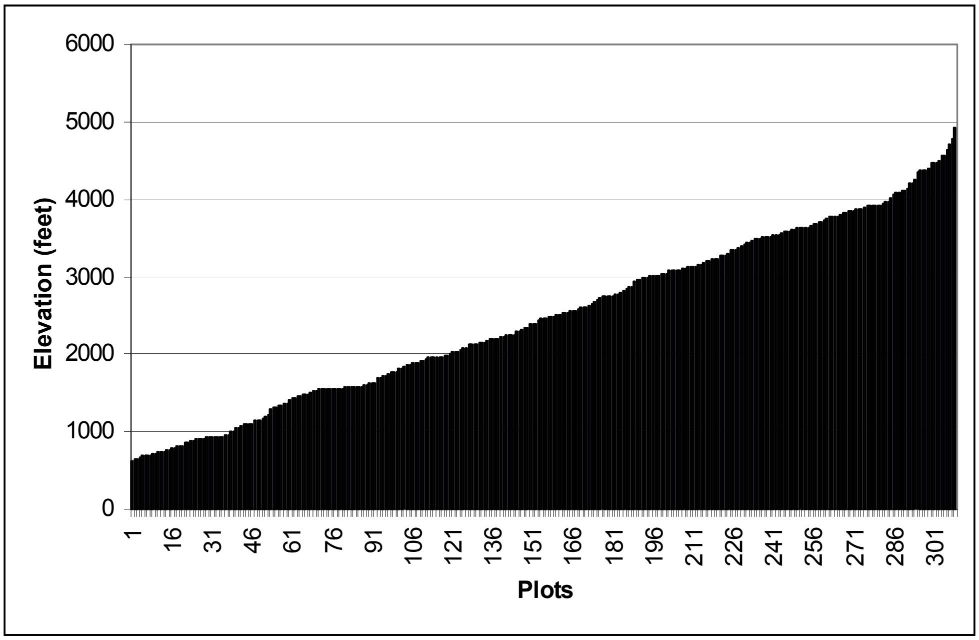


Figure 2. Elevation at each of 310 PSP locations, sorted in ascending order.

## 4.3 The Grid System of PSPs as a Spatial Framework for Data Management

The PSPs, in part because of the sampling design, provide a sound basis for organizing and integrating other field data and observations. The standard plot set (310 PSPs – see Section 4.2) has been densified to the level where there is one point every 225 feet, or one per 1.16 acres, that form a grid of equally spaced points covering the CRW. These 70,000+ points, referred to as inventory points, are keyed to the standard plot set based on proximity, and provide a random systematic grid over the entire watershed that can be used for project level monitoring as well as other field data collection. The advantages to utilizing inventory points are numerous:

- The points can be located using GPS and used to support project-level monitoring.
- A selected subset, such as those falling within a restoration management unit, can be selected and randomly ranked to get a representative sample for project level monitoring.
- Tying data into known points will support spatial queries and access. These linkages are important to long term data management, access, analysis and integration of data gathered at different scales and for different purposes.

- Consistency in sampling methodology and integration via a common geography such as that provided by the inventory points will increase sample size for some efforts when used with the standard plot set of PSPs.

# 5.0 IMPLEMENTATION

Implementation of PSPs will involve installation of 300+ plot centers and data collection at each location throughout the CRW. This will occur in phases, including:

- Conducting a pilot study on PSP establishment and data collection, to evaluate the proposed sampling design, techniques, and time involved. This will be completed during winter and spring 2003.
- Installing and monumenting (permanently marking and documenting) the plots. This is proposed to be completed during 2003, when access is available – generally year round in lower elevations and during spring, summer and fall in higher elevations.
- Measuring trees, shrubs, snags and CWD, which may be combined with installation and monumenting the plots to decrease travel and access costs. These measurements can be made any time when access is available, which is generally year round in lower elevations and during spring, summer and fall in higher elevations. These measurements are proposed to be completed in 2003-2004.
- Measuring herbaceous vegetation, which may be combined with the tree measurements, or may be separate, depending on expertise of the field crew, time of year, and elevation. These measurements are restricted to appropriate seasons when the plants are growing and able to be identified. This will likely be spring/summer at lower elevations and summer in higher elevations, and is proposed to be completed in 2003-2004.
- Collecting other data that requires specific expertise (e.g., cryptogams, insects, soils), and is proposed to be completed in 2004 either at all PSPs or at appropriate subsamples.

Implementation will be phased in order to assess the methods and protocols and to assure that once an initial effort has been made that the dataset represents the entire Watershed. Specifically, a subsample of 103 plot centers that are distributed throughout the Watershed will be established and sampled first (Section 3.0).

## 5.1 PSP Installation

Determination of exact plot locations in the field will be accomplished using a combination of Global Positioning System (GPS) and standard field methods. The known coordinates and elevations of each plot will be loaded into a GPS data logger and used for navigation. If it is not possible to use the GPS for navigation (e.g., dense tree canopy precludes obtaining signals) standard field methods (using a map and compass) will be used for navigation. A GPS coordinate will be taken at plot center, and will be post-processed.

### *5.1.1 Edge Effects*

Edge effects can complicate data analysis and trend assessment for forested habitats. For this reason, any plots that fall directly on a clear edge between old-growth and young second-growth forest will be moved into the old-growth, because we anticipate that old-growth will be under-sampled compared with second-growth in the CRW. In addition, we want the maximum amount of data possible from the PSPs to contribute to the old-growth characterization project. If any old-growth edge plot exist, the field crew will move perpendicular to the edge into the old-growth, such that they are a minimum of 1.5 times the radial distance of the tree plot (see Section 5.2) from the edge. If other edges are encountered during plot installation (e.g., an edge between forest and non-forested habitat), the plot will remain on the edge, which will allow us to sample changes through time.

### *5.1.2 Plot Center*

Carsonite (fiberglass) posts will be placed over rebar to mark plot centers. These posts are appropriate because of their ease in installation, long term durability, and visual recognition. The posts will be of one designated color, and will be labeled with the appropriate plot center identification number with standardized decals.

### *5.1.3 Reference Points*

Three healthy dominant or co-dominant trees, close to plot center and located in different quadrants, will be used as bearing trees, with their tag number and distance and azimith to plot center recorded. The purpose of these reference points is to ensure that plot center can be reliably relocated over time. In addition, a GPS reading will be taken at plot center, and detailed information on the most efficient access route to plot center will be recorded.

## 5.2 Plot Design

Permanent Sample Plots have been used for several long-term ecological research projects in the Pacific Northwest (Dyrness and Acker 1999, Dyrness and Acker 2000, Harmon et al. 1998, Henderson and Lesher 2002). Measurement protocols have varied according to the goals and objectives of the study and type of habitat being monitored, but have generally utilized circular, square or rectangular fixed plots, with plot size tailored to the species being measured (Max et al. 1996, Dyrness and Acker 2000, Henderson and Lesher 2002). While a variable radius plot is frequently used to measure trees for timber cruises, it is not appropriate for long-term monitoring because the same trees are not necessarily subsequently re-measured. In order to evaluate forest development and the process of succession, it is essential to monitor an adequate number of individual trees for growth and development over a long period of time (Henderson and Lesher 2002). Monitoring the recruitment of new trees, number and decay rate of snags, volume and decay rate of CWD, and species presence and percent cover of understory plants allows an extensive examination of the process of forest development.

The plot design used for CRW PSPs closely follows the methods developed by Henderson and Lesher (2002) for Forest Service ownership in western Washington. The USFS has monumented and sampled over 3,000 permanent plots in western Washington, including areas in the western Cascades in close proximity to the CRW. By using a similar sampling design, our data will be comparable, facilitating exchange. The data collection protocols we will use are standard methods from the fields of forest ecology, plant ecology, and wildlife science, which will facilitate application of data collected in the CRW to regional studies.

The CRW PSP plot design for forested habitat types will consist of a circular plots on which trees and snags will be measured, coupled with transects to measure CWD and shrubs, belt transects to measure saplings and estimate cover of tall shrubs, and square plots on which percent cover by herbs will be estimated (Figure 3). Tree plots follow exactly the protocol described by Henderson and Lesher (2002). Shrub and herb plots will vary from the Henderson and Lesher (2002) protocol, consisting of the line-intercept method for shrubs and sub-samples of the tree plot for herbs, to allow greater latitude in skill level and a shorter time commitment to complete the sampling. These plots will follow standard plant ecology protocols (Cain and Castro 1959, Daubenmire 1968, Kuchler and Zonneveld 1988).

Coarse woody debris transects will follow the location described in Henderson and Lesher (2002) in relation to plot center, but will be a standard length, following the recommendations in Harmon and Sexton (1996) rather than varying with the tree plot size.

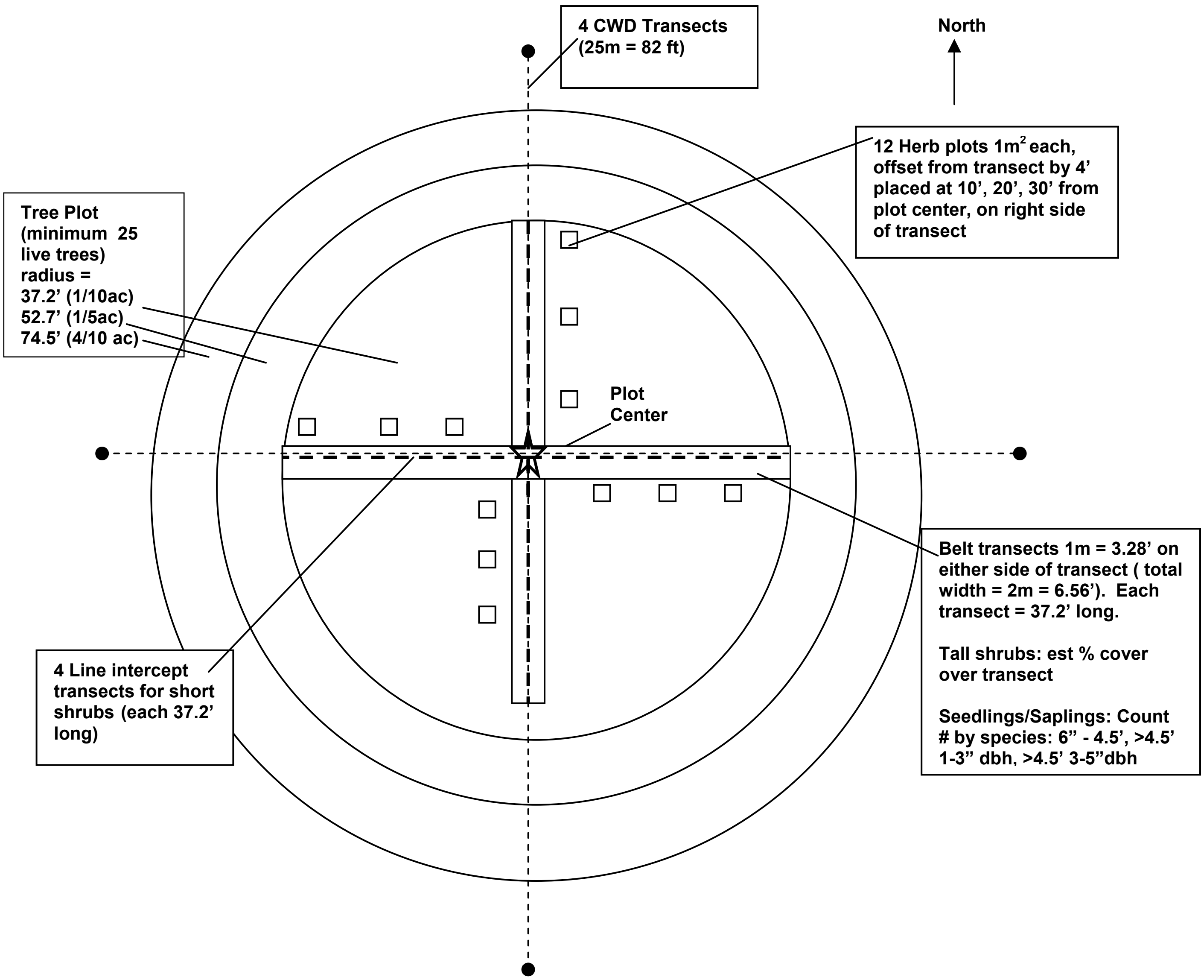


Figure 3. PSP Plot Layout for forested environments, Cedar River Watershed (not to scale)

A sampling design for other species in the forested environment, (e.g., cryptogams, insects) will be developed in consultation with experts, but will likely include fixed plots of varying sizes for ground living species, and use of the tree plot for arboreal species. Soil samples will be offset a fixed distance and direction from plot center, to ensure that the tree, shrub and herb plots are not disturbed.

In the non-forested areas of the CRW (meadows, open wetlands, talus slopes), tree plots will be omitted, but herb plots and CWD and shrub transects will be established as described for the forested habitats. Pilot studies will be conducted to determine whether the number of shrub transects and herb plots will be sufficient to adequately sample these types of habitats. Sections 5.2.1 – 5.2.4 describe plot layout in detail for the Tree, CWD and Shrub Transects, Belt Transects, and Herb Plots.

### *5.2.1 Tree Plot*
The plot to measure trees and snags ≥5.0 inches dbh will be established first and centered on plot center. We estimated that a minimum of 25 trees in the plot will be required in order to track forest development and processes through time. So the tree plot will vary in size depending on the tree density. An initial count of trees ≥5.0 inches dbh in a 0.1 ac circular plot (37.2 ft radius, horizontal distance) will be taken. If more than 25 trees are present, this plot will be marked as the permanent tree plot. If less than 25 trees are present in the 0.1 ac plot, a count of trees in a 0.2 ac plot (52.7 ft radius) will be conducted. If more than 25 trees are present in the 0.2 ac plot, it will be marked as the permanent tree plot. If less than 25 trees are present in the 0.2 ac plot, a 0.4 ac tree plot (74.5 ft radius) will be established as the permanent tree plot (Henderson and Lesher 2002).

Once the tree plot size is determined, boundaries of the plot will be marked from plot center, measured with a tape or a laser rangefinder. Sufficient number of boundary flags will be placed, with a minimum of one placed in each cardinal direction. If there is a question about whether a tree is in or out of the plot, a measurement to the tree will be made.

All trees ≥5.0 inches dbh within the plot will then be permanently tagged with a pre-numbered aluminum tag placed at 4.5 feet above normal ground level (dbh) facing plot center. Tree Number 1 will be the first tree east of due north, then proceeding in a clockwise direction marking all remaining trees.

### *5.2.2 CWD and Shrub Transects*
Four transects, each 82 ft (25m) in length, will be established in the four cardinal directions from plot center and used to measure CWD (Harmon and Sexton 1996). Shrubs (large woody-stemmed perennial plants) will be measured along the first 37.2 feet of the CWD transect, using the line intercept method.

### *5.2.3 Belt Transects*
A 2 meter wide belt transect, centered on each of the four shrub transects, will be used to measure saplings and estimate percent cover of tall shrubs (vine maple).

### *5.2.4 Herb Plots*
Percent cover of herbaceous vegetation (non-woody vegetation, including all ferns, forbs, grasses, sedges, and mosses, plus 'sub-shrubs' or small woody vegetation) and tree germinants (with green cotyledon still attached) will be estimated in 10.8 $ft^2$ ($1m^2$) square plots (Cain and Castro 1959). Three herb plots will be located along each shrub transect, for a total of 12 per PSP (Figure 3).

## 5.3 Measurements

The complete list of variables to be measured at each PSP, along with the justification and use for each variable, specific methodology and literature reference is found in the Appendix I Table 1. Appendix I Tables 2-7 further clarify methods and codes used in data collection, and Appendix I Table 8 includes variables that will be calculated using the measured data. An extensive literature review was conducted during the development of the measurement protocols (Appendix II).

### *5.3.1 Plot Center*
At plot center, a digital photograph will be taken in each of the four cardinal directions, starting with due north, then proceeding east, south, and west. Slope, aspect, topographic position and habitat type will also be recorded at plot center. Tree canopy closure will be estimated using a spherical densiometer at 20 feet from plot center along each CWD transect. Four measurements, one in each of the cardinal directions, will be averaged. Canopy closure data correlate with understory development and forest succession, and allow us to directly monitor canopy development and differentiation through time.

### 5.3.2 Tree Plot

In the Tree Plot, a complete list of all plant species occurring in the plot will be tallied (Henderson and Lesher 2002). All trees ≥5.0 inches dbh will be marked and individually numbered (as described in Section 5.2.1) and the species recorded, which will allow us to monitor individuals through time as the forest develops, and give a density estimate. The trees will then be placed into a stratum and crown class, the dbh measured, and the presence of mistletoe, damage, or epicormic branches noted. These variables are indicators of the process of successional and structural development of the forest, and allow us to track long-term trends. Presence of epicormic branches indicate the successional process of canopy thinning and differentiation is occurring, and can be a critical wildlife habitat element. If epicormic branches are present, height to lowest epicormic branch will be estimated. This will provide a general index of the vertical penetration of photosynthetically active radiation, which is a function of the amount of canopy thinning. A sample of three trees from each stratum, (see Appendix I Table 4) will be measured for height, height to live crown, age, and growth rates. If only one stratum is present, a minimum of five trees will be measured. These data will allow us to monitor long-term trends in forest succession and structure by calculating average heights and variances in different layers.

All snags will be measured for diameter at breast height, height, and decay class, and whenever possible identified to species. These variables are critical to evaluate wildlife habitat quality, and characterize reference sites. As trees become snags through time, this ecological process will be documented and monitored. Only those snags ≥10 inches dbh will be individually tagged, to allow tracking longevity of larger snags that are important wildlife habitat.

### 5.3.3 CWD Transects

On the CWD transects, each piece of downed wood ≥ 5 inches diameter at the point of intersection with the transect will be tallied, and the diameter, decay class, species (if possible), and whether it is suspended above the ground at the point where the transect crosses it recorded. The length of each piece (to the point where it becomes <5 inches in diameter, breaks, or is buried) will be estimated. These data will allow us to calculate volume of dead wood, evaluate the wildlife habitat, monitor successional trends through time, and evaluate the processes associated with dead wood.

### 5.3.4 Shrub Transects

Along each shrub transect shrubs will be identified to species and measured to the nearest centimeter. Gaps in foliage of <3 cm will be ignored. Documenting species presence and the amount of area covered by each species allows us to evaluate amount of light penetration, nutrient and moisture availability, wildlife habitat, and monitor successional and structural processes through time.

### 5.3.5 Belt Transects

All saplings will be counted by species by category (1) 6in-4.5ft; (2) >4.5ft 1-3in dbh; (3) >4.5 ft 3-5in dbh. Average height of each sapling category will be estimated. Amount and survival of tree regeneration is critical in monitoring successional development and evaluating a site for restoration, as well as documenting the natural regeneration process. In addition, percent cover and average height of vine maple will be estimated by cover class over the belt transect (Appendix I Table 1). These data also contribute to information about trends in forest succession and structure.

### 5.3.6 Herb Plots

In the Herb Plots, all forbs, grasses, ferns, sub-shrubs, sedges and mosses will be identified to species, if possible. Cover classes used (<1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-95%, >95%) are a combination of those developed by Daubenmire (1968) and Kuchler and Zonneveld (1988). These classes allow us to characterize both sparse and abundant plant cover, while having broad enough categories to provide reliable repeatability among observers, since it is unlikely that the same observers will be making measurements from one sampling interval to the next. Percent cover by mineral soil, bare rock, and duff will also be estimated by cover class. Total percent cover can be >100% due to overlapping foliage. Tree seedlings $\leq$6 inches in height (dead or alive) will be counted by species. Use of the data are similar to shrub data, allowing us to evaluate environmental conditions, wildlife habitat, and monitor successional and structural development.

#### *5.3.7 Specialty Measurements*

The team proposes that specialty measurements, including soils, fungi, cryptogams, insects, canopy communities, and specific habitats and habitat use, be measured on all PSPs (Appendix I Table 1). If funding does not permit this level of sampling, then these variables should be sampled at an appropriate subsample of the PSPs. Methods of measurement will be developed in conjunction with appropriate experts, but will use standard methods for the specialty.

### 5.4 Re-Sampling Of PSPs

One of the major benefits of PSPs is the ability to precisely track change over time, via re-sampling. Sampling intervals can vary depending on the age of the forest; for example, younger forests (<50 years old) should likely be re-measured at shorter intervals than old-growth forest, because significant changes are expected in young forests over a shorter time period when compared to changes in old-growth. A reasonable re-measurement interval for young forests could be in the range of every 5 to 10 years, while a reasonable re-measurement interval for older stands could be in the range of every 10 to 20 years. We do not anticipate that the PSPs will be resampled frequently enough to cause vegetation damage, and resultant “wearing out” of the plots.

Navigation to the PSP for re-sampling will follow the same procedure as for initial establishment. If the permanent Carsonite post or any plot or reference flagging is missing or damaged, it will be replaced. All plot sizes initially established will be used on subsequent re-sampling, and all previously described sampling protocols will be used. Biological, but not physical, variables (Appendix I Table 1) will be re-sampled.

On the Tree Plot, any newly recruited or missed trees will be permanently tagged and numbered. The plot will be inspected and trees on the border re-checked to ensure they really are in the plot and weren’t incorrectly marked during the initial establishment. The tree data collected on the previous visit should be consulted. If the diameter of a tree is smaller or much larger than would be expected, then an increment bore will be taken. If the height is shorter than previously recorded and there is no damage to the tree top, a note about an initial error in measurement will be made. If a previously numbered live tree is now dead, that will be noted, and appropriate snag measurements made. Attempts will be made to measure herbaceous vegetation at each PSP at approximately the same phenological point in the year when it was previously measured, so that more accurate estimates of changes can be made.

## 6.0 DATA MANAGEMENT

The value and utility of this effort will largely be lost if the data and field notes are not well managed and the database in which they reside not well designed. In particular this includes linking nested plots, multiple dates, spatial location, and archiving of field notes. The data itself and the construction of the database constitute infrastructure, a necessary element for staff to do their work. Additionally the cost of data input and management need to be integrated into overall cost estimates.

### 6.1 Database Design

The City of Seattle standard for geoprocessing software (ArcGIS) has recently evolved to integrate with high-end databases, including Oracle. This integration allows the power of relational database technology to be leveraged in the design and implementation of the PSPs and related databases. In particular nested plots measured multiple times can be modeled in a relational database. This can then be linked to a known spatial location to support mapping and spatial queries.

The first critical step has been completed as each sample location has a known location and unique name. This name will act as a primary key to all related information. A series of tables will be required to store observations, whether they are trees, shrubs, herbs, or physical conditions. Data will be available via the web for generating maps of each PSP and related information. Field data will be entered directly into tables that are already linked to the map of locations, which will allow the database to be reviewed as soon as field data are entered.

Underlying the data management aspect of the project is the Information Framework being developed by the Seattle Public Utilities Watershed Management Division (WMD). This effort is constructing a common vocabulary with explicit definitions for sampling methods, field protocols, and data elements. The data dictionaries will be documented and accessible via *ShedCat*, a web-based catalog of information and resources pertinent to the WMD.

These data management efforts will benefit from, and help inform, the implementation and management of PSPs and related data. Capturing metadata, or data about data, will utilize accepted standards developed by the Federal Geographic Data Committee, International Standards Organization and Dublin Core Metadata Initiative. The sampling methods outlined here lend themselves to the specification and documenting of variables and their domains. Advances in web services and related technologies such as XML and SOAP (technologies currently used within ArcGIS) offer opportunities for serving these data and related findings over the web to stakeholders and other interested parties.

Making sampling protocols explicit, conducting field pilot studies, and seeking to standardize protocols to the degree possible will all be important to data quality. Using predefined lists of values will also bring consistency to data entry. The use of data loggers may also be incorporated to minimize the need to re-enter data from field notes.

The computer systems used for this effort are currently well supported. We have a Unix server running Oracle 9.2, ArcGIS 8.2 and with a stripped and mirrored raid array for disk storage. Backups of the data are done daily and tapes regularly stored off-site.

### 6.2 PSPs as a Framework for Other Field Data Collections

In addition to synthesizing the collection, analysis and retrieval of a long-term data set, the PSPs also provide a framework for the organization, integration and analysis of other field data. Over 70,000 inventory points, each covering an area of 1.16 acres, have been generated and are uniquely identified based on proximity to the PSPs (see Section 4.3). While not intended as part of the PSP sampling design, the existence of these points create a dense set of 'known locations' to which other observations and field data can be referenced. This will facilitate data access and query by associating a unique key to each of these locations, and associating field data with such a key value or identifier. Similarly, these data can be associated with the PSP in closest proximity. In this way a diverse set of queries can be supported (e.g., 'Show me all field data collected within the area, regardless of the project or study for which it was collected’). Of even more significance is the fact that this densified set of points provides a set that can be used in designing subsequent sampling designs, such as a riparian study, or a characterization of special habitats.

This set of known ‘inventory’ points also supports the use of GPS equipment to navigate to predetermined, or pre-selected, sampling locations. This has the advantages of facilitating repeated visits and of not needing to take a straight line from point to point in order to navigate to the location.

The intention is to store field data in ‘flat’ files (a file format that creates an ASCII format metadata file and a binary file containing the actual data) and to construct tools that facilitate access and use. Preliminary database design has been completed, and the variables identified in Appendix I and Section 5 have been incorporated and provisions made for location and time variables. It is important that these data be easily accessible in order to run models, perform analysis, and generate maps.

# 7.0 COST ESTIMATES

## 7.1 PSP Installation and Initial Data Collection

PSP installation will occur with dedicated staff or a contractor, whichever is deemed to be the most economic and efficient. It is anticipated that a team of three people can access, install, and collect initial data for one PSP in an eight-hour day. The PSP initial data collection will involve 44 variables (six physical and 38 biological variables, Appendix I Table 1). An additional 15 variables may be sampled on either all or a subset of the PSPs, and are anticipated to require experts to perform the measurements. The first 103 plots would take approximately 2,472 person hours. If a contractor is used at an assumed cost of $60 per hour per person, the approximate cost would be $148,000. If staff are used, it would simply involve prioritization of PSP installation among other job tasks, but no additional funding. Equipment costs are negligible (rebar, Carsonite, flagging, tags).

There are a variety of contributing factors that drive the expense of PSPs. Some of these variables include accessibility, complexity of the sampling at each plot, seasonality, and available expertise. Initial measurements do not include cryptogam, fungus, insect, soil, or canopy community surveys, or specific habitat components or habitat use, which will incur additional costs. We recommend sampling all of these variables at every PSP. If funding is limited, however, these specialized data could be collected at a random sub-sample of each classified habitat type identified by the more comprehensive vegetation and remote sensing data. Future re-sampling costs are anticipated to be less, because the installation time would not need to be repeated, and the physical attributes would not need to be re-sampled. Costs relating to information management, map production, and other support such as vehicle costs, would be incurred, but are not estimated here.

# 8.0 SUMMARY AND CONCLUSIONS

The Watershed Characterization ID team proposes to establish and measure a set of PSPs in the CRW that will:

- Support a suite of baseline characterization activities for the CRW that expresses the range of variation in the land base, vegetation composition, complexity and structure.
- Provide a long-term dataset for assessing changes and trends over time.
- Provide data for evaluating and understanding forest processes.
- Inform image classification efforts, both as training and validation sites.
- Provide an invaluable long-term dataset that can be used by current and future researchers.

The PSPs will provide the framework for long-term monitoring to assess changes in habitat condition and examine forest processes over the entire Watershed. The PSP infrastructure and core data will be invaluable for more specialized sampling to be conducted in later phases. Permanent Sample Plots also provide watershed-wide data, which will be used along with forest inventory data, for verification of remote sensing images, thus will provide a part of the needed data to develop a strategic upland restoration plan and select and prioritize upland forest restoration sites. Establishing a set of PSPs in the CRW is a keystone in both the Watershed Characterization and Monitoring projects and will provide benefits to the CRW for many decades.

The Watershed Characterization ID Team believes that it is important to begin installation and sampling of the PSPs in 2003, so that essential data will be available as soon as possible. It is important to obtain early baseline information for monitoring, especially in those habitats that are expected to change rapidly, and that will require frequent re-measurement. It is also important to characterize old-growth as soon as possible, as these reference data will be used in designing management interventions. While PSPs do not provide a complete sampling design that will address all the planning and monitoring needs of the WMD, they will provide an essential piece that it is advantageous to complete while other elements are being designed.

## 8.0 GLOSSARY

| | |
|---|---|
| Adaptive management | As applied in the CRW-HCP, the process of adaptive management is defined with three basic elements: (i) an initial operational decision or project design made in the face of uncertainty about the impacts of the action; (ii) monitoring and research to determine impacts of actions; and (iii) changes to operations or project design in response to new information. |
| ArCGIS | A suite of Geographic Information System (GIS) software tools currently in use at the Cedar River Watershed. |
| Attributes | A term commonly used in GIS development to describe a *condition* existing at a given location, over a specified distance or over a bounded area. |
| Biodiversity | Biological diversity; the combination and interactions of genetic diversity, species composition, and ecological diversity (including factors such as age, form, structure, and location) in a given place at a given time. |
| Canopy | The cover of branches and foliage formed collectively by the crowns of trees or other growth. Also used to describe layers of vegetation or foliage below the top layer of foliage in a forest, as when referring to the multi-layered canopies or multi-storied conditions typical of ecological old-growth forests. |
| Canopy closure | The degree to which the boles, branches, and foliage (canopy) block penetration of sunlight to the forest floor or obscures the sky; determined from measurements of density (percent closure) taken directly under the canopy. |
| Cedar River Watershed | An administrative unit of land owned by the City of Seattle for the purposes of providing a municipal water supply. The 90,546-acre municipal watershed within the upper part of the Cedar River Basin lies upstream from the City's water intake at Landsburg Diversion Dam. It is composed of eight major subbasins and 27 subbasins, 26 of which drain into the Cedar River. It supplies about 2/3 of the drinking water to Seattle Public Utilities' water service area. |
| Co-dominant Trees | Trees with crowns receiving full light from above, but comparatively little from the sides. Crowns usually form the general level of the canopy. |
| Competitive exclusion | A phase in which the canopy closes and competition among trees becomes intense in a developing stand. Also sometimes called stem exclusion. |
| Condition | Measures or series of measures that qualitatively or quantitatively characterize habitat components. Encompasses the physical, compositional and structural properties of habitat. |
| Diameter at breast height (dbh) | The diameter of a tree, including bark, measured 4.5 ft above the ground on the uphill side of the tree and measured in inches. |

| | |
|---|---|
| Disturbance | Significant change in forest structure or composition through natural events (such as fire, flood, wind, earthquake, or disease) or human-caused events (forest management). |
| Dominant Trees | Trees with crowns receiving full light from above and partly from the side; usually larger than the average trees or shrubs in the stand, with crowns that extend above the general level of the canopy and that are well developed but possibly somewhat crowded on the sides. A dominant tree is one which generally stands head and shoulders above all other trees in its vicinity. |
| Epicormic Branching | Epicormic branches are small sprout-type limbs that originate from dormant or adventitious buds. They can develop on Douglas-fir tree stems as the canopy opens. |
| Even-aged forest | A forest with minimal differences in age, generally less than 10 years, between trees. |
| Extent | The location, dimensions, area, shape and boundaries of a set of habitat patches. |
| Forest Stand | A group of trees that possess sufficient uniformity in composition, structure, age, spatial arrangement, or condition to distinguish them from adjacent groups of trees. Also referred to as stand. |
| Forest succession | The sequential change in composition, abundance, and patterns of species that occurs as a forest matures after an event in which most of the trees are removed. The sequence of biological communities in a succession is called a sere, and the communities are called seral stages. |
| Habitat | The sum total of environmental conditions of a specific place occupied by plant or animal species or a population of such species. A species may require or use more than one type of habitat to complete its life cycle. |
| Habitat Conservation Plan (HCP) | As defined under Section 10 of the federal Endangered Species Act, a plan required for issuance of an incidental take permit for a listed species. Called “conservation plans” under the Act, HCPs can address multiple species, both listed and unlisted, and can be long term. HCPs provide for the conservation of the species addressed, and provide certainty for permit applicants through an implementation agreement between the Secretary of the Interior or Secretary of Commerce and a non-federal entity. |
| Interior forest conditions | Forest conditions that are largely not affected by edge effects, which occur where large openings abut the forest. Edge effects that are know to occur in some areas include penetration of light and wind, temperature changes, and increased predator activity. Interior forest condition are achieved at sufficient distance from an edge so that edge effects are minimal. |
| Inventory Points | A grid of 70,000+ evenly spaced points across the CRW, with one point every 225 feet, or one per 1.2 acres. |

| | |
|---|---|
| Late-successional forest | Forest in the later stages of forest succession; the sequential change in composition, abundance, and patterns of species that occurs as a forest matures. As used in the CRW-HCP, refers to conifer forests 120-189 years of age. Characterized by increasing biodiversity and forest structure, such as a number of canopy layers, large amounts of coarse woody debris, light gaps (canopy openings), and developed understory vegetation. |
| LIDAR | Light Detection and Ranging sensors that record the height of a surface via rapidly pulsed laser systems. |
| Management prescriptions | A set of procedures designed to accomplish a specific management objective. |
| MASTER | *M*odis *ASTER* Simulator instrument. Airborne scanning sensor capable of collecting hyperspectral image data in 50 bands at a pixel size of 5 meters. |
| Metadata | Data that provide a succinct and standardized summary of the content and format of data. “Data about data”. |
| Monitoring | The process of collecting information to evaluate if objectives and anticipated results of a management plan are being realized or if implementation is proceeding as planned. This may include assessing the effects upon a species’ habitat. |
| Monumenting | Permanently marking a location (of the PSP). |
| Native species | Any wildlife species naturally occurring in a specific area of Washington for purposes of breeding, resting, or foraging, excluding introduced species not found historically in this state; defined by WAC 232-12-297. |
| Old-growth conditions | Conditions in older conifer forest stands, with vertical and horizontal structural attributes sufficient to maintain some or all of the ecological functions of natural “ecological old-growth” forest, which is typically at least 200 years old and often much older. |
| Old-growth forest | As used in the CRW-HCP, native unharvested conifer forest in the Cedar River Municipal Watershed that is at least 190 years of age, but which does not necessarily exhibit “ecological old-growth” conditions. |
| ORACLE | A suite of commercial software designed for storage, access and retrieval of data based upon a *Relational Database Management System* (RDBMS) model. |
| PDOP | *P*recision *D*ilution *O*f *P*osition. A value that is used to represent the average error present in a GPS location calculation as a consequence of the number and relative positions of the Space Vehicles used to calculate that location. |
| Permanent Sample Plots | Sample plots that are permanently marked and from which data are repeatedly collected over long periods of time. |
| Post-processing | A method used to refine the accuracy of locations measured in the field with portable GPS receivers that incorporates base station data from a network of local fixed GPS receivers. |

| | |
|---|---|
| Pre-commercial Thinning | Cutting trees from a young stand so that the remaining trees will have more room to grow to marketable size. Trees cut in a precommercial thinning have no commercial value and normally none of the felled trees are removed for utilization. The primary intent is to improve growth potential for the trees left after thinning. |
| Relational Database | A means of organization for databases used to describe a way of organizing and presenting information in a database so that the user perceives it as a set of tables |
| Restoration Thinning | A silvicultural intervention strategy applied in areas of young (usually 10 to 30 year-old) over-stocked forest with the intent of increasing biological diversity and wildlife habitat potential, accelerating the development of mature forest characteristics, and minimizing the amount of time a stand remains in the stem exclusion stage (a stage characterized by minimal light penetration and low biological diversity). Techniques for restoration thinning include cutting, girdling, or otherwise killing some trees in variable density thinning patterns, retaining a mix of species that is characteristic of natural site conditions, and leaving small gaps or openings characteristic of naturally regenerated forests that result from small natural disturbances such as wind or disease. |
| Road Decommissioning | Road Deconstruction; work on roads no longer to be used that leaves them in a condition suitable to control erosion and maintain water movement. Methods of decommissioning include removal of bridges, culverts, and fills in accordance with WAC 222-24-050. |
| Second-growth | Forest stands in the process of regrowth after an earlier cutting or disturbance. |
| Seral stage | A particular stage (ecological community) in a sere, or pattern of succession. As used in the CRW-HCP, applies to forest succession |
| Slope | A measure of the steepness of terrain, equal to the tangent of the angle of the average slope surface with the horizontal, expressed in percent. A 100 percent slope has an angle with the horizontal of 45 degrees, a 70% slope has an angle of 35 degrees, and a 30 percent slope has an angle of 17 degrees. |
| Snag | A standing dead tree. |
| Species | A unit of the biological classification system (taxonomic system) below the level of genus; a group of individual plants or animals (including subspecies and populations) that have common attributes and are capable of interbreeding. The federal Endangered Species Act defines species to include subspecies and any “distinct population segment” or “evolutionarily significant unit” of any species. |
| Stand | See forest stand. |
| Stratify | Grouping similar habitat types together. |

| | |
|---|---|
| Take | To harass, harm, pursue, hunt, wound, kill, trap, capture, or collect a federally listed threatened or endangered species, or to attempt to do so (ESA, Section 3[10]). Take is prohibited under federal law, except where authorized. Take may include disturbance of the listed species, nest, or habitat when disturbance is extensive enough to disrupt normal behavioral patterns for the species, although the affected individuals may not actually die. |
| UNIX | A trademark for a widely used computer operating system, developed in 1969 at AT&T Bell Laboratories, that can support multitasking in a multi-user environment. |
| Watershed | A basin contributing water, organic matter, dissolved nutrients, and sediments to a stream, lake, or ocean. As applied in the CRW-HCP, used to refer to the Cedar River Municipal Watershed above the Landsburg Diversion Dam and water intake, some of which does not drain into the Cedar River above the Landsburg water intake. |

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**Appendix I, Table 1. Variables to be measured at PSPs. See text for plot layout and discussion of which attributes to measure at each plot;**

Specific descriptions and category codes are provided in accompanying tables

| Measured Attribute | Justification, Utility | Methodology | Reference |
|---|---|---|---|
| **PHYSICAL - data obtained from ground measurements at PSP or GIS data** | | | |
| Slope | Plant species distribution; Slope stability; Ecological gradient(s); Management prescriptions; Physical parameter for variety of analysis | To be determined by GIS specialists; and measured with a Relaskop or clinometer. Measure maximum uphill and downhill slope from plot center and average the two measurements. Record slope to nearest 1%. | WADNR 1996 |
| Aspect | Plant species distribution; Microclimate; Management prescriptions; Physical parameter for variety of analysis | To be determined by GIS specialists and measured using a hand compass. Site in the direction of the maximum downhill slope at plot center. Read the direction in degrees azimuth and record the aspect to the nearest degree. | WADNR 1996 |
| Elevation | Plant species distribution; Microclimate; Ecological gradient(s); Management prescriptions; Physical parameter for variety of analysis | To be determined by GIS specialists | |
| Topographic Position | Hydrologic regimem; Plant species distribution variability with hydrologic influence; Management prescriptions; Animal distribution; | To be determined by GIS specialists and noted in field as category. Categories: 1)hydrological influenced, 2) valley bottom, 3) midslope, 4) ridge, 5) plane. Specific descriptions and codes provided in Table XX. | WADNR 1996 |
| Geology | Litho-topo process models; Stream channel classification; Animal distribution | To be determined by GIS specialists | |
| Site Class | Growing potential for a site; Restoration site selection (ecological thinning); Management prescriptions; | To be determined by forestry specialists | |
| **BIOLOGICAL - data obtained from ground measurements at PSP** | | | |
| **Site Characteriztion** | | | |
| Habitat type | Animal habitat characterization & distribution; | Place site in one of 4 categories: 1) forested, 2) non-forested wetland, 3) rock dominated, 4) meadow | |
| Canopy Closure | Restoration site selection (ecological & restoration thinning); Management prescriptions; Reference site characterization; Indicator of successional development; Surrogate for direct light readings; Light availability; Understory plant growth; Animal habitat characterization & distribution; | Measure amount of light penetrating to the ground using a spherical densiometer. | |
| Plant Diversity | Restoration site selection (ecological & restoration thinning); Management prescriptions; Reference site characterization; Indicator of successional development; | Record all plant species present in the Tree Plot | |
| **Live Trees ≥5.0 inches DBH** (Tree Plot) | | | |
| Plot size | Use to calculate tree density; Monitor forest development and succession | Record one of 3 plot sizes: 1) 1/10 ac, 2) 1/5 ac, 3) 4/10 ac | Henderson & Lesher 2002 |
| Number | Use to calculate tree density. Restoration site selection (ecological & restoration thinning; planting). Management prescriptions; Reference site characterization; Indicator of successional development; Carbon sequestration; Animal habitat characterization & distribution; ; | All trees ≥5.0 inches dbh in Tree Plot counted by species. | Henderson & Lesher 2002 |
| Species | Restoration site selection (ecological thinning; planting); Management prescriptions; Reference site characterization; Indicator of successional development; Animial habitat characterization & distribution; ; | Record to standard genus and species classifications. Species and codes provided in Appendix Table 2. | Henderson & Lesher 2002 |
| DBH | Restoration site selection (ecological & restoration thinning); Management prescriptions; Reference site characterization; Indicator of successional development; Carbon sequestration; Animal habitat characterization & distribution; ; | Measure diameter outside the bark (to nearest 0.1 inch - DNR) at 4.5 feet above the ground on the uphill side. Mark point on tree where dbh measured. Butt swell that extends up the stem 4.5 feet or more will require that diameter be measured at a point immediately above the swell where the stem resumes normal form. When a bole form irregularity occurs at the normal dbh point, field crews will adjust the point of measurements and note the circumstances in remarks. For any dbh not measured at 4.5 feet due to an irregularity, note the height at which it was measured, and explain the reason in remarks If tree is forked at or above 4.5 feet, measure as 1 tree immediately below swelling butt. If tree is forked below 4.5 feet and forks are ≥5.0 inches in diameter, measure as 2 trees, 2 feet above the beginning of the crotch. If all the forks are less than 5.0 inches diameter, record them as a single tree according to the procedures outlined for the trees <5.5 inches diameter and shrubs. Record the diameter of the largest fork and use it to define the tree size class. If trees have grown together, record as separate diameters. | BC 2001, Johnson 1998 |
| Stratum | Restoration site selection (ecological thinning); Management prescriptions; Reference site characterization; Indicator of vertical structure; Indicator of successional development; | Assign tree to one of 4 strata: A = Emergent, B = Main canopy, C = Middle canopy, D = Lower canopy. | Oliver and Larson 1996 |
| Crown Class | Restoration site selection (ecological thinning); Management prescriptions; Reference site characterization; Indicator of vertical structure; Indicator of successional development; | Assign tree to one of 5 crown classes: 1) Isolated 2) Dominant 3) Codominant 4) Intermediate 5) Overtopped. Trees of each crown class can be found in each stratum. See Appendix Table 4 for specific descriptions and codes. | Henderson & Lesher 2002, BC 2001 |
| Percent Live Crown | Restoration site selection (ecological thinning); Management prescriptions; Reference site characterization; Indicator of successional development; | Estimate the percent of the height of the tree that has a full live crown, to nearest 10%. | Henderson & Lesher 2002 |

| Measured Attribute | Justification, Utility | Methodology | Reference |
|---|---|---|---|
| Damage | Restoration site selection (ecological thinning); Management prescriptions; Reference site characterization; Indicator of successional development; Animal habitat characterization & distribution; | Place in category: 1) none; 2) Insect; 3) Disease; 4) Fire; 5) Weather; 6) Physical damage. See Appendix Table 3 for codes and specifics within each category. | Henderson & Lesher 2002 |
| Presence of mistletoe | Reference site characterization; Animal habitat characterization & distribution; Indicator of successional development; | Presence/Absence; If present, place in category: 1) None; 2) Light (≤50% of branches infected) 3) Heavy (>50% of branches infected) | Johnson 1998 |
| Epicormic Branching | Restoration site selection (ecological thinning); Reference site characterization; | Presence/Absence. | Mark Swanson, UW pers comm 2002 |
| Height to lowest epicormic branch | Restoration site selection (ecological thinning); Reference site characterization; | If epicormic branches are present, estimate distance from ground level at the base of the tree to the lowest epicormic branch. | Mark Swanson, UW pers comm 2002 |
| Tree Height | Restoration site selection (ecological thinning); Management prescriptions; Reference site characterization; Indicator of vertical structure; Indicator of successional development; Carbon sequestration; Animal habitat characterization & distribution; ; | Measure from ground level at base of tree to its highest point (to nearest foot). Measure three trees/stratum, with a minimum of five/plot. | WADNR 1996, Johnson 1998 |
| Height to Live Crown | Restoration site selection (ecological thinning); Reference site characterization; Indicator of vertible structure; Animal (e.g., spotted owl, goshawk) habitat characterization & distribution; | Measure from ground level on the uphill side of the base of the tree to the lowest whorl with three or more live branchs, continuous with the main crown (not counting epicormic branching) (to nearest foot). Must measure tree height in same tree. | Mark Swanson UW pers comm 2002, WADNR 1996, Henderson & Lesher 2002 |
| Age, Growth Rates | Growth rates; Restoration site selection (ecological thinning; planting); Management prescriptions; Reference site characterization; | Increment core trees, count the riings for age at dbh; measure the growth rings (to 0.05 inch) for the previous 10 and 20 years. | Henderson & Lesher 2002 |
| **Standing Dead Wood** (self-supporting, snags are >6' in height, stumps are <6') (Tree Plot) | | | |
| Number | Used for snag density calculations; Reference site characterization; Management prescriptions; Carbon sequestration; Nutrient availability; Soil development; Indicator of successional development; | All snags >5.0 inches diameter in Tree Plot counted by species. | Henderson & Lesher 2002 |
| Species | Reference site characterization; Animal habitat characterization & distribution; Historical reconstruction; | Record to standard genus and species classifications, if possible. | Henderson & Lesher 2002 |
| DBH | Reference site characterization; Management prescriptions; Carbon sequestration; Indicator of successional development; Nutrient availability; Soil development; Site potential indicator; Animal habitat characterization & distribution; Historical reconstruction; | Use same procedure as for live trees. Dead trees will have actual diameters recorded, with no adjustments made for minor irregularities. Do not reconstruct diameter to account for missing bark or rotten wood. If stump is >4.5 feet tall, measure diameter at top | BC 2001, Johnson 1998 |
| Height | Reference site characterization; Management prescriptions; Carbon sequestration; Animal habitat characterization & distribution; Historical reconstruction; Indicator of successional development; | Estimate from ground level at base of snag to its highest point. | WADNR 1996 |
| Decay class | Reference site characterization; Management prescriptions; Indicator of successional development; Nutrient availability; Soil development; Animal habitat characterization & distribution; Historical reconstruction; | Place into one of 5 decay classes. See Appendix Table 5 for complete description. | Cline 1980, Johnson 1998 |
| **Tall Shrubs (Vine Maple)** (Tree Plot) | | | |
| Species | Reference site characterization; Indicator for environmental site conditions (nutrients, moisture, light); Forage availability; Animal habitat characterization & distribution; | Tall shrub species are defined as vine maple | |
| Percent Cover | Reference site characterization; Indicator for environmental site conditions (nutrients, moisture, light); Indicator of successional development; Forage availability; Animal habitat characterization & distribution; | Place in percent cover categories using ocular estimate of percent cover by vine maple over the Belt Transect. Cover categories: <1%, 1-5%, 6-25%, 26-50%, 51-75%. 76-95%, 96-100% | Daubenmire 1968, Kuchler and Zonneveld 1988 |
| Average height | Reference site characterization; Indicator of vertical structure; Indicator of successional development; Animal habitat characterization & distribution; ; | Estimate average height of vine maple throughout the tree plot, to nearest foot. | |

| Measured Attribute | Justification, Utility | Methodology | Reference |
|---|---|---|---|
| **Downed Dead Wood** (not self-supporting) (CWD Transects) | | | |
| Species | Reference site characterization; Tree regeneration; Animal habitat characterization & distribution; Historical reconstruction; | Record to standard genus and species classifications, if possible | Henderson & Lesher 2002 |
| Diameter | Reference site characterization; Management prescriptions; Tree regeneration; Carbon sequestration; Indicator of successional development; Nutrient availability; Soil development; Animal habitat characterization & distribution; Historical reconstruction; | Measure diameter (to nearest inch) where transect crosses CWD piece, and the maximum and minimum (to 4 inches) at each end, measuring perpendicular to bole, using calipers. Measure only pieces $\geq$ 5 inches in diameter. | Harmon & Sexton 1996, Henderson & Lesher 2002 |
| Length | Reference site characterization; Management prescriptions; Tree regeneration; Carbon sequestration; Indicator of successional development; Nutrient availability; Soil development; Animal habitat characterization & distribution; Historical reconstruction; | Measure from area above surface organic layer of soil or base of log to point of abrupt physical change or discontinuity or to a point where the outside diameter is $\leq$5inches (to nearest foot) using a laser range-finder, tape, or by pacing. Breakage, advanced decomposition, branching, or buried by soil or organic layer will define the limits of a piece. | BC 2001, Johnson 1998 |
| Decay Class | Reference site characterization; Management prescriptions; Tree regeneration; Carbon sequestration; Indicator of successional development; Nutrient availability; Soil development; Animal habitat characterization & distribution; Historical reconstruction; | Place into one of 5 decay classes. See Appendix Table 6 for complete description. | Maser et al. 1988, Johnson 1998 |
| Suspended | Nutrient availability; Soil development; Animal habitat characterization & availability; | Place in one of 2 categories: 1) >50% of log suspended above ground; 2) $\geq$50 of log in contact with ground | |
| **Trees <5.0 inches DBH** (Sapling, Small Sapling, & Seedling Plots) | | | |
| Number | Reference site characterization; Management prescriptions; Indicator for environmental site conditions; Indicator of successional development; Forage availability; Animal habitat characterization & distribution; | Count number by species and category in the Belt Transect, and classify as live or dead. Categories: 1) 6 inches-4.5 feet tall. 2) >4.5 feet tall & 1-3 inches dbh. 3) >4.5 feet tall & 3-5" dbh. Count seedlings <6 inches tall in Herb Plots by species. | Henderson & Lesher 2002 |
| **Shrubs** (Shrub Plots) | | | |
| Measured cover by shrubs | Reference site characterization; Indicator for environmental site conditions (nutrients, moisture, light); Indicator of successional development; Forage availability; Animal habitat characterization & distribution; | Measure using line-intercept method by species (to nearest centimeter). See Appenidx Table 7 for species lists and codes. | Daubenmire 1968, Kuchler and Zonneveld 1988 |
| **Herbaceous Vegetation** (Herb Plots) | | | |
| Percent cover by grasses, forb, sedges, ferns, mosses | Reference site characterization; Indicator for environmental site conditions (nutrients, moisture, light); Indicator of successional development; Forage availability; Animal habitat characterization & distribution; | Place in percent cover categories using ocular estimate of percent cover to species whenever possible. See Appendix Table 9 for species, genera, and life form codes. Cover categories: <1%, 1-5%, 6-25%, 26-50%, 51-75%. 76-95%, 96-100% | Daubenmire 1968, Kuchler and Zonneveld 1988 |
| Percent cover by mineral soil | Reference site characterization; Availability for seed germination; Animal habitat characterization & distribution; | Place in percent cover categories using ocular estimate of bare mineral soil. Cover categories: <1%, 1-5%, 6-25%, 26-50%, 51-75%. 76-95%, 96-100% | Daubenmire 1968, Kuchler and Zonneveld 1988 |
| Percent cover by rock | Unavailable for rooting substrate; Animal habitat characterization & distribution; | Place in percent cover categories using ocular estimate of bare rock. Cover categories: <1%, 1-5%, 6-25%, 26-50%, 51-75%. 76-95%, 96-100% | Daubenmire 1968, Kuchler and Zonneveld 1988 |
| Percent cover by duff | Reference site characterization; Nutrient availability; Soil development; Animal habitat characterization & distribution; | Place in percent cover categories using ocular estimate of organic debris on mineral soil. Cover categories: <1%, 1-5%, 6-25%, 26-50%, 51-75%. 76-95%, 96-100% | Daubenmire 1968, Kuchler and Zonneveld 1988 |
| **Specialty Measurements (requires experts)** | | | |
| **Soils** | | | |

| Measured Attribute | Justification, Utility | Methodology | Reference |
|---|---|---|---|
| Soil Type | Indicator of site potential; | Use existing soil survey | Soil Conservation Service 1992 |
| Soil Profile | Indicator of site potential; | Document soil horizons and subordinate distinctions using vertical exposure (soil pits) | Brady 1990 |
| Soil Microbial Communities | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Biodiversity; | Methods to be developed by experts | |
| Soil Invertebrate Communities | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Biodiversity; | Methods to be developed by experts | |
| **Fungi** | | | |
| Species List | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Biodiversity; Forage availability; Animal habitat characterization & distribution; | Methods to be developed by experts | |
| Abundance | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Forage availability; Animal habitat characterization & distribution; | Methods to be developed by experts | |
| **Cryptogams** | | | |
| Species List | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Biodiversity; Forage availability; Animal habitat characterization & distribution; Ectomicorhizal association; | Methods to be developed by experts | |
| Abundance | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Forage availability; Animal habitat characterization & distribution; Environmental characteristic of site; Ectomicorhizal association; | Methods to be developed by experts | |
| **Insects** | | | |
| Species List | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Biodiversity; | Methods to be developed by experts | |
| Abundance | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development | Methods to be developed by experts | |
| **Canopy Communities** | | | |
| Species List | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; Biodiversity; | Methods to be developed by experts | |
| Abundance | Reference site characterization; Indicator for environmental site conditions; Indicator of successional development; | Methods to be developed by experts | |
| **Specific Habitat Components of Interest** | | | |
| Presence/Number of Platforms | Reference site characterization; Murrelet habitat distribution; Indicator of successional development; | Count number of areas on branches >6 inches in diameter at a height of >100 feet above the ground in the upper third of the canopy. | |
| **Habitat Use** | | | |
| Nest cavities | Reference site characterization; Animal characterization, distribution and habitat use; | Present/absent in live trees/snags in all trees/snags in fixed plot. If present, count number/tree or snag by category. (Categories to be provided.) | |
| Foraging Use | Reference site characterization; Animal distribution and habitat use; | Present/absent in live trees/snags in all trees/snags in fixed plot. If present, place in category (Categories to be provided) | |

**Appendix I, Table 2. Tree species and codes for PSPs**

| Code | Common Name | Genus | Species |
|---|---|---|---|
| **Conifer Species** | | | |
| CHNO | Alaska yellow cedar | Chamaecyparis | nootkatensis |
| PSME | Douglas-fir | Pseudotsuga | menziesii |
| PIEN | Engelmann spruce | Picea | engelmannii |
| ABGR | Grand fir | Abies | grandis |
| TSME | Mountain hemlock | Tsuga | mertensiana |
| ABPR | Noble fir | Abies | procera |
| ABAM | Pacific silver fir | Abies | amabilis |
| TABR | Pacific yew | Taxus | brevifolia |
| PISI | Sitka spruce | Picea | sitchensis |
| ABLA | Subalpine fir | Abies | lasiocarpa |
| TSHE | Western hemlock | Tsuga | heterophylla |
| THPL | Western red cedar | Thuja | plicata |
| PIMO | Western white pine | Pinus | monticola |
| | | | |
| **Hardwood Species** | | | |
| ACMA | Bigleaf maple | Acer | macrophyllum |
| PREM | Bitter cherry | Prunus | emarginata |
| POBA | Black cottonwood | Populus | balsamifera |
| RHPU | Cascara | Rhamnus | purshiana |
| MAFU | Crabapple | Malus | fusca |
| CONU | Dogwood | Cornus | nuttallii |
| CRDO | Black Hawthorn | Crataegus | douglasii |
| FRLA | Oregon ash | Fraxinus | latifolia |
| ARME | Pacific madrone | Arbutus | menziesii |
| BEPA | Paper birch | Betula | papyrifera |
| ALRU | Red alder | Alnus | rubra |
| SASI | Sitka willow | Salix | sitchensis |
| SALU | Pacific willow | Salix | lucida |
| SASC | Scouler's willow | Salix | scouleriana |
| SASP | Willow species | Salix | unknown |

**Appendix I, Table 3. Damage codes and descriptions for live trees >4.0 inches DBH.**

| Code | Name |
|---|---|
| **0** | **None** |
| **10** | **Insect** |
| 11 | Bark Beatles |
| 12 | Defoliators |
| **20** | **Disease** |
| 21 | White Pine Blister Rust |
| 22 | Rust or Canker |
| 23 | Conk |
| 24 | Visible interior rot |
| 25 | Root disease |
| 26 | Other disease |
| 27 | Heart or butt rot |
| **30** | **Fire** |
| **40** | **Weather** |
| 41 | Lightning |
| 42 | Wind |
| 43 | Frost Crack |
| 44 | Other weather |
| **50** | **Physical Damage** |
| 51 | Deformed top |
| 52 | Forked |
| 53 | Deformed stem |
| 53 | Dead top |
| 55 | Broken top |
| 56 | Excessive lean (>45 degrees) |

**Appendix I, Table 4.  Crown class codes and descriptions for live trees >4.0 inches DBH.**

| Code | Name | Description |
|---|---|---|
| Is | Isolated | Tree crowns receive full light from above and all sides.  Usually the general level of the canopy is not evident. |
| Do | Dominant | Trees with crowns that extend above the general level of the trees immediately around the measured trees. They are somewhat taller than the codominant trees, and have well-developed crowns, which may be somewhat crowded on the sides, receiving full light from above and partly from the side. |
| Co | Codominant | Trees with crowns forming the general level of the trees immediately around the measured trees. The crown is generally smaller than those of the dominant trees and is usually more crowded on the sides, receiving full light from above and little from the sides. |
| In | Intermediate | Trees with crowns below, but extending into, the general level of the trees immediately around the measured trees. The crowns are usually small and quite crowded on the sides, receiving little direct light from above but none from the sides. |
| Ov | Overtopped | Trees with crowns entirely below the general level of the trees around the measured trees, receiving no direct light either from above or from the sides. |

**Appendix I, Table 5.  Snag decay class descriptions for Dougals-fir.**
See accompanying graphic

| | Stage of Decay | | | | |
|---|---|---|---|---|---|
| **Snag Characteristic** | **I** | **II** | **III** | **IV** | **V** |
| Bark | Tight, Intact | 50% loose of missiong | 75% Missing | 75% Missing | 75%+ Missing |
| Limbs & Branches | All present | Few limbs, no fine branches | Limb stubs only | Few or no stubs | None |
| Top Breakage | May be present | May be present | ~1/3 | ~1/3 to 1/2 | ~1/2+ |
| Sapwood condition | Sound, incipient decay, hark, original color | Advanced decay, fibrous, firm to solft, light brown | Fibrous, solft, light to reddish brown | Cubical, soft reddish to dark brown | |
| Sapwood decay | None to incipient | None to incipient | None to 25% | 25%+ | 50%+ Advanced |
| Heartwood condition | Sound, hard, original color | Sound at base, incipient decay in outer edge of upper bole, hard, light to redish brown | Incipient decay at base, advanced decay throughtou upper bole, fibrous, hard to firm, reddish brown | Advanced decay at base, sloughing from upper bole, fibrous to cubical, soft, dark reddish brown | Sloughing, cubical, soft, dard brown, OR fibrous, very soft dard reddish brown, encased inhardened shell |
| Bole form | Intact | Intact | Mostly intact | Losing form, soft | Form mostly lost |

**Appenidx I, Table 6. Downed wood (CWD) decay class descriptions for Dougals-fir.**
See accompanying graphic

| | Stage of Decay | | | | |
|---|---|---|---|---|---|
| **Snag Characteristic** | **I** | **II** | **III** | **IV** | **V** |
| Bark | Intact | Intact | Trace | Absent | Absent |
| Twigs | Present | Absent | Absent | Absent | Absent |
| Texture | Intact | Intact to partially soft | Hard, large pieces | Soft, blocky pieces | Soft, powerdy |
| Shape | Round | Round | Round | Round to oval | Oval |
| Color of Wood | Original | Original | Original to faded | Light brown to faded or reddish brown | Faded to light yellow or gray, or red brown to dark brown |
| Portion of tree bole on ground | None; Tree elevated on supports | Parts touch; tree still elevated on supports, but sagging | Tree sagging near ground, or bole on ground | All of tree on ground, or partially below ground | All of tree on ground or below ground |
| Invading roots | None | None | In sapwood | In heartwood | In heartwood |

**Appenidx I, Table 7.  Shrub species and codes for PSPs**

| Code | Common Name | Genus | Species |
|---|---|---|---|
| **Common Shrubs** | | | |
| ACCI | Vine maple | Acer | circinatum |
| ALCR | Sitka alder | Alnus | crispa |
| ARUV | Kinnikinnick | Arctostaphylos | uva-ursi |
| COST | Red-osier dogwood | Cornus | stolonifera |
| CYSC | Scotts broom | Cytisus | scoparius |
| GASH | Salal | Gaultheria | shallon |
| HODI | Oceanspray | Holodiscus | discolor |
| JUCO | Common juniper | Juniperus | communis |
| MANE | Oregon grape | Mahonia | nervosa |
| OECE | Indian plum | Oemleria | cerasiformis |
| OPHO | Devils club | Oplopanax | horridus |
| RIBR | Stink currant | Ribes | bracteosum |
| RILA | Black gooseberry | Ribes | lacustre |
| RISA | Red flowering currant | Ribes | sanguineum |
| RIVI | Sticky currant | Ribes | viscosissimum |
| RUDI | Himalayan blackberry | Rubus | discolor |
| RULE | Blackcap | Rubus | leucodermis |
| RUPA | Thimbleberry | Rubus | parviflorus |
| RUSP | Salmonberry | Rubus | spectabilis |
| RUUR | Trailing blackberry | Rubus | ursinus |
| SARA | Red elderberry | Sambucus | racemosa |
| SOSI | Sitka mountain ash | Sorbus | sitchensis |
| SPDO | Hardhack | Spirea | douglasii |
| SYAL | Snowberry | Symphoricarpos | albus |
| VAME | Black huckleberry | Vaccinium | membranaceum |
| VAOV | Oval-leaved blueberry | Vaccinium | ovalifolium |
| VAPA | Red huckleberry | Vaccinium | parvifolium |
| RHPU | cascara | Rhamnus | purshiana |
| VAAL | Alaska blueberry | Vaccinium | alaskaense |
| COCO | beaked hazelnut | Corylus | cornuta |
| AMAL | Saskatoon, serviceberı | Amelanchier | alnifolia |
| MEFE | fool's huckelberry | Menziesia | ferruginea |
| | | | |
| **Common Ferns** | | | |
| ADPE | Maidenhair fern | Adiantum | pedatum |
| ATFI | Lady fern | Athyrium | filix-femina |
| BLSP | Deer fern | Blechnum | spicant |
| POGL | Licorice fern | Polypodium | glycyrrhiza |
| POMU | Sword fern | Polystichum | munitum |
| PTAQ | Bracken fern | Pteridium | aquilinum |
| GYDR | Oak fern | Gymnocarpium | dryopteris |

## Appendix I, Table 8. Calculated Variables

| Variable | Justification, Utility | Methodology | Reference |
|---|---|---|---|
| Length of Live Crown | Restoration site selection (ecological thinning); Reference site characterization; Indicator of successional development; Animal (e.g., spotted owl, goshawk) habitat characterization & distribution; | Use total height and height to crown measurements. Length of live crown = Total height - Height to crown | |
| Crown Ratio | Restoration site selection (ecological thinning); Reference site characterization; Indicator of successional development; Animal (e.g., spotted owl, goshawk) habitat characterization & distribution; | Use total height measurements and length of live crown calculation. Crown ratio = Length of live crown/Total height. This is a check of the percent live crown estimate. | Henderson & Lesher 2002 |
| Tree Density | Restoration site selection (ecological thinning); Reference site characterization; Indicator of successional development; Animal (e.g., spotted owl, goshawk) habitat characterization & distribution; | Number of trees/area of fixed plot | |
| Snag Density | Reference site characterization; Indicator of successional development; Animal (e.g., spotted owl, goshawk) habitat characterization & distribution; | Number of snags/area of fixed plot | |
| Growth Rate | Restoration site selection (ecological thinning); Indicator of successional development; | Width of tree rings | |

**Appendix II**
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