Cedar River Municipal Watershed

FOREST MANAGEMENT PLAN

2023

Seattle Public Utilities | Watershed Management Division

Seattle Public Utilities

Cedar River Municipal Watershed Forest Management Plan

Prepared by Seattle Public Utilities and
Triangle Associates

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Acknowledgments

Seattle Public Utilities gratefully acknowledges the dedication and hard work of the HCP Oversight Committee members, Water Line of Business staff, and consultants who contributed to the Cedar River Municipal Watershed Forest Management Plan. These individuals have put forth outstanding efforts and many dedicated hours to provide Seattle Public Utilities with a comprehensive plan for the protection and stewardship of the Cedar River Municipal Watershed forests into the future.

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Charlie Raines (Sierra Club), Bill Vogel (US Fish and Wildlife Service), Crystal Raymond (University of Washington), Dave Vales (Muckleshoot Indian Tribe), Jim Erckmann (Seattle Public Utilities retiree, public at large), Mike Middleton (Muckleshoot Indian Tribe), Richard Bigley (Washington Department of Natural Resources retiree) Tim Romanski (US Fish and Wildlife Service), and Jerry Franklin (University of Washington)

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University of Washington consultant that provided the decision model: Sándor Tóth (Associate Professor, Environmental and Forest Sciences)

This forest management plan was developed in response to concerns about climate change impacts and limited active management in the Cedar River Municipal Watershed, which were voiced during the programmatic review meeting of the HCP Oversight Committee in 2018.

Based on input and interest from HCP Oversight Committee members, I established a sub-committee representing diverse interests and expertise to develop a comprehensive science-based forest management plan for the Cedar River Municipal Watershed that incorporates a broader suite of goals and is flexible and adaptive, for recommendation to the HCP Oversight Committee and Parties.

This plan incorporates new and existing management goals to guide watershed forest management activities for the next 28 years, coordinates with other watershed management activities, and has obtained HCP Oversight Committee and SPU Executive support.

Thank you for supporting this process, trusting SPU Watershed Management Division with the protection and stewardship of watershed forests, and holding us accountable in the years to come.

In gratitude,

Amy LaBarge, SPU Watershed Management Director

Note on Key Terms:

Please refer to the Cedar River Habitat Conservation Plan and the Upland Forest Restoration Strategic Plan for a comprehensive glossary of terms used in this Forest Management Plan.

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1 Summary and Recommendations

1.1 Purpose

The Forest Management Plan (FMP) for the Cedar River Municipal Watershed is the guiding document for managing the upland forest ecosystems owned and managed by Seattle Public Utilities (SPU).

The FMP pursues the goals of the Cedar River Habitat Conservation Plan (HCP) and adds new management objectives based on recent reviews and recommendations.

The FMP is both a guidance document and a tool for involvement of stakeholders, regulators, and Tribes. The FMP analyzes trade-offs between management objectives and addresses concerns that stakeholders raised during the plan development process.

1.2 Summary

The FMP was developed by Water Line of Business staff in collaboration with a subcommittee of the Cedar River HCP Oversight Committee (OC). The subcommittee included representation from the HCP OC, US Fish and Wildlife Service, Muckleshoot Indian Tribe, Sierra Club, University of Washington Climate Impacts Group, Watershed Management Division staff, and SPU managers. The subcommittee had deep engagement in developing objectives, prioritizing actions, and reviewing recommendations. Technical support for multi-criteria decision making was provided by the University of Washington's School of Environmental & Forest Sciences.

The FMP is organized into four sections to accommodate different audiences:

- Background and Rationale
- Monitoring and Adaptive Management
- Planning
- Methods

The main goal of the FMP is to ensure the continuation of the goals and objectives of the HCP, support the primary use of the watershed as a municipal water source, and incorporate new goals identified in the 15-Year HCP Comprehensive Review (2016). The subsequent Conservation Measures Review (2018) proposed incorporating climate change impacts in management activities and identified the need to respond to Tribal concerns regarding ungulate habitat. Based on those recommendations, the FMP incorporates new goals, including adaptation to climate change, Tribal wildlife habitat concerns, and wildfire hazard management.

The FMP identifies the following goals:

Goal	Intent
Municipal Water Supply	Manage the forest ecosystem to maximize production of unfiltered high-quality source water for instream and municipal water supply.
HCP Wildlife Habitat	Protect and restore habitats of the species addressed in the HCP, in particular those listed species that use late-seral forest.
Climate Resilience	Improve ecological resilience in upland forests to recover from disturbance and adapt to changing climate conditions.
Ungulate Habitat	Maintain and improve ungulate habitat to address the Muckleshoot Indian Tribe's concerns about maintaining viable deer and elk populations.
Wildfire Risk Mitigation	Protect high-value watershed resources and assets by assessing wildfire risk and forest fuels hazard. Determine mitigation measures to minimize risk to water supply, infrastructure, and biological resources.

Table 1.1: Management goals for the Cedar River Municipal Watershed forest management plan.

Management objectives were identified for all forest units across the watershed to minimize trade-offs or negative impacts on HCP and primary use goals. Activities for new management objectives were prioritized in areas with less importance for HCP and water resources goals. Where synergy existed among objectives, actions that benefit multiple management objectives were elevated to increase efficiency.

The Cedar River Municipal Watershed CRMW is managed primarily for source water supply. Developing mature and late-seral forests will benefit water supply by improving the water cycle regulation of upland forests. The FMP prioritizes maintaining forest cover on unstable hillslopes over other management objectives to minimize erosion and maintain water quality. In addition, young dense forests in upper catchments were selected for thinning to improve snow water storage and improve wetland hydrology.

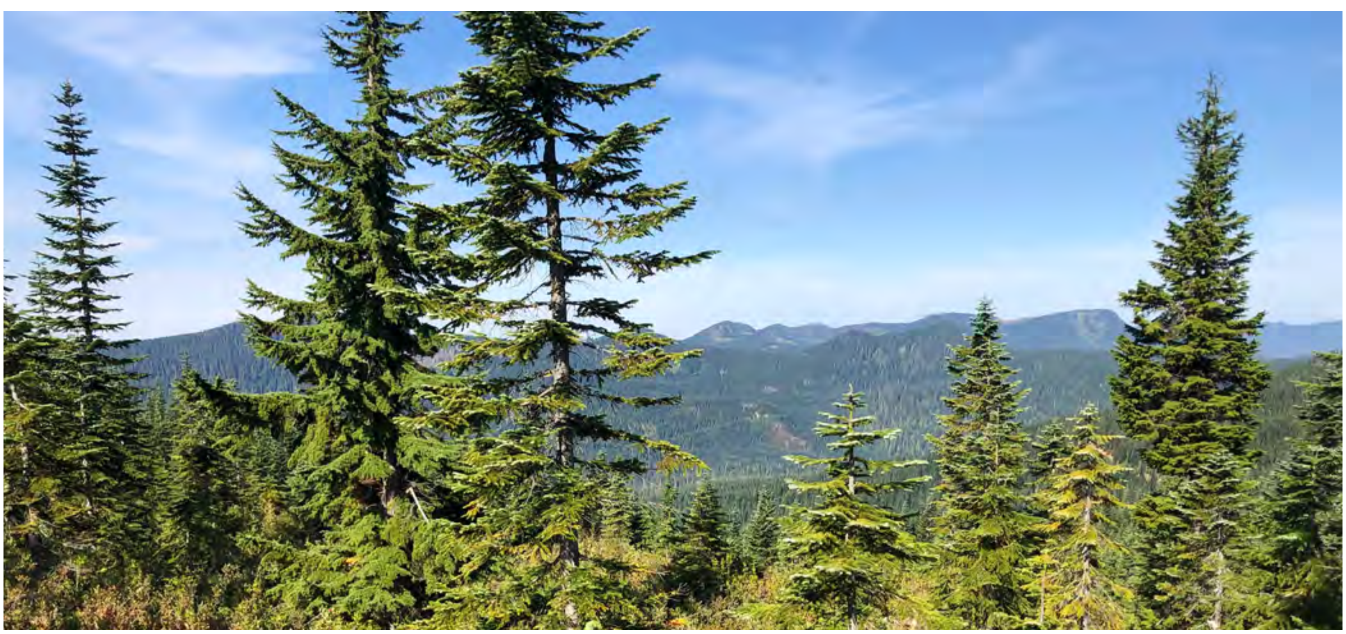
Overall, the FMP emphasizes natural processes for forest recovery and plans active management to meet specific objectives. About 35% of the watershed's upland forests will be managed as reserves, including all old-growth and mature second-growth forest, where no active management will occur. Active management under the FMP is planned on 3,874 acres, or 4.4% of the watershed's upland forest, over 28 years. The remaining second-growth forest, 61% of the upland forest, will be managed without active intervention to develop late-seral forest habitat over time. However, applying adaptive management implies that the approach, location, and extent of active and passive management may change in the future if the proposed methods do not meet long-term management objectives or if changes to management are required to protect the watershed from catastrophic damage.

Climate change already impacts long-term forest development in parts of the watershed. To ensure long-term habitat for species of concern, the FMP prioritizes areas for forest habitat development that will be less impacted by climate change. In forests with declining tree vigor and mortality from drought, insect, and disease impacts, the FMP prioritizes climate adaptation by recommending planting trees that are adapted to dryer and warmer climate conditions.

To address Tribal concerns about deer and elk populations, active management for ungulate habitat was proposed in young forests that have less habitat value for species that depend on late-seral forest habitat. These sites were proposed in areas that would not further fragment patches of older forest. Thinning and canopy gap creation will improve ungulate forage quality, increase the vegetative cover of culturally important plants such as huckleberry, and support other wildlife species that depend on early-seral habitat.

Wildfire is an important risk factor for watershed management and municipal water supply. The FMP prioritizes reducing wildfire fuel hazards to improve suppression around critical built assets. Creating defensible space around assets by reducing wildfire fuels is a widely applied approach to protect critical assets. Wildfire fuels reduction in priority areas such as ridge tops and watershed boundaries will also be implemented with thinning projects for other objectives. Additional mitigation measures to reduce wildfire fuels hazard may be adopted based on the results of the ongoing Wildfire Risk Analysis. The Wildlife Risk Analysis is assessing wildfire impacts on water quality and how wildfire risk may be changing with longer, warmer dry seasons. Any additional mitigation measures to reduce wildfire fuels will be incorporated in an FMP review process.

To ensure the greatest value from investment in active forest management, the FMP ranks the management actions by their importance and likelihood of achieving a given objective. The selection of management actions and balance among objectives was achieved using a multi-criteria optimization model, which was developed in collaboration with the University of Washington. The modeling results were presented to the subcommittee in multiple stages, which provided feedback that was incorporated into planning and recommendations.



The FMP continues to emphasize passive restoration for developing late-seral forest habitat as proposed for most of the watershed's forests in the HCP. We expected that most second-growth forest in the watershed will develop into a landscape dominated by late-seral forest habitat. However, some forests are likely to deviate from this trajectory due to disturbance and changing climate conditions. Active thinning to promote late-seral habitat development will reduce fragmentation of existing habitat and promotes understory plant development, which is beneficial for many wildlife species, including ungulates.

Thinning projects may involve cutting and removing trees to promote ecological and fuel hazard objectives. These projects are not designed as commercial timber harvests to generate revenue in keeping with the CRMW ecological reserve designation (HCP 2000; Ordinance 121040). The revenues from the sale of surplus timber will be deposited into the Water Fund to offset the costs associated with implementing the HCP and FMP.

The FMP specifies locations for active management for the first five years of the plan and includes an explicit monitoring and adaptive management approach. Active management is planned for 1,474 acres for the first five years, and 2,400 acres are proposed for active management in years six through 28. All forest management will be documented, monitored, and reviewed every five years to ensure cost-effective management meets the objectives of the plan or is adapted accordingly. Based on the cost and labor analysis in the FMP, the planned actions require additional funding and hiring a full-time position to conduct the work. The overall management horizon of this plan is the duration of the HCP (2050) or its extension. During this time, the FMP will undergo regular review, and modifications will require review and approval.

1.3 Recommendations

The following recommendations will enable the successful implementation of the planned activities:

- Continue managing CRMW forests under the HCP and incorporate new management objectives including climate resilience, ungulate habitat management, and wildfire risk mitigation.
- Approve the priorities and balance of active and passive management for forest management objectives outlined in the FMP, including monitoring and adaptive management.
- Actively manage upland forest for multiple objectives on 3,874 acres over 28 years.
- Approve an additional annual Operation & Maintenance budget of $213,000 for program administration, implementation, and monitoring for 28 years.
- Approve hiring of one additional Full Time Employee (Senior Environmental Analyst) for plan implementation based on the labor analysis in the FMP.
- Approve the sale of surplus timber from thinning projects and deposit the proceeds into the Water Fund to offset costs associated with implementing the HCP and FMP.

2 Background and Rationale

This section provides the rationale for the forest management objectives in the Forest Management Plan (FMP) for the Cedar River Municipal Watershed (CRMW). It shows which management goals were considered and why, and how specific objectives were developed to plan forest management activities. Each objective is supported by a rationale that underpins where management actions may be taken and what type of action would be appropriate. The FMP concludes with an Outcome Section, which describes candidate pools of map units where management actions are considered.

2.1 Motivation

A strategic approach for the Habitat Conservation Plan (HCP) upland forest restoration programs in the Cedar River Municipal Watershed was prepared in 2008. This strategic plan addressed the scientific rationale and operational approaches for implementing forest restoration programs. Most of the HCP forest restoration work outlined in this plan has been completed or is ongoing, but new management considerations have been raised to specifically address climate change and Tribal objectives. In response to the HCP Oversight Committee's (HCP OC) 15-year review of HCP implementation, Seattle Public Utilities (SPU) committed to review conservation measures considering climate change impacts. The review was completed in 2018, and recommendations were presented to the HCP OC. To address questions regarding the objectives and extent of forest management in the CRMW, SPU established a Forest Management Subcommittee to the HCP OC to develop an FMP. The subcommittee identified the following goals to be included in the FMP: HCP wildlife habitat, municipal source water supply, climate resilience, Tribal wildlife habitat concerns, and wildfire hazard management. The following sections review previous policy and management directives, vision, and goals that provide a basis for the subsequent analysis of rationale and guidance for management objectives.

2.2 Vision and Goals

Previous policy documents provide important guidance for developing goals for the FMP and are briefly reviewed here. The Secondary Use Policies (1989, Ordinance 114632) states that the primary goal for

CRMW management is to "ensure the supply of high-quality water without requiring additional treatment" by protecting the source of the Cedar River surface water supply. The secondary use goals for forest management included:

- Protect all existing species in the Cedar River Watershed
- Provide opportunities for education and research of the unique features in this large natural area
- Pursue habitat protection through acquisition and preservation
- Manage second growth forests on City-owned lands

After the passage of the Secondary Use Policies, the City successfully completed a land exchange with the United States Forest Service in 1996, which manifested the vision of nearly 100% City ownership of the CRMW. By 1999, the City had developed a draft HCP under the Endangered Species Act to provide regulatory certainty for the municipal water supply in the face of the Endangered Species Act requirements. The HCP reaffirmed most of the Secondary Use Policies and, after many Resolutions and public review of the HCP, ultimately replaced the "long-term timber harvest on designated City-owned second growth lands" with a focus on forest protection, restoration for fish and wildlife habitat, and biological diversity.

Upland forest habitat restoration is a key conservation measure of the Cedar River Watershed Habitat Conservation Plan. Approved in April 2000, the HCP designated the CRMW as an ecological reserve, which prohibits the commercial harvest of timber for purposes of generating revenue[1] and commits to conservation measures that are intended to restore or improve habitat for species covered by the HCP. Many of these species, such as the marbled murrelet and the northern spotted owl, depend on old-growth forest habitats to complete their life cycle.

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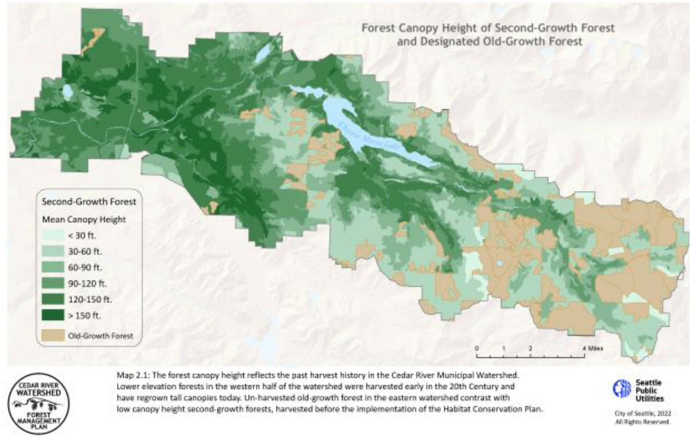
1 Regarding designation of the CRMW as an ecological reserve: "In response to the comments received during the public review of the Draft HCP in early 1999, the Mayor and City Council made a decision to forgo opportunities for revenues from a commercial timber harvest program in the municipal watershed and to commit to no timber harvest for commercial purposes in the watershed, effectively placing all watershed forests outside of developed areas in reserve status … The commitment in this HCP not to harvest timber for commercial purposes will be described hereafter as managing the watershed as an ecological reserve or the designation of forests outside developed areas to reserve status. … the commitment not to harvest timber for commercial purposes does not prevent the City from cutting trees to protect the drinking water supply, to provide drinking water and hydroelectric power, to meet ecological objectives, to protect the watershed from catastrophic damage, or for general administration of the watershed and management of its facilities. In short, the commitment does not in any way prevent the City from conducting operations and activities associated with water supply, hydroelectric power generation, watershed management, and general administration of the municipal watershed other than timber harvest for commercial purposes." (HCP 4.2-6-7)

Second-growth forests occupy lands that were logged prior to the adoption of the HCP and make up 71,500 acres of the CRMW. The remaining 15,000 acres are late-seral or old-growth forest (Map 2.1). Active forest management for the purpose of habitat restoration may only occur within the second-growth forest, as most old-growth forests are protected by deed restrictions or critical habitat designations[2]. The FMP describes forests in different stages of development using terms that relate to their condition in either structure (old-growth), process (late-seral), or history (primary forest). These terms are further defined in the Methods Section.



Click to view Map 2.1 full size in Supporting Information.

Over the 50-year term of the HCP, it is expected that most watershed forests will develop without further active management. However, goals for upland forest habitat restoration include facilitating the development of late-seral forest attributes in second-growth forest, improving habitat for species of concern that depend on late-seral forest, and reducing the risk of catastrophic disturbances that could threaten drinking water quality or habitat for species of concern.

The goals for HCP conservation measures for upland forests include (HCP-4.2):

- Develop an integrated, landscape approach that addresses the spatial relationship of habitats within the watershed and nearby areas to improve the ability of the watershed, over time, to support the species addressed by the HCP.
- Develop strategies to restore and sustain the natural processes that create and maintain key habitats for species addressed by the HCP and that foster natural biological diversity of native species and their communities.
- Pursue land management approaches that, as practicable, help avoid catastrophic events such

2 Regarding deed restrictions and critical habitat designations: "… in 1992, Congress directed an exchange between the City and USFS [United States Forest Service]. This exchange, completed in 1996, transferred to the City all of the federal land in the municipal watershed (nearly 17,000 acres), including many thousands of acres of old-growth forest. As a result of deed restrictions on the land exchanged to the City, the City cannot harvest timber on about 90 percent of the land acquired from the USFS. On the former federal land, no old growth can be harvested, and commercial timber harvest is not allowed on former federal lands within the northern spotted owl CHU [Critical Habitat Unit] in the eastern portion of the watershed (CHU WA-33: Fed. Reg. Vol. 57, Pp. 1796-1838), although some thinning can be done in second-growth forest under exceptions related to safety, water quality, and biological diversity." (HCP 4.2-5)

as forest fires that would jeopardize drinking water or habitats for species addressed by the HCP.

- Develop a forest management program that would sustain the forest ecosystem in the municipal watershed to better support the species addressed by the HCP over time.
- Protect existing old-growth forest in the municipal watershed and promote development of additional late-seral forest that will better support the native organisms, characteristic of late-seral and old-growth forest communities.

As a 50-year plan, the HCP is intended to be managed adaptively, informed by its monitoring and research programs, and changed circumstances, which were anticipated in the HCP and addressed therein. Global climate change and its potential impacts on watershed ecosystems and water quality were noted as an unforeseen circumstance, meaning that it was anticipated but not specifically planned for. Since the HCP 8-year Comprehensive Review (2010), the HCP OC has urged the City to incorporate climate change impacts into HCP implementation. In addition, in the more than two decades since HCP approval and implementation, the interests of the HCP OC's regional partners (including the Muckleshoot Indian Tribe and environmental stakeholders) have developed. Using adaptive management, the FMP incorporates a broader suite of objectives than are specifically addressed in the HCP forest restoration conservation measures and the ecological reserve designation.

The HCP indicates that "the City may prepare a companion Forest Management Plan for the Cedar River Municipal Watershed (CRMW) that is consistent with the final HCP" (HCP 2.3.12). An updated Forest Management Plan would "specif[y] goals for watershed management, including timber harvest, and prescribe[d] use of timber revenues. … the Forest Management Plan would be a regularly updated document with more detail on implementation for: (1) forest inventory, timber stand projections, and harvest scheduling (if appropriate); (2) protection of cultural resources during timber harvest; (3) the silvicultural program, including reforestation and thinning to restore and improve habitat; (4) harvest monitoring (if appropriate); and (5) program costs" (HCP 2.3.12). An adaptive management approach is included in this plan to address different levels of adapting implementation and management strategies for new management objectives.

2.3 Plan Structure

The FMP serves in multiple ways as a process to integrate new objectives into existing plans, a guidance document for adaptive forest management, and a rationale for programmatic approval of resource requests and allocations. The structure of the FMP is aligned with multiple purposes and audiences and has the following sections:

The Summary Section provides the purpose of the plan, summarizes the rationale about the purpose of this work, and lists recommendations.

The Background and Rationale Section identifies the vision and goals for the management plan, identifies specific objectives for each goal, and provides a rationale for each objective. The rationale for each goal concludes with a mapped pool of candidate units where management actions may be planned (candidate pool). This section shows current understanding of the scientific background and has had substantive input from and discussion in the FMP Subcommittee.

The Planning Section of the FMP provides guidance for Water Management Division (WMD) staff to implement the approaches outlined in the Background and Rationale Section. This section includes a five-year plan with specific project locations (i.e., in which analysis units should certain actions take place and when) and general prescriptions to prioritize actions and balance among objectives. The section also includes projections for management in years six through 28 of the plan and guidance on monitoring and data management.

The Adaptive Management and Monitoring Section describes the indicators that will be used to track forest ecosystem changes following active management, monitoring approach, and how monitoring will aid the adaptive management process for the FMP.

Much of the FMP development was supported by modeling of spatial attributes, multi-criteria decision making, and subcommittee input. These processes are described in the **Methods Section** of the plan and allow future managers to understand and reproduce the approach to make decisions in this complex socio-environmental system. This section has the technical information that was not included in other sections but is referenced where needed for in-depth understanding of the process.

Additional elements of forest management as indicated in the HCP are addressed in other planning documents. Forest inventory is addressed in the Research and Monitoring Review utilizing the Long-term Forest Monitoring and Forest Health Monitoring Programs. Protection of cultural resources during timber harvest is addressed in the existing Cultural Resource Management Plan.

2.4 Upland Forest Conditions

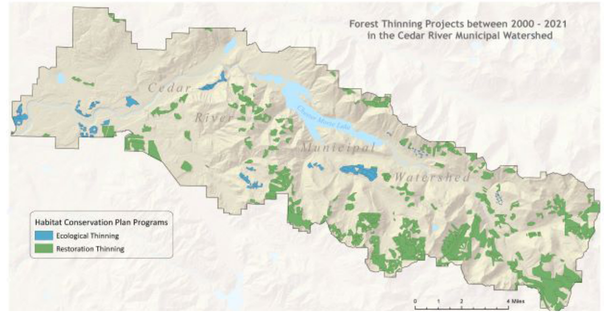
A prerequisite to forest management prioritization is understanding the current forest conditions. This section provides a high-level account of the state of watershed upland forest, updating previous work. The forest ecosystems of the watershed and their current conditions are described extensively in the Upland Forest Restoration Strategic Plan (2008). Updates on conditions and management programs are given in the Conservation Measures

Review (2018). The following section provides a brief update on forest conditions that are important to understanding the rationale for management objectives and approach to identifying management actions.

The development of forests in the watershed is best visualized using forest canopy height as a proxy for stand development (Map 2.1). Second-growth forest canopy height was derived from 2014 LiDAR data, showing a wide range of stand height in the watershed, depending largely on time since harvest, site quality, and interaction with natural disturbances. LiDAR data was used to identify analysis units of similar mean canopy height and further refined using topography and landscape features. The canopy height map shows the uneven distribution of forest stand development across the landscape. Most taller forests are found in lower elevations where the first historic harvests were conducted. Stands of smaller trees are predominantly found in higher elevations where the most recent even-aged harvests were conducted in the watershed. These younger stands are a stark contrast in structure, composition, and function to the remaining primary forest that was not harvested and is designated as old-growth forest.

Most of the forest stands in the watershed have increased in height and canopy cover since the first LiDAR inventory in 2003. Some forest stands show decreases in average canopy height and canopy cover due to natural disturbance and forest thinning. Wind throw, insects, and pathogens have created complex canopy structures in some stands at lower elevations. Few stand-replacing disturbances have occurred in the watershed during the past 20 years; those few disturbances include low and mid-elevation patchy wind throw, avalanches, and small-scale landslides. Some of the disturbance sites have been actively replanted with trees; others show natural tree regeneration or remain in an early-seral stage of vegetation development.

Most of the forests in the CRMW will develop late-seral forest habitat over time without human intervention. Older forest conditions consistent with the restoration goal of the plan would take a century or more to develop through natural disturbance and self-thinning of trees through competition. A landscape analysis of canopy structure using LiDAR (Kane et al. 2011) showed that development of a mosaic of complex canopy structures was the result of forests interacting with natural disturbances. SPU's strategic approach to achieving this goal across the watershed is to reduce human disturbance and to promote natural stand development processes in second-growth forests. In addition to this passive management approach, SPU WMD has conducted selective thinning of young forest stands in the watershed under the Restoration Thinning program, as well as Ecological Thinning of mid-aged stands to help facilitate the natural structural development processes. Map 2.2 shows the extent of Restoration and Ecological Thinning Program activities between the years 2000 and 2021. Most thinning occurred in upper elevation young stands to reduce stand density, reduce competition, and maintain understory species diversity. Many of those stands have again reached canopy closure. Thinning of trees in mid-aged stands (ecological thinning) was conducted to jump-start diversification of tree size classes and spatial arrangement to emulate older forest structures. Several thinning experiments have been conducted to investigate the understory and overstory response to gap and thinning treatments. In addition to thinning second-growth forests, SPU increased species diversity in second-growth forests under the Restoration Planting Program. Following thinning and creation of canopy gaps in older second-growth forests, site-appropriate understory species were planted to increase tree species diversity and facilitate development of vertical canopy structure. Forest development is being monitored using permanent sample plots, disturbance, and treatment effectiveness monitoring (e.g. HCP Monitoring Strategic Plan, 2008; HCP Monitoring and Research Review, 2017).



Click to view Map 2.2 full size in Supporting Information.

The following sections describe management goals guiding the FMP. The FMP addresses the silvicultural activities and passive forest management to achieve management objectives (HCP 2.3.12), monitoring of forest conditions and effectiveness of management activities, and program costs. These sections specifically address the questions of why the goals are important for watershed management and where within the watershed it is most important to meet them. Other sections address timeframe and implementation (Five-Year Plan), and measures of success (Monitoring and Adaptive Management).

2.5 Management Goals

The following five goals are addressed in this plan:

Table 2.1: Management goals for the Cedar River Municipal Watershed forest management plan.

Goal	Intent
Municipal Water Supply	Manage the forest ecosystem to maximize production of unfiltered high-quality source water for instream and municipal water supply.
HCP Wildlife Habitat	Protect and restore habitats of the species addressed in the HCP, in particular those listed species that use late-seral forest.
Climate Resilience	Improve ecological resilience in upland forests to recover from disturbance and adapt to changing climate conditions.
Ungulate Habitat	Maintain and improve ungulate habitat to address the Muckleshoot Indian Tribe's concerns about maintaining viable deer and elk populations.
Wildfire Risk Mitigation	Protect high-value watershed resources and assets by assessing wildfire risk and forest fuels hazard. Determine mitigation measures to minimize risk to water supply, infrastructure, and biological resources.

2.5.1 HCP Wildlife Habitat - Protect and restore habitats of wildlife species addressed in the HCP

Protecting and restoring the habitats of late-seral forest-dependent wildlife species is central to the Secondary Use Policies and the HCP. The HCP addresses 82 species of concern or those considered at risk (HCP 3.4 – 3.6), including those federally listed as threatened species: the northern spotted owl, marbled murrelet, chinook salmon, and bull trout. The conservation status of species listed under the Endangered Species Act is a result of habitat degradation or loss across their ranges, which the HCP addresses through habitat protection and restoration.[3] The HCP proposes multiple approaches for protecting, maintaining,

3 Note that the HCP Ordinance repealed certain Secondary Use policies: Ordinance 121040, Section 5. The Secondary Use Policies adopted by Ordinance 114632 relating to Timber Resources and numbered 6-5 through 6-12, are hereby repealed and sections 1 through 4 of this ordinance are hereby adopted in their place as Secondary Use Policies 6-5 through 6-8, respectively. To the extent that any other Secondary Use Policies adopted in 1989 by Ordinance 114632 conflict with the provisions of the HCP approved by Resolution 29977 in 2000, the provisions of the

and restoring habitat: protecting existing upland habitat from further commercial forestry disturbance, fostering natural processes that maintain habitat features, and restoring second-growth forest composition and structure to improve forest habitat and biodiversity. These approaches informed the following forest management objectives.

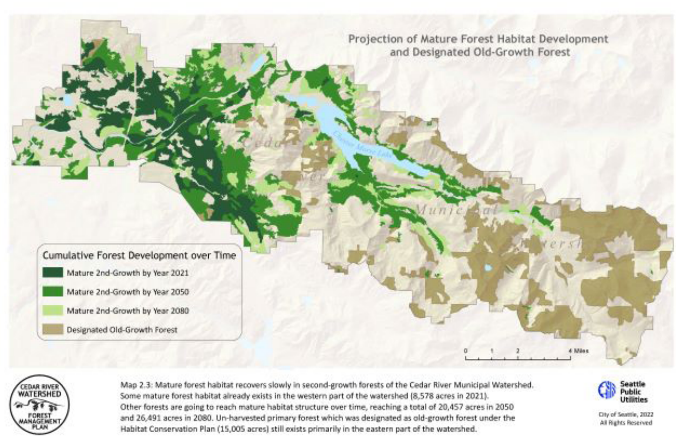
2.5.1a. Management Objectives

Based on the three primary habitat goals put forth in the HCP, corresponding FMP objectives have been identified to guide forest management and define expected management outcomes.

Table 2.2: Wildlife habitat goals of the Cedar River Habitat Conservation Plan and their corresponding forest management objectives.

HCP Wildlife Habitat Goals	Corresponding FM Objectives
Protect all existing old growth forest habitat.	Protect and maintain the existing primary forest habitat.
Restore late-seral forest habitat for species of concern.	Increase the total area of late-seral forest habitat through natural stand development processes in well-developed second-growth forests over the life of the HCP.
Maintain natural biological diversity of species and communities within the municipal watershed (HCP 4.1-114)	Promote species and structural diversification in second-growth forests with homogeneous structure and composition through forest restoration thinning and planting.

Protect all existing old-growth forest habitat (1). Many of the species listed under the HCP are dependent on, or thrive in, late-seral forest habitat (Map 2.3). The existing primary forest (previously not harvested) comprises the most functional old-growth forest habitat in the CRMW and includes old-growth forest characterized by large trees, multiple canopy layers, and large amounts of standing and down dead wood. Primary forest may also include forest with simple structural characteristics including single canopy layers, fewer dead trees, and old but smaller-size trees. Primary forests in the



Click here to see Map 2.3 full size in Supporting Information.

HCP shall prevail.

watershed will be excluded from active management under the FMP, fulfilling the objective to protect and maintain the existing primary forest habitat.

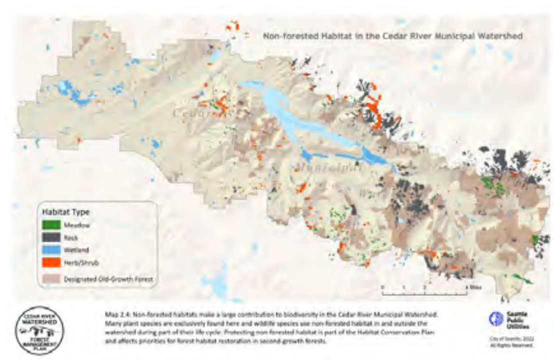
Restore late-seral forest habitat for species of concern (2). The forest management objective for species of concern is to increase the total area of late-seral forest habitat through natural stand development processes in well-developed second-growth forests. Forests develop habitat characteristics over time in a predictable series of developmental stages through interaction of forest growth and natural disturbance. Attributes of late-seral forest habitat structure that are important to wildlife species of concern include diverse tree species, large trees, multiple canopy layers, and dead and down wood. The development of these complex forest canopies depends in part on interaction with small-scale natural disturbances that kill or damage individual trees, or groups of trees, and redistribute growing space. At the landscape scale, recovery of late-seral forest habitat is primarily achieved through protection from timber harvest and development, while forest restoration activities facilitate forest development through thinning and planting. Many previously-harvested forest stands in the CRMW have already developed characteristics of late-seral forests and their internal processes such as growth, mortality, and diversification are likely to improve forest habitat over time. Forest stands growing in climate refugia with better soil moisture and low climate exposure will develop forest structure sooner than forests growing on exposed or low-productivity sites. The area of mid-seral second-growth forest that is starting to develop functional habitat for species dependent on late-seral forest conditions is projected to increase from 8,578 acres in 2021 to 26,491 acres in 2080 (Map 2.3). Indicators such as canopy height, canopy roughness, and canopy layers can be used to identify areas of advanced development and disturbance interaction, including thinning, that will be excluded from further active management to develop late-seral forest habitat through natural stand development.

Maintain natural biological diversity of species and communities (3). The forest management objective is to promote species and structural diversification in second growth forests with homogeneous structure and composition by thinning, gap creation, and planting in 20–80-year-old second-growth stands. Forest development following stand replacement disturbance or even-aged harvest can undergo phases of poor habitat functions and intense resource competition. Forest restoration activities are designed to improve the developmental pathways to late-seral forest habitat through bypassing competitive forest development processes and increasing biodiversity. Fostering biodiversity at the forest stand and landscape level are important elements of upland forest restoration under the HCP; creating a diverse mosaic of habitat types will benefit a broad list of species by supporting all life history stages, diverse habitat requirements, and a broad trophic network.

2.5.1b. Passive and Active Restoration Approach

Two categories of forests in the watershed provide the best functional late-seral habitat: existing primary forest (designated old-growth forest) and mature second-growth forest. Active management in primary forest is already restricted and mature second-growth forest (defined by canopy height, not age) is placed into reserve status with no active management under this plan. Map 2.3 shows primary and mature second-growth forest. To project natural forest development under the HCP and beyond, height growth development of forest stands was modeled using site index equations to show how much of the landscape would reach late-seral forest definition (mean canopy height/site index greater than 1.2) at the years 2050 and 2080. While the projection is conservative, it predicts a substantial increase of late-seral second-growth forest habitat in the watershed, expecting natural forest development over the next 30 to 60 years.

Key areas for restoration have been identified in the Landscape Synthesis Plan (2006) that benefit multiple habitat objectives and have been prioritized for activities, such as thinning and planting. These areas are identified through their proximity to existing old-growth forest, special habitats, and aquatic habitat, as well as connectivity corridors, which continue to be priorities for habitat development in this FMP. A similar approach is taken in the FMP with greater emphasis on upland forest habitat connectivity and climate vulnerability. To avoid disturbance at known nesting sites of sensitive species, the plan will place restrictions of certain activities in the vicinity of old-growth forest and other special habitats. Non-forested habitat, often created by edaphic conditions that are not suitable for tree growth, exist in the watershed and are being protected from management impacts. These habitats are often biodiversity hotspots, making a disproportional contribution to habitat and species diversity. Many wildlife species are associated with non-coniferous vegetation in the Pacific Northwest (Hagar 2007) and may benefit from increased plant species diversity. The FMP's objective in protecting these habitats is to maintain their current size and function, and where necessary create non-management buffers where planned actions may have impacts on habitat functions (see Map 2.4: Non-Forested Habitats).



Click here to view Map 2.4 in Supporting Information.

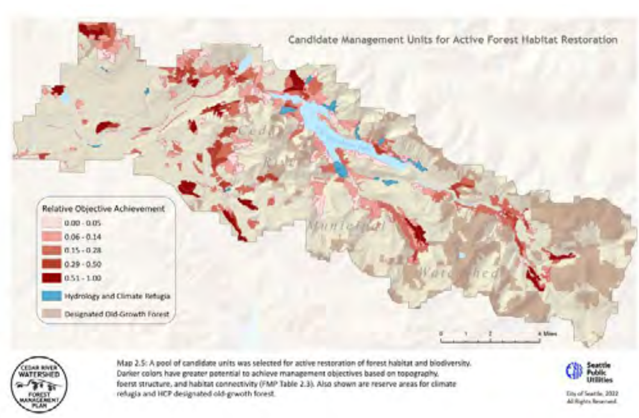
The protection of mid-seral forest in productive valley locations, also known as climate refugia (Morelli et al. 2016), is a high priority for increasing cover of late-seral forest habitat (Objective 2). The FMP assumes that forests growing on productive sites maintain growth and structural development to develop late-seral forest attributes in a shorter time frame than low-productivity sites (Larson at al 2008).

Active restoration of late-seral forest habitat will focus on areas that provide the greatest likelihood of meeting management objectives under changing climate conditions. Active intervention in the structural development of these forests through thinning and planting will be constrained to stands of intermediate tree sizes and closed canopy conditions where the development of multiple canopy layers could be facilitated to initiate vertical diversification and ecological resilience. Table 2.3 shows the criteria used to identify stands where active restoration of late-seral forest is most important (location) and where treatment is most effective (structure).

The long-term development of late-seral forest structures in second-growth forests can be promoted through an approach called "biodiversity pathways," aiming to maintain the biological diversity inherent in young regenerating forests (Carey and Curtis, 1996). Multiple pathways to the development of late-seral forest structures are possible depending on forest composition, site conditions, and disturbance regime. Those pathways that maintain increased biological diversity during early and mid-seral development stages also increase ecological resilience to disturbances and climate change. This approach is reflected in the objectives of the Ecological and Restoration Thinning programs of the HCP, which were designed to select for minor species, increase individual tree growth, introduce vertical and horizontal diversification, and maintain species diversity.

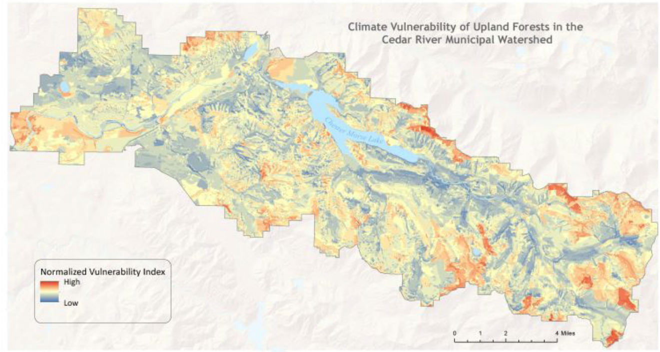
Practices that are outlined in the Upland Forest Strategic Plan will be applied to meet these objectives through active management. Restoration activities in these areas are aimed at increasing biological diversity and facilitating development of late-seral forest habitat attributes (canopy layers, dead wood, large trees, complexity). This work may include thinning dense forests to reduce competition for limited resources (e.g., Belmonte et al 2022), which is proposed for the development of late-seral forests. This approach can be applied to younger and mid-aged forest, as well as diverse and homogeneous forests, and aims to increase adaptive capacity.

A candidate pool of forest areas for these activities was defined by forest structural attributes and proximity to mature and old-growth forest (Objective 3). Map 2.5 shows the candidate pool for active management to facilitate development of late-seral forest habitat. We calculated an index of potential achievement towards the objective using stand attributes, operational area of each analysis unit, and relative unit location. Calculating potential achievement for each analysis unit and objective allowed us to prioritize management actions and balance effort and achievement among objectives. The selection of units for the first five years was made using a multi-criterial op-



Click here to view Map 2.5 full size in Supporting Information.

timization model for different budget scenarios. The model is further described in the Methods Section and the results are shown in the Planning Section. The spatial distribution of the candidate pool shows the preference for locations with higher productivity and connectivity to existing high functional habitat.



CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 2.7: Climate vulnerability of upland forests in the Cedar River Municipal Watershed was rated based on exposure, sensitivity, and adaptive capacity as part of the 2018 HCP Conservation Measures Review. Blue colors show forests with low climate vulnerability and red areas show forests with high climate vulnerability. We use climate vulnerability to identify forests for active cliamte adaptation (high vulnerability) as well as climate refugia and late-seral forest restoration (low vulnerability).

Seattle Public Utilities

Click here to view Map 2.7 full size in Supporting Information.

Some second-growth forests in lower elevations, growing on outwash gravel soil, experience extended summer drought and tree mortality due to pathogens and insects. Forests in these areas are unlikely to develop late-seral habitat conditions given the current species composition. These forests appear to undergo a shift in species composition towards dry, warm-adapted shrub and tree species and a lower, open canopy structure. In a similar way, regenerating forests on exposed ridgetops with shallow soils exhibit very slow tree growth, maintain an open character with deciduous understory, and are likely to experience increased summer water deficit in the future. These sites are likely to benefit species that depend on open and early-seral vegetation habitat. HCP goals for development of late-seral forest habitat may not be met in these forests. Management emphasis on these sites will be intended to maintain a diverse biological community that can adapt to a changing climate and maintain critical ecological functions such as habitat diversity and biological productivity (see Climate Resilience Objectives below). A candidate pool of forest areas for climate adaptation and resilience was defined by forest structural attributes and climate exposure as identified in the Upland Forest Vulnerability Assessment (see Map 2.7 for forest vulnerability). Forest managers have little experience with adapting forest composition and function in a changing climate. While existing practices to increase ecological resilience and reduce additional stressors can be applied, adapting species composition to changing climate conditions is largely untested and will require monitoring and testing.

The HCP habitat development objectives for previously harvested forests are “designed to restore structural and biological diversity to conditions similar to those that would be present as a result of certain types of natural disturbance and other natural processes. On the landscape level, these conservation measures will result in the following: (1) recruitment of substantial additional late-seral forest habitat through maturation and (2) acceleration of development of late successional forest characteristics through silvicultural interventions" (HCP 4.2-8). However, neither the HCP nor subsequent strategic plans identified the extent necessary of any habitat type to sustain at-risk populations, nor what balance or proportion of habitat types should be achieved. This lack of information led to an overly narrow interpretation of the HCP by only promoting development of late-seral forest habitat.

Forest ecology studies have pointed out the importance of habitat diversity (Carey and Curtis 1996, Swanson et al. 2011), including early-seral stages of forest development. A more recent focus on landscape level ecological resilience also supports a greater diversity of habitat types and stages to support biodiversity at the species level (Chambers et al. 2019). Landscape-level resilience indicators include habitat distribution and diversity, habitat connectivity, disturbance patterns, and adaptive capacity.

Because the HCP emphasizes species that are dependent on late-seral and old-growth forest, species that depend on early-seral habitat will receive relatively less benefit or may lose habitat under the HCP (Footnote HCP 4.2-10[4]). However, the assumption that mere focus on late-seral forest development will result in self-sustaining ecological communities at the landscape level misses the importance of resilience and trophic networks which build upon a mosaic of vegetation types, including complex early-seral vegetation. Complex early-seral habitat, including open forest habitat, make disproportional contributions to the overall species diversity and might be reduced on the managed-forest landscape through proactive reforestation practices (Swanson et al. 2011).

Photo Source: Triangle Associates

Map 2.1 shows the spatial distribution of old-growth and young open-forest habitat in the watershed. Low canopy height is an indicator for early-seral and open forest habitat which exists in the higher elevations of the watershed. Very few patches of this habitat exist in the lower-elevation forests.

The focus on developing late-seral forest does not preclude activities such as young forest thinning that promote species diversity and benefit species dependent on early-seral habitat. Considerable acreage of young forests exists in the watershed from pre-HCP forest harvesting, some of which exhibits high species diversity and important ecological functions (Campbell and Donato 2014). Early-seral vegetation is sometimes defined as pre-canopy closure vegetation following stand-replacing disturbance and includes abundant, co-dominant, short-statured broadleaf vegetation and abundant biological legacies or residual structures from pre-disturbance ecosystems (Swanson et al. 2011). Most of the young forests have been thinned under the Restoration Thinning Program of the HCP (Map 2.2) to have more open canopy conditions. Those stands growing on sites with greater site productivity are again approaching canopy closure while others exhibit slower tree growth, less canopy cover, and maintain greater species diversity. Under current and projected climate conditions, an extended period of early-seral forest vegetation is expected on lower-productivity sites that are impacted by extended summer drought and less snowpack under changing climate conditions. These sites make an important contribution to the overall ecosystem diversity and function and will also contribute to other management objectives such as ungulate forage habitat. Given the slow forest development on these sites, late-seral forest conditions are not expected to develop during this century, contributing to the landscape mosaic of forest vegetation types.

There are limited opportunities to create and maintain early-seral and open-forest habitat in lower elevations of the watershed. Windthrow events (1983, 2003) have created small open-canopy patches that have increased cover of early-seral shrub species. Canopy gaps created in ecological thinning projects have also created growing space for early-seral species, however, tree regeneration in many of these patches will suppress early-seral species over time.

The HCP foresaw a “significant increase in the amount of late successional forest” as the goal for the upland forest restoration program (see HCP Resource Maps 14 and 15). Measuring the success of this program over the lifetime of the HCP will be focused on identifying biological processes that will eventually lead to the development of individual attributes of late successional forests, due to the time required to develop such attributes. These processes include tree growth, mortality, regeneration, and succession. More detail on the indicators that will be monitored for this objective are provided in the Adaptive Management and Monitoring Section.

2.5.2 Forest Hydrology: Manage Forest ecosystems to sustain production of unfiltered high-quality source water for instream and municipal water resources.

The primary management goal for the CRMW is to manage the watershed for unfiltered high-quality source water for instream and municipal water supply. Forest ecosystems of the CRMW play a vital role in water cycle regulation affecting runoff and water storage. Forest structure and composition affect hydrologic processes such as infiltration, interception, and evapotranspiration, making forest cover the preferred land cover form for watershed management. Specific hydrologic objectives are explained below, including watershed yield, erosion, infiltration, and transpiration, and the resulting forest management objectives.

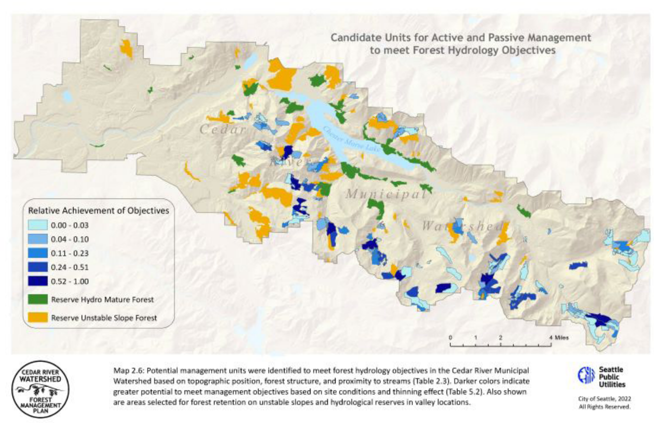
The hydrologic goals for CRMW forest management range from watershed scale to local stand and small catchment hydrology. The corresponding objectives focus on maintaining development of older forests, retaining canopy cover, and reducing canopy cover in young stands.

Table 2.4: Hydrology Goals of the Cedar River Municipal Watershed and their corresponding forest management objectives.

Hydrology Goals	Corresponding FM Objectives
Maintain watershed yield	Maintain and increase the amount of hydrologically mature forest older than 80-100 years.
Minimize surface erosion	Maintain forest cover in all areas that have been identified as unstable slopes. Minimize synchronized surface runoff from rain-on-snow events.
Increase water infiltration in forest soils	Promote the development of organic soil layers in second growth forests.
Maintain wetland hydrology in headwater catchments	Reduce canopy cover of young second-growth forests in headwater basins.

2.5.2a. Management Objectives

Maintain watershed yield (5). The primary forest management objective for forest hydrology at the landscape scale is to maintain and increase the amount of hydrologically mature forest older than 80-100 years. Our hydrology goals for forest management aim to regulate runoff and maintain watershed yield. The ability of forest canopies to intercept precipitation, limit surface erosion, and increase infiltration makes forest an ideal landcover for water cycle regulation. These functions differ with forest age, or time since forest harvest, and are highest in older, hydrologically mature forests. Research has shown that overall watershed yield (runoff) is inversely related to canopy cover (Bosch and Hewlett 1982), but peak flow and associated erosion have been shown to increase following forest removal (Jones and Grant 1996, Beschta et al. 2000). Due to rapid vegetation growth in western Cascade forests, increase in runoff associated with canopy removal is short lived, lasting five to 15 years (Coble et al. 2020), followed by a period of reduced runoff during the growing season, lasting possibly 60 to 80 years (Perry and Jones 2017). Conifer forests are expected to regain pre-disturbance runoff regulation after 80 to 100 years. The strategy to achieve this objective includes protecting primary forest and second-growth forest older than 80 years with mature forest structure growing in valley locations (Objective 5, Map 2.6).



Map 2.6: Potential management units were identified to meet forest hydrology objectives in the Cedar River Municipal Watershed based on topographic position, forest structure, and proximity to streams (Table 2.3). Darker colors indicate greater potential to meet management objectives based on site conditions and thinning effect (Table 5.2). Also shown are areas selected for forest retention on unstable slopes and hydrological reserves in valley locations.

Click here to view Map 2.6 full size in Supporting Information.

The secondary objective, at the scale of headwater catchments, is to reduce the effect of transpiration from young second-growth forests (20 to 80-year-old) on low flows (Bond et al 2002). Reduced water supply in catchments is of concern to wetland hydrology and in-stream habitat. Transpiration rates of young Douglas-fir can be two to three times higher than old-growth trees (Moore et al. 2004) on sites that provide ample soil moisture during the growing season, such as valley locations. In addition, modeling projections have shown that deficits in summer runoff from densely forested catchments can be mitigated by forest thinning for an additional 20 to 30 years (McKane et al. 2016). However, the extent of thinning, i.e., reducing canopy density, required to affect summer stream flows is substantial (greater than 50% reduction of leaf area index) and depends on catchment size and distribution of stand types (Saska et al. 2017). Hence, the overall effect of thinning on low flows is relatively small and is affected by variable summer precipitation (Kurzweil et al. 2021) and distribution of forest age classes. Therefore, reducing the effect of transpiration on water yield is a secondary objective of importance at catchment scale.

Minimize surface erosion (4). The forest management objective is to maintain forest cover and rooting in all areas that have been identified as unstable slopes. Soil erosion from forests that causes sedimentation of streams and reservoirs should be minimized. Forests play an important role in reducing surface runoff and associated erosion and sediment transport. Interception of precipitation through one or multiple canopy layers of foliage reduces surface erosion and increases infiltration into the soil. Forest litter and organic soil layers increase infiltration and water holding capacity. Extensive root structures also reduce soil movement. Reducing surface erosion is of particular importance on sites that have unstable surface geology and are prone to mass wasting and sediment transport, as well as in riparian areas. Maintaining canopy cover and active root structures is a commonly applied strategy to minimize surface erosion on these sites. The candidate pool for this objective (4) is shown on Map 2.6. Analysis units with more than 50% unstable slopes were selected to be reserved from active management. In areas with active management, best management practices for avoiding sediment delivery into streams will be implemented, and vegetation recovery will be facilitated to increase cover and rooting in disturbed sites to reduce surface flow and sediment delivery.

Increase water infiltration in forest soils. The forest management objective is to maintain and increase the amount of late-seral forest and to increase the development of organic soil layers in second-growth forests. Forest cover and litter layers also aid infiltration of precipitation, reduce soil evaporation, and increase of subsurface flows, which delay storm runoff and increase summer base flows. Litter and organic soil layers develop slowly over time, reaching a peak in mature and old-growth forest structures. The FMP assumes that managing for late-seral forest structures will increase infiltration rates. Management strategies would include avoiding large canopy openings (great than 10 acres), retaining slash and pulp wood in the forest from thinning, developing deciduous understory and overstory vegetation to increase litter decomposition, and maintaining forest productivity for litter input. The candidate pool for this objective (6) is shown on Map 2.6 together with Objective 7 where darker areas show higher achievement towards the objectives being possible through active management.

Maintain wetland hydrology in headwater catchments (6 and 7). The forest management objective is to reduce canopy density of young second-growth forests in headwater basins. Montane wetlands often represent only a small portion of the landscape but have been found to be important contributors to landscape-scale biodiversity. Because wetlands occur as small discrete patches in the matrix of montane conifer forests, their hydrology is closely linked to topography and forest hydrology. Transpiration and interception of precipitation by trees can reduce runoff by 10 to 50% depending on precipitation regime and evaporative demand (Coble et al. 2020). The effect also depends on the level of canopy removal and re-growth of vegetation. Given the focus on headwater catchments and slower growth rates at higher elevation, this effect is expected to last up to 20 years until ingrowth of trees increases transpiration and interception. Interception of snow through forest canopies reduces snow accumulation and melt and affects the snow duration (Dickerson-Lange et al. 2021) and hydrology of upper-elevation catchments. Canopy interception of snow is an important factor for snowpack accumulation and duration which can be managed by creating small canopy openings. Small canopy openings not only increase snow accumulation but also delay snow melt, potentially improving amphibian habitat in upper-elevation wetlands. Snow water storage can delay runoff and water supply to wetlands and affect breeding success of amphibians (Blaustein et al. 2010). Delayed snow melt timing is also advantageous for water supply management. However, the extent of canopy openings in a given catchment should be limited to avoid wide-spread simultaneous snow melt caused by rain-on-snow events, which can lead to channeled overland flow and soil erosion. Management actions towards this objective (7) include thinning young forests, creating clumped tree distribution and small canopy openings. This management approach may increase cover of understory vegetation and create co-benefits for ungulate forage objectives.

2.5.2b. Management Approach

Meeting the above objectives for long-term hydrologic regulation is important throughout the hydrographic area of the watershed. At the landscape scale, this goal will be met through continuous forest development and improving hydrologic functions over time. Approximately 1,700 acres of mature forest and valley locations have been identified for this objective (Map 2.6). In valley locations, with greater summer soil moisture availability and higher productivity, water loss through transpiration can be reduced by developing old forests with lower transpiration rates and deep, shaded canopies, which simultaneously provide late-successional forest habitat (Table 2.3). In contrast, watersheds with young forests or non-forest landcover types typically show higher and shorter duration peak flows which lead to increased scour and sedimentation. The long-term development of late-seral forest conditions also promotes development of soil organic layers and down wood that support infiltration. We will also retain slash from thinning in locations that do not conflict with fuel hazard mitigation for long-term soil development. Where possible, all pulp wood less than five inches in diameter and slash will be retained in the stand.

In upper-elevation catchments with moderate slope and deeper colluvial soils, reducing interception and transpiration by lowering canopy density can improve wetland hydrology. Previous projects in the Fish Creek, Lindsey, and Rex River Basins created 1,000 to 1,500 square foot canopy gaps around wetlands for snow accumulation and reduced canopy cover through restoration thinning. The FMP's approach will open canopy gaps on up to 5% of catchment area and thin dense conifer stands in up to 30% of catchment area to 50% canopy cover or less. Map 2.6 shows additional candidate areas in upper-elevation catchment areas where thinning and gap creation are considered.

Retaining forest cover in areas that are prone to surface erosion or have unstable slopes supports water quality objectives. Reducing fine sediment inputs, increasing bank stabilization, and increasing shading through forest cover are ongoing management objectives in riparian forests along streambanks. These efforts are especially important in the drainages downstream of the reservoir where turbidity resulting from a bank or slope failure can a have a major impact on surface water quality. Analysis units that have greater than 50% unstable slopes were excluded from active management unless forest disturbance reduces canopy cover and requires reforestation. Unstable slopes will be excluded from thinning and fuels management.

Recovering vegetation cover following stand-replacing disturbances is an important objective for managing surface water quality. While post-disturbance recovery can be facilitated through active restoration, managing for ecosystem resilience is also an important approach. Managing forests for diverse species composition and multiple age classes, as addressed in other management goals, creates greater resilience to impacts from natural disturbances and can help recover hydrologic functions sooner after disturbance. Mixed-species forests are less likely to lose the ecological functions during a species-specific disturbance such as insects or pathogens, and multi-aged forests require less time regenerating following a disturbance that kills overstory trees. Management actions designed for late-seral forest development or climate resilience have relevant long-term co-benefits for surface water quality (Maps 2.5 and 2.8). Thinning second-growth forests to promote species and structural diversity will improve the resilience of the forest to disturbance and climate impacts and eventually lead to stability of water cycle regulation function.

2.5.3 Climate Resilience - Improve ecological resilience in upland forests to improve recovery from disturbance and adapt to changing climate conditions

The overall goal of forest management in the watershed is to maintain ecological functions and provide ecosystem services. Following a century of forest harvest, the recovery of forest habitat became the goal of the HCP Forest Restoration Program (2000). The Conservation Measures Review 2018 added climate resilience as an important goal for watershed forest management, recognizing that ongoing climate change can move ecosystems outside their historic range of variability of structure and composition by changing climatic conditions. The FMP's approach to incorporating climate resilience in watershed forest management follows the approach of conservation, restoration, and transition towards novel conditions framework (Rissman at al. 2018; Millar et al. 2007). As outlined in the HCP Conservation Measures Review, the FMP's approach utilizes (1) conservation of existing and developing late-seral forest, (2) restoration of forest structure and composition to promote habitat development, and (3) transition of forests impacted by changing climate conditions to forest communities that are adapted to novel conditions.

The FMP's approach was based on a landscape scale vulnerability assessment of forest habitat, using climate exposure, ecosystem sensitivity, and adaptive capacity to differentiate forests by their vulnerability to maintain ecological functions. This approach emphasized the importance of topography for climate vulnerability to maintain functional resilience at the landscape level. The mosaic of ecosystem types and stages would maintain overall functions at the landscape level, while individual locations undergo changes in species composition and structure with temporarily reduced ecological function to adapt to new environmental conditions. Areas of high climatic exposure and ecosystem sensitivity are more likely to incur climate-driven mortality and altered forest development. The FMP prioritizes these areas for actively adapting species composition. Areas of low exposure and sensitivity, sometimes referred to as climate refugia, were prioritized to maintain current growth trajectories towards late successional forest habitat. Map 2.7 shows upland forest vulnerability based on climate exposure and ecosystem sensitivity. Higher vulnerability exists in low-elevation forests on droughty soils and upper-elevation south-facing ridges. Valley locations typically have lower vulnerability.

2.5.3a. Management Objectives

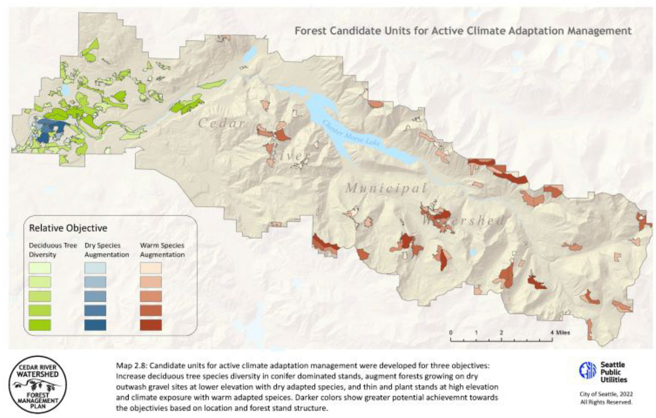
Maintaining ecological resilience at the landscape scale is aided by diversity across all scales of biological organization, from the landscape to the organism scale. The FMP's approach to improving ecological resilience, described in the HCP Conservation Measures Review, includes conservation of functional habitat in climate refugia and promoting recovery of habitat functions. The proposed activities below are aimed at the forest community at the stand and patch scale.

Table 2.5: Climate resilience goals of the Cedar River Municipal Watershed and their corresponding forest management objectives.

Climate Resilience Goals	Corresponding FMP Objectives
Increase biological diversity	Promote or augment the diversity of conifer species and genotypes to be better adapted to changing climate.
Promote adaptation of forests that are most vulnerable to climate change.	Augment existing tree species composition with warm/dry-adapted species.
Increase deciduous tree species	Maintain and increase deciduous tree numbers and cover in conifer-dominated second-growth forests.
Respond to Disturbance	Introduce pathogen-resistant and drought-tolerant tree species in areas with disturbance mortality.

Increase biological diversity (8). The forest management objective is to augment the diversity of conifer species and genotypes with those expected to be better adapted to future conditions in areas identified as having greater climate vulnerability on the landscape. Climate change has the potential to affect the recovery process by changing environmental conditions, productivity and trophic relations, disturbance thresholds, and species composition. While there is uncertainty about the frequency, extent, and severity of future disturbances, evidence suggests that disturbance and climate-driven mortality is changing regionwide (Van Mantgem et al. 2009). Although the biological response to climate change is uncertain, greater ecological diversity at all levels of biological organization increases the chances that some members of the community will be better adapted to future disturbance regime and environmental conditions and will maintain ecological functions such as late-seral forest habitat. Some parts of the forest ecosystem such as annual plants or animals with short generation turnover are likely to adapt better to disturbances and climate impacts. On the other hand, long-lived species such as conifers are more likely to be impacted by long-term changes in climate and disturbance regime. Thus, we focus on conifer species for improving climate resilience in meeting our long-term, late-seral forest habitat goals. In addition, there is uncertainty about ecosystem response in higher elevation forests to increasing temperature, higher carbon dioxide levels, loss of snow cover, and a shift in the growing season. While some species may experience an increase in productivity, others are likely to experience a maladaptation of their phenology or reduced vigor, be less competitive, and have greater susceptibility to disturbance agents.

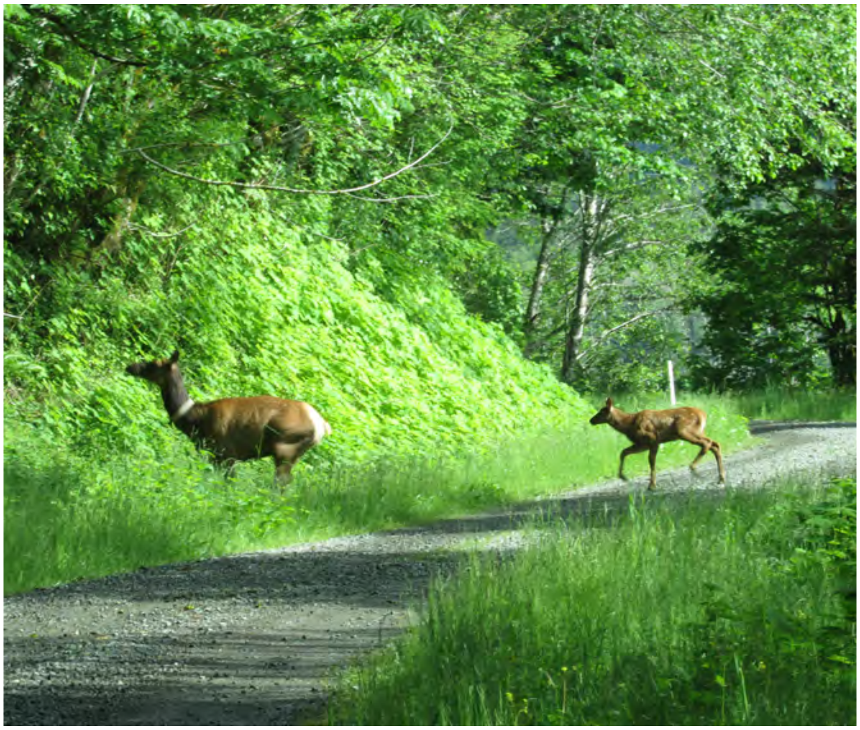
This management objective includes young forests in higher elevations, which have been previously thinned. The forest vulnerability assessment identified upper elevation young forests growing on shallow soils as being increasingly exposed to climate extremes and being sensitive to climate change due to their species composition (Map 2.7). The management objective in these higher elevation forests would be to augment the species composition with genotypes and species that are adapted to less snow cover and periodic summer drought conditions.



Click here to view Map 2.8 full size in Supporting Information.

Promote community adaptation in forests that are most vulnerable to climate change and disturbance (9). The forest management objective in lower elevation forests growing on droughty soils is to augment existing species composition with warm/dry-adapted species, either in existing canopy openings or by creating canopy gaps and introducing such species. Forests of greater climate vulnerability in the lower watershed, growing on drought-prone soils, are already undergoing loss of canopy cover and habitat function. They are expected to undergo a transition from their historical composition to a more warm/dry-adapted species composition. Insects and disease also contribute to loss of forest productivity and overstory mortality. Ungulate browse and seedling damage have also shown to complicate the establishment of alternative species in this area (Resilience Planting Trial, 2011). Future planting projects in this area will receive additional seedling protection. Transition to more resilient forest composition will require establishing species that are drought and pathogen tolerant while also providing ecological functions of water and nutrient cycle regulation, and habitat refugia. Although lower-elevation areas of the watershed are not expected to have a substantial increase in wildfire hazard with climate change (Halofsky et al. 2020), some increase in fire potential is expected with warmer, drier summer conditions. A climate-adapted forest community may also increase forest resilience to impacts from wildfire by reducing tree mortality. Map 2.8 shows areas identified for potential climate resilience management.

Increase deciduous cover (10). The objective is to maintain the existing deciduous forest cover and to increase the canopy cover of deciduous trees within conifer-dominated second-growth forests by thin-



ning, gap creation, and planting. Deciduous tree species such as alder, big leaf maple, cottonwood, cherry, and willow have a disproportionate effect on biodiversity in the region's conifer-dominated landscape. Deciduous tree species tend to have very different associations with insects and wildlife compared to dominant conifer species (Narango et al. 2020, Hagar 2007). Their contribution to ecological resilience is likely the widening of the trophic network in upland forest ecosystems, which increases the stability of ecological functions of the ecosystem. Mixed forests of conifers and deciduous trees appear to have greater resilience to drought (Pardos et al. 2021), which could help maintain ecological functions in a changing climate. While understory shrub and herb species have similar effects on ecosystem processes and resilience, management for overstory species is emphasized in the FMP because of the limited available data on the distribution of understory species and their recovery. Forest thinning, canopy gap creation, and planting have positive effects on establishment and propagation of shrub and herb species. Increase of deciduous cover has co-benefits for wildfire risk mitigation (Hely et al. 2000) and ungulate habitat as mentioned in Section 2.6.4.

Respond to Disturbance. The objective is to underplant pathogen-resistant and drought-tolerant species in areas of existing overstory mortality.

Disturbances such as wind throw, insects, fire, and landslides, are part of the natural forest dynamics and development of the forest landscape mosaic. Disturbances not only reset forest development, but small-scale disturbances are also part of the natural development of late-seral forest structures, and they create an opportunity for adapting species composition to changing environmental factors such as climate. While landscape-scale management aims to avoid large-scale disturbances which may cause loss of ecological function (e.g., hydrologic regulation, late-seral forest habitat), restoration activities often mimic the effects of small-scale disturbances, and can be an opportunity to introduce climate-adapted species in the forest community which may not have existing seed sources. The landscape template of management objectives (candidate pools) also provides guidance on how to respond to disturbances in different places within the watershed. The FMP will prioritize areas that were identified for climate adaptation actions to augment species composition with dry and warm adapted species or genotypes following a disturbance, while those areas identified for connectivity of late-seral forest development will be prioritized for developing and maintaining late-seral forest habitat attributes. Criteria for inclusion of analysis units in the candidate pool for active late-seral forest development included a low climate vulnerability score and a proximity to existing old-growth or mature forest.

Some conifer forests in the watershed are undergoing increased overstory tree mortality because of an existing insect/pathogen complex. Armillaria spp. root pathogens and Douglas-fir bark beetles have killed many overstory trees in the lower watershed, initiating vertical diversification of canopy structure. While this mortality is part of the forest development process, the extent of the disturbance and the response of the existing shade-tolerant understory may increase susceptibility to disturbance and climate change. Besides increase of deciduous species in the understory, regeneration is mostly of shade tolerant western hemlock, a species that is susceptible to Armillaria root pathogens and summer drought. Projections of Armillaria root disease and its host species under climate change show increasing maladaptation of host species in areas where the pathogen is well adapted, increasing the impacts of the pathogen on forest productivity and development (Kim et al. 2021). Future generations of Douglas-fir/hemlock forests are likely to undergo mortality events until alternative species become established that are more drought tolerant and resistant to root pathogens. The current disturbance mortality provides an opportunity to introduce species that are more resistant to root pathogens and have greater drought tolerance. While the disturbance complex described above is specific to lower-elevation Douglas-fir/hemlock forests, other climate-induced disturbance events are likely to develop in other forest types that would trigger a similar response to the disturbance.

2.5.3b. Management Approach

Adapting forest communities to increase ecological resilience does not indicate an intention to respond to every disturbance impact. Forest disturbances play an important role in ecosystem development, preservation of biodiversity, and ecosystem stability. They also initiate the natural transition of forest communities to adapt to changing climates by lessening community inertia of long-lived species (Jentsch and Beierkuhnlein 2003). Individual strategies are developed based on the current disturbance regime and climate change projections that have the potential to change the disturbance regime in the future. Small-scale disturbances are part of the development process to create late-seral forest habitat structure (Franklin et al. 2002). Medium-scale disturbances, including landslides, wind, forest insect and disease outbreaks, and wildfire that remove forest cover can lead to the establishment of new plant communities, aiding species migration and climate adaptation. While large-scale disturbances have a similar effect on plant community change, their effect on ecological functions such as water cycle regulation and habitat development are detrimental to FMP management goals. Hence, the importance of responding to disturbance depends on the intensity and scale of the disturbance and the existence of natural recovery processes. Increasing ecological resilience can either reduce the scale or severity of the disturbance or facilitate the recovery of ecological functions.

Planting climate-adapted species to augment the existing forest community will be an ongoing process that becomes more important where natural seed sources of adapted species are not present or where large disturbances have removed viable seed sources. In addition, the management approach will rely on natural processes such as establishment of early-seral species to aid the process of ecosystem recovery. Early seral species can rapidly colonize disturbed sites, limiting erosion and competing with non-native invasive species, and often change the environmental condition that enable establishment of long-lived late-seral species. If non-native invasive species cannot be controlled through natural processes, those species will be actively removed. Early-seral vegetation creates temporary forage habitat for ungulates which is unpredictable due to natural disturbance regimes. If large-scale disturbance creates areas of early-seral vegetation, active management of ungulate forage habitat may be reduced in the same area.

Climate adaptation of long-lived species adapted to stable conditions of late-seral forests is of particular concern to FMP management goals. Climate change is already moving many forest tree populations to outside the adapted climate envelope, causing maladaptation to environmental conditions (Atiken et al. 2008; St. Clair et al. 2020). Tree species migration due to ongoing climate change is expected to be slower than the changing climate (Hamann et al. 2015; Iverson et al. 2004; Zhu et al. 2012). The FMP's climate adaptation strategy includes augmenting the existing forest community with species and genotypes that are adapted to warmer and drier climate conditions (Williams and Dumroese 2013; O'Neill et al. 2017). Because this approach is relatively novel, planting of climate-adapted species and genotypes will be implemented at a small scale, augmenting the existing community rather than replacing it, and will be accompanied by planting trials. Warm/dry-adapted species that co-occur with Douglas-fir and western hemlock in the region should be considered for interplanting in existing forests, including western white pine, grand fir, Garry oak, and shore pine. Assisted migration within the extent of existing populations is considered for Douglas-fir, grand fir, bigleaf maple, western white pine, western redcedar, and noble fir. Northward extension of existing population zones is considered for incense cedar, white fir, sugar pine, and black oak. Other species may be considered as experience with assisted migration and climate adaptation develop over time. The introduction of any of the species to forest ecosystems is an ongoing discussion and exploration in the forest restoration community and should be done with caution and at small scale at first. SPU will collaborate with other forest landowners on these approaches and adapt as new information is developed.

2.5.4 Ungulate Habitat - Maintain and improve ungulate habitat to address the Muckleshoot Indian Tribe's concerns about maintaining viable deer and elk populations.

Tribal wildlife goals outlined in this plan are guided by the 2006 Settlement Agreement between the City of Seattle and the Muckleshoot Indian Tribe (MIT) and the resulting Draft Cooperative Plan. The objectives are further informed by wildlife management studies carried out by MIT since 2006 in the CRMW and the surrounding area, and other peer-reviewed literature on western ungulate ecology.

Elk and black-tailed deer, ungulate species managed by MIT for sustainable harvest, have declined from historic population highs in the CRMW. These declines have been driven by tree regeneration following the cessation of commercial logging. At present, the elk population in the CRMW is estimated to be stable or slightly declining, with 80 resident elk, as well as nonresident animals from the Yakima elk herd, North Bend, Landsburg, and other peripheral areas that make seasonal use of the watershed. Stabilizing the population would help ensure the sustainability of Tribal harvest. There are opportunities for the City of

Seattle, in collaboration with MIT, to improve habitat conditions for ungulates in the CRMW, as directed by the cooperative plan. The FMP's objectives target the resident elk herd and aims to positively affect deer and migratory elk.

Improving ungulate habitat conditions in the CRMW may have synergistic and cascading impacts on a suite of HCP species. Wolves and grizzly bears, absent from the watershed, are HCP-listed species of greatest conservation concern that rely on ungulates as a major component of their diet throughout their range. Wolf populations in Washington state are expanding into new areas, and wolves may make seasonal or year-round use of the watershed at some point if these trends continue, provided there are adequate elk and deer populations in the watershed to support them. Interior populations of grizzly bear also rely on ungulates, particularly in spring and fall. As is the case with wolves, robust ungulate populations are a necessity if grizzly bears are ever to naturally recolonize the watershed.

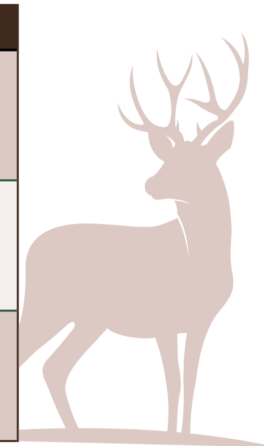
Huckleberry shrubs and other herbs and shrubs that are part of early-seral vegetation communities have responded positively to past forest thinning projects in the upper watershed and should increase in similar project areas that are proposed in this plan. Higher huckleberry density provides cultural benefits for MIT and habitat improvement for potential grizzly bears. Huckleberries, in concert with other plants that respond to canopy gaps and forest thinning, benefit rodents, which are prey to HCP species such as northern spotted owl and fisher, as well as many bird species. While clearcutting for resource extraction no longer occurs in the CRMW, diverse early-seral vegetation can be maintained for the express purpose of wildlife habitat through thinning and maintaining canopy gaps in young second-growth forests.

2.5.4a. Management Objectives

The following management objectives have been formulated to meet long-term management goals of improving ungulate habitat:

Table 2.6: Ungulate habitat goals for the Cedar River Municipal Watershed and their corresponding forest management objectives.

Ungulate Habitat Goals	Corresponding FM Objectives
Enhance summer forage in upper watershed	Reduce conifer canopy cover and increase forage plant biomass to enhance summer forage in the upper watershed.
Enhance forage in the lower watershed	Maintain existing hardwoods and increase understory forage by reducing conifer canopy cover at the stand scale through gap creation and thinning.
Maintain extreme winter weather refugia	Maintain dense coniferous canopy cover in areas that elk have used as a refuge in extreme winter weather events.



Enhance summer forage in upper watershed (11). In productive young forests, clumpy thinning and openings can maintain and increase the vegetative cover of grasses, herbs, and shrub species with high nutritional value for elk. This objective is focused in higher elevation areas where forests are unlikely to achieve old-growth characteristics within the next century, and in locations that may have received ungulate habitat treatments in the past. Elk tend to use the same areas for foraging year-to-year, making the approach of concentrating forage areas viable for supporting the resident elk population. Elk forage habitat should be located and maintained in existing known use areas. Projects will be located in areas that will not contribute to potential fragmentation of late-seral forest.

Enhance forage in the lower watershed (12). Forest thinning and canopy gaps in the lower watershed can improve forage availability for resident elk during winter. This objective is focused in areas of second-growth forest that are comparatively younger and with smaller trees compared to the mature second-growth stands of the lower watershed. Locating elk forage habitat in second-growth forests should be supported by information of existing use, existing hardwood cover, and sites that support growth of hardwood species. Existing hardwood trees will be retained, as they are associated with greater nutritional value relative to conifers at a landscape scale. These treatments will help provision understory shrubs and herbaceous plants for forage in both summer and winter. Projects will be in areas that will not contribute to potential fragmentation of late-seral forest.

Photo Source: Triangle Associates

Maintain extreme winter weather refugia (13). Dense conifer forest stands adjacent to Masonry Pool and along the north shore of Chester Morse Lake will be preserved. Elk are known to use these areas in winter, and retaining forest cover will preserve a thermal and snow refuge for resident elk and deer during extreme winter events. These stands, if passively managed, also hold value for water quality, mature forest habitat, and shoreline stability.

2.5.4b. Management Approach

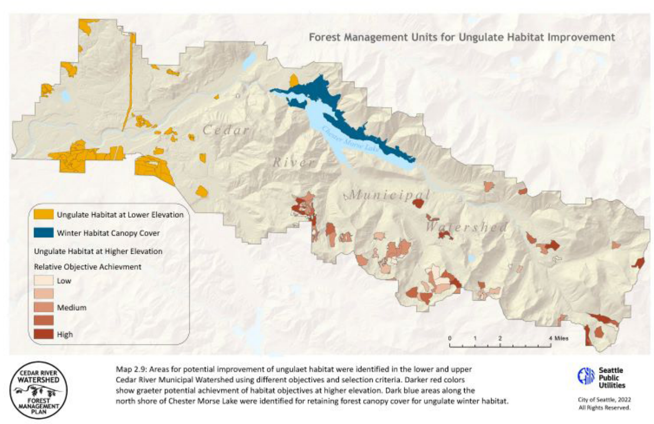
Ongoing MIT studies in the Cedar and White River drainages have identified key landscape factors of importance to elk and deer populations. Both species rely on early-seral vegetation communities, diverse hardwoods, and forb and graminoid meadows to meet their nutritional requirements (Vales et al. 2017). MIT research on local elk populations indicates that, at a landscape scale, areas with more canopy cover hold lower total digestible dietary energy (DDE) for elk and that elk select areas with higher DDE values (Rowland et al. 2018; Vales et al. 2017). Elk in the CRMW also select habitats closer to forest edges, farther from open roads, and positioned on lower slope angles (Rowland et al. 2018).

A major determining factor in population maintenance and growth of ungulates is their ability to store nutritional reserves as body fat (Cook et al. 2016; Parker, Barboza, and Gillingham 2009; Monteith et al. 2014). For elk on the west side of the Cascades, the availability of high-quality summer range ultimately determines those fat reserves (Cook et al. 2016). Therefore, improving summer range conditions should increase the nutritional carrying capacity of the watershed. Deciduous shrubs in forests and riparian areas also have nutritional value for elk and deer. While shrub cover is often highest in forest clearings, patches with scattered shrubs in a matrix of trees still have some habitat value. Map 2.9 shows areas in upper elevation basins with potential to manage for ungulate forage habitat.

Animals must be aware that habitat exists to make use of it. For example, research on deer and other ungulate species shows that migration routes are maternally transmitted and are not innate knowledge (Jakopak et al. 2019; Jesmer et al. 2018). This suggests that elk habitat improvements will be most effective in areas that elk already use. As a result, the FMP prioritizes habitat improvements and protections in areas of known use over areas that may not be regularly used by ungulates.

MIT conducts projects in collaboration with SPU through forest thinning and gap creation to improve ungulate forage opportunities in the CRMW. These actions mimic natural disturbance processes by decreasing the coniferous canopy cover, which increases grass, forb, and shrub cover. The forage benefits for ungulates from forest disturbance are realized for several years following the treatment, and the value of the treatment declines somewhat thereafter. As a result, repeated projects, or maintenance of existing gaps, are necessary to prevent net losses in habitat availability. Forest gaps need to be of sufficient size to allow adequate light penetration for forage plant growth, while also provisioning the edge habitat that ungulates can use to bed, thermoregulate, and escape predators. In the CRMW, ungulates preferentially select larger gaps (i.e., one to three acre) over small ones (i.e., 0.25 to 0.5 acre), presumably because of greater forage availability (M. Middleton and D. Vales pers. comm.).

Winter presents challenges for deer and elk, both from the reduced quality and abundance of forage, and the increased energy expenditures associated with snow depth. Ungulates can reduce the energetic costs of deep snow by moving to steeper terrain, south-facing slopes, or thicker forest canopies (Irwin 2002; Skovlin et al. 2002). Elk also seek lower elevations and thicker vegetative cover when air temperatures



Map 2.9: Areas for potential improvement of ungulaet habitat were identified in the lower and upper Cedar River Municipal Watershed using different objectives and selection criteria. Darker red colors show graeter potential achievment of habitat objectives at higher elevation. Dark blue areas along the north shore of Chester Morse Lake were identified for retaining forest canopy cover for ungulate winter habitat.

Click here to view Map 2.9 full size in Supporting Information.

approach their lower critical threshold of-4° F (Hudson et al. 2002). MIT wildlife studies have demonstrated the importance of forest near Masonry Pool and along the northern edge of Chester Morse Lake (Map 2.9) as a refuge for elk during extreme winter events.

The importance of elk habitat features was derived from elk use data and should guide the creation and maintenance of habitat. In addition to the forest thinning and creation of small gaps in the lower watershed, a three-acre gap will be created in each of two locations, identified by MIT biologists as being key areas to explicitly increase ungulate forage (Map 2.9). Though not currently forested, the Bonneville Power Administration powerline corridor will also be identified as an area managed for ungulate forage, and mechanical treatments and seeding to support graminoids should further bolster the habitat quality of the lower watershed for ungulates.

Creating canopy gaps and thinning in second-growth forests to achieve other forest management objectives could create a co-benefit that simultaneously improves ungulate forage. As a result, these treatments are considered as those that may hold co-benefits for elk and deer, and the relative co-benefit potential for a given stand will be used as a factor in prioritizing forest treatments. Co-benefits were considered where overlap of candidate pools existed for ungulate habitat and thinning for late-seral forest development (Objective 3), thinning and planting for climate resilience (Objectives 8 and 9), and thinning for forest hydrology (Objective 7). Co-benefits were estimated based on the amount of canopy openings created and potential response of understory development for ungulate forage. (See Section 5.1 for definitions of achievement and co-benefit.)

Stands thinned to meet ungulate objectives are intended to receive periodic maintenance to delay conifer canopy closure. This approach should ensure continued habitat benefit in areas of known habitat use. Periodic cutting of conifer regeneration will extend the nutritional benefits of forest treatments for elk, while enabling mature second growth forests to continue developing late-seral characteristics. Maintenance will be prioritized in treatment areas that have robust understory responses following treatment, and areas that receive ungulate use. Stands that provide a co-benefit to ungulates through different objectives will not be maintained.

2.5.5 Wildfire Risk Mitigation

Wildfire in the Cedar River Municipal Watershed poses a significant risk to the ability to reliably deliver drinking water to SPU customers and maintain function of watershed resources and assets. Wildfire risk mitigation was added as a management goal for the FMP following the Wildfire Risk Management Assessment (Triangle Associates, Inc. 2017). The SPU Watershed Management Division has conducted several analyses on wildfire in the past which cumulated in the ongoing Wildfire Risk Assessment (WRA). While the WRA takes a comprehensive approach to analyzing the risk wildfires pose to SPU's ability to provide municipal water supply by analyzing effects of wildfire and effectiveness of mitigation approaches, the FMP develops strategies to meet multiple management objectives, including fuel hazard mitigation.

2.5.5a Management Objectives

The goals for wildfire management in the CRMW are (1) maintain ability to reliably deliver drinking water, (2) limit harm to people, assets, and habitats, and (3) maintain ecosystem services and functions. Current wildfire management strategy is characterized by four objectives:

1. Prevention of ignitions through watershed access controls, adherence to fire precaution regulations, and operational best management practices.
2. Detection of wildfire starts through lightning detection mapping, regular watershed protection patrols, and smoke patrols.
3. Suppression of all fires through initial direct attack and mutual aid partnerships.
4. Recovery of ecosystem function and mitigation of negative impacts through post-wildfire treatments.

The wildfire management goals are strengthened by inclusion of the following objectives in this FMP:

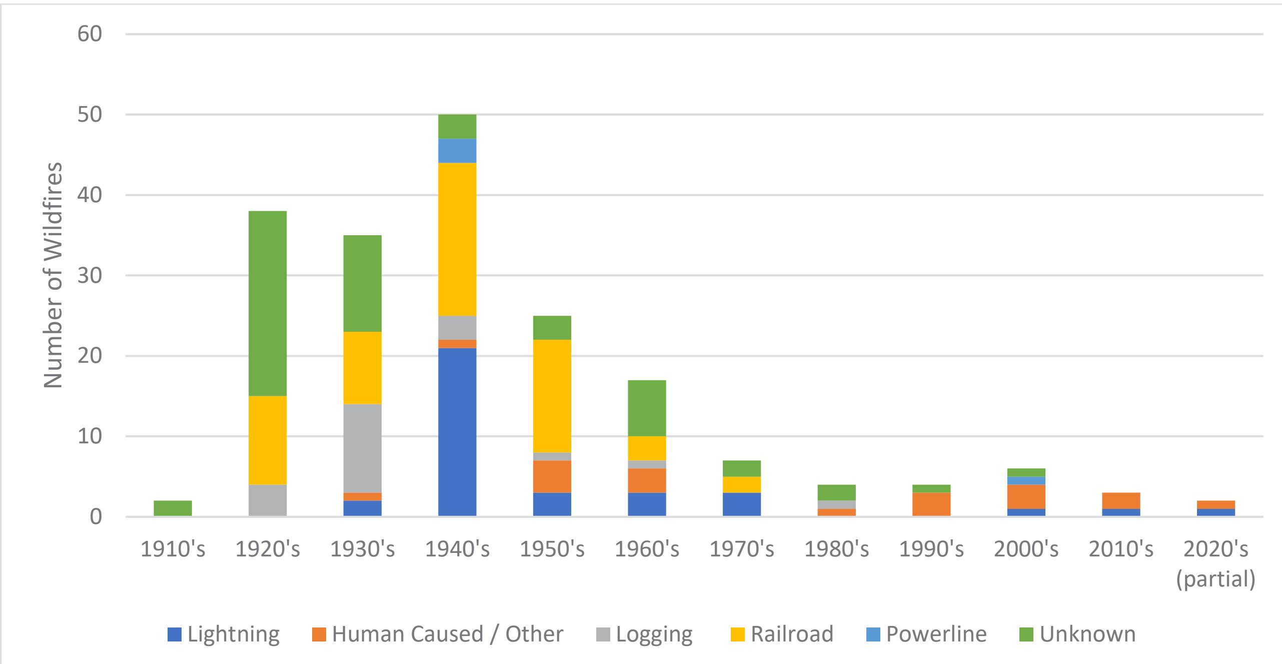
1. Mitigation of forest fuel hazards adjacent to watershed assets critical for continued SPU and SCL operations.
2. Mitigation of slash resulting from forest management actions for other objectives in locations with the greatest accomplishment of reducing wildfire risk.

The following section provides background on wildfire science and management in the western Cascades and outlines a rationale for creating defensible space for assets at risk.

Historic wildfire in the CRMW can be characterized as infrequent in occurrence, high severity (high tree mortality across large patches and establishment of new tree cohorts), and large in extent (Agee 1993). Research of historical fires occurring within the CRMW show sizeable wildfires in 1317, 1704 and 1772 (Figure 2.1, Henderson and Peter 1981). An accounting of wildfires in the CRMW since 1910 indicates a much larger number of wildfires in the first half of the 20th century and fewer in the second half of the

20th century and throughout the 21st century (Seattle Public Utilities 2022). Since 1989, wildfires have not exceeded two acres in size and there have been less than five fire occurrences per decade on average (Figure 2.2). Wildfires exceeded 10,000 acres in size during the early portion of 20th century when harvest practices created large areas with heavy wildfire fuels. Changing forest harvest practices from large harvest units with dense logging slash to smaller harvest units with active logging slash management lead to smaller and less frequent fires (Cedar River Watershed Commission 1944).

Figure 2.2: Recent history of documented wildfires within the Cedar River Municipal Watershed.



The largest western Washington/Oregon wildfires in the 20th century were driven by sustained dry, easterly winds (e.g., Yacolt Burn of 1902). Contemporary large wildfires in western Washington (e.g., Norse Peak of 2017 and Big Hollow of 2020) conform to the pattern of sustained dry, easterly winds being necessary for the occurrence of large, high-severity wildfires. Overall, in the western Cascades, weather is the dominant factor driving fire activity, while fuel distribution and topography are less important factors. Even within this high-severity, stand-replacing wildfire regime there exists variation in size, mortality, soil burn severity, frequency of occurrence, and secondary effects such as sediment delivery, regeneration, and habitat (Agee 1993).

Absent sustained dry, easterly winds, most western Washington wildfires are severe (high mortality) but do not experience rapid growth with extensive crown-fire activity. Flame lengths and rate of spread are considerably lower in the absence of sustained winds; fuel moisture and distribution, topography, and other weather factors contribute to fire activity.

With the current practice of wildfire suppression in western Cascade forests, two types of wildfires are likely to occur:

1. Small and slower-moving fires characterized by surface fire and individual trees burning. Tree mortality is dependent on local conditions, tree size, and species. Local weather, fuels, and topography influence wildfire behavior and severity.

2. Very large and fast-moving fires. Fires are characterized by extensive fire activity in the forest canopy. High tree mortality occurs in large patches. Fire behavior and severity are less influenced by fuel and topography with winds the dominant factor (Pritchard et al. 2020).

The frequency, size, and average annual area burned by wildfires is expected to increase with a changing climate, although less so for the CRMW relative to more fire-adapted forest ecosystems because of the central role of winds in wildfire occurrence and spread in this region (Littell et al. 2010). A warming climate is likely to create drier wildfire fuels, leading to more successful ignitions, and changing wildfire behavior (faster spread and higher flame length). Climate modeling projections indicate that extreme easterly winds are more likely to decline under future climates. (Brewer and Mass 2016). However, the number of wildfires present during an east wind event could increase due to lower fuel moisture and the greater potential for ignitions to grow and escape traditional fire suppression efforts (Barbero 2015).

A large wildfire poses the greatest threat to management of the City of Seattle's mountain watersheds for municipal water supply and late-seral forest habitat development. Due to its unpredictable nature and infrequent occurrence, there are few options to prepare for the event at the watershed scale. Smaller wildfires with more predictable behavior and occurrence are more readily managed with prevention and suppression. There is very little experience with active fuel hazard management in the western Cascades compared to drier forest types on the east side of the Cascades. The moist, temperate climate makes fuels

less flammable except during dry summer weather. In addition, the development of late-seral forest habitat entails accumulation of fuels and forest structure that contradict common fuels management goals for wildfire hazard management, including low forest density, less ground fuels, and high canopy base height. Because landscape-level approaches to fuels hazard management on the west side of the Cascades are still unproven, the FMP's approach to wildfire risk management will focus on existing strategies of prevention, detection, and suppression and will add proactive fuel hazard management for protecting assets in the watershed. In places where fuel hazard management does not stand in conflict with other objectives, the FMP also proposes managing wildland fuels resulting from other management activities under the FMP.

2.5.5b. Management Approach

Defensible space fuel treatments manage fuel directly adjacent to vulnerable assets and are widely considered a first step in mitigating wildfire fuel hazards. Defensible space fuel reduction seeks to reduce flame lengths, reduce the rate of spread, and limit direct flame impingement on the asset, thereby allowing firefighters to protect the asset more successfully with fewer resources needed and increased firefighter safety. These objectives address protection of assets determined to be of high value or critical for the reliable supply of drinking water, including Masonry Dam, Seattle City Light penstocks, the Cedar Falls facilities, and the Landsburg facilities.

Defensible space fuel treatments for this objective combine:

1. Removal and alteration of flammable vegetation adjacent to the asset ("Ignition Zone")
2. Separation of horizontal and vertical fuel continuity adjacent to the Ignition Zone ("Defense Zone")
3. Shaded fuel breaks surrounding the defensible space area as a buffer ("Shaded Fuel Break")

The intended outcome of the Ignition Zone is to minimize ignitions and direct flame impingement of assets by removing flammable material within 30 feet of the asset. Flammable material is removed, replaced by inflammable material, or kept moist through summer irrigation. Assets should be protected from catching fire by using fire-retardant building materials and construction methods, and preventing plant material fuel buildup.

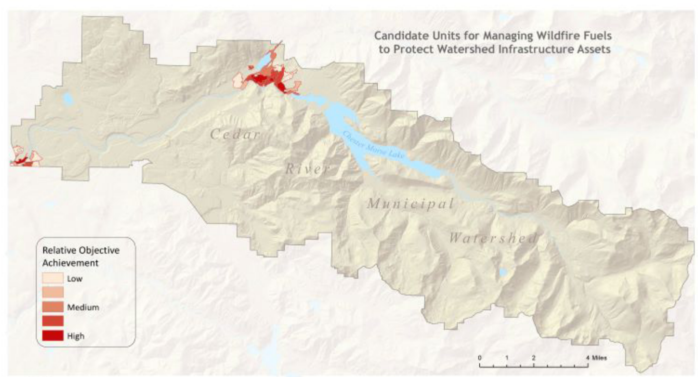
The intended outcome of the Defense Zone is to reduce fire behavior in proximity to the asset by removing dead fuels within 100 feet of the asset, pruning limbs, and isolating tree canopies. Vertical and horizontal separation of flammable vegetation reduces flame lengths and likelihood of crown fire activity, thereby allowing suppression to be more effective.

The intended outcome of the Shaded Fuel Break is to reduce likelihood of crown fires and reduce flame lengths prior to a wildfire entering the defensible space area. The desired forest structure is dominant and co-dominant trees, high canopy base heights, minimal small-diameter surface fuel, and low understory herbaceous and shrub cover. Understory tree regeneration is only a hazard when there is progression from understory into the middle canopy, thereby creating fuel ladders. Shaded fuel break treatments remove dead surface fuel less than three inches in diameter, remove shorter/smaller trees that create ladder fuels, retain larger/taller trees with greater diameter growth, retain understory vegetation, and prune lower limbs to reduce ladders fuels and decrease likelihood of crown fire initiation. The width of shaded fuel breaks depends on slope and location and varies between 100 and 240 feet in width (Dennis 2007).

Hazardous surface fuel resulting from fuel reduction treatments would be mitigated appropriately through removal, mastication, and/or lopping and piling. Prescribed burning of slash piles or broadcast burning to reduce surface fuel is not currently an option due to restrictions within the Secondary Use Policies (Footnote 3). Where tree sizes, terrain, and road infrastructure allow thinning with yarding, thinning slash can be removed or pulled by machine. Where those conditions do not exist, cut-and-leave treatments with appropriate slash mitigation (hand pilling, mastication) can be used.

Circumstances that may negate the effectiveness of treatments include steep slope angles, disturbance processes that create dead surface fuel, heterogenous stands where fuel ladders cannot be sufficiently mitigated, or where cost of slash mitigation is prohibitive or not operationally feasible. Because of regrowth of vegetation following treatment, the effectiveness of fuels hazard mitigation is likely to decrease over time. Re-treatment intervals of canopy fuel ladders in thinned areas may be as low as fifteen years where trees are relatively short, and forty years or longer where tree size and conditions will allow for limited fuel ladder development. Regular monitoring of live fuel development in defensible space zones (photo points) will help determine future fuel maintenance and may be accompanied by monitoring of humidity and fuel moisture monitoring to compare treated and untreated stands upon changes of understory climate following various fuel treatments.

Areas for managing defensible space are shown on Map 2.10. Most of the areas are concentrated around built assets (Landsburg, Cedar Falls, Masonry Dam) and transmission lines.



CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

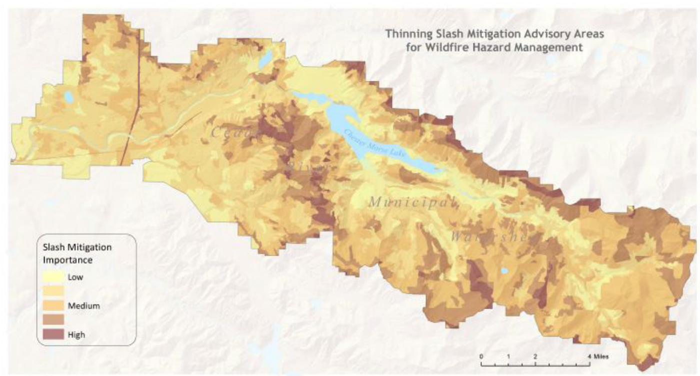
Map 2.10: Management units around critical infrastructure assets were identified for potential wildfire fules management in the Cedar River Municipal Watershed. Darker colors show greater potential achievement towards the management objective based on location and forest structure. Emphasis was placed on structures around Masonry Dam, Cedar Falls, and Landsburg Dam.

Seattle Public Utilities

Click here to view Map 2.10 full size in Supporting Information.

2.5.5c. Slash Mitigation and Synergy with Other Objectives

While the current scientific consensus does not support landscape-level fuels management to change wildfire hazard in forests on the western slope of the Washington Cascades, wildfire fuel structure and younger conifer forests affect fire behavior and propagation. Management actions for other objectives that reduce stand density and create patchy tree distributions will convert fuel from live to dead. This modification notably increases fire behavior and decreases the ability to control wildfire behavior for several years until slash decomposes. The FMP includes slash mitigation for objectives that would manipulate young forests, including for elk habitat, climate resilience, and upper catchment hydrology to remove fuels in the form of thinning slash. Priority areas for slash mitigation include ridgetops, watershed boundaries, and anchor points such as roads, rock pits, and helicopter landing sites (Map 2.11). Priority areas are selected to include young forest stands where slash management would be more effective. Location of high-value resources and assets are also included in prioritized slash mitigation areas. High value assets are water management and conveyance facilities that are critical to our water supply mission. High value resources includes streams, lakes, and critical habitat. This approach does not incorporate slash mitigation as a separate management objective but seeks to create a co-benefit from other management actions for the landscape-level effectiveness of wildfire management and the overall risk of wildfire to watershed management goals. Some conflicts in management objectives exist, including shading of regeneration through thinning slash and maintaining down wood to increase organic matter and soil water-holding capacity. In these cases, priorities of management objectives will be evaluated in the project development phase.



CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 2.11: Areas for thinning slash mitigation were identified to manage wildfire fuel hazards following active forest management in the Cedar River Municipal Watershed. Areas of greater importance were identified based on topography, forest structure, fire fighting achor points, and watershed infrastructure. Areas in red show greater importance for thinning fuels management.

Seattle Public Utilities

Click here to view Map 2.11 full size in Supporting Information.

Risk mitigation strategies other than forest fuel management for defensible space are addressed in the Cedar River and South Fork Tolt Wildfire Risk Analysis (WRA) (in preparation). The WRA seeks to understand: 1) What risk wildfire poses to high-value resources and assets, most notably reliable drinking water supply; 2) How risk changes due to climate conditions; 3) What are appropriate wildfire risk mitigation strategies; 4) What actions are needed to reduce wildfire risk to SPU; 5) What further research is needed to understand and/or mitigate risk?

2.6 Outcome

The candidate pools of forest stands (analysis units) to achieve each objective comprise the outcome of the Analysis Section of the FMP. The candidate pools identify locations in the watershed where it is most important to meet a given objective and forest conditions under which it is most likely to meet that objective. The criteria that were used to select those locations and forest stands are summarized in Table 2.3 (Goals Objectives Criteria). The criteria are derived from available data sources and local knowledge and may provide only part of the information to implement projects. Forest inventory data may need to be collected to develop treatment plans for individual projects. The candidate pools also provided an opportunity to prioritize management actions and to avoid management conflicts or excessive trade-offs. For example, identifying unstable slopes enabled analysis units to be excluded from active management where maintaining the existing canopy cover was the highest priority to prevent erosion and surface water sedimentation. Using this approach, many negative effects of management actions on other objectives were avoided. However, there exist synergistic effects of passive or active management on multiple objectives, which were quantified in the multi-criterial optimization model. The approach is described in the Methods Section and results are presented in the Planning Section.

Candidate pools for developing late-seral forest habitat were based on multiple objectives including passive and active management to meet the overall long-term goals of the HCP (Table 2.3). Candidate pools incorporate all analysis units that meet criteria for location and forest structure that would be suitable for active management towards a given objective. However, only a subset of analysis units will be managed for a given objective, based on the achievement rank of each unit, a given budget scenario, and possible co-benefits for other objectives. Because analysis units may have value for multiple objectives and can be incorporated in multiple candidate pools, the total sum of all candidate pools exceeds the total area of the watershed forest. 15,005 acres of existing designated old-growth forest that is protected from active management in the HCP were identified (Map 2.3). Also, 8,578 acres of second-growth forest in the lower watershed that have developed mature characteristics were identified and will be placed in reserve status to develop late-seral forest through natural processes. 14,107 acres of second-growth forest were identified and prioritized for active restoration to facilitate development of late-seral forest habitat. Areas identified for this objective with higher objective achievement are located between existing areas of functional late-seral habitat and maturing second-growth forest (not shown on map). Also, 1,700 acres of second-growth forest were identified growing in climate refugia, which have low climate exposure and climate sensitivity, for the long-term development of late-seral structures. Because this objective overlaps completely with hydrology objectives, they were combined in the prioritization and optimization.

To meet long-term watershed hydrology goals, 1,700 acres of hydrologically mature second-growth forest were identified for passive management and 3,895 acres were identified on steep unstable slopes to prevent surface erosion (Map 2.6). Most of the areas identified with concentrations of unstable slopes were located in the center of the watershed in steep topographic terrain. For active forest management to improve local hydrologic conditions, young forests were identified in valley locations (1,982 acres) and in upper catchments (5,237 acres). Most of the analysis units with higher achievement towards these objectives were located in the southern basins of the upper watershed. The overlap of selected analysis with those for ungulate habitat objectives shows that synergy exists between these objectives. The effects were quantified and used in the multi-criteria optimization model.

To meet climate resilience objectives for CRMW forests (Map 2.8), 637 acres of low elevation forests (less than 800 feet elevation) were identified for interplanting with dry/warm-adapted species, 4,310 acres of higher elevation analysis units for interplanting with warm-adapted species and genotypes, and 3,727 acres of analysis units for release of deciduous trees in the lower watershed to increase species diversity. While low-elevation objectives for planting are concentrated on droughty outwash gravel, sites are spread over a much larger area at higher elevations (above 2,800 feet elevation). Analysis units with highest achievement towards climate resilience objectives are located on ridgetops at higher elevations. Areas in lower elevation were also identified as candidates for individual release of deciduous trees in conifer forests by girdling and cut-and-leave treatments. This is a lower intensity treatment than thinning that maintains the existing deciduous stand component and adds standing dead trees as habitat element.

Analysis units identified for improving ungulate habitat are divided into upper- and lower-elevation objectives. Upper-elevation areas are mostly distributed in basins along the southern watershed border and provide habitat for the watershed resident population. As Map 2.9 shows, 3,167 acres of analysis units that were identified for this objective. Most of the analysis units identified for lower-elevation ungulate habitat (1,903 acres) are located along the southern watershed border and in the center of the lower watershed. Analysis units identified for winter cover habitat (1,672 acres) are located along the north shore of Chester Morse Reservoir.

Analysis units identified for fuel hazard management in defensible space and shaded fuel breaks around watershed management assets (1,086 acres) are located in the Landsburg, Cedar Falls, and Masonry Dam area (Map 2.10). Areas of greater achievement towards the objective are more closely centered around specific assets.

3 Planning

The Planning Section of the Forest Management Plan (FMP) provides guidance on short- and long-term projects to meet the objectives outlined in the Background and Rationale Section. The plan development process used an optimization model to balance management objectives, their relative levels of achievement, and resource allocations, using both passive and active management approaches. The short-term plan is intended to help Seattle Public Utilities (SPU) allocate resources to FMP programs and identify work locations in the watershed to coordinate related management activities, such as road management. The long-term planning of management activities sets targets which may be altered through adaptive management.

3.1 Management Objectives

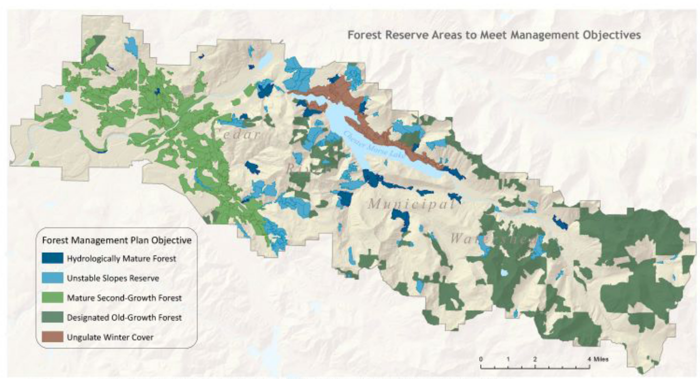
The 13 management objectives identified in the Background and Rationale Section are the basis for planning active and passive management for forests in the Cedar River Municipal Watershed (CRMW). Analysis units that were identified in the spatial analysis as reserves will have no active forest management unless circumstances arise that require intervention, for example planting of trees on unstable slopes following stand-replacing disturbance. Passive and active management approaches are grouped in Table 2.3 by management goals. For analysis units that have multiple objectives, a multi-criteria decision model was used to identify options for management actions.

3.2 Objective Achievement

Management objectives cannot be achieved to the same degree in every location across the watershed landscape. The FMP identifies criteria (Table 2.3) for each objective that assign location and forest structure to potential objective candidate pools to avoid management conflicts and to narrow the pool of potential locations for active management (Candidate Pools, Background and Rationale Section). The level of achievement for a given management objective depends in part on the location of the analysis unit (site conditions, proximity to features) and the stand characteristics (structure and composition) that make it more likely to achieve an objective through active or passive management. For example, meeting the objective for development of late-seral habitat is more likely to be achieved in forests that are already taller, and is of greater value in places where it reinforces or restores functional habitat connectivity. The likelihood of achieving the objective and the relative value of that achievement was considered in order to develop a single “objective achievement” rating, which was unique to each objective and to each analysis unit considered for a given objective. This made it possible to optimize and balance management for 13 different objectives and to allocate limited resources to multiple objectives across a large watershed landscape. Model scenarios were only created for the first five-year period of the FMP.

3.3 Passive Management

Most of the upland forest in the CRMW will be managed passively, which is in alignment with the Habitat Conservation Plan (HCP) “ecological reserve” designation. It is expected that forest vegetation dynamics and interactions with natural disturbances will develop late-seral forest and a mosaic of different forest structure types over time. The FMP designates approximately 50% of the forested area as reserve, where passive restoration has priority. Table 3.2 shows the different forest types that are designated as reserve areas and the acreage of passive management versus active management forest types. Map 3.1 (FMP Reserves) shows the location of the designated reserve areas under this plan. The largest area of reserves in the watershed (15,004 acres) are the designated old-growth forest patches which are excluded from active management unless required for forest protection (wildfire) and water quality (erosion control). The second largest area of reserves are mature second-growth forest in lower elevations that have developed characteristics of late-seral forest habitat (8,579 acres). Analysis units with unstable slopes (as defined by Washington Department of Natural Resources Forest Practice Rules) covering more than 50% of its area were also designated as reserve areas. Analysis units that met this criterium were designated as reserves in their entirety, to protect streams and reservoir from sediment input through mass wasting and surface erosion, and to account for spatial uncertainty and include unmanaged buffers. The primary objective in these areas was to maintain canopy cover and tree rooting strength to prevent surface soil movement, which would require no action. In cases where tree mortality from natural disturbances may cause loss of canopy cover and rooting strength, restoration activities such as planting may be performed to recover ecosystem functions. Several analysis units in valley locations with mature forest cover have been designated as reserves to protect their hydrologic function. Approximately 1,700 acres of forest were designated as reserve areas because of their hydrologically important location in valley bottoms and on alluvial soils. Some overlap with mature second-growth forest reserves exists.



Map 3.1: No active forest management will occur in reserve areas that were designated to meet specific forest management objectives in the Cedar River Municipal Watershed. Mature second-growth forests have canopy heights greater than 145 feet. Unstable slopes reserves have more than 50% of their area in unstable slope conditions. Hydrologically mature forest grows in valley locations and has mature forest canopy height. Ungulate winter cover areas along the north shore of Chester Morse Lake have closed canopy. Designated old-growth was identified in the Habitat Conservation Plan.

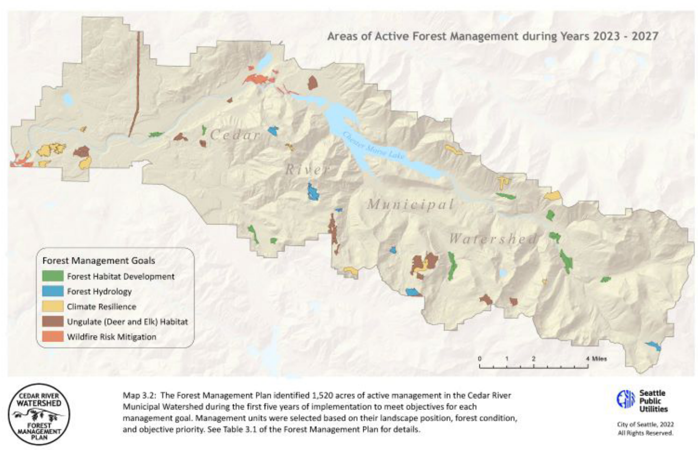
Click here to view Map 3.1 full size in Supporting Information.

1,672 acres of closed canopy forest on the north side of Chester Morse Lake were designated as a reserve area for multiple purposes: snow interception, water quality, shoreline of the State, and forest maturity. These acres of dense conifers adjoining deciduous stands may serve as a refuge from deep snows during extreme winter storm events and are therefore included in the ungulate objectives for parity.

In addition to designated reserve areas and active management units, 53,624 acres of second-growth forest will be managed passively to develop a landscape mosaic of diverse forest habitat over time. It is expected that some of these forests will develop late-seral forest structure over time; others will be disturbed and develop intermediate forest development stages. No active forest management is planned in these forests unless required for forest protection and management for water quality.

3.4 Five-Year Plan

The selection and scheduling of management units and recommended actions was based on the decision model and input from sub-committee members. The planning horizon used in the multi-criteria optimization model was five years, including a total five-year budget for implementing management actions. The project list developed in this process (Table 3.1: Active Management Units Five-Year Plan) allows for selection of projects each year based on available resources and access conditions. The project list includes actions for eight different management objectives. Not all objectives will have active management in each year, and multiple management units may be combined into annual projects. The list corresponds to Map 3.2 (CRMW Active Forest Management Areas for Management Plan Years One through Five) that shows the location of the analysis units that were selected for active management in years one through five.



Map 3.2: The Forest Management Plan identified 1,520 acres of active management in the Cedar River Municipal Watershed during the first five years of implementation to meet objectives for each management goal. Management units were selected based on their landscape position, forest condition, and objective priority. See Table 3.1 of the Forest Management Plan for details.

Click here to view Map 3.2 full size in Supporting Information.

The following sections provide general guidance on management activities to meet specific objectives. Most of the analysis units were selected by the optimization model based on objective achievement, location, and forest structure. Analysis units for ungulate forage habitat improvement were selected with additional input from wildlife biologists from the Muckleshoot Indian Tribe who participated in the FMP development. How the actions will be prescribed depends on the local site and forest conditions and other factors such as regulatory restrictions and operational constraints. Detailed prescriptions will be developed with those conditions in mind, considering that some objectives may not be achieved based on numerous factors (e.g., sensitive species presence, cultural resource protection, and design and implementation challenges) and may be moved to alternate analysis units with favorable conditions. Over time, experience with implementing the actions should inform the adaptive management review and modification to the programs will be suggested at the next review period.

3.4.1 Late-Seral Forest Habitat

Active thinning to restore late-seral forest habitat conditions (Objective 3) is planned in 15 analysis units totaling 265 acres over five years (Table 3.1). Two or more of these units can be combined into one project each year, based on proximity and yarding equipment used to facilitate contracting. Most of the restoration activities are planned in the upper watershed valley of the Upper Cedar and Rex River (Map 3.2). These locations are important for connectivity of functional habitat between existing patches of old-growth forest. The long-term development of functional habitat is more likely in these valley locations that have better soil moisture availability. The cost of planning, implementation, and revenue from surplus timber sale will fluctuate between years. In most analysis units, less than half of the total acreage will be actively thinned. Trees cut in these projects have market value and ecological objectives are not fully met if all cut trees are left on the ground. Hence, some cut trees are removed via yarding methods appropriate for the site and sold as surplus property. The proposed method of log yarding is based on average slope in the analysis unit, may differ locally, and may employ mixed methods. Proximity to core roads is important for these activities to have cost-effective project implementation and enable log haul. Road maintenance requirements for these activities are shown in the Road Management Section below.

3.4.2 Forest Hydrology

Thinning to improve forest hydrology in upper-elevation recharge basins (Objective 7) is proposed in seven analysis units and 148 acres over the first five years of the plan (Table 3.1 and Map 3.2). These analysis units are located above 2,800 feet elevation in forests with smaller trees where no log yarding is planned. Some analysis units may be combined into annual projects to reduce cost of administration. Projects located in priority areas for thinning slash mitigation will see additional work of piling and removing thinning slash (described below). The selected analysis units include wetlands or wet meadows in upper elevations which are special habitat for amphibians and other species. These habitats are relatively rare in the watershed and require careful analysis and implementation when planning thinning projects. Due to location at higher elevations, snow water storage is an important ecological factor which will be affected by thinning and gap creation. Monitoring for thinning effects on soil moisture or snow water storage is recommended to determine effectiveness of the applied actions.

3.4.3 Climate Adaptation

Three different objectives for climate adaptation are planned for low- and high-elevation forests with different proposed actions. Actions for lower-elevation forests (below 850 feet) include thinning and planting in dry Douglas-fir forests that grow on outwash gravel soil (Objective 8) and increasing forest species diversity by releasing deciduous trees in conifer-dominated stands (Objective 10). A limited amount of thinning and planting (58.6 acres) is planned for the first five years (Table 3.1). Some of the thinning includes cutting and yarding merchantable timber. Planting warm and dry-adapted species is planned in both thinned areas and in canopy gaps created by natural disturbances. Planting trials will be installed to test survival and growth of genotypes and species planted for assisted migration. Thinning and planting is planned on less than half the acreage of the analysis units for Objective 8. The planned activities are clustered at the western end of the watershed where outwash gravel is a dominant soil type that creates droughty site conditions.

Release of deciduous trees in lower-elevation conifer forests (Objective 10) is planned in five analysis units over 132 acres of second-growth forest. Deciduous trees will be identified in each unit and directly neighboring conifer trees will be cut or girdled to release the deciduous trees from canopy competition. Girdling can be applied where increase of standing dead wood for wildlife habitat is desired. Deciduous species to release from competition will include bigleaf maple, black cottonwood, red alder, and bitter cherry. Other important deciduous species such as willow and crab apple will be promoted where open stand edges can be maintained along edaphic gaps and rights-of-way.

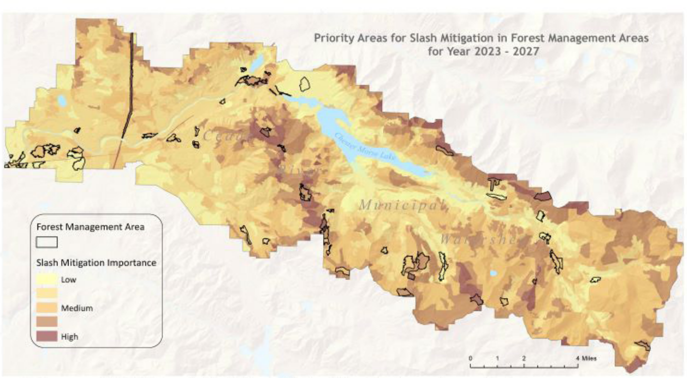
Upper-elevation projects for climate adaptation (Objective 9) are planned in younger forests growing above 3,400 feet elevation. Seven analysis units are planned with a total of 225 acres of thinning and planting. Analysis units for these projects are located along the ridge above the Main Stem Cedar River, at the head of Boulder Creek, and in the Lindsey Creek Basin (Map 3.2). These units are south-facing ridge top locations that have high climate exposure and show slower vegetation recovery compared to other locations. Establishing climate-adapted species may be challenging due to shallow soils and exposed climate conditions. The proposed interplanting of warm-adapted species and genotypes requires acquiring suitable seed sources and contract growing of plant material prior to the project implementation. Analysis units will be combined into annual projects by proximity and will be monitored for seedling survival, growth, and plant community adaptation. Project units that require thinning of existing small trees for interplanting and are located in priority areas for wildfire fuels mitigation will receive additional management of thinning slash by hand piling or removing cut trees.

3.4.4 Ungulate Habitat

Managing forests to improve ungulate forage habitat is planned in lower- and upper-elevation forests separately because of differences in objective and approach. Upper-elevation areas for Objective 11 are mostly located in southern basins and ridges with younger forests that have potential to improve ungulate forage (Map 3.2). Most of these areas (344 acres) are located above 3,400 feet elevation and have seasonal access limitations due to snow cover (Table 3.1). Multiple analysis units can be combined into annual projects based on proximity. Slash from thinning will be lopped and piled in the active management areas to accelerate the vegetative response in the understory, facilitate ungulate movement, and provide refuge habitats for small mammals. Lower-elevation ungulate habitat improvement (Objective 12) is planned in eight different analysis units, which include a wider range of forest ages and canopy structure. Planned activities are site-specific and include cutting canopy gaps of up to three acres in size or thinning trees to increase understory forage cover and deciduous canopy cover. A total of 90 acres of active management is planned during the first five years. The proportion of thinning and canopy gaps will differ by project and depend on site and forest conditions. Activities may be grouped with other thinning activities to increase administrative efficiency. Forage plant responses to thinning will be monitored to determine effectiveness of actions and whether maintenance of the forage habitat is necessary. Any maintenance deemed necessary is planned to start 10 years after treatment. Previous habitat improvement projects that predate the FMP may be included in the maintenance, such as the Barneston Thinning Project or the Bonneville Power Administration Right of Way habitat patches.

3.4.5 Wildfire Fuels

Managing forests for wildfire defensible space (Objective 14) is planned in 14 analysis units with a total of 246 acres of active management (Table 3.1). These units are located in proximity to important built assets surrounded by second-growth forests where management of live and dead fuels will reduce wildfire hazard and support effective wildfire suppression (Map 3.2). Management intensity will decline with increasing distance from built assets. Near built assets, canopy density will be reduced to remove live and dead fuels. Actions to promote stand structure that increases canopy base height and reduces ladder fuels (i.e., understory trees) will be undertaken in outlying areas. Reduction of fuels density and distribution may include yarding of merchantable logs and sale of surplus logs as road access permits. The projects will be monitored to track understory development and to determine when fuels maintenance in the defensible space becomes necessary.



CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 3.3: Priority areas for slash mitigation are rated by how thinning slash can be removed or managed to affect fire behavior and increase ability to fight a wildfire. Locations along ridges, boundaries, and roads have a higher rating, as do forests with lower canopy height. Areas with active management (thinning, canopy gaps, planting, fuels) during the first 5 years of the plan are shown. Fuels management from thinning will be conducted in areas with high slash mitigation importance.

Seattle Public Utilities

Click here to view Map 3.3 full size in Supporting Information.

In addition to managing fuels to protect built assets, SPU will manage wildfire fuels in key areas that are important to wildfire management on the landscape. The objective is to manage fuels that are created by thinning forest stands for other objectives that would otherwise increase fuels hazard. In areas with low amounts of fuels generated by thinning, slash will be lopped and piled to create discontinuous slash distribution. In areas with more fuel loading, slash will be piled and removed by yarding to reduce fuel loads in stands where larger trees were cut. Mastication of fuels, which involves grinding with a machine in the stand, may be applied but will be constrained to areas with poor understory vegetation cover. The amount of fuels management conducted each year will depend on the amount of thinning conducted for other objectives. Fuels management may be conducted the year following the thinning activity to allow for needle drop and drying of the slash. An average of 45 acres of thinning slash management is expected annually. Priority areas for fuels management were developed using an assets and risk framework that is described in the Methods Section. Map 3.3 shows the priority rating for planned management areas which are located along ridges, roads, and boundaries.

3.5 Measures to Protect Sensitive Fish and Wildlife Species

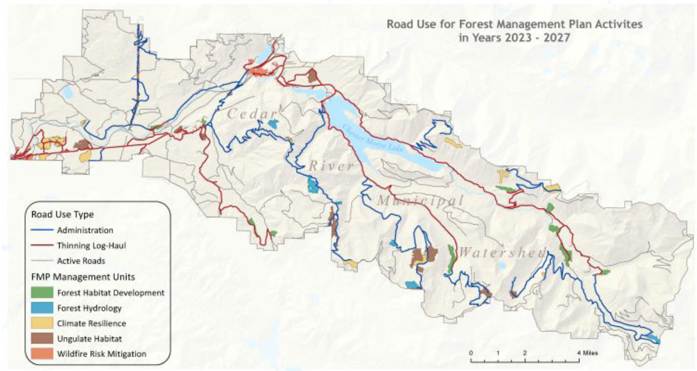
All FMP activities will, at a minimum, follow the guidelines in section 4.2 of the HCP: Watershed Management Mitigation and Conservation Strategies. These guidelines detail temporal and spatial restrictions near nest sites, reproductive centers, or demographically-significant periods in the lifecycle for sensitive fish and wildlife species. All watershed activities will meet or exceed Washington Forest Practice Rules that are not encompassed by exemptions for the HCP (HCP 4.2-9).

In addition, projects will be designed to incorporate riparian and wetland buffers to protect fish and amphibians and reduce microclimate changes near sensitive habitats. If projects are located near designated old-growth stands, no thinning will take place at old-growth boundaries to ensure that “hard edges” are not created that may potentially increase murrelet exposure to predation. Further, time of day restrictions will be implemented, assuming that any designated old-growth stand could be or become occupied by nesting murrelets. Last, site visits and pre-project monitoring will be conducted for sensitive wildlife species to reduce the chances of thinning occurring in stands that are occupied by HCP-listed species of greatest conservation concern, such as marbled murrelets and northern spotted owls. If these species are detected, the project will be abandoned or redesigned so that it does not negatively impact those species.

3.6 Road Management

Access to forest units for active management and monitoring is critical for implementing this plan. Road management has multiple effects on the distribution of active management units. Achievement of management objectives was in part calculated by the area of analysis unit that was accessible by roads. While most active management requires administrative access and contractor access to perform thinning and planting, some activities involve log yarding and haul and require a higher standard of road maintenance for safe access, transportation, and water quality protection. While the distribution of active management is affected by the existing road network, the planned forest management activities over the next five years also will determine the necessary road maintenance to allow access and transportation. The remaining road network may be reduced by future road decommissioning which has been an active HCP management activity to minimize sediment inputs in the stream systems where roads are no longer required for administration and management. The following maps show the road systems that will be used for active management planned in three time periods, years one through five (Map 3.4a), years six through 11 (Map 3.4b), and years 12 through 28 (Map 3.4c).

The first five years of plan implementation will require 81.6 miles of roads for administrative access and 65 miles of roads for log-haul access for thinning projects, which require a higher maintenance standard. Road access needs for subsequent administrative periods are similar, though the need for log-haul roads will decline over time (Table 3.3). Road maintenance for log-access is only required for the first 15 years of plan implementation. Given the uncertainty in project locations in the later phase of plan implementation, the road access requirements are likely to change in location and overall road distance. No new road construction above the existing allowance in the HCP (5 miles) is planned.



Map 3.4a: Access to forest management units in the Cedar Rilver Municipal Watershed requires different maintenance standards for administration and log-haul or heavy machine access. This map shows forest management activites by goals for the first five years of the Forest Management Plan, and the corresponding access roads for administration (blue) and log haul (red). Road use type for each period can be used to schedule road mantenance activities in each planning period.

[Click here to view Map 3.4a-c full size in Supporting Information.]

Table 3.3: Projected road use during implementation periods of the Forest Management Plan; total miles of roads used for administrative use and log-haul and machine access for thinning projects.

Plan Period	Years 1 – 5	Years 6 – 11	Years 12 – 28
Administrative Road Use (miles)	81.6	60	76
Log-haul Road Use (miles)	65	56	49

3.7 Cultural Resources Considerations

All activities associated with the FMP carry the risk of disturbing cultural resources. Therefore, it is imperative that procedures outlined in the Cultural Resources Management Plan (CRMP), 2012, are followed to ensure compliance with federal, state, county, city, and Tribal laws. These laws serve to protect all cultural resources, both historic and pre-contact, located within the closed boundaries of the CRMW.

Before implementing the FMP, the Project Manager is advised to consult with the Watershed Management Division's Cultural Resources Strategic Advisor and review the CRMP, with special attention given to:

- Introduction
- 4.0 Standards for Cultural Resource Management: 4.1.4- Traditional Cultural Properties Standards
- Appendix B: Laws and Regulations
- Appendix F: Cultural Resource Work Standards, Forms, Permit Holder Requirements, and Archaeological Site Monitoring Forms

- Appendix H: Archaeological Research Domains for the Cedar River Watershed, #4 Culturally Modified Trees

All parties involved in implementing the FMP, from project supervisors to staff and contractors in the field, are required to be familiar with the regulations and procedures outlined in the CRMP. This ensures that cultural resources are protected to comply with existing laws, with the ultimate purpose of preserving the story of people's relationship with these lands since time immemorial.

3.8 Monitoring and Adaptive Management

The Monitoring and Adaptive Management Section outlines monitoring activities for several management objectives and actions that will be used to demonstrate the effectiveness of thinning, gap creation, planting, and fuels management. Monitoring is closely tied to the activity schedule. The monitoring approach will differ between activity and between projects. All projects will receive a minimum amount of monitoring through compliance monitoring, photo documentation, and repeat photography. Selected projects will be monitored more intensively with permanent sample plots, instrumentation, intermittent sampling, or aerial surveys. Applying a nested approach to monitoring intensity will allow us to extrapolate monitoring results across activities while reducing the overall monitoring effort.

Figure 4.1 shows examples of monitoring schedules for different objectives. Some projects (Objective 7, Objective 11) will require pre-treatment monitoring and monitoring control plots. Planting projects (Objective 9) can be tracked with post-treatment monitoring alone. If multiple projects are monitored for the same objective but in different years, it may be necessary to track variables such as snow cover or temperature to explain annual variability of the response. Monitoring frequency will depend on the indicators being observed and the expected response time (Table 4.5). Some variables (soil moisture) will have annual monitoring intervals while others may have a bi-annual (seedling growth) or longer interval (forage plant cover, wildfire fuels). The number of projects that will be monitored for a given objective/action will depend on the range of site conditions and available resources.

Monitoring data for adaptive management will become available at different times during the review cycle. When reports are available (multiple projects or monitoring cycles), the adaptive management review will be conducted for the given objectives at the next management review interval. If it is determined during the adaptive management review that actions or objectives are to be modified, additional projects may be monitored with adapted prescriptions or objectives.

3.9 Data Management

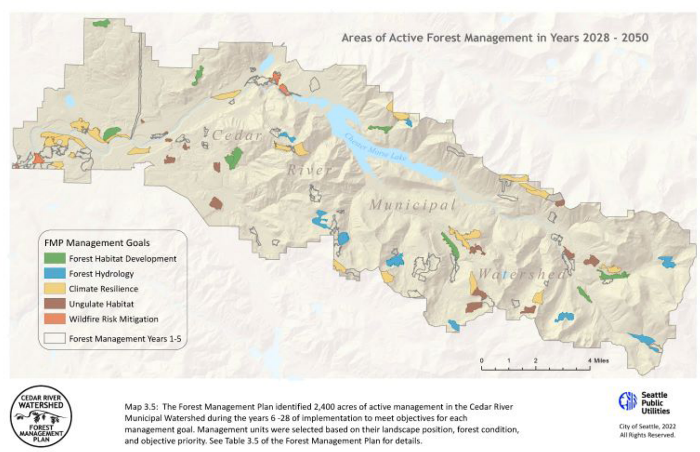
Management review and adaptive management will only be successful if they are supported by comprehensive documentation and complete monitoring data. To facilitate this process, a dedicated information management system will be established that tracks management records, budget information, and monitoring data. The information types that will be tracked include planning documents, project plans, project design maps and documents, as-built information, compliance monitoring data, contracting documents, accounting and budget information, timber volumes and revenues, monitoring plans, monitoring maps and design, monitoring as-built, monitoring data, monitoring reports, review cycle documents and decisions, and adaptive management documents and decisions.

3.10 28-Year Plan

The FMP makes a commitment for long-term management of the upland forest ecosystems over the life of the HCP. Objectives derived from HCP goals continue, including passive and active restoration of late-seral forest habitat. Management for climate resilience can be expected to increase in importance over time. Table 3.4 shows the allocation of planned management units and acres by time period.

New activities, including management of ungulate habitat and wildfire fuels management, are planned for implementation over the first 10 years of the FMP, after which the project areas will receive maintenance activities to continually provide the functions for which they were designed. Cover of forage plants for ungulates will be maintained by thinning competing tree regeneration. In units that are managed for defensible space, developing fuel ladder (tree regeneration) will be removed during maintenance activities.

Activities planned for years six through 28 of the FMP bear greater uncertainty in location, timing, approach, and cost. Table 3.5 and Map 3.5 can guide long-term planning because they show analysis units that were identified for actions. The analysis units were selected based on management goals, candidate pools, objective achievement, and available resources. Some of the project locations may change as forest ecosystems develop or are disturbed. The management activities and objectives themselves may change in approach based on the outcome of monitoring and adaptive management and may change the location, timing, and approach of active management across the watershed. Any significant changes to the implementation of the FMP will require review and approval from the HCP Oversight Committee.



Map 3.5: The Forest Management Plan identified 2,400 acres of active management in the Cedar River Municipal Watershed during the years 6 -28 of implementation to meet objectives for each management goal. Management units were selected based on their landscape position, forest condition, and objective priority. See Table 3.5 of the Forest Management Plan for details.

Click here to view Map 3.5 full size in Supporting Information.

3.11 Budget Allocation

Active management to achieve planned objectives of the FMP has budget implications for Capital Improvement Project (CIP) and Operation & Maintenance (O&M) budgets. Table 3.6 shows the annual budget allocations and estimated labor days to implement this FMP. CIP budgets are derived from HCP cost commitments for labor and services, including actions for Objectives 3, 7, 8, 9, and 10. The labor costs include planning (design, permits, layout) and implementation (contractor supervision, compliance, accounting). Services include appraisal, reports, thinning, and planting. Planning and implementation for action under Objectives 11, 12, and 14 are O&M budgets that include installation and maintenance of ungulate habitat and management of wildfire fuels. This budget also includes additional fuels management in thinning projects for other objectives in areas where fuels management is advised (Map 3.3), and it includes maintenance of projects for ungulate forage and wildfire fuels management. The overall program administration and monitoring activities for adaptive management are included as separate O&M budgets. An average annual breakdown for cost and work phases (years one through five) for each objective is shown in Table 3.7, separated by HCP CIP and O&M budgets. Costs and revenue are estimated based on previous projects and shown in 2023 dollars. Future budgets will be adjusted for inflation based on rules outlined in the HCP (HCP 5.3.3). Any significant changes to the implementation budgets require consultation with the HCP Oversight Committee. Cost of road maintenance is not included in the new O&M budget and will be covered through the existing HCP Road Maintenance Budget. If road maintenance for specific projects that involve log-haul exceed the available budget, the road maintenance cost will be included in the implementation contract.

Table 3.6: CIP and O&M Budget Allocation to Labor and Services

Annual Budget (Year 1-5)		**Amount**	**Labor Days**
HCP CIP Budget			
Planning and Implementation	Labor	$55,098	49.9
	Service	$40,657	
O&M Budgets			
Planning and Implementation	Labor	$51,637	72
	Service	$60,682	
Program Administration	Labor	$61,662	86
Program Monitoring	Labor	$39,327	54.9
Total		$309,062	263

The annual budgets do not include revenue generated from the sale of surplus timber from thinning operations. While the sale of surplus timber can offset the implementation cost of the operation, any surplus revenue will be deposited into the SPU Water Fund to offset the cost associated with the HCP. Details of the estimated revenue generation by forest type and thinning operation are included in Section 5.4 and Table 5.4.

4 Monitoring and Adaptive Management

4.1 Adaptive Management Process

This Forest Management Plan (FMP) prescribes management actions to be implemented over an extended period in the face of uncertain climate conditions, natural disturbances, socio-economic changes, and shifting demands on natural resources. Tracking the effectiveness of the FMP through monitoring is essential to ensure that it continues to meet management objectives. Monitoring and adaptive management is especially important for the subset of prescribed actions designed to meet these uncertain climate conditions, as they are relatively untested.

The City and other stakeholders recognized the importance of adaptive management in the creation of the Habitat Conservation Plan (HCP), stating: "Adaptive management, in which learning is explicitly defined as a project goal, is an essential component of the Cedar River Watershed Habitat Conservation Plan because of the uncertainty involved with ecosystem restoration and the experimental nature of some restoration techniques" (Cedar River Municipal Watershed Strategic Monitoring Plan 2008). The adaptive management framework serves several purposes in developing and implementing the FMP. It promotes flexible decision-making in the face of uncertainty, helps to adjust policies through a learning process, recognizes the importance of natural variability in contributing to ecological resilience, integrates environmental, social, and economic goals, and allows for stakeholder input (Williams et al. 2009).

In its 20-year review of the HCP (2022), the HCP Oversight Committee recommended (1) completing the FMP and Wildfire Risk Analysis (WRA) and (2) " [including] monitoring in the Forest Management Plan to track forest resilience in the face of climate change and restoration activities, and [continuing] to develop and include an explicit process for adaptive management in the watershed that will be based on measures of progress and allow flexible responses to new information." The Monitoring and Adaptive Management approach outlined below is developed in response to the request for integrating monitoring in forest management and builds upon previous plans and programs.

The FMP adaptive management process includes the following six stages, some of which are covered in other plan sections:

- Assessment - The FMP identifies management goals and objectives, identifies trade-offs, and balances between management objectives (Background and Rationale Section).
- Design - The FMP guides the design of management actions by identifying locations, priorities, and approaches for active management (Planning Section).
- Implementation - Site-specific implementation will be affected by local conditions and feasibility and is not covered by the FMP but guided by objectives and priorities.
- Monitoring – The monitoring stage (this section) identifies indicators for management objectives and approaches to evaluate the effectiveness of prescribed actions.
- Evaluation – The evaluation stage (this section) is outlined below in terms of response function models, timing, and scope to assess the design, implementation, and outcome of prescribed actions.
- Adjustment – The FMP allows for changes in design and prescriptions for actions of future projects to meet management objectives. Modifications will be based on the biological response relative to the modeled response function and field observations.

4.2 Monitoring

The City conducts ecosystem monitoring in the CRMW based on guidance and commitments in the HCP (2000) and the HCP Strategic Monitoring Plan (2008). These programs include fish and wildlife monitoring, ecological trend monitoring, and disturbance monitoring, and they incorporate ground-based fieldwork and remote-sensing analysis. New concerns and uncertainties stemming from global climate change resulted in SPU modifying and expanding monitoring efforts in consultation with the HCP Oversight Committee (Monitoring and Research Review 2017). Though these monitoring programs predate and exist separately from the FMP, they can contribute to the FMP by providing baseline conditions, trajectories, and insight from past projects (such as the upland forest thinning programs). Monitoring for listed fish and wildlife species, such as marbled murrelet and spotted owl, will continue watershed-wide, as outlined in the 2017 Monitoring and Research Review. There are no proposed reductions in existing HCP-related monitoring programs in the FMP.

The FMP proposes new management objectives for forests in the CRMW, many of which require forest thinning, planting, and other active management interventions. Monitoring for management objectives was assigned to existing and new monitoring programs depending on the proposed actions and monitoring goals (Table 4.4). FMP objectives that do not include active management, such as retaining forest cover on unstable slopes, will not require added monitoring efforts through the FMP because they are already being tracked by existing programs. New monitoring programs were created to develop evidence for effectiveness and objective achievement through active management, including climate resilience, ungulate habitat, forest hydrology, and wildfire fuels management objectives. These programs can also observe long-term changes in plant community parameters to determine objective achievement over time. In response to requests made in the 20-year HCP review, the new monitoring efforts include tracking the effectiveness of management activities and a greater emphasis on monitoring the climate resilience of forests.

The following monitoring goals are described below:

- Track progress toward long-term forest development goals.
- Create measurable evidence to support active forest management.
- Track indicators of forest ecosystem resilience to climate change impacts.

4.2.1 Long-term Forest Development

The existing long-term forest monitoring program under the HCP relies on permanent sample plots distributed throughout the watershed to sample plot-level information of forest metrics. Because forests develop slowly over a long time and site conditions and disturbances affect development, the plot-level information will be augmented by remote sensing information to track structural changes and habitat distribution. This information can also be used to extrapolate plot-level information to the landscape level. Table 4.1 shows the goals and parameters for long-term forest development.

Table 4.1: Objects and parameters for long-term forest development monitoring

Monitoring Object	Parameter
Late-seral forest structure	Canopy height and variance
Late-seral forest canopy	Vertical and horizontal canopy structure
Non-forest habitat	Habitat size and distribution
Second-growth forest development	Canopy height and structure, species composition

4.2.2 Inform Active Forest Management

The FMP identifies new management objectives and activities that bear uncertainties in outcome and effectiveness. Active management for these objectives is costly and potentially risky if unintended effects emerge. Therefore, active management will include new monitoring programs to ensure it is cost-effective and produces the desired structural and compositional changes. Using measurable parameters and a response function that defines expected changes in these parameters (Tables 4.2 and 4.3), project success can be quantified, and future projects can be adapted as necessary. Monitoring will be designed to capture the effect scale and natural variability and will consider the anticipated response time of the biological change. If possible, monitoring will include descriptive co-variables to extrapolate the results to other sites and explain variability in the monitoring results.

Table 4.2: Objects and parameters for active management monitoring

Monitoring Object	Parameter
Ungulate forage	Forage species productivity, plant and animal community effect
Wildfire fuel structure	Dead and live fuel loading and distribution
Catchment hydrology	Wetland hydrology, wetland plant community
Climate resilience	Survival and growth of plantings, plant community change, invasive species

4.2.3 Forest Ecosystem Resilience

Forest resilience is an important element of long-term watershed and habitat management and has received renewed interest through climate change impacts. Forest ecosystems are inherently resilient, however, anticipated forest trajectories are based on past environmental conditions, while future climate conditions may result in slower growth, higher mortality, and different forest development. As climate change alters ecosystem processes, the expected response of forests to active and passive management may change as well. Monitoring parameters of forest resilience may provide early signs of altered processes that could be addressed through adaptive management (Table 4.3). Besides observing the state of forest structure and community parameters (e.g., state-based indicators, Liu et al. 2021), the dynamic nature of forest ecosystems requires observation of process parameters to measure landscape-level resilience and ecosystem functions (i.e., response-based indicators). The monitoring goals below are specific to assessing resilience and adaptive capacity. The parameters in Table 4.3 were only partially included in the existing HCP Monitoring Programs and will require the expansion of monitoring to include additional locations such as disturbed forest sites and by adding resilience indicators. Because ecological resilience is expressed at larger spatial and temporal scales, monitoring resilience indicators at larger scales is important for meeting the programmatic goals of the HCP and FMP.

Table 4.3: Objects and parameters for monitoring ecological resilience

Monitoring Object	Parameter
Forest Disturbance	Disturbance agents and severity
Recovery process	Tree establishment, demography
Habitat function	Distribution and size of forest and non-forest habitats
Ecosystem productivity	Normalized Vegetation/Tree Ring Index
Functional redundancy	Plant species diversity and distribution
Adaptive capacity	Plant species diversity and distribution

Forest disturbance monitoring is currently designed to be a scaled approach, using aerial surveys conducted by the US Forest Service and WA Department of Natural Resources (USFS/WA-DNR) and follow-up ground surveys to track agents and impacts. If disturbance persists, more intensive surveys will be conducted to track the dynamic spread of the disturbance. Forest recovery following disturbance is an important indicator of resilience that will be tracked by monitoring vegetation establishment on new permanent sample plots in recently disturbed areas. The establishment of early-seral vegetation and the successional shift towards longer-lived late-seral species are indicators for the forest recovery process. Changes in habitat function from forest development and its spatial distribution are important indicators for ecosystem resilience. Disturbance interaction is expected to change the location of habitats while the overall extent of habitat remains stable in a resilient forest landscape. The rate of recovery of forest ecosystem functions depends in part on the productivity of the forest. The rate of forest structural development towards late-seral forest habitat has been shown to depend on site quality of long-term monitoring plots. Ecosystem productivity can be assessed at multiple scales through remote sensing (Normalized Difference Vegetation Index, computed as relative the difference between near-infrared and red vegetation reflectance, indicating moisture stressed and green vegetation) or at the individual plant level from tree ring series. A survey of the distribution and diversity of forest plant species on existing sample plots can be used for two additional indicators of forest resilience. Greater diversity and spatial distribution of species in functional groups indicate redundancy of ecological function and potential persistence in the face of disturbance. Species diversity in functional groups also indicates greater adaptive capacity because species with different life history traits will be likewise differently affected by, respond to, and adapt to changes in disturbance regimes due to climate change.

4.3 Evaluation Stage - Evidence of Response

The FMP pairs measurable parameters for management objectives with active treatments of structure and composition to determine the success of the action and a timeframe over which the response is expected. The combination of response parameters and timeframe informs the monitoring approach, methodology, and schedule. The parameters include an expectation or model for the response of the parameter that can be described by the direction of the response and the relative magnitude and scale, including fluctuation and time of expected response. This description of the response function will be based on data, scientific literature, or professional experience and may bear significant uncertainty for some parameters.

Several of the proposed management actions are relatively novel, untested, or not widely used in the region. These include planting warm-adapted species to increase climate resilience, improving catchment hydrology, and creating defensible space through wildfire fuel management. Monitoring will be conducted to ensure that the implemented actions effectively achieve the objectives and that limited resources are allocated responsibly. Management actions can be modified, replaced, or abandoned if the expected change does not occur.

Table 4.5 shows examples of parameters, response function descriptions, and co-variables that can guide monitoring for the effectiveness of active management. Management objectives and actions can have multiple parameters. The response function is described by direction, baseline, scale of effect, and response time. These variables will guide the creation of monitoring protocols. While a rigorous application of the scientific method would typically require a control to test the response, monitoring of active management may not include suitable control sites, in which case the measured response will be tested against the expected outcome defined by the response function (Wortley et al. 2013). A more explicit description of the response function in the model will support this approach. However, there is substantial uncertainty in many response functions regarding how much diversion from the expected response will be tolerated for management success. Therefore, response functions should be seen as a guide for monitoring and adaptive management, rather than being strictly prescriptive.

4.4 Adjustment Stage - Review Cycle and Analysis

The FMP will have a regular review cycle of five years, for the purpose of management adaptation (Figure 4.1). The five-year review cycle will cover program elements such as planning, implementation, and budgeting. Based on the outcomes of the review, effort and resources can be adjusted as needed to meet program objectives. The review includes a summary and documentation of all projects conducted under the FMP, a review of whether planning and design deviated from guidelines in the FMP, a review of implementation challenges and minor adaptations, and a comparison of budget allocations with actual expenditures. The review will be conducted internally and shared with the HCP Oversight Committee.

The management review will be supported by annual visual inspection and photo monitoring of projects. Visual inspection and photo monitoring are not intended to replace quantitative sampling of response variables but rather to support observations following active management. It also allows for a scaled approach of monitoring where effort is placed on selected objectives and variables while a minimum level of observation is applied to all activities.

Results from project monitoring, which show the effects of active management and inform adaptive management, will be produced at different times depending on the objective, action, and response parameters. Adaptation of action prescriptions or management approaches will be made after data becomes available, a review has been conducted, and recommendations have been approved. Figure 4.1 shows examples of the review cycles and monitoring periods for different objectives. While some monitoring parameters (e.g., seedling survival) will become available at one-to-five-year measurement periods, other response variables such as understory vegetation cover or plant community change following treatment may not be measurable before five to 10 years. If results from monitoring multiple projects in successive years are required, those results will not be available at the same time, requiring a longer evaluation period before data are compiled and analyzed. Collecting pre-treatment data will also extend the monitoring period. Some response variables may not show measurable differences during the expected response time, requiring a decision to either abandon the action or extend the monitoring period and adjust the expectations for the biological response.

To inform future management actions, the design of initial treatments and monitoring should incorporate the scope and scale of future actions. This will ensure that the results are transferable to the expected range of variability of future actions proposed in the FMP. The selection of monitoring projects should be based on topography, forest structure, and prescriptions.

4.5 Adaptation of Management

Adaptation of forest management should be expected given the planning horizon and changes in climate and natural disturbance. If the implemented prescriptions do not achieve the objective or if conditions change that make it unlikely that the objective can be reached, prescriptions or objectives will be modified. In either case, adaptation will be based on documented evidence and the expected response model. If the desired outcome can be achieved by modifying the prescription, the assessment will be documented, and modified prescriptions will be introduced at the next feasible management action. A new monitoring schedule will be initiated to track the development of response variables. If the proposed management action fails to produce any response or circumstances change that make achievement unlikely, the action itself may be abandoned and replaced by a more appropriate approach to meet the management objective. The HCP Oversight Committee will be consulted if changes in management approaches are proposed. Programmatic changes to overall goals and objectives will be reviewed and approved by the HCP Oversight Committee. This includes effects of large scale disturbances as foreseen in the HCP as changed circumstances, which are likely to change management objectives entirely and may require review and approval.

Management actions can include trigger points at which management is adapted (Lindenmayer 2020). Such trigger points can be defined for the following conditions:

- Meets expectations – outcome meets expectations, and action can be expanded to new project sites.
- Does not meet expectations – outcome does not meet expectations, and modification in action is applied to improve outcome.
- Unintended consequences – applied action has unintended consequences on either the response parameter or other ecosystem elements, and action is modified to mitigate the outcome.
- Changed conditions – external conditions change, modifying the response function or requiring mitigation and adaptation of action to meet the objective.

Management actions can be adapted based on a wide range of evidence, including visual observation or quantified parameter values. To effectively assess and modify management actions, the following conditions should be met:

- Actions must be based on pre-determined prescriptions and deviations from the prescriptions will be documented.
- Response of the parameter can be compared to a baseline condition, either pre-treatment or control.
- Any changes in the system following the action which affect the response can be documented.
- Future management actions fall within the scope and scale of the tested prescriptions.

- Actions must include description of co-variables affecting parameter response.
- Effect of treatments is measurable within the review and adaptation cycle.
- Adaptation of future prescriptions falls within the range of the response function.
- Changes in the prescription will be documented for future monitoring and review.

5 Methods

This section describes the methods used in developing the Forest Management Plan (FMP). These include descriptions of the landscape and forest metrics that were used to create candidate pools of analysis units where the various management objectives could be pursued in the watershed. The methods also include a description of the multi-criteria optimization model that was built to prioritize and balance where these management objectives should be pursued given budgetary constraints and scenarios. Additionally, this section documents methods for long-term projection of forest development and criteria used to identify priority areas for thinning slash management.

The multi-criteria planning approach incorporated input from structured interaction with a subcommittee of Seattle Public Utilities (SPU) staff, stakeholders, regulators, Tribal staff, and forest management professionals. A detailed description of this interaction (interactive multi-criteria optimization) is documented in this section.

5.1 Definitions

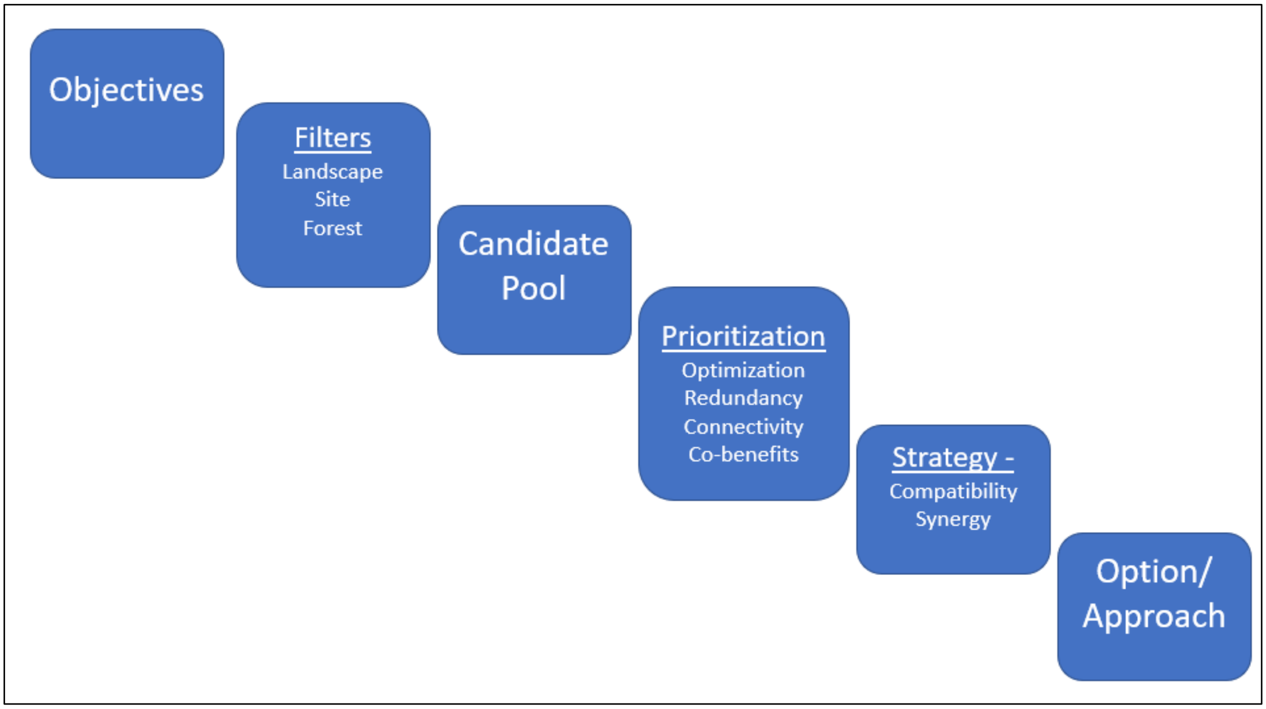
Throughout the implementation of the Habitat Conservation Plan (HCP) delineation of the watershed into discrete management units has been avoided for two reasons: The majority of the upland forests in the watershed will not be actively managed and the functional goals for upland forests, including habitat and water cycle regulation, transcend the concept of defined management units. However, for the purpose of developing the FMP, the watershed upland forests were divided into discrete **analysis units** to support the spatially explicit multi-criteria optimization approach. Analysis units were identified similarly to the concept of the **"stand"** in forest management, which is an administrative unit of sufficiently homogenous structure and composition to be managed with the same objective and approach. Once a **management objective and approach** were identified for an analysis unit, it was considered a management unit for the FMP.

The FMP developed approaches for meeting long-term goals and specific management objectives. The choice of **activities**, such as thinning, planting, or reserve status to implement the approaches, was site-specific; detailed **prescriptions** (scope and details of work) will be developed during project implementation. The **options analysis** applied landscape-scale filters, site conditions, and forest conditions to describe candidate pools for each objective. Each set of **landscape parameters** (location, site, stand) could be seen as a decision node regarding whether to apply management approaches and actions. The location parameters in Table 2.3 indicate the relative position of an analysis unit in the landscape and relative to other features. The **site parameters** described mostly abiotic conditions such as soil, hydrology, and exposure. Stand parameters of an analysis unit describe structure and composition of the forest in terms of canopy height, closure, heterogeneity, and tree species type. Management approaches may include passive restoration (removing disturbance agent and recovery by natural processes), active restoration (changing abiotic or biotic conditions to facilitate recovery), or active management including maintenance to produce predictable ecosystem functions. Each of the approaches may employ different actions, including forms of thinning, natural regeneration or planting, wildfire fuels management, or site amelioration. Each **management action**, when combined with an analysis unit, was further assigned a set of **objective achievement indices**, one for each objective that the action would contribute to if implemented on that specific analysis unit (Table 5.2). These indices were developed based on such factors as operational access to the unit to implement the action as well as likelihood and magnitude of success in achieving the corresponding objective. If a specific action was projected to contribute to the realization of multiple objectives on a given analysis unit, the FMP refers to these contributions as **co-benefits**. These objective achievement indices were then used to parameterize the multi-objective optimization model. This prioritized which analysis units should be applied to which actions to best achieve the management objectives in the watershed within **budget constraints**. To construct the budget constraints, the costs of each action (Table 5.3) were calculated when applied to a specific analysis unit and multiplied these cost coefficients with the corresponding binary decision variables in the optimization model. The sums of these product terms were then restricted to be less than or equal to whatever the available budget was assumed to be. Multiple budget scenarios with alternative budget constraints were analyzed.

5.2 Landscape Model Approach

A spatial analysis of candidate pool areas was used to determine compatibility and conflict of management approaches with other objectives. For instance, where a passive management approach was indicated, active management that would alter structure and composition of the forest was not recommended. This approach also identified areas where multiple objectives could be achieved through active management, improving the efficiency of forest management actions. Figure 5.1 below shows the conceptual approach of developing candidate pools for management objectives and management options by applying prioritization, compatibility, and synergy. The final steps of prioritization and weighing different objectives via multi-criteria optimization created multiple alternative plans of management actions across all analysis units. These alternatives were reflections of the different weights that could be assigned to the different objectives. The alternatives were presented to the subcommittee of SPU staff, stakeholders, regulators, Tribal staff, and forest management professionals for feedback. Based on their input, more alternatives were generated to compare and, ultimately, to select units and actions for implementation.

Figure 5.1: Conceptual approach for developing management options for the Forest Management Plan involving SPU staff and the subcommittee at each step of the process.



5.3 Developing candidate pools of analysis units by goal and objective

Each management goal was broken down into several objectives (Table 5.1). Not every objective outlined in Section 2 was used in the landscape model because some could not be spatially attributed or modeled (e.g., developing organic soil layers). Modeled management objectives were associated with landscape features, site and climate conditions, and vegetation structures that determine if an analysis unit was suitable to meet a specific objective. Analysis units were identified as having a common canopy structure (height, gap structure) and topographic position. In total, 2,058 analysis units were identified across the Cedar River Municipal Watershed (CRMW). For each objective, thresholds or value ranges were then identified for each attribute to determine if a particular analysis unit was able to meet management objectives based on site and stand parameters (Table 2.3).

Table 5.1: Management Goals and Specific Objectives (from Background and Rationale Section)

Goal	No.	Objective
Late-Seral Forest Habitat	1	Protect and maintain the existing primary forest habitat
	2	Increase the total area of late-seral forest habitat through natural stand development processes in well-developed second-growth forests over the life of the HCP.
	3	Promote species and structural diversification in second growth forests with homogeneous structure and composition through forest restoration thinning and planting.
Hydrology	4	Maintain forest cover in all areas that have been identified as unstable slopes. Minimize synchronized surface runoff from rain-on-snow events by limiting area with open canopy.
	5	Maintain and increase the amount of hydrologically mature forest older than 80-100 years in valley locations.
	6	Thin young stands to limit effect of increased transpiration during early stand development.
	7	Reduce canopy cover of young second-growth forests in headwater basins.
Climate Resilience	8	Promote or augment the diversity of conifer species and genotypes to be better adapted to changing climate.
	9	Augment existing tree species composition with warm/dry-adapted species.
	10	Maintain and increase deciduous tree numbers and cover in conifer-dominated second-growth forests.
Ungulate Habitat	11	Reduce conifer canopy cover and increase forage plant biomass to enhance summer forage in the upper watershed.
	12	Maintain existing hardwoods and increase understory forage by reducing conifer canopy cover at the stand scale through gap creation and thinning.
	13	Maintain dense coniferous canopy cover in areas that elk have used as a refuge in extreme winter weather events.
Fire Hazard Mitigation	14	Reduce hazardous fuel risk around critical utility infrastructure

5.3.1 Late-Seral Forest Habitat

The following maps show the spatial distribution of analysis units that would meet the three management objectives to conserve and develop late-seral forest habitat.

Objective 1 (Protect and maintain the existing primary forest habitat, Table 5.1) applied to analysis units that are designated as old-growth forest in the HCP and those mature second-growth forests that had a mean canopy height of greater than 145 feet (Map 2.3). Canopy height was calculated as the mean of the 95th percentile of LiDAR returns above ground for the analysis unit polygon. The canopy height threshold was chosen because it exceeds the dominant tree height for the most productive sites in the watershed.

Objective 2 (Increase the total area of late-seral forest habitat through natural stand development processes in well-developed second-growth forests over the life of the HCP) applied to analysis units located in valley topography with low climate exposure and canopy height of greater than 128 feet. Analysis units for Objectives 2 and 5 were identical and only Objective 5 was mapped and used in the subsequent analysis (Map 2.6). Stands on these sites are assumed to have higher soil moisture available and are most likely developing late-seral forest habitat in the near future. A lower height threshold was chosen to include tall second-growth forests that have not reached dominant site index height. Site index height was defined as height of dominant trees at age 100, referring to King's site index tables (King 1966).

Objective 3 (Promote species and structural diversification in second growth forests with homogeneous structure and composition through forest restoration thinning and planting) applied to analysis units outside of but within one mile of old-growth forest, experiencing low climate exposure on slopes of less than 70%, with a range of canopy height between 90 feet to 139 feet, and homogenous canopy surface with low to medium canopy rumple (less than 1.4) (Map 2.5). Canopy rumple refers to the LiDAR-derived roughness of the forest canopy surface in a given analysis unit. The selected stands were expected to add to existing habitat and create habitat connectivity. The canopy height range placed these stands in a size class where thinning with log yarding can be used, while the low canopy rumple indicated homogeneous canopies that have not incurred agent-induced mortality, indicative of active canopy development. Analysis units in areas that were previously thinned were excluded from Objectives 2 and 3. Table 2.3 shows attributes of landscape, site, and forest structure that identify analysis units to be assigned to candidate pools for specific objectives.

5.3.2 Forest Hydrology

Map 2.6 shows the spatial distribution of analysis units that would meet the four hydrology management objectives.

Objective 4 (Maintain forest cover in all areas that have been identified as unstable slopes; Minimize synchronized surface runoff from rain-on-snow events by limiting area with open canopy) applied to all analysis units that contain more than the 60% unstable slope features in their total area (Table 2.3). Unstable slope features were identified in a previous landslide and unstable slopes analysis. A threshold of 60% was chosen to indicate dominance of unstable slopes in the analysis unit and allowed for spatial location uncertainty.

Objective 5 (Maintain and increase the amount of hydrologically mature forest older than 80-100 years in valley locations) applied to those analysis units in predominantly valley locations with low climate exposure and forest canopy height of greater than 128 feet. This objective had complete overlap in forest structure and location with Objective 2 (see above).

Objective 6 (Thin young stands to limit effect of increased transpiration during early stand development) applied to analysis units in valley topography with low climate exposure, canopy height between five feet and 70 feet tall, and homogenous canopy structure with low rumple (less than 1.25). Stands of this canopy height range and structure consisted of fast-growing trees with high transpiration rate and can be thinned without log yarding.

Objective 7 (Reduce canopy cover of young second-growth forests in headwater basins) applied to analysis units in mid-slope topography above 2,800 feet elevation, on sites with low to medium climate exposure, located within 1,000 feet of hydrologic features (ponds, wetlands, major streams), and canopy height of less than 95 feet. Stands above the elevation threshold had consistent snow accumulation and were close enough to streams and wetlands to directly affect their hydrology. Stands taller than 95 feet are expected to accumulate high amounts of down wood during canopy gap cutting to require log yarding for fuels reduction and understory vegetation growth.

5.3.3 Climate Resilience

Map 2.8 shows the distribution of analysis units that meet either of the three forest management objectives to increase functional resilience to climate change.

Objective 8 (Plant areas with existing disturbance mortality with pathogen--resistant and drought tolerant tree species to meet FMP objectives) applied to analysis units with moderate to high climate exposure, forest canopy height between 50 and 135 feet tall, which have lost more than 15% of canopy cover between 2004 and 2014 (based on LiDAR data analysis), and have medium to high canopy rumple. Stands in this canopy height range can be thinned with log yarding and have incurred significant canopy mortality from drought, insect, and disease disturbance. Stands for this objective were selected from elevations below 1,600 feet where droughty outwash gravel soils occur.

Objective 9 (Augment existing species composition with warm/dry-adapted species, either in existing canopy openings or by creating canopy gaps and introducing such species) applied to analysis units with moderate to high climate exposure, canopy height of less than 50 feet, with less than 30% deciduous canopy in either understory or overstory. Stands of smaller canopy height can be thinned without yarding slash and logs. Stands with greater cover of deciduous shrubs and trees typically indicate high soil moisture and do not require interplanting.

Objective 10 (Maintain and increase deciduous tree species number and cover in conifer dominated second-growth forests by individual tree release, gap creation, and planting) applied to analysis units with low to high climate exposure, canopy height between 75 and 120 feet tall, and between 25% and 40% deciduous overstory canopy cover. Stands in this canopy range, at lower elevations, have fast growing conifers that are actively overtopping existing deciduous trees. Release will be effective only where enough deciduous trees exist (greater than 25% cover), but not in deciduous-dominated stands.

5.3.4 Ungulate Habitat

Map 2.9 shows the distribution of analysis units that meet the three forest management objectives to maintain and develop ungulate habitat, which include increasing ungulate forage opportunities and protecting habitat used for winter cover.

Objective 11 (Reduce conifer canopy cover and increase forage plant biomass to enhance summer forage in the upper watershed) applied to analysis units in the upper watershed (above elevation of 1,560 feet) and on gentle slope angles (less than 31%), which elk prefer over steep slopes (Rowland et al. 2018). To focus on stands where trees may be limiting understory growth but are unlikely to achieve old-growth characteristics, canopy heights are restricted to between 15 and 60 feet. Analysis units that are mostly meadow (greater than 75%), rock (greater than 90%), or water (greater than 90%), are excluded; meadows are already elk habitat and will not be readily improved through active management. Thinning will most effectively improve elk habitat in areas that already have some forage plants that can be released by overstory thinning. LiDAR data was used to generate an index of understory abundance and selected analysis units with comparatively more understory (index value greater than 1.8) and more dietary digestible energy (greater than 2) (Cook et al. 2016; see achievements section for more information on dietary digestible energy).

Analysis units for **Objective 12 (Maintain existing hardwoods and increase understory forage by reducing conifer canopy cover at the stand scale through gap creation and thinning)** were hand-selected to include analysis units in the lower watershed that did not include substantial areas of spotted owl habitat. Spotted owl habitat outside of old-growth stands was defined using two models: LiDAR-derived tree height greater than 157.4 feet (Hagar et al. 2020; North et al. 2017), and the US Geological Service Gap Analysis Project predicted Northern spotted owl habitat model (USGS 2018). The GAP model, based on landcover type, designates the majority of the lower watershed as potential habitat. Emerging research using LiDAR data has indicated that the cover of large trees (greater than 48 meters) is the best single predictor of spotted owl habitat for both California (North et al. 2017) and Northern (Hagar et al. 2020) spotted owls. Analysis units that were predominantly outside of the habitat predicted by the GAP model, and those that contained little-to-no large trees, were selected. A few selected analysis units that did contain small patches (approximately two to 10 acres per analysis unit) were included due to their proximity to other units without large trees, or where the patches were relatively isolated from the contiguous swaths common in the lower watershed.

Analysis units for **Objective 13 (Maintain dense coniferous canopy cover in areas that elk have used as a refuge in extreme winter weather events)** were hand-selected to include analysis units bordering the north shore of Chester Morse Lake. These are areas that provide refuge areas for ungulates during extreme winter storm events, and have value for water quality, mature forest habitat, and shoreline stability.

5.3.5 Fire Hazard Mitigation

Map 2.10 shows analysis units that were identified for wildfire fuels mitigation.

Objective 14 (Reduce hazardous fuel risk around critical utility infrastructure) is to create defensible space around at-risk infrastructure for watershed operations. Analysis units within 2,000 feet of infrastructure were selected, except those that had unstable slopes. These areas were selected to actively change fuel structure, potentially change fire behavior, and improve fire-suppression activities around critical infrastructure.

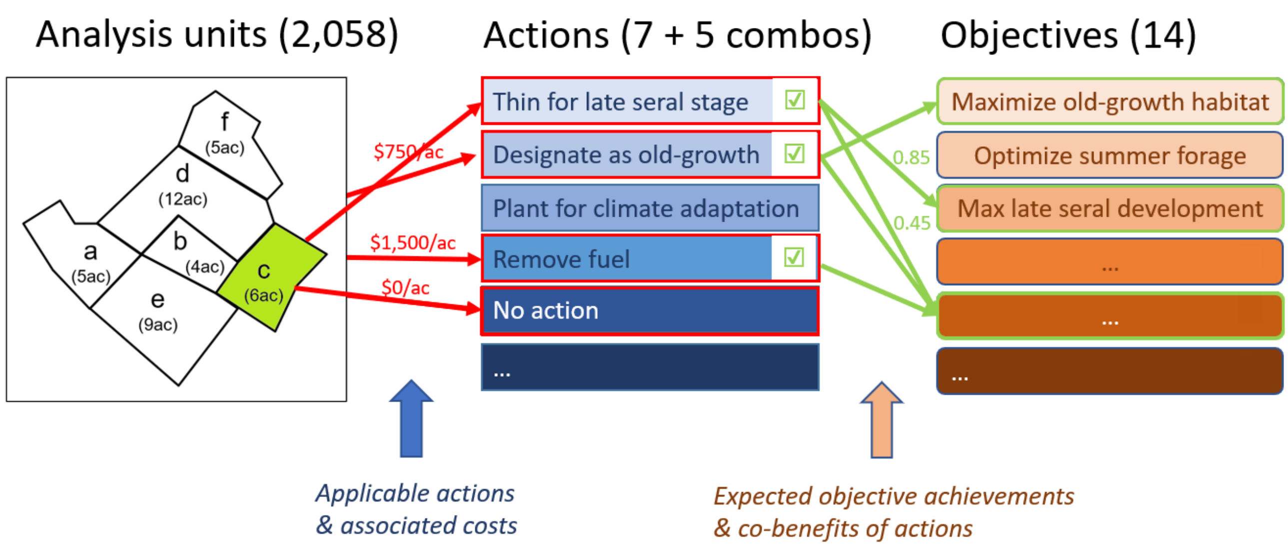
5.4 Multi-Criteria Optimization Model

A multi-criteria optimization model was developed by Dr. Sandor Toth, University of Washington to create a transparent process of balancing achievement among objectives and prioritizing analysis units for active management. The model was cast as a multi-objective linear integer program where each objective function served to capture the 14 management objectives described above, while the decision variables represented the choices SPU had to make with regards to applying alternative actions (including non-actions) to the 2,095 analysis units to best achieve these objectives.

The number of actions applicable to an analysis unit determined the number of decision variables that were needed to create for that unit in the model. Some units had only one while others had two or more applicable decision variables. Mathematically, these variables were binary (or 0-1) representing the yes or no decisions that had to be made with regards to applying or not applying the associated action to the unit. Apart from the objective functions, the model also contained a set of mathematical inequalities meant to represent the budgetary and logical constraints inherent in the management problem. An example of a logical constraint would be a mathematical statement (inequality) that allows one and only one action to be applied to a given analysis unit, e.g., a unit can only be thinned or not thinned but not both. The formulation of budget constraints required estimating the total costs of each action when applied to a given unit. The constraint would then state that the sum of the products of these cost coefficients and the values of the corresponding 0-1 variables could not exceed the budget. Several budget scenarios were developed and analyzed by adjusting this budgetary threshold. The model was built to also recognize multiple sources of budgets, some of which could only be used to finance certain actions. When more than one budget was available to pay for a certain action, the model could select the budget that would help best achieve all the objectives.

In order to represent the connections between analysis units, actions, and objectives, the optimization model assigned to each decision variable a measure of achievement, defined as the ability of the analysis unit to meet a management objective should a given management action be applied to that unit. These measures of achievement corresponding to each of the 14 objectives were then multiplied with each associated decision variable. The sum of these product terms was then maximized by the optimization model. The achievement metrics were calculated as the sum of a location value, defined as the importance of meeting an objective at a given location and structural forest conditions, defined as forest conditions (height and composition) that make it more likely to meet the objective. Achievement values for individual analysis units were calculated using spatial data and remotely sensed forest structure and composition data. Variables and functions for value and structure are provided in Table 5.2. Value and structure were normalized to range between 0 and 1 prior to summation to yield a total achievement value. Multiple potential management scenarios were created using weights and threshold values for objectives that create differences in achievement of each management objective, given the overall budget allocation. A combination of value and effectiveness of management was used to calculate an achievement value for each analysis unit. See Figure 5.2 for the conceptual structure of the optimization model.

Figure 5.2: The conceptual structure of the multi-objective optimization model



A single primary objective was assigned to those analysis units for which multiple objectives were identified during the development of candidate pools. The notion of "primary objective," as opposed to secondary or tertiary objective, was an artifact of the landscape model approach whereby SPU identified pools of analysis units that could best meet one of each of the 14 objectives. Thus, each unit was associated with a primary objective and the associated action was designed specifically to meet that objective. However, applying a specific action to a specific unit did not preclude other objectives to receive benefits from that action. These objectives are "secondary" for the unit only because the original choice of adding the unit to a pool was meant to serve another, "primary" objective. The benefits projected to be realized for these secondary objectives were then called "co-benefits."

For certain management objective-action combinations, it was possible to quantify co-benefits for secondary objectives that were not identified as the primary management objective. Determination of co-benefits utilized the same variables and functions as used for primary objectives. The cost of actions, however, was only assigned to the primary objective with no cost assigned to secondary objectives. Co-benefit achievements were used in the process of maximizing and balancing objective achievements in the optimization model. Total achievement for a management objective was the sum of direct benefits from the primary objective and co-benefits. Achievements for Objective 6 were entirely derived of co-benefits from thinning young stands for other objectives.

Because the optimization model used management budgets, each action/objective combination was assigned a cost for implementing the action. Action cost was calculated based on accessible acres within an analysis unit and estimated per-acre cost of administration and implementation of each action. The estimated cost of actions is shown in Table 5.3. Areas accessible for machine work were assumed to be within 1,000 feet from existing roads. Areas for actions that require walk access, such as planting or thinning of small trees, were assumed to be within 2,000 feet of existing roads.

Revenue from sale of surplus logs generated during thinning or gap creation of commercial-size trees was estimated based on mean tree height, elevation, and method of logging (ground-based or cable yarding). Elevation bands were used to differentiate timber value of typical combinations of dominant tree species. Timber value was estimated from valuations of recent timber sales. Timber value does not include timber sale preparation or administration costs which are associated action costs. Revenue was calculated but not used in the optimization model for selecting and prioritizing management actions. Estimated timber sale values per acre are given in Table 5.4.

Table 5.4: Variable revenue calculation for ground-based and cable thinning. Dollar values are shown per acre of thinning area; Administrative cost is not included; Revenue values include operational cost of $360/acre for ground-based and $460/acre for cable logging; Canopy height classes relate to per acre timber volume; Elevation classes relate to timber value of dominant species; Revenue estimates are based on timber valuation and timber stumpage bids from past projects.

	Ground-based logging (MeanSlope <20%)			**Cable-logging (Mean Slope >20%)**		
Canopy Height	**Elevation**			**Elevation**		
	<1550 feet	<2800 feet	>2800 feet	<1550 feet	<2800 feet	>2800 feet
60-90 feet	$2,850	$2,500	$2,100	$1,350	$1,000	$600
90-120 feet	$3,780	$3,500	$3,000	$2,000	$1,700	$1,200
>120 feet	$5,000	$4,500	$3,800	$3,000	$2,500	$1,800

The first step in optimizing the overall achievement was to calculate the maximum possible budget for each management objective. This approach allowed for comparison of the relative achievement of each objective to what is possible given the budget. Several scenarios were created using different budget combinations as well as weights and threshold values for objective achievements. The scenario output files can be provided as supporting information upon request. The model was provided with a five-year budget to optimize allocation among objectives. Management objectives for elk habitat (Objectives 11 and 12) and fuel hazard management (Objective 14) had separate budgets from all other objectives. Objectives that had no prescribed actions but rather assigned analysis units into a reserve status (Objectives 1, 4, 5, and 13) had no cost associated.

The optimization model and input from FMP sub-committee members was used to balance the achievement of objectives and the allocation of resources. For example, a greater quantitative weight was assigned to managing for upper-elevation ungulate habitat compared to lower-elevation habitat. Based on subcommittee input, a minimum threshold for achievement for late-seral forest habitat development was set. Setting minimum achievement thresholds was particularly useful in balancing among six objectives that shared the same budget based on the HCP Conservation Measures Review (2016). Separate budgets were established for ungulate habitat management (Objectives 11 and 12) and wildfire fuels management (Objective 14).

The optimization model enabled management actions to be prioritized and objective achievement to be optimized. The process of assigning a value to an analysis unit for a given objective and a potential achievement based on forest structure and composition created a ranking of analysis units within each candidate pool. This ranking, combined with estimated management action costs, allowed active management projects to be prioritized to meet each objective. Annual projects can be developed by combining multiple analysis units to balance effort and resources each year. The selection of management actions for the subsequent time period (plan years six through 28) was based on the same resource allocation and objective balance as used in the first five-year period (Budget Allocation in Section 3 Planning) and analysis units and actions were chosen by ranking achievement values.

5.5 Developing an Achievement Index for Actions and Objectives

The following section describes the process of calculating relative achievement values for actions taken to meet each management objective, using attributes of analysis units, cost, and revenue.

A multi-criteria decision support system was used to prioritize analysis units for actions to achieve management objectives and to balance overall achievement towards the 14 management objectives. For each objective only analysis units that were identified as belonging to the candidate pool, previously constrained by topology, site, and stand conditions to meet the conditions for management actions were used. For each analysis unit within a given candidate pool, indicators were identified for (1) the value (importance) of meeting an objective in this location, (2) the area (acres) within the analysis unit in which the objective could be achieved (operational area), (3) the level of achievement towards the objective outcome if an action was taken within the analysis unit, and (4) the cost associated with the prescribed action based upon the operational area, administrative and implementation cost, and potential revenue. Analysis unit attributes and objective indicators are described below and are summarized in Table 5.2. Potential co-benefits of an action that was prescribed for a different objective in an analysis unit but would result in an added achievement in another objective were also identified. The same calculations were used for achievements and co-benefits.

Objective 1: Late-seral Forest Reserve

All 2,095 analysis units were assigned value and achievement indices for this objective. The value of an individual analysis unit for this objective (late-seral forest reserve) was calculated as the product of (inverse) climatic exposure and site index. The inverse of climatic exposure and site index were normalized by dividing by the maximum value. Calculations for climate exposure made in the CRMW Forest Vulnerability Analysis were used, including indices for topographic position, snow cover loss, reference evapotranspiration, and soil type. The achievement towards Objective 1 was calculated by dividing mean canopy height by site index value (dominant tree height at age 100) and normalizing by dividing by the maximum value. All analysis units that were identified as "designated old-growth" or "mature forest" (mean canopy height greater than 145 feet) were assigned an achievement value of one. The total acres of each analysis unit were used as area achievement towards the objective. No cost was associated with placing the analysis units in reserve status. Mean canopy height was calculated from first LiDAR return above the 95th percentile of elevation above ground returns for each 30-meter pixel, excluding returns below two meters above ground. The mean site index value was calculated from the National Resource Conservation Service soil type coverage based on the King County Soil Map.

Objective 2: Mature Forest in Climate Refugia

Indices for individual analysis units to reserve mature forests in climate refugia were calculated for 41 analysis units. The calculations were the same for Objective 5. The value was calculated as the product of topographic position index and mean site index value. Both variables were normalized by dividing by the maximum value. An achievement value towards reaching the objective was calculated by dividing mean canopy height by mean site index value and normalizing by the maximum value. Achievement towards this objective was calculated as the total area (acres) of the analysis unit. No cost was associated with placing the analysis units in reserve status.

Objective 3: Restoring Late-Seral Forest Conditions

Values for actively restoring late-seral forest habitat conditions in second-growth forests were assigned to 366 analysis units. An importance value for this objective was calculated for each analysis unit based on its distance to the next analysis unit designated as either old-growth or mature forest. Closer distances were assigned a higher value. The achievement value towards this objective was calculated as the product of the importance value, the operational acres in the analysis unit, the inverse of canopy roughness (mean rumple value), and the normalized mean site index value. Distance to old-growth and mature forest was calculated between the centroid of an analysis unit and the closest perimeter of an old-growth or mature forest unit. The average canopy roughness was calculated from the rumple value of 30-meter pixels from the LiDAR canopy height model. Operational acres within each analysis unit was calculated as the area within 1,000 feet distance from a drivable road. The FMP distinguishes three different active approaches to meeting this objective: thinning with ground-based equipment (Action 2), thinning with cable yarding equipment (Action 3), and low intensity thinning, leaving cut trees on the ground for downwood augmentation (Action 4). Action 2 was assigned to analysis units with average slope less than 20%. 70% of the operational area within an analysis unit was assigned to achievement acres. For those analysis units that had less than 30 acres assigned to Action 2 or 3, 70% of the unit walk-access area was assigned to Action 4. Walk access was defined as being within 2,000 feet from a drivable road. Total cost of each action was calculated as operational areas multiplied by administration and implementation cost, and potential revenue. A separate cost and revenue table was created based on action type, elevation, and canopy height (Table 5.4).

Objective 4: Retain Forest Cover on Unstable Slopes

Analysis units with more than 50% of area and unstable slopes were assigned to this objective. Unstable slope area was derived from a previous landslide inventory and the Washington Department of Natural Resources coverage for unstable slopes that includes convergent headwalls, deep-seated landslides, alluvial fans, and inner gorges. Value for analysis units was calculated as the percentage area of unstable slopes in the analysis unit. The potential acres achieved under this objective were calculated as the analysis unit's area multiplied by the percentage of unstable slope. The objective achievement was calculated as acres multiplied by mean canopy cover, divided by 100. Mean canopy cover was derived from the proportion of LiDAR returns above 2-meter height, relative to the number of last returns within a 30-meter pixel. No cost was associated with analysis unit assignment to Objective 1. A total of 136 analysis units were assigned to this objective, and no other actions were allowed in these analysis units.

Objective 5: Reserve Mature Forest in Valley Climate Refugia

See Objective 2 for identifying indices of value and achievement for this objective.

Objective 6: Thin young stands in valley locations to reduce canopy transpiration

This objective was assigned to stands with young trees, close canopies, and growing in valley locations. A total of 43 analysis units were identified in the candidate pool. An objective value was calculated for each analysis unit as the normalized site index value. The actionable acreage for thinning in each unit was assumed to be 70% of the total area. An achievement value for young forest thinning was calculated by multiplying the objective value by thinning acres. The cost of thinning and administration was assumed to be $500 per acre.

Objective 7: Increase snow storage and reduce transpiration around streams and meadows in upper catchment basins

The candidate pool for this objective had 78 analysis units with a total of 1,270 acres in higher-elevation catchments. An importance value for each analysis unit was calculated as the distance to hydrologic features in upper-elevation catchments, such as wet meadows or higher-order streams, normalized by dividing by the greatest distance of analysis unit to hydrologic features. The area within an analysis unit on which thinning and gap creation would occur was calculated as 70% of the walk-access area in the unit.

An achievement value for this action was calculated as the product of the importance value of the analysis unit, the actionable acres, and the mean canopy roughness (LiDAR rumple value normalized by maximum rumple value in candidate pool). The cost for this activity was assumed to be $500 for administration and implementation. This activity was assumed to have a co-benefit for development of late-seral forest habitat (Objective 3).

Objective 8: Add dry-adapted tree species to drought affected stands

A total of 14 analysis units were included in the candidate pool for this objective, located on lower-elevation sites with outwash gravel soils. An importance value for each analysis unit was calculated as the climate exposure value, using the index developed in the forest vulnerability analysis, divided by the highest exposure value in the candidate pool. Acres for thinning and planting in the analysis units were calculated as 30% of the machine access area in each unit. An achievement value for this action, thinning and planting, was calculated by multiplying the actionable acres and the percent canopy loss calculated from LiDAR analysis. The cost for the activity was calculated by multiplying acres by $750, for administration and implementing planting. Revenue from thinning and harvest was calculated separately.

Objective 9: Add warm-adapted tree species to higher elevation climate exposed sites

For this objective, 22 analysis units in the candidate pool, which were located at ridge top of upper slope locations with shallow soils, were identified. The importance values were calculated using the climate exposure index, relative to the highest index value in the candidate pool. Actionable acres for thinning and planting were calculated using walk-access area for each unit and estimating 30% of the unit requiring thinning and planting. The achievement value for this action was calculated by multiplying the actionable acres by the inverse of the deciduous cover percent and multiplied by the importance value. The cost was calculated as $800 per acre for thinning and planting and $600 per acre for planting only.

Objective 10: Thin to promote deciduous cover

For the objective to promote deciduous cover in lower elevation conifer dominated stands, a total of 95 units in the candidate pool were identified. The location importance value for this objective was calculated as the mean climate exposure value from the climate vulnerability analysis. The objective achievement value for the action of thinning and downwood was calculated as the inverse of deciduous cover, multiplied by actional walk acres, and location importance value. The cost of this action was calculated as $300 per acre.

Ungulate Objectives 11 and 12

Research conducted by the Muckleshoot Indian Tribe, US Forest Service, and other partners on elk nutritional ecology in the Pacific Northwest enabled a quantitative estimate of elk habitat value. The FMP leverages those techniques to estimate the projected improvement in elk habitat for a given treatment at a given site ("Elk Forage Index Gain," described below) and used that number as the "achievement" input in the optimization model. Ungulates in the CRMW are highly mobile, and the candidate pool was structured to focus on areas already used by ungulates, so analysis units did not have a discrete value/importance input; we focused solely on achievement and cost in balancing these objectives within the optimization model.

Cook et al. (2016) describe an index of elk forage (dietary digestible energy, or "DDE") that is effective in predicting the demographic performance of populations and holds predictive power in habitat selection (Rowland et al., 2018). DDE can be calculated using freely available remote sensing products and equations presented in Rowland et al. (2018). Gradient nearest neighbor-derived forest structure data from 2017 of estimated canopy cover and percent hardwoods greater than 1 inch Diameter at Breast Height (LEMMA Team 2020) was used. Potential natural vegetation zone data was obtained from Henderson (2009) and calculated DDE for the watershed as described in other studies at the scale of a 30-meter pixel ($900m^2$) (Rowland et al., 2018). Pixels with erroneously high DDE values from moss-covered felsenmeer were excluded using hand-delineated polygons housed in a shapefile of special habitats.

Vales et al. (2017) describe an extension of DDE called the Elk Forage Index (EFI). The EFI is defined by the DDE value, the nutritional requirements of an average elk, and an areal unit of arbitrary size to yield the number of elk per year that area can support. This presents a direct way to evaluate the elk population potential held within each analysis unit and estimate the potential improvements garnered by a treatment. The EFI was calculated for each 30-meter pixel with a DDE value and summed within each analysis unit to describe the baseline value of that unit for elk. The analysis-unit-specific resultant EFI for its given treatment was calculated and the baseline EFI value was subtracted from it to yield the EFI gain for a given unit. The achievement for a given analysis unit and treatment was its EFI gain.

Objective 11: Reduce conifer canopy cover and increase forage plant biomass to enhance summer forage in the upper watershed

There was high variability in tree cover within the candidate pool for Objective 11. Because much of the second-growth forest at upper elevations are comprised of short-statured, small trees, it was determined that treatments that resulted in an average density of 125 trees per acre could be accommodated without unduly shifting the trajectory of forest recovery.

To calculate EFI gain for the Objective 11 candidate pool, an operational area subset for each analysis unit was made, which reflected places close to roads and more than 150 feet from streams, wetlands, and designated old-growth forest. We then obtained the trees per acre within the operational area using a layer of "tree approximate objects" (TAOs) derived from a 2014 LiDAR acquisition. It was assumed that the number of TAOs was proportional to the Gradient Nearest Neighbor Imputation-derived canopy cover within a given area because the boundaries of each unit were defined by stand similarity. The resultant forest canopy reduction was thereby estimated by taking the proportion of 125 to the current TAOs/acre in the operational area. The canopy cover was then reduced for each pixel in the operational area by this proportion in kind. For example, if the operational area for a unit averaged 250 TAOs/acre, 125 was divided by 250, yielding 50%, and a resulting canopy cover for each pixel in the operational area was projected to be 50% of its current value. The EFI was then recalculated for the analysis unit with that resulting canopy cover to derive the EFI gain. A cost of $500 per acre was assigned to the actionable acres for the optimization model.

Objective 12: Maintain existing hardwoods and increase understory forage by reducing conifer canopy cover at the stand scale through gap creation and thinning

Analysis units in the candidate pool for Objective 12 are located in the lower watershed and uniformly forested compared to Objective 11. Therefore, a more straightforward analytical approach was taken with this objective, reducing canopy by a fixed percentage across analysis units.

In estimating the EFI gain for this objective, areas available for yarding were considered to represent the operational area of the analysis units because cut-and-leave (and therefore walk-in only areas) are less likely to affect understory composition in these stands. Operational areas were further constrained to the same protective buffers (150 feet) implemented in Objective 11. Retaining extant deciduous cover in the lower watershed promotes climate resilience, maintains biodiversity, and contributes to ungulate habitat quality; canopy cover value was not reduced in pixels with greater than 50% hardwoods. The resultant EFI was calculated based on an anticipated 35% reduction in canopy cover, similar to past ecological thinning projects, within the remaining pixels. Finally, the predicted EFI gain was reduced by 50% to reflect anticipated skips in the treatment prescriptions, particularly around areas with larger trees. Costs associated with activities for this objective were taken from comparable thinning activities for late-seral forest development (Objective 3) and used in the optimization model.

Co-benefits for ungulates from other objectives

Several other objectives in the FMP require a reduction in the forest canopy to accomplish their goals, including climate resilience, hydrology improvement, and late-seral forest restoration. Because the value of elk habitat in the Pacific Northwest is closely tied to conifer cover, it is possible to predict the relative effect a given objective could have on elk habitat value. Co-benefits were considered along with the achievement value and cost in the optimization model. As was the case in all objectives, a given analysis unit may exist in several candidate pools, and the co-benefit for that analysis unit was unique to its objective.

To calculate the co-benefit, the baseline EFI value was first calculated for each analysis unit in the candidate pool for each objective with potential co-benefits. The average canopy reduction required to achieve each objective was then estimated (Table 5.5) and it was assumed that 70% of a given analysis unit would be treated to account for operational constraints. A post-treatment EFI value was created by reducing the canopy cover by 70% of the canopy reduction value (i.e., an analysis unit for Objective 7 would have the average canopy reduced by 20*0.7=14%). The difference between the post-treatment and baseline EFI values for each analysis unit in each objective, “EFI Gain,” was the calculated co-benefit.

Table 5.5: Estimated average canopy reduction factors for objectives with potential ungulate co-benefits.

Objective	Canopy Reduction (%)
3	15
6	15
7	20
8	10
9	10
10	5

Objective 13: Maintain dense coniferous canopy cover in areas that elk have used as a refuge in extreme winter weather events

This objective aimed to protect areas that provide a refuge for resident elk during extreme winter storms. The more snow the forest canopy intercepts from landing on the forest floor, the greater the energetic relief to elk trying to avoid those costs. It was determined that higher conifer canopy cover stands would have greater value for elk during extreme winter storms. As a result, percent canopy cover was used as the importance value for analysis units in the candidate pool for Objective 13. This objective was prioritized over other management objectives in the optimization model and no other actions were allowed in these analysis units.

Objective 14: Reduce hazardous fuel risk around critical utility infrastructure

This objective aims to mitigate hazardous fuels near high-value infrastructure assets. Assets were assessed on the criticality to water supply management, hydropower generation, and watershed management functions. The location value index was calculated using the relative proximity to water conveyance structures and administrative infrastructure. The achievement values for this objective were calculated as the inverse of the average canopy height of the analysis unit. The administrative cost of this action was assumed to be $750 per acre while the potential revenue from thinning and fuels removal depended on logging method, canopy height, and elevation (Table 5.4). The potential thinning acres for this activity was estimated as 50% of the machine access acres.

5.6 Long-term Forest Development (Through 2080)

The HCP assumes that second-growth forests in the watershed develop over time into late-seral forest habitat and that the amount of said habitat will substantially increase by 2050. Forest ecosystems in the western Cascades have historically shown predictable development trajectories towards late-seral forest with notable exceptions under extreme site conditions. It is assumed that late-seral forests have benefits for water cycle regulation at the landscape scale, provide habitat for species of concern, and are resilient to maintain and recover these functions at the landscape scale. However, climate change has the potential to alter this trajectory, introducing greater uncertainty for improving ecosystem functions. As a baseline for expected forest development over time, forest growth was projected and a threshold for reaching late-seral forest habitat stage was identified (Map 2.3). Deviations from the expected forest development would indicate climate-induced changes in forest resilience and may require further adaptation to management approaches.

5.6.1 Projection of forest development

Mature second-growth forest was identified as having canopy heights greater than 145 feet, mainly in the lower Taylor River drainage. We also projected forest development using height and site index to determine which stands would likely reach mature forest conditions by 2050 and 2080. We used the ratio of average canopy height of each analysis unit divided by site index to determine a maturity threshold. The average height/site index ratio of existing old growth in the watershed is 1.31 (s.d. 0.31).

Generic site index equations were constructed for the watershed based on King's site index curves with a base height of 100 years. Six site index curves were constructed based on dominant tree height at age 50, 100, and 130, using logarithmic equations. Current mean canopy height for a given analysis unit was used to estimate stand age. Canopy height was estimated from LiDAR data from 2014 using the 95th percentile of first LiDAR returns of each 30meter pixel. The mean canopy height was calculated from all tiles within an analysis unit. Site index for each analysis unit was calculated from National Resource Conservation Service soil maps for the Snoqualmie Region, based on a raster of site index values from soil polygons.

Mean stand height development was estimated as the 36- and 66-year growth on each site index growth curve. Height growth was calculated from the projected stand height and added to the actual average canopy height of a given analysis unit.

It was estimated that a given analysis unit reached mature forest character when the ratio of projected canopy height to site index reached a value of 1.10. This value represents 110% of the canopy height that a dominant tree would reach at age 100 at a given site.

5.7 Priority Areas for Thinning Slash Management

Priority areas for thinning slash management to mitigate wildfire fuel hazard were identified using the following approach. Topographic features that are important to wildland fire fighting and fire behavior were identified; features included the ownership boundary, primary roads, helicopter landing sites, rock pits, and strategic ridges. A 500-foot buffer was drawn around those features, except roads and boundaries, which received a 250-foot buffer. Strategic ridges were ranked in importance in five classes by landscape zones. The buffers were spatially overlain and where multiple buffers occurred, their number was added. Strategic ridges were given three times the weight of any other feature when buffers were overlain and added. Analysis units that overlapped with buffers were ranked by canopy height in five classes with the lowest trees having the highest class and those with canopy height greater than100 feet having the lowest class. Height class values and sum of topographic values were added and normalized to calculate an importance value for each analysis unit for thinning slash mitigation. The resulting landscape pattern of slash mitigation priorities is shown on Map 2.11 and was used as an advisory for thinning slash management to mitigate wildfire fuels.

5.8 Habitat Conservation Plan Oversight Committee Forest Management Plan Subcommittee Overview

5.8.1 Background

The FMP articulates forest management strategies for the Cedar River Municipal Watershed (CRMW) to meet the goals of water quality and supply, habitat for fish and wildlife species that depend on old forests, climate resilience, Tribal objectives, and wildfire risk management. FMP development includes diverse technical participants as well as stakeholders, Tribes, executives, and regulators.

5.8.2 Process

Seattle Public Utilities convened a meeting in October 2018 to establish a subcommittee of the HCP Oversight Committee to support development of a comprehensive science-based forest management plan for the Cedar River Municipal Watershed. The plan was to incorporate new management objectives to guide watershed forest management activities, coordinate with other activities (roads, security, fire management) and obtain subcommittee member, executive, and regulator support. The initial subcommittee included members of the HCP Oversight Committee (Tim Romanski (USFWS), Jerry Franklin (UW), Richard Bigley (DNR), Mike Middleton (MIT Wildlife, with Melissa Calvert as alternate), Crystal Raymond (UW CIG), Charlie Raines (Sierra Club, with Jesse Piedfort as alternate), Jim Erckmann (former SPU staff, public at large), Dave Vales (MIT Wildlife) joined the group in 2022) and SPU staff (Amy LaBarge (chair, Natural Resources Manager), Rolf Gersonde (silviculturist), Michele Koehler (HCP Program Manager), Bill Richards (Wildlife Biologist)).

5.8.3 Subcommittee Meetings

The group met five times in 2019 to discuss the HCP, vulnerability analysis, wildlife research by the Muckleshoot Indian Tribe, structure and content of the forest management plan, wildfire research, forest hydrology, and visited ongoing field projects. During two meetings in 2020, the group discussed current ecological thinning projects, the wildfire strategic plan, and development of the forest management plan.

In July of 2021, SPU contracted Triangle Associates, a neutral third-party facilitation firm, to provide process support for the project and to facilitate the completion of the FMP. Triangle's scope of work on the project included conducting a mid-project assessment, developing a report with process recommendations, facilitating meetings, providing 'between meeting' communications, FMP review and comment integration support.

Between October 2021 and August 2022, Triangle facilitated six meetings with the FMP subcommittee. The subcommittee includes representatives of diverse interests from local, state, and federal agencies, Tribal representatives along with other stakeholder organizations. This group met monthly with SPU staff responsible for the development of the FMP to provide input on where and how SPU will direct the resources allocated as part of the plan. During these meetings, SPU staff and consultants updated the subcommittee on progress in the development of FMP components including budget scenarios and a modeling approach to forecast impacts of proposed actions on forest health. Subcommittee members provided input on suggested ecological priorities and advised SPU on any further information or changes required for the members to support moving the items on to the decision-making level at SPU.

5.8.4 Document Review

Between April and August 2022, the subcommittee engaged in a review of each section of the draft FMP. Triangle and the SPU Project Lead coordinated the review and tracked all comments along with responses before incorporating them into revisions to the draft document.

5.8.5 Recommendations

The development of the FMP resulted in recommendations (Memo 10-19-2022 FMP to HCPOC) that were supported by all committee members and handed to the HCP Oversight Committee for approval. The HCP Oversight committee submitted the recommendations on 10/26/2022.

Table 5.6: Meetings of the Forest Management Plan Sub-committee of the HCP Oversight Committee between 2018 and 2022.

Date	Topics	Decisions	Meeting Summary *Note: Meeting materials can be made available upon request.*
10/22/18	• Introductions • Subcommittee purpose • Ground Rules • Goals • Schedule	Document sharing	Meeting Minutes 10-22-2018 Goal_and_approach_Final
05/31/19	• Wildfire modeling • Wildlife research • Plan development	Field Tour July 2019	2019-05-31 Final Meeting Minutes
12/16/19	• Ecological Thinning Projects • Outline of FMP	None	2019-12-16 FMP HCP-SC Minutes
04/07/20	• Ecological Thinning Projects • Wildfire Strategic Plan • Forest Management Plan • Communication	None	2020-04-07 FMP Meeting Minutes

08/12/20	• Wildfire Risk Assessment • Forest Management Plan	Use decision-support model	2020-08-12 FMP Meeting Notes AM
10/13/21	• Watershed Field Tour Recap • Mid-Process Assessment Summary • Optimization Model Scenario Presentation and Discussion of Scenarios	None	Meeting Summary for 10-13 FMP Subcommittee Meeting.pdf
11/23/21	• Overview of Forest Management Plan Decision-Making Steps • Subcommittee Feedback from Review of Alternate Model Scenarios	Concurrence on support for the proposed scenarios	Meeting Summary for 11-23 FMP Subcommittee Meeting.docx
12/14/21	• Group Discussion on Open/ Early Seral Habitat Questions: total area and maintenance	Concurrence that the meeting provided needed clarity on the discussion topics	Meeting Summary for 12-14 FMP Subcommittee Meeting.docx
4/11/22	• Updates on WLOB Review • Discussion of Analysis Section Review • Update on Monitoring Goals for the FMP	None	Meeting Summary for 4-11 FMP Subcommittee Meeting
8/22/22	• Review of the updated Forest Management Plan Document • Discussion of Next Steps in the Forest Management Plan process	The subcommittee agreed that the discussed changes to the draft FMP should be made before presenting it to the HCP Oversight Committee on 10/26.	Meeting Summary for 8-22 FMP Subcommittee Meeting.docx

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Maps, Tables and Figures

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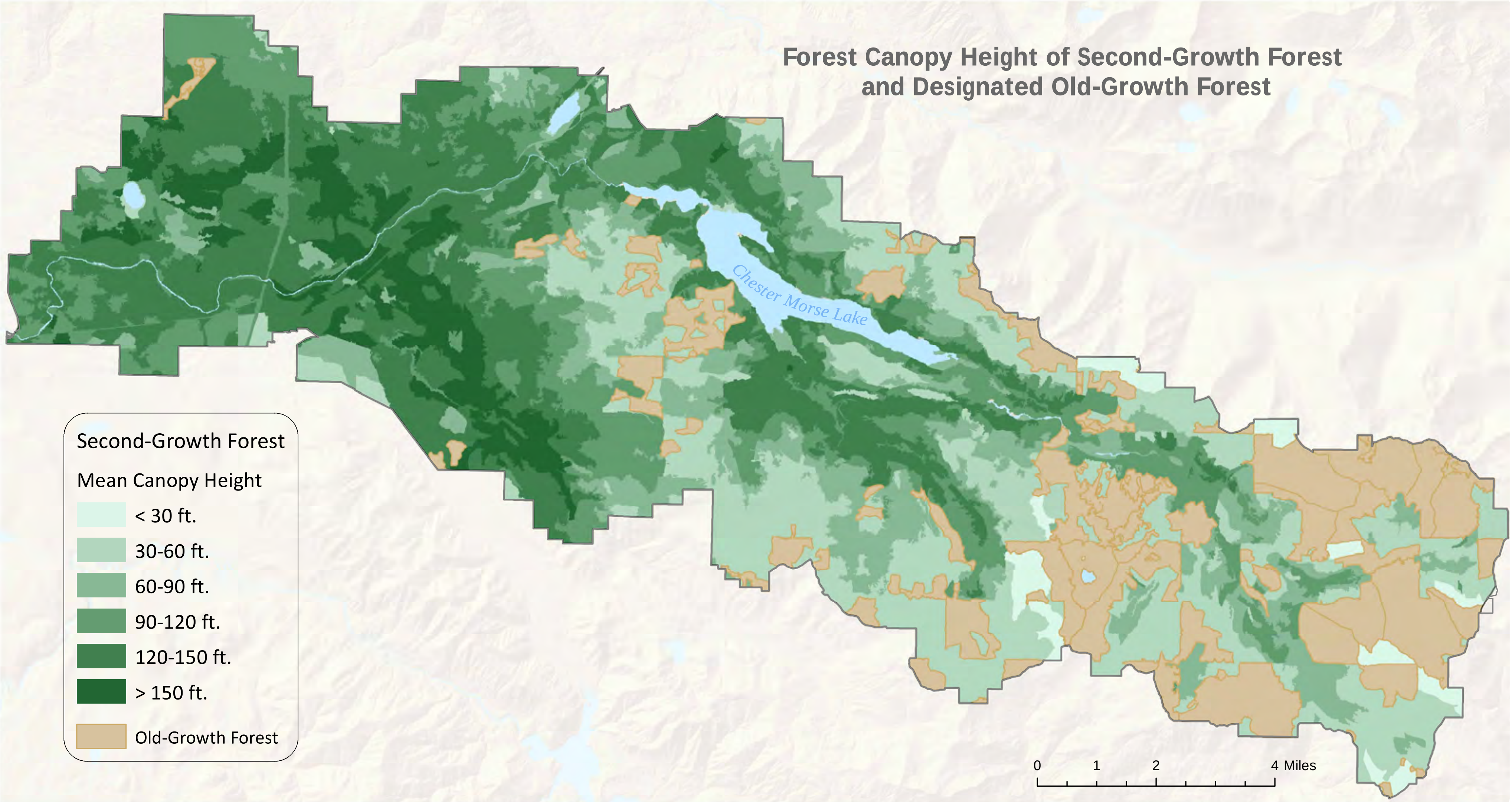

Map 2.1: The forest canopy height reflects the past harvest history in the Cedar River Municipal Watershed. Lower elevation forests in the western half of the watershed were harvested early in the 20th Century and have regrown tall canopies today. Un-harvested old-growth forest in the eastern watershed contrast with low canopy height second-growth forests, harvested before the implementation of the Habitat Conservation Plan.

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

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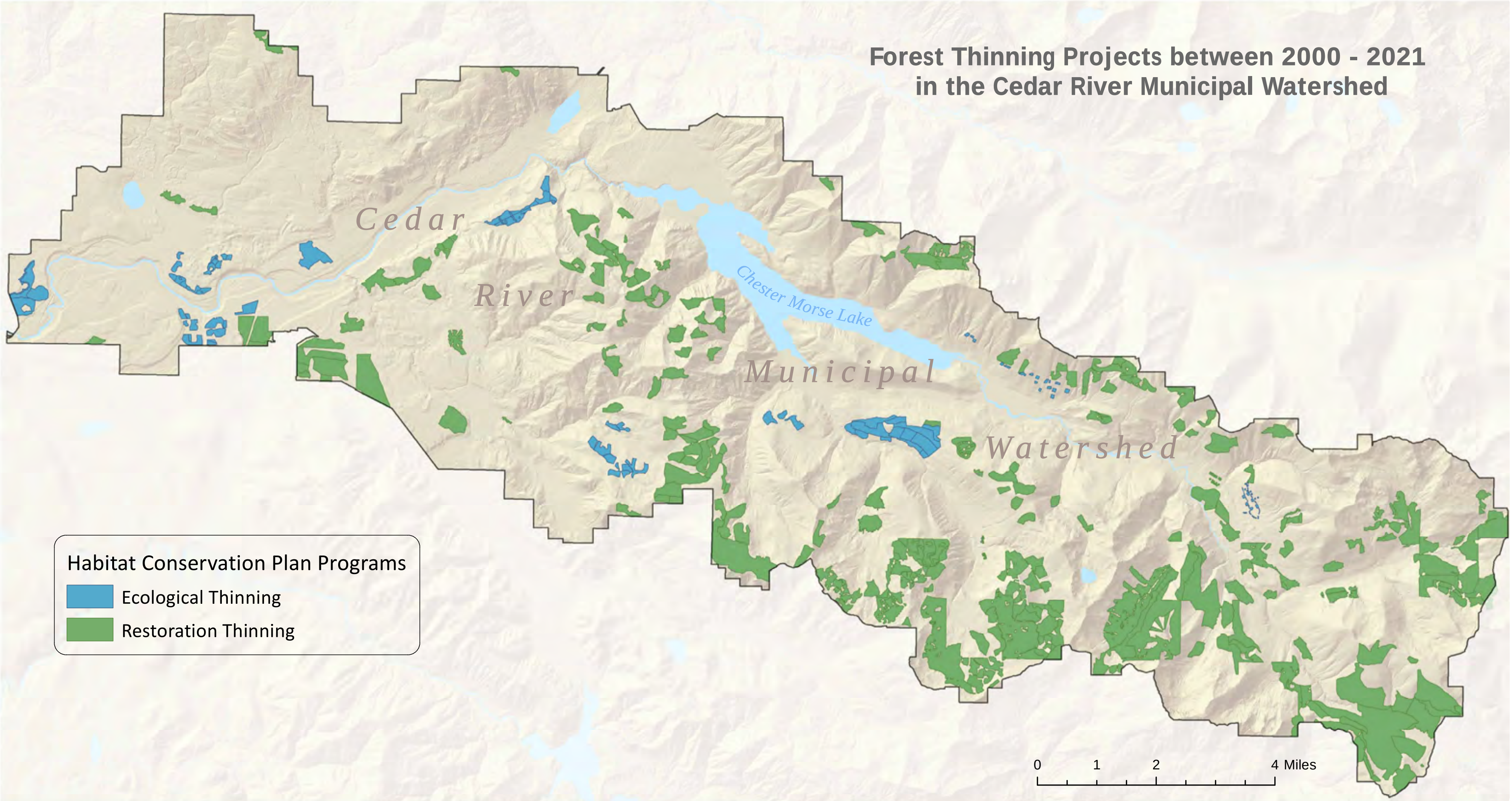

Map 2.2: The Cedar River Habitat Conservation Plan specified forest thinning programs that were implemented between 2000 and 2021. These included 10,700 acres of restoration thinning in young second-growth forests and 1,142 acres of ecological thinning in older forests to improve habitat development and biodiversity. Several thinning trials were implemented to test the efficacy of thinning and canopy gaps on understory development and tree growth.

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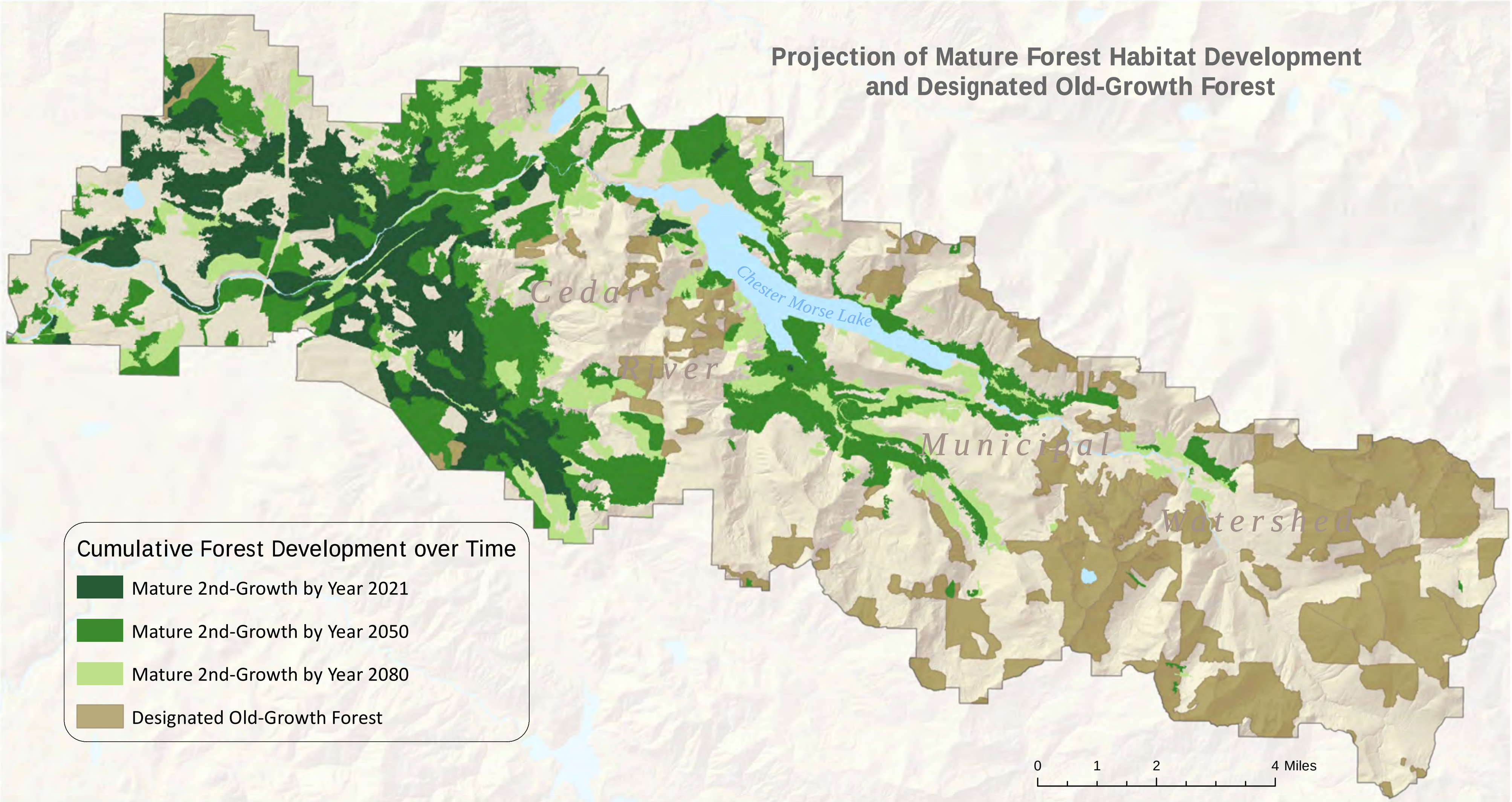

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 2.3: Mature forest habitat recovers slowly in second-growth forests of the Cedar River Municipal Watershed. Some mature forest habitat already exists in the western part of the watershed (8,578 acres in 2021). Other forests are going to reach mature habitat structure over time, reaching a total of 20,457 acres in 2050 and 26,491 acres in 2080. Un-harvested primary forest which was designated as old-growth forest under the Habitat Conservation Plan (15,005 acres) still exists primarily in the eastern part of the watershed.

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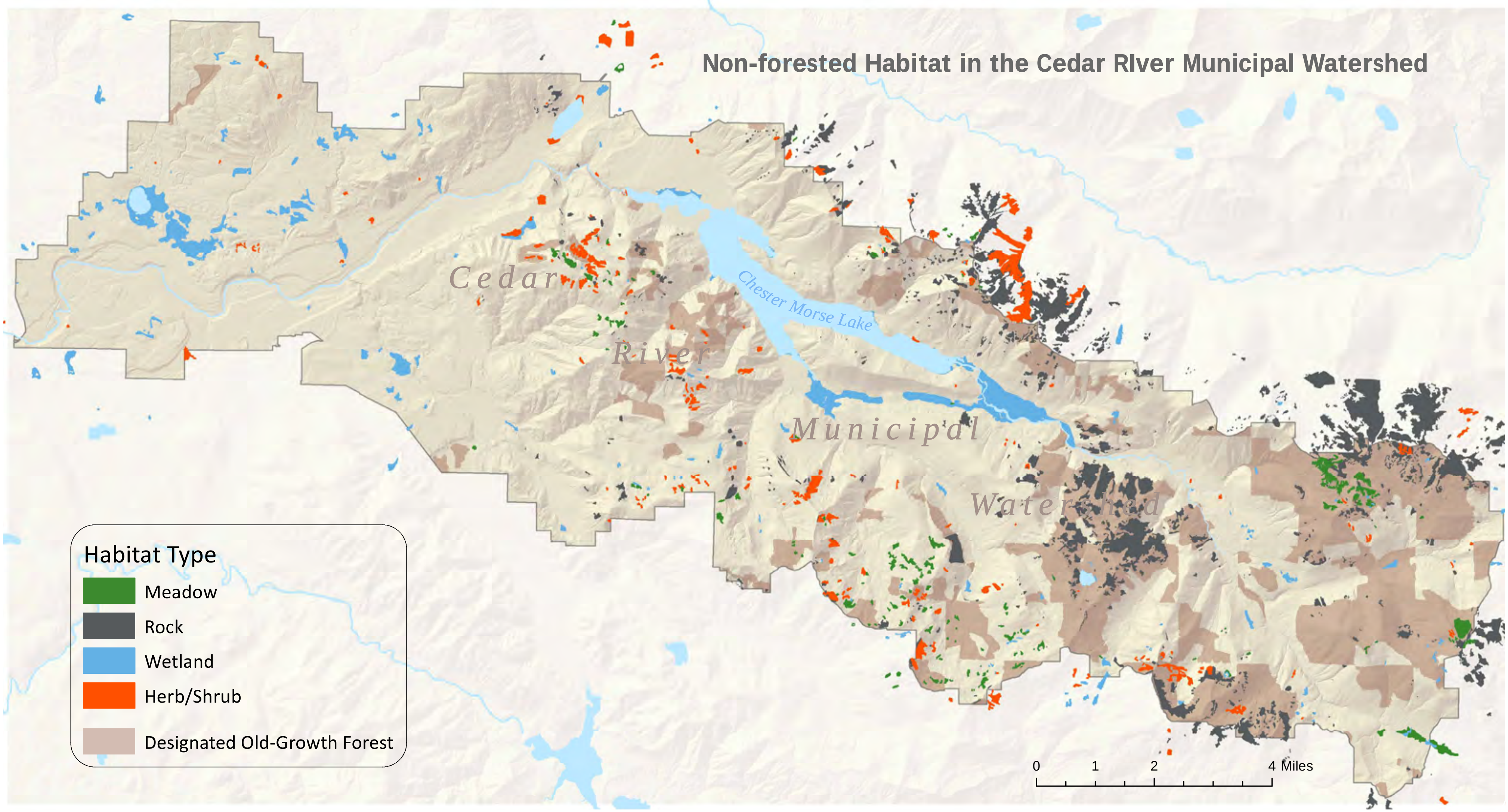

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 2.4: Non-forested habitats make a large contribution to biodiversity in the Cedar River Municipal Watershed. Many plant species are exclusively found here and wildlife species use non-forested habitat in and outside the watershed during part of their life cycle. Protecting non-forested habitat is part of the Habitat Conservation Plan and affects priorities for forest habitat restoration in second-growth forests.

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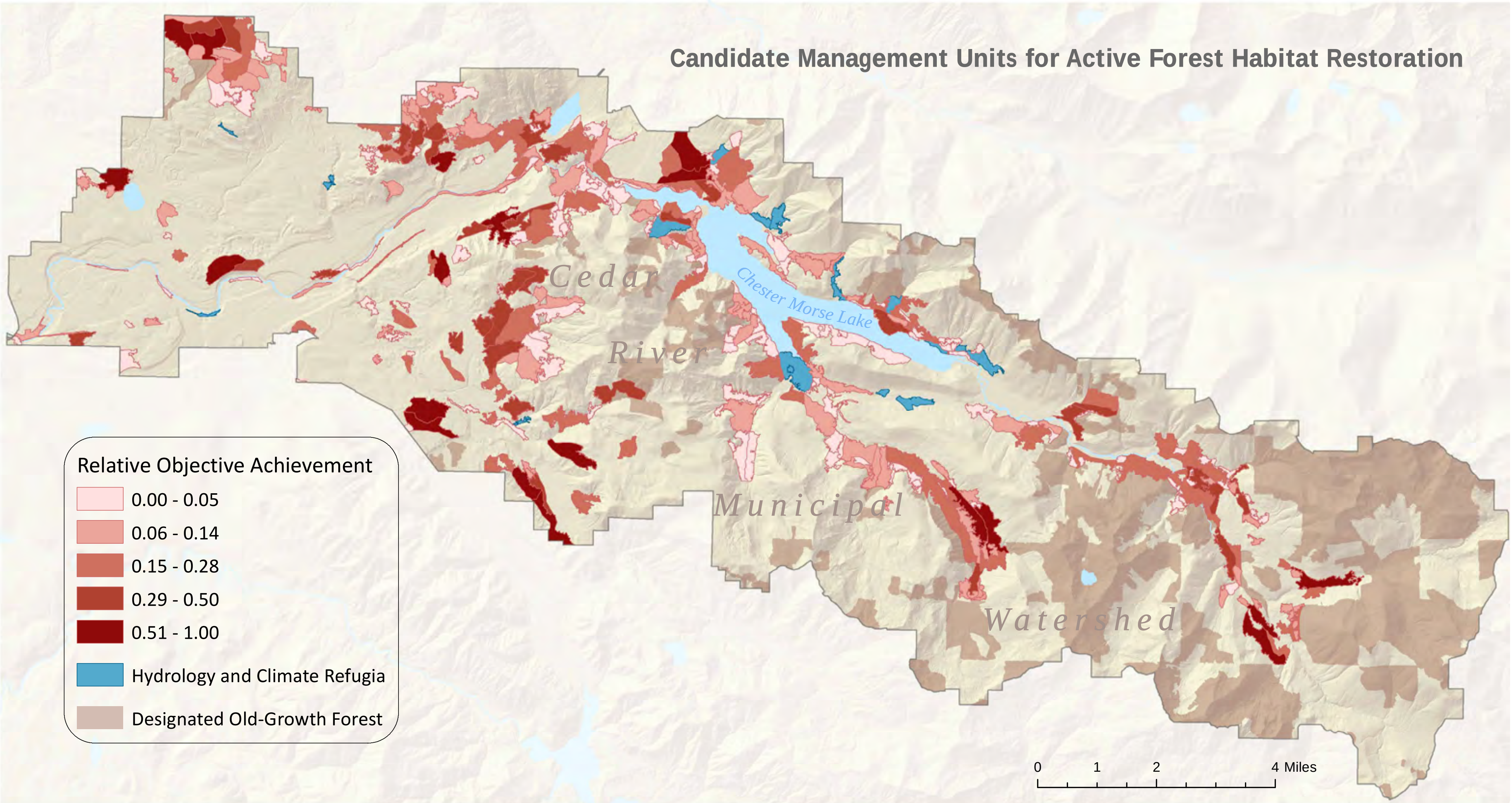

Map 2.5: A pool of candidate units was selected for active restoration of forest habitat and biodiversity. Darker colors have greater potential to achieve management objectives based on topography, forest structure, and habitat connectivity (FMP Table 2.3). Also shown are reserve areas for climate refugia and HCP designated old-growth forest.

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Map 2.6

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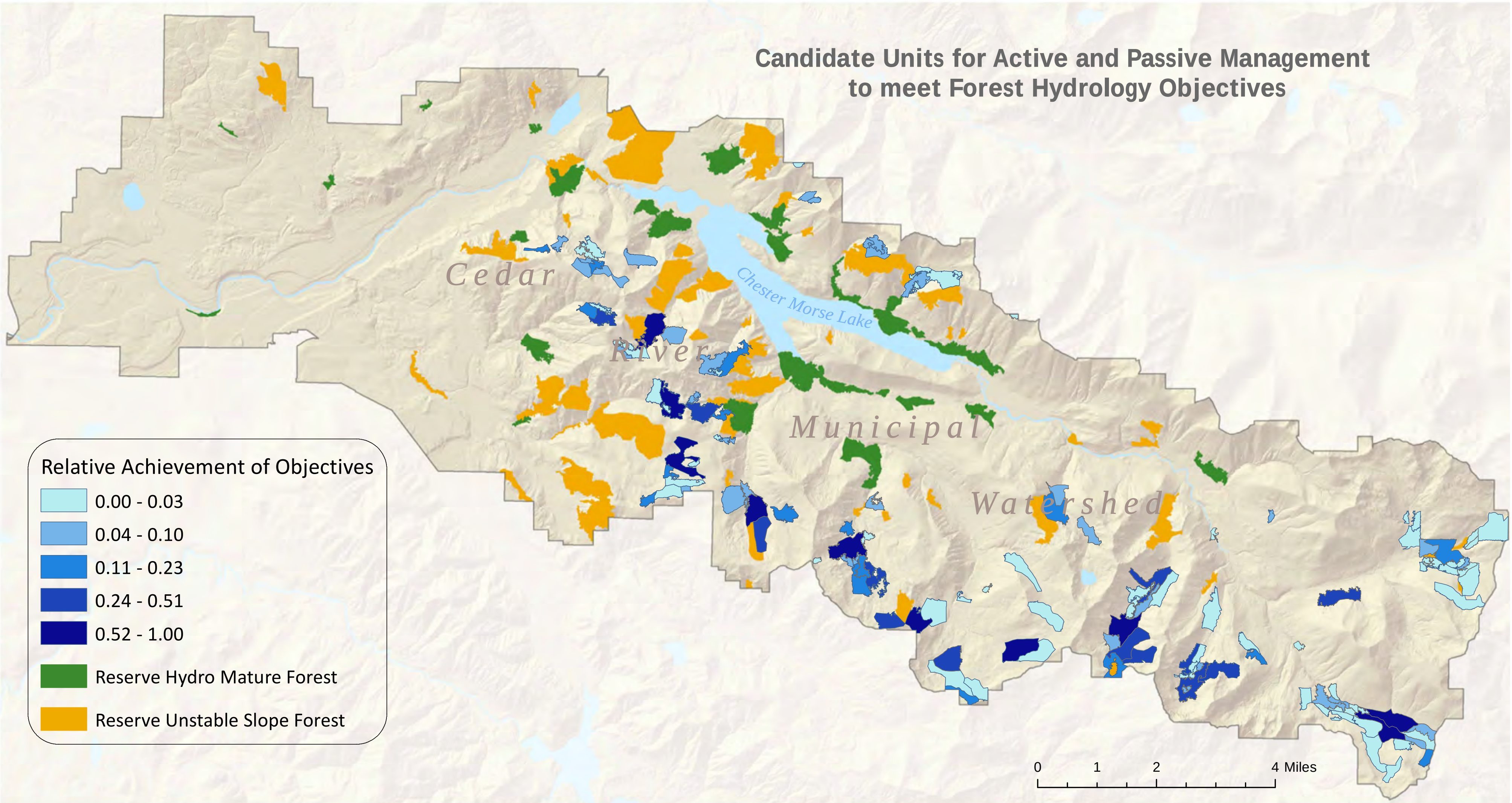

Map 2.6: Potential management units were identified to meet forest hydrology objectives in the Cedar River Municipal Watershed based on topographic position, forest structure, and proximity to streams (Table 2.3). Darker colors indicate greater potential to meet management objectives based on site conditions and thinning effect (Table 5.2). Also shown are areas selected for forest retention on unstable slopes and hydrological reserves in valley locations.

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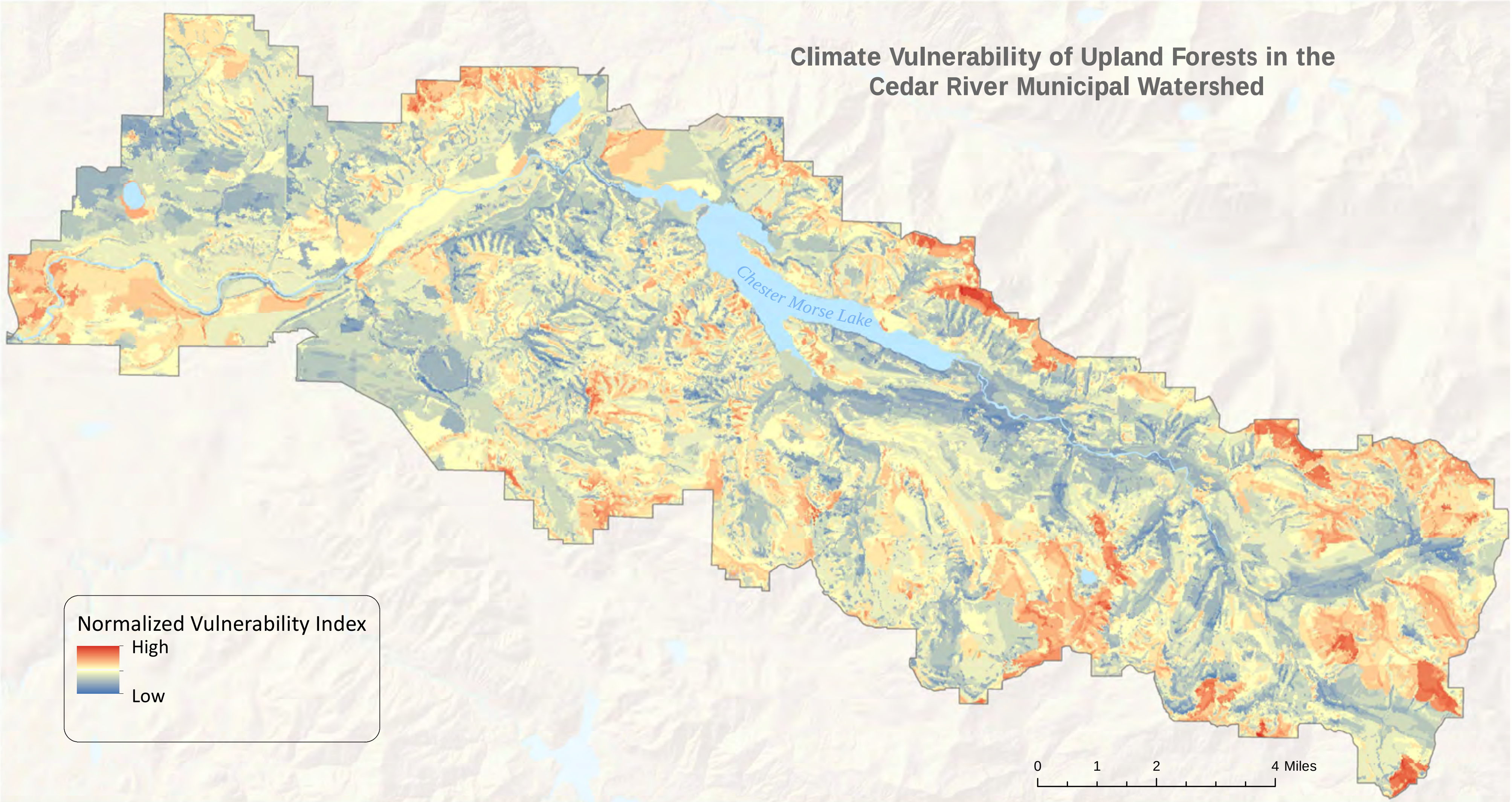

Map 2.7: Climate vulnerability of upland forests in the Cedar River Municipal Watershed was rated based on exposure, sensitivity, and adaptive capacity as part of the 2018 HCP Conservation Measures Review. Blue colors show forests with low climate vulnerability and red areas show forests with high climate vulnerability. We use climate vulnerability to identify forests for active climate adaptation (high vulnerability) as well as climate refugia and late-seral forest restoration (low vulnerability).

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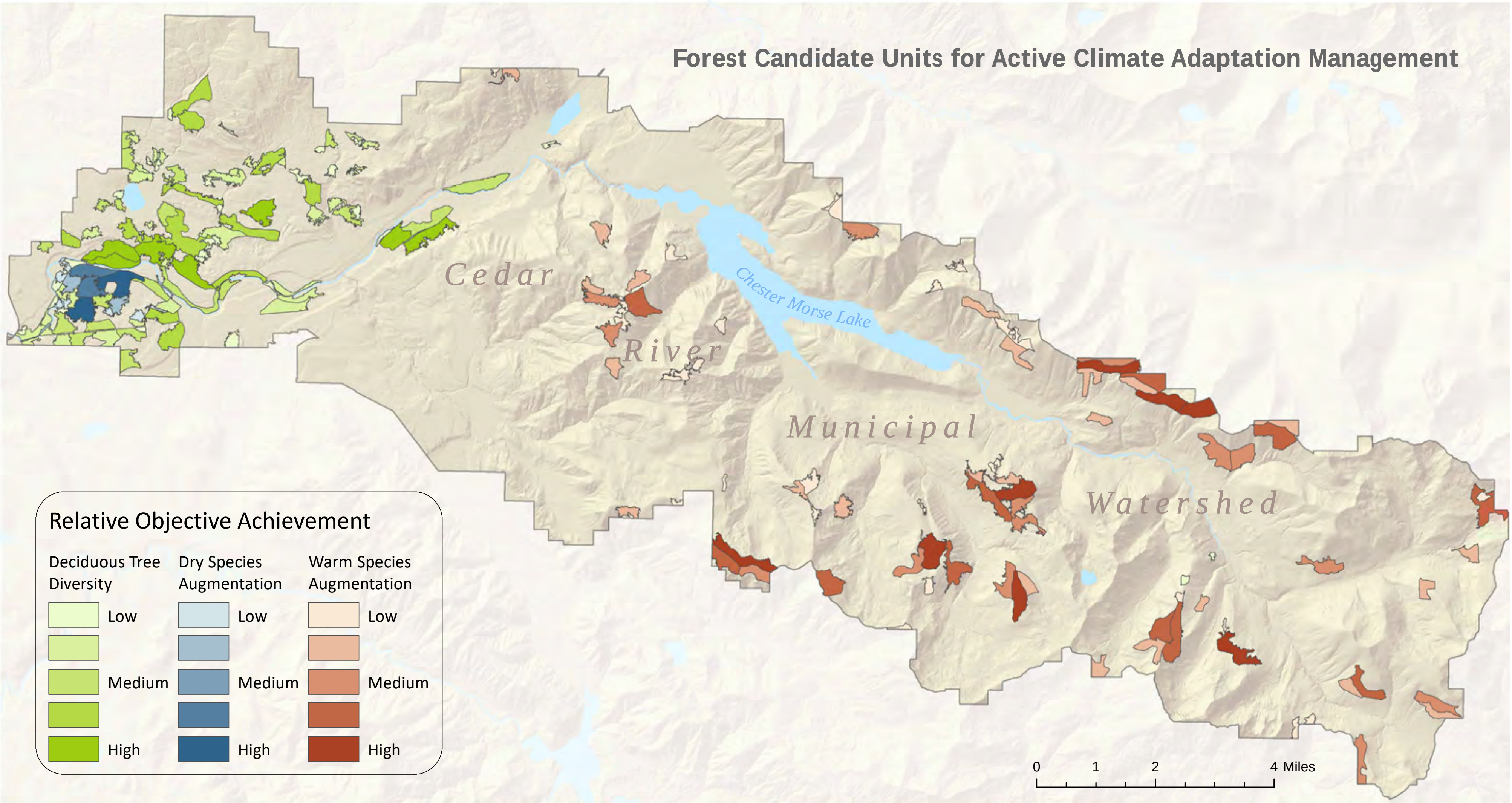

Map 2.8: Candidate units for active climate adaptation management were developed for three objectives: Increase deciduous tree species diversity in conifer dominated stands, augment forests growing on dry outwash gravel sites at lower elevation with dry adapted species, and thin and plant stands at high elevation and climate exposure with warm adapted species. Darker colors show greater potential achievement towards the objectives based on location and forest stand structure.

Map 2.9

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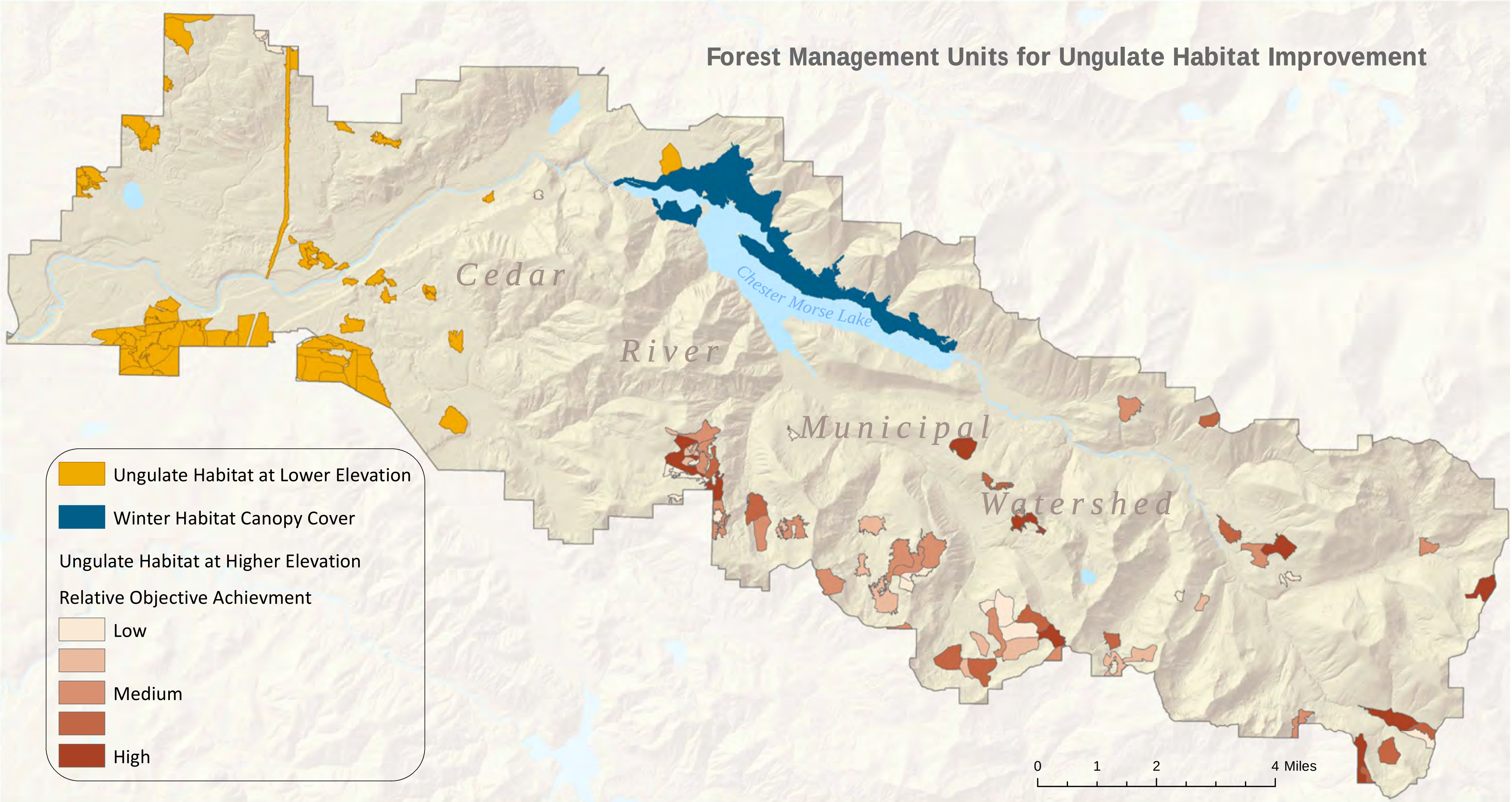

Map 2.9: Areas for potential improvement of ungulate habitat were identified in the lower and upper Cedar River Municipal Watershed using different objectives and selection criteria. Darker red colors show greater potential achievement of habitat objectives at higher elevation. Dark blue areas along the north shore of Chester Morse Lake were identified for retaining forest canopy cover for ungulate winter habitat.

Map 2.10

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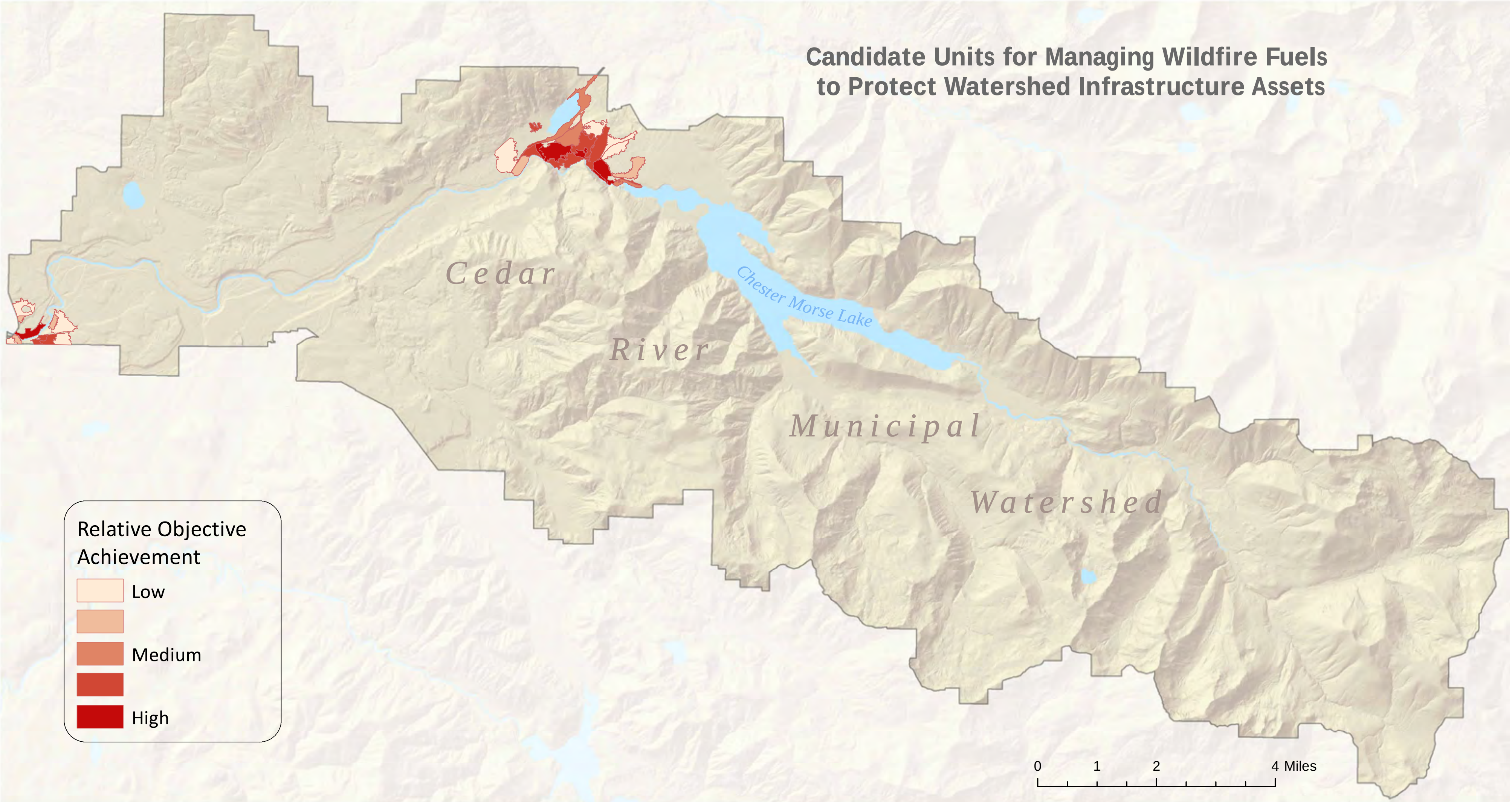

Map 2.10: Management units around critical infrastructure assets were identified for potential wildfire fuels management in the Cedar River Municipal Watershed. Darker colors show greater potential achievement towards the management objective based on location and forest structure. Emphasis was placed on structures around Masonry Dam, Cedar Falls, and Landsburg Dam.

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Map 2.11

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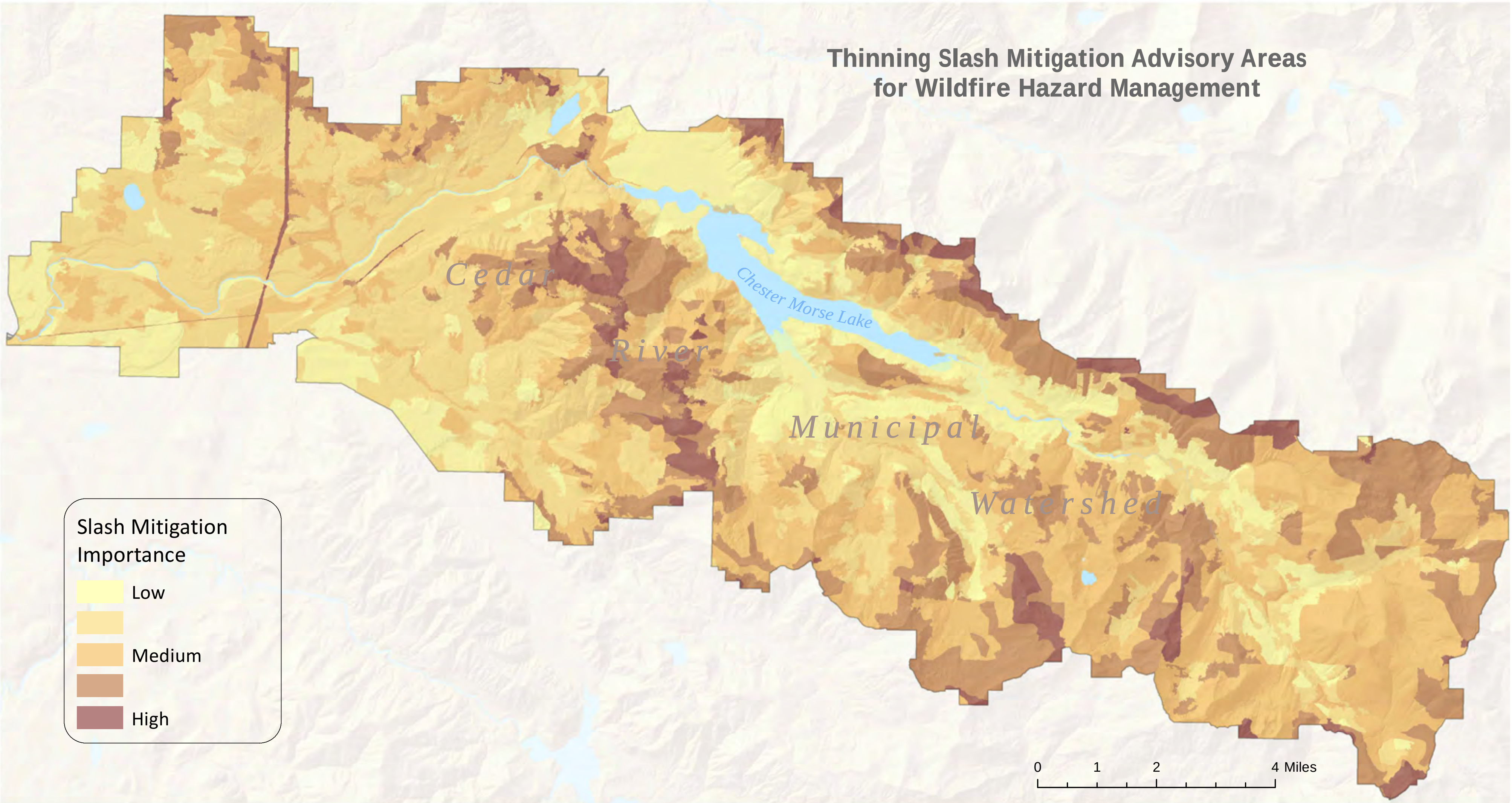

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 2.11: Areas for thinning slash mitigation were identified to manage wildfire fuel hazards following active forest management in the Cedar River Municipal Watershed. Areas of greater importance were identified based on topography, forest structure, fire fighting anchor points, and watershed infrastructure. Areas in red show greater importance for thinning fuels management.

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Map 3.1

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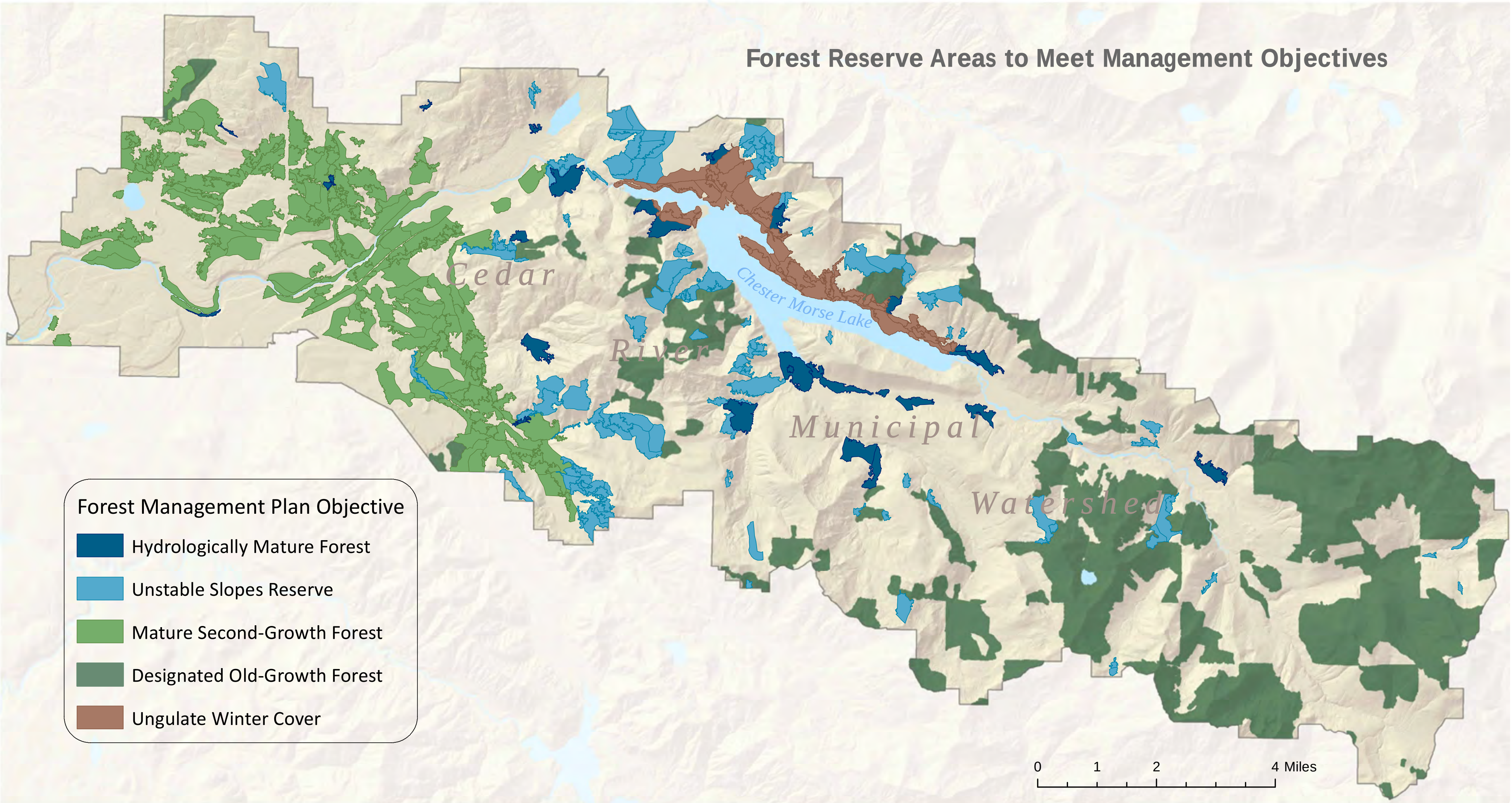

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 3.1: No active forest management will occur in reserve areas that were designated to meet specific forest management objectives in the Cedar River Municipal Watershed. Mature second-growth forests have canopy heights greater than 145 feet. Unstable slopes reserves have more than 50% of their area in unstable slope conditions. Hydrologically mature forest grows in valley locations and has mature forest canopy height. Ungulate winter cover areas along the north shore of Chester Morse Lake have closed canopy. Designated old-growth was identified in the Habitat Conservation Plan.

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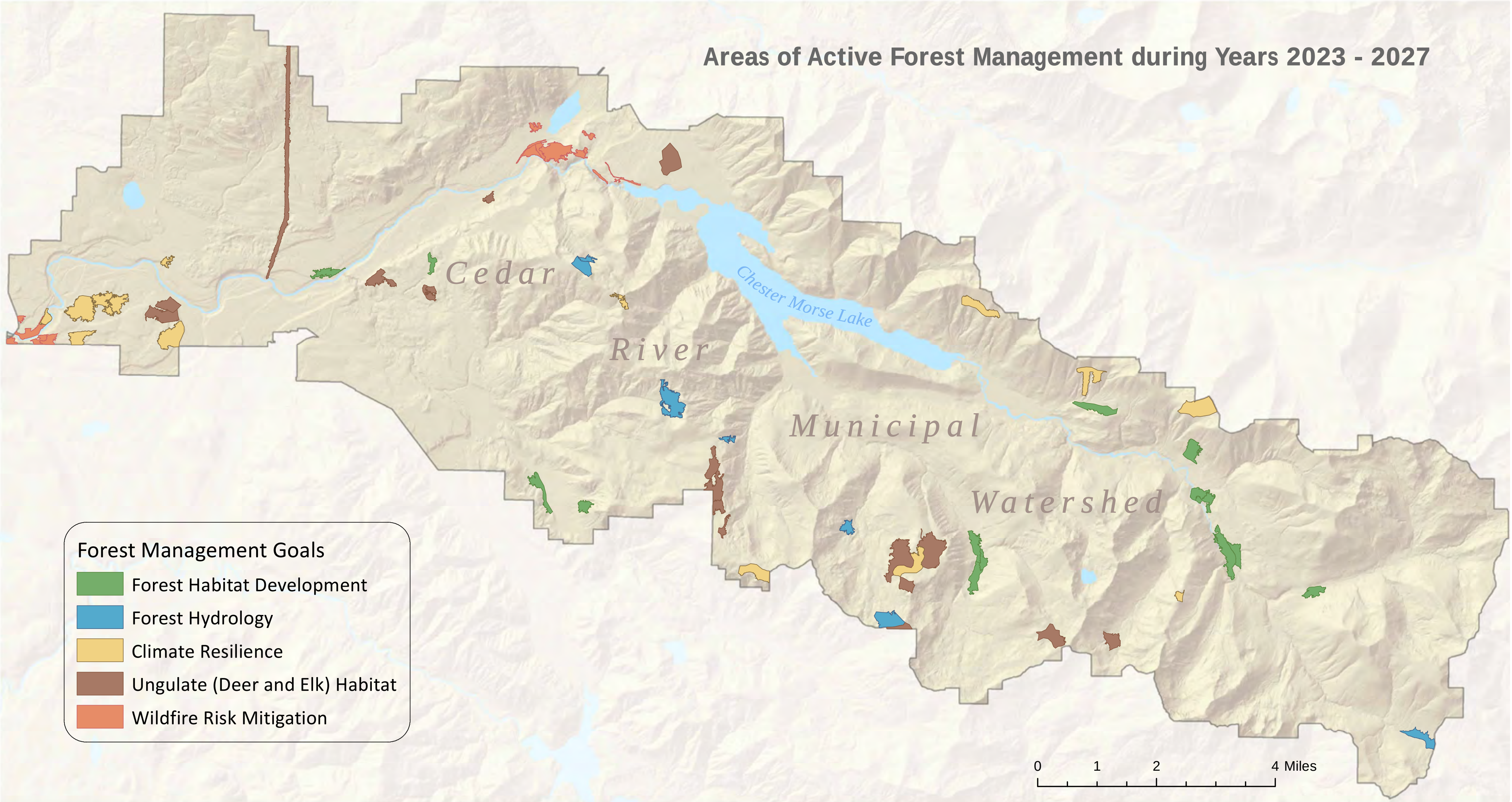

Map 3.2: The Forest Management Plan identified 1,520 acres of active management in the Cedar River Municipal Watershed during the first five years of implementation to meet objectives for each management goal. Management units were selected based on their landscape position, forest condition, and objective priority. See Table 3.1 of the Forest Management Plan for details.

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Map 3.3

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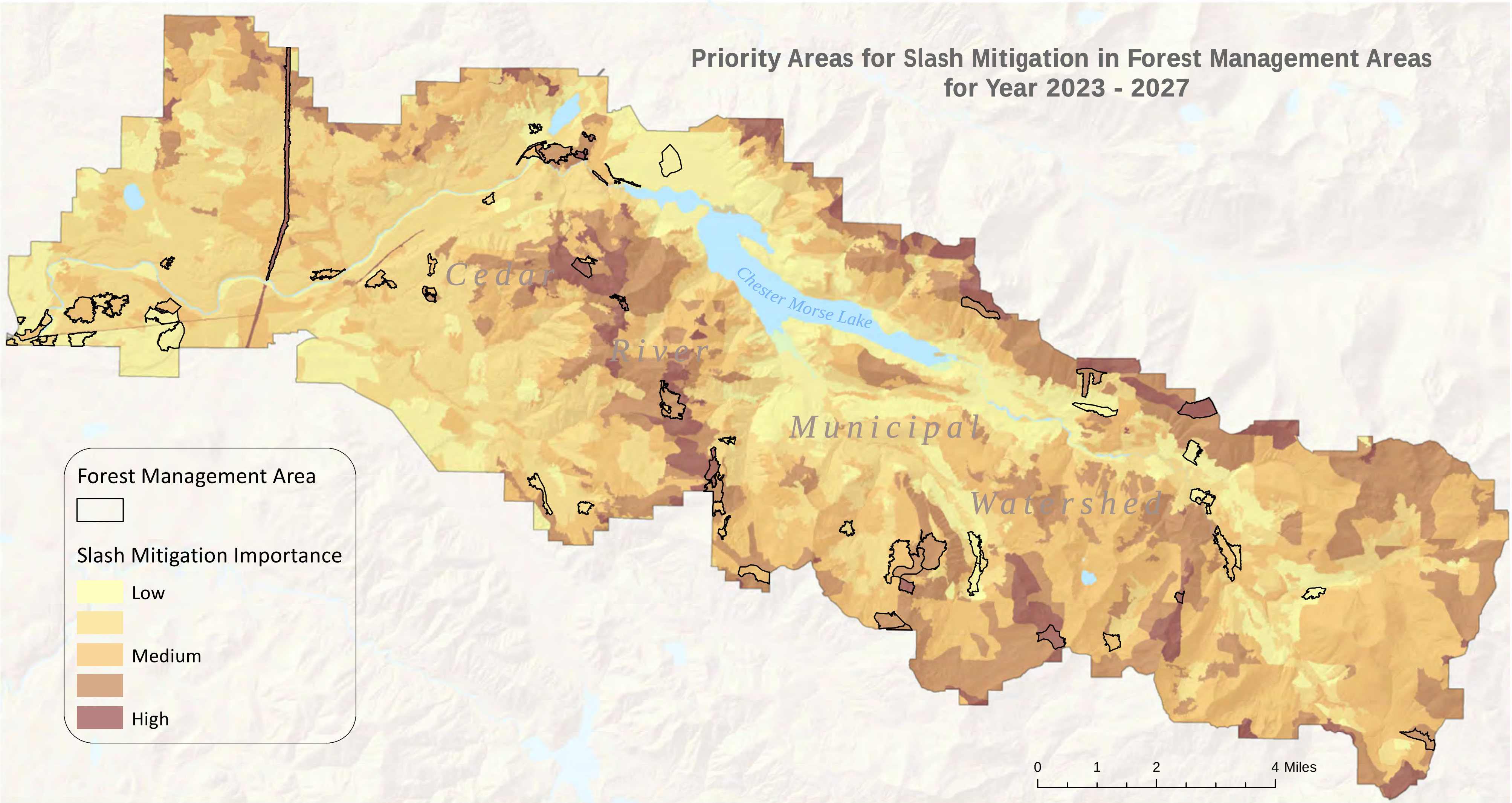

Map 3.3: Priority areas for slash mitigation are rated by how thinning slash can be removed or managed to affect fire behavior and increase ability to fight a wildfire. Locations along ridges, boundaries, and roads have a higher rating, as do forests with lower canopy height. Areas with active management (thinning, canopy gaps, planting, fuels) during the first 5 years of the plan are shown. Fuels management from thinning will be conducted in areas with high slash mitigation importance.

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Map 3.4a

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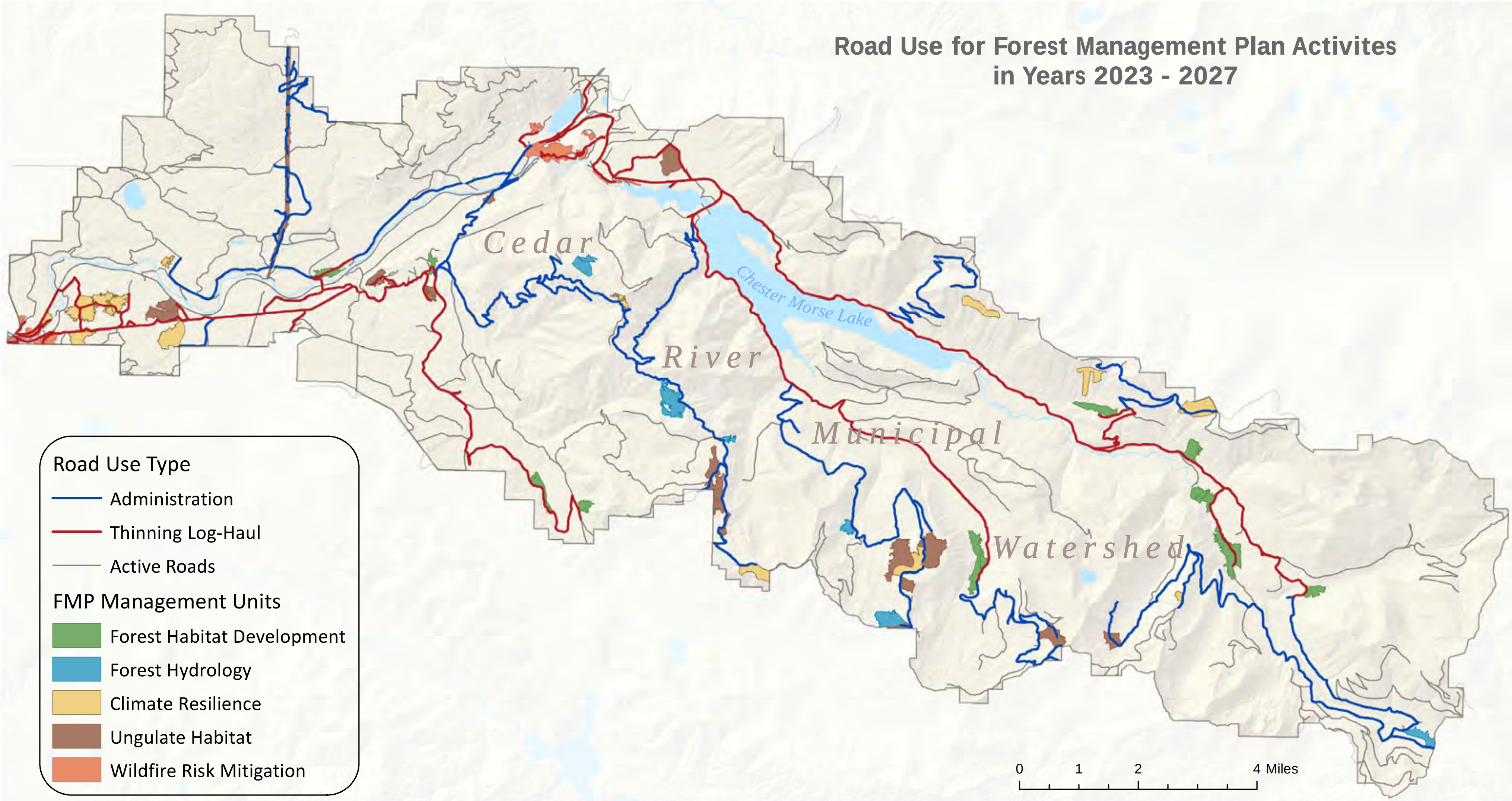

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 3.4a: Access to forest management units in the Cedar River Municipal Watershed requires different maintenance standards for administration and log-haul or heavy machine access. This map shows forest management activities by goals for the first five years of the Forest Management Plan, and the corresponding access roads for administration (blue) and log haul (red). Road use type for each period can be used to schedule road maintenance activities in each planning period.

Seattle Public Utilities

Map 3.4b

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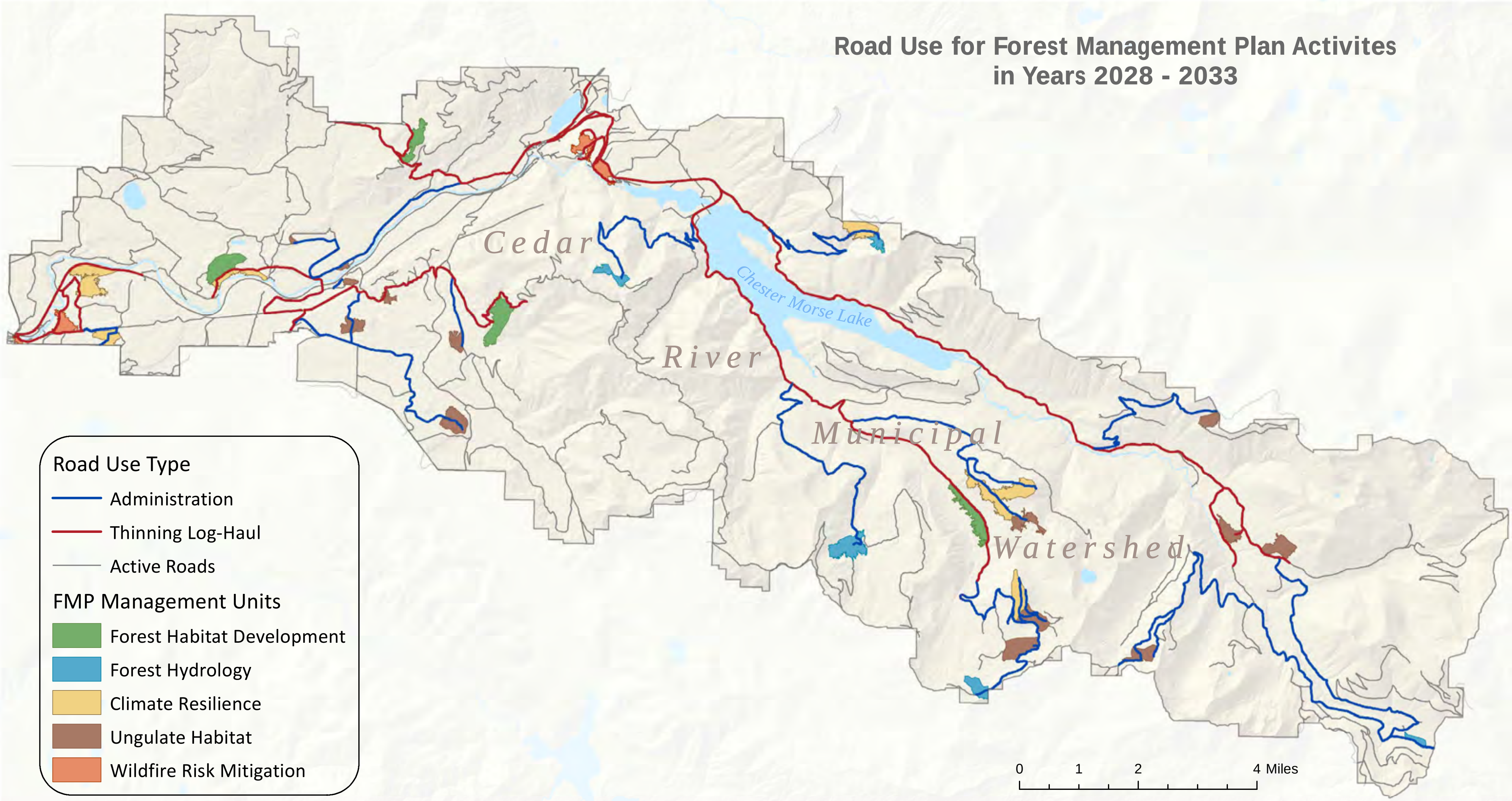

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 3.4b: Access to forest management units in the Cedar River Municipal Watershed requires different maintenance standards for administration and log-haul or heavy machine access. This map shows forest management activities by goals for the years 2028 to 2033 of the Forest Management Plan, and the corresponding access roads for administration (blue) and log haul (red). Road use type for each period can be used to schedule road maintenance activities in each planning period.

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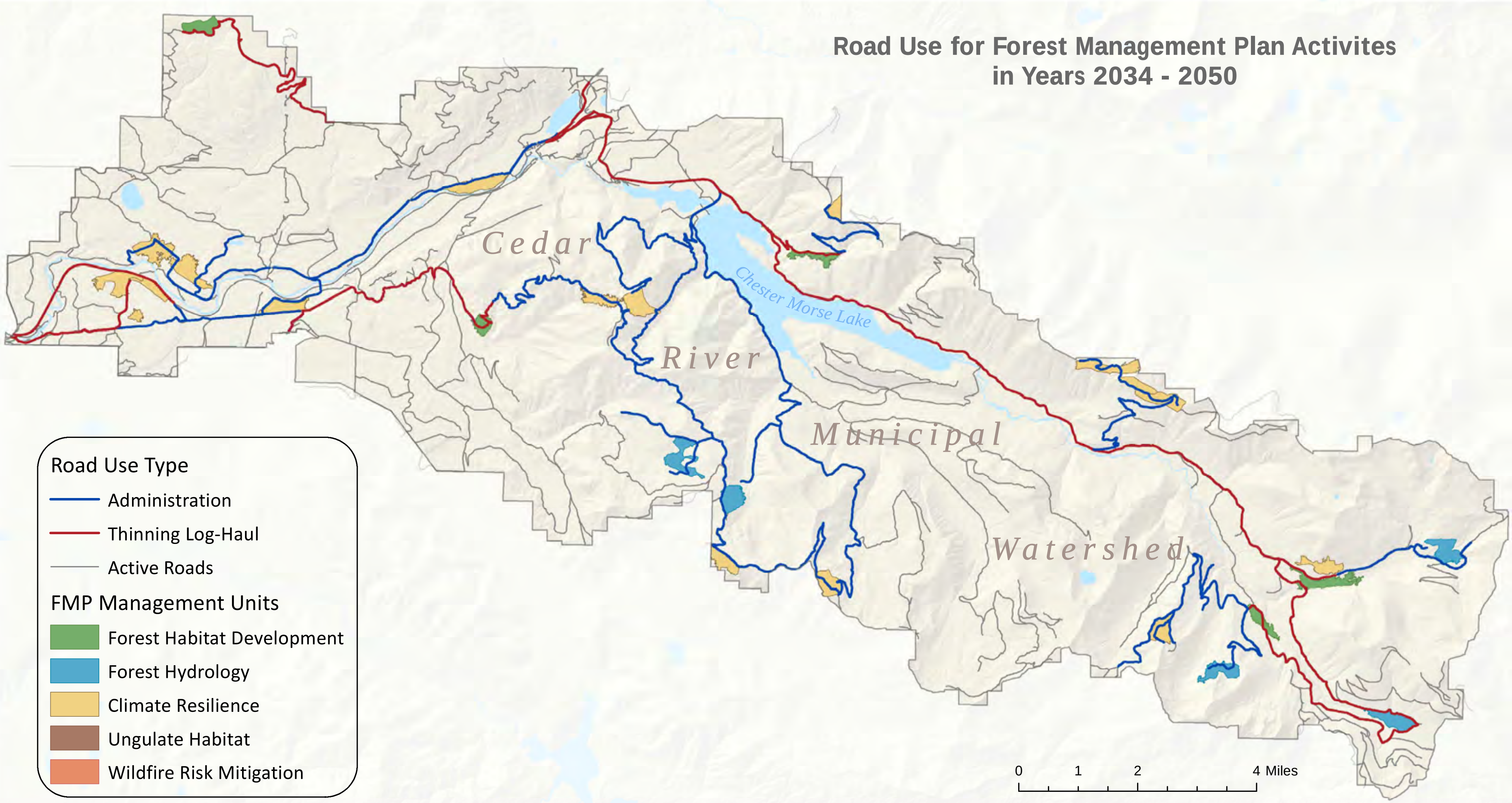

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 3.4c: Access to forest management units in the Cedar River Municipal Watershed requires different maintenance standards for administration and log-haul or heavy machine access. This map shows forest management activities by goals for the years 2034 to 2050 of the Forest Management Plan, and the corresponding access roads for administration (blue) and log haul (red). Road use type for each period can be used to schedule road maintenance activities in each planning period.

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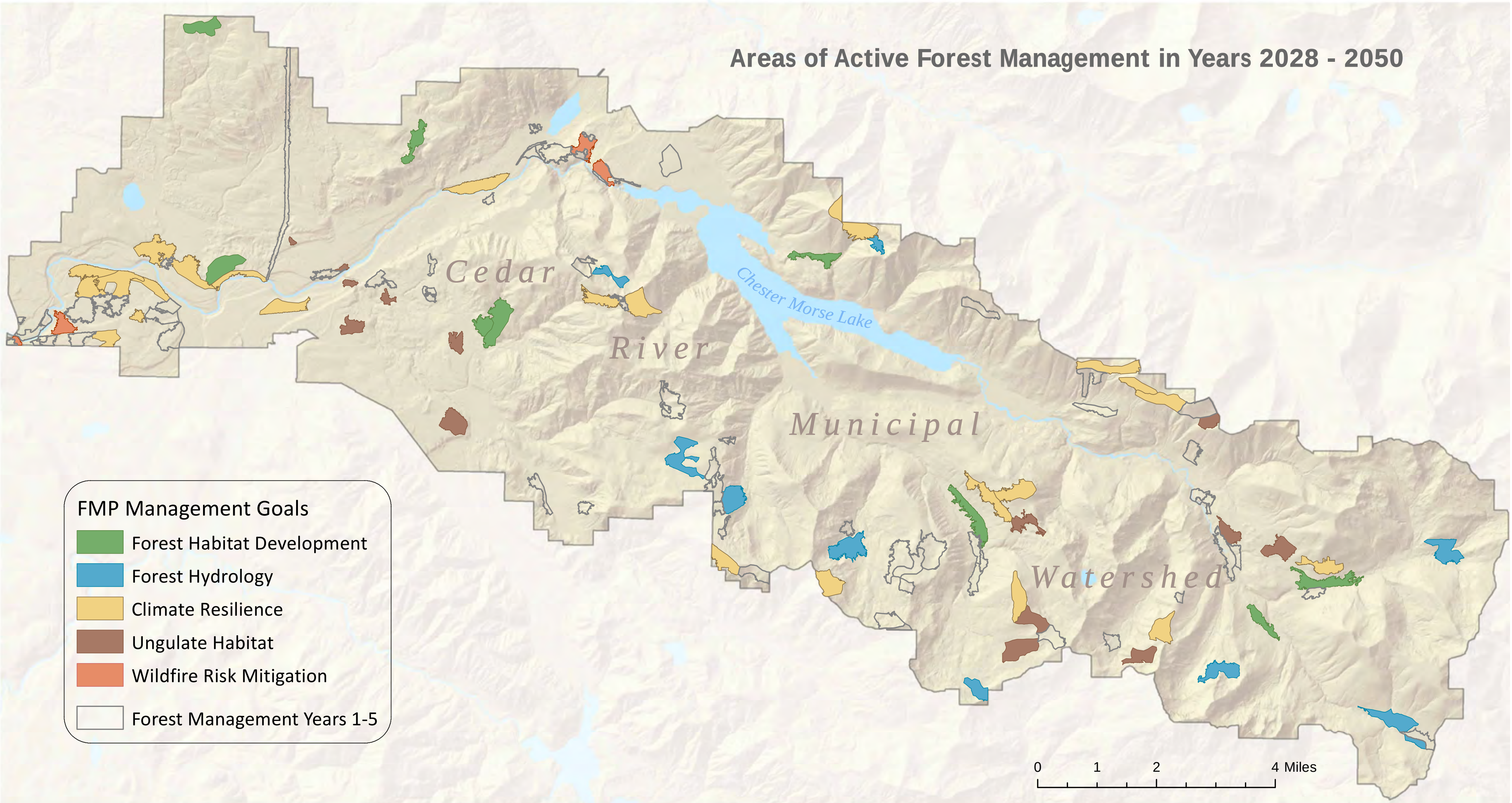

CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Map 3.5: The Forest Management Plan identified 2,400 acres of active management in the Cedar River Municipal Watershed during the years 6 -28 of implementation to meet objectives for each management goal. Management units were selected based on their landscape position, forest condition, and objective priority. See Table 3.5 of the Forest Management Plan for details.

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Table 2.3

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Table 2.3: Management goals, objectives, and constraints identifying candidate pools of analysis units for potential active and passive management of the Cedar River Municipal Watershed Forest Management Plan; Attributes were derived from spatial and remotely sensed data for each analysis unit; CML - Chester Morse Lake; TPI - Topographic position index; Details for calculated attributes are provided in the Methods Section.

Goal	Objective	Obj. No.	Management	Topography/ Location	Assets	Elevation (median)	Slope (mean)	Unstable Slopes Area	Climate Exposure	Canopy Height	Canopy Density	Canopy Rumple	Deciduous Canopy	Meadow	Wetlands	Rock/ Water	Grass/ forb/ shrub	Veg. Dietary Energy	Previous Thinning
Late-Seral Forest Habitat	Protect old-growth and mature forest	1	Passive		all Old-Growth					≥ 145 ft									
	Protect mature forest in climate refugia	2	Passive	Valley (TPI < 5)					Low (≤ 5)	≥ 128 ft									
	Thin second-growth forest to develop late-seral forest	3	Active	≥ 10 ac. yarding access	within 1 mile of old-growth or tall forest (>145 ft)			≤ 50% of unit in unstable areas	(Low (≥ 6)	90 - 139 ft		Low-Mod (≥ 1.4)	≤ 40%						No Ecological Thinning
Forest Hydrology	Retain forest cover on unstable hillslopes	4	Passive					> 50% of unit in unstable areas											
	Protect hydrologically mature forest in valley locations	5	Passive	Valley (TPI < 5)					Low (≤ 5)	≥ 128 ft									
	Thin young productive forest in valley locations	6	Co-Benefit	Valley (TPI < 5)				≤ 50% of unit in unstable areas	Low (≤ 5.6)	5 - 70 ft		Low (≤ 1.25)			≤ 50%	≤ 65%			Not Thinned
	Thin/gap dense forests in groundwater recharge areas	7	Active	Mid-slope (TPI ≤ 8); within hydrologic boundary	within 1,000ft of wetlands/ large streams	≥ 2800 ft		≤ 50% of unit in unstable areas	Low (≤ 5.8)	≤ 95 ft					≤ 50%	≤ 65%			≤ 50% of unit area Thinned
Climate Resilience	Thin and plant drought affected forest with dry adapted species/ genotypes	8	Active	100-Year Site Index ≤ 120 ft; within hydrologic boundary					Mod (≥ 5.6)	50 - 135 ft	≥ 15% loss	Mod-High (≥ 1.3)							No Ecological Thinning
	Thin/plant young exposed stands with warm adapted species/genotypes	9	Active					≤ 50% of unit in unstable areas	High (≥ 6)	≤ 50 ft			≤ 30% deciduous canopy cover						No Ecological Thinning
	Thin to promote deciduous tree cover	10	Active					≤ 50% of unit in unstable areas		75 - 120 ft	≥ 10% loss		2 - 50% deciduous canopy cover						No Ecological Thinning

Table 2.3 (Cont.)

Goal	Objective	Obj. No.	Manage-ment	Topography/ Location	Assets	Elevation (median)	Slope (mean)	Unstable Slopes Area	Climate Exposure	Canopy Height	Canopy Density	Canopy Rumple	Decid-uous Canopy	Meadow	Wetlands	Rock/ Water	Grass/ forb/ shrub	Veg. Dietary Energy	Previous Thinning
Ungulate Habitat	Thin trees in young stands to increase biodiversity in south basins	11	Active			≥ 1,560 ft	≤ 31%	≤ 50% of unit in unstable areas		15 - 60 ft				≤ 75%	≤ 75%	≤ 90%	High (≥ 1.8)	High (≥ 2)	No Eco-logical Thinning
	Thin second-growth forest to increase biodiversity in lower watershed	12	Active	The candidate pool for Objective 12 was hand-selected within the lower watershed to exclude areas of mature second growth forest, include some areas that were previously thinned, and incorporate guidance from MIT biologists															
	Retain forest canopy cover on the north-side CML	13	Passive	lower slope, North Shore CML				≤ 50% of unit in unstable areas					Conifer Canopy						
Fire Hazard Mitigation	Create defensible space around at-risk infrastructure	14	Active	Critical infra-structure	within 2,000ft of in-frastructure		< 70%	excluded											

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Table 3.1

Table 3.1: Active Management Units for years one to five of the Cedar River Municipal Watershed Forest Management Plan; Analysis unit numbers refer to maped landscape units; relative objective achievement refers to achievement indicators defined in the Methods Section.

Obj#	Primary Objective	Analysis Unit Num.	Action Methods	Action Acres	Total Unit Acres	Median Elevation [ft]	Mean Canopy Height [ft]	Mean Canopy Cover [%]	rel. Objective Achievement
3	Late-Seral Forest Restoration	247	Thinning/Cable Yarding	11.8	21.4	2409	110	99	0.19
		403	Thinning/Machine Yarding	11.7	17.3	2442	98	95	0.17
		508	Thinning/Machine Yarding	20.1	29.4	854	114	82	0.33
		703	Thinning/Cable Yarding	14.4	26.0	2085	118	95	0.22
		845	Thinning/Machine Yarding	12.2	17.4	1400	110	91	0.15
		1175	Thinning/Cable Yarding	29.8	75.0	2059	90	94	0.38
		1605	Thinning/Cable Yarding	10.8	28.8	2414	94	98	0.15
		1607	Thinning/Machine Yarding	35.5	53.9	2470	91	97	0.53
		1620	Thinning/Cable Yarding	14.8	42.7	2340	120	97	0.15
		1649	Thinning/Machine Yarding	21.2	40.3	2498	105	96	0.31
		1652	Thinning/Cable Yarding	10	38.0	2306	108	97	0.13
		1732	Thinning/Cable Yarding	24.6	39.7	1662	121	95	0.41
		1955	Thinning/Cable Yarding	16.4	28.1	2134	105	97	0.25
		2020	Thinning/Machine Yarding	10.6	26.1	1968	118	96	0.15
		2043	Thinning/Cable Yarding	21.4	48.4	2626	105	98	0.32
7	Recharge Basin Hydrology	517	Cut and Leave Thinning	13.7	21.4	2918	83	97	0.23
		958	Cut and Leave Thinning	4.8	10.5	2861	81	96	0.08
		1000	Cut and Leave Thinning	35.6	63.2	3789	47	55	0.28
		1007	Cut and Leave Thinning	3.8	10.8	3344	70	84	0.06
		1156	Cut and Leave Thinning	10.4	44.0	3229	50	40	0.15
		1868	Cut and Leave Thinning	16	36.5	3757	45	51	0.08
		1948	Cut and Leave Thinning	64.1	91.7	3133	74	95	1.00

Obj#	Primary Objective	Analysis Unit Num.	Action Methods	Action Acres	Total Unit Acres	Median Elevation [ft]	Mean Canopy Height [ft]	Mean Canopy Cover [%]	rel. Objective Achievement
8	**Climate Resilience Dry Adapted Species**	198	Thinning/Machine Yarding	16.1	40.4	698	116	77	0.33
		433	Planting	5.3	10.6	698	121	61	0.16
		1911	Thinning/Machine Yarding	37.2	94.7	680	110	74	1.00
9	**Warm Climate Adaptation**	11	Cut and Leave / Planting	60	89.7	3926	31	43	0.85
		934	Planting	3.2	11.0	3789	38	30	0.11
		1061	Cut and Leave / Planting	16.9	14.8	3958	48	91	0.16
		1534	Cut and Leave / Planting	28.7	55.3	3464	42	38	0.36
		1615	Cut and Leave / Planting	35.9	51.3	3998	30	31	0.39
		1701	Cut and Leave / Planting	44.7	54.9	4006	40	68	0.60
		1773	Cut and Leave / Planting	47.6	53.9	3988	40	51	0.31
10	**Deciduous Diversity**	872	Individual Tree Release	28	40.0	751	102	82	0.23
		1434	Individual Tree Release	11.7	17.2	572	121	77	0.13
		1897	Individual Tree Release	57.8	82.6	846	106	86	0.48
		1904	Individual Tree Release	25.9	37.1	708	137	84	0.22
		2031	Individual Tree Release	8.5	12.2	728	116	92	0.09
11	**Ungulate Habitat Upper Elevation**	53	Cut and Leave Thinning	32.5	39.6	3518	60	89	0.40
		169	Cut and Leave Thinning	45.8	49.3	3568	58	91	0.75
		643	Cut and Leave Thinning	64.5	111.5	3552	46	55	0.31
		733	Cut and Leave Thinning	14.3	14.0	3553	51	76	0.22
		1361	Cut and Leave Thinning	17.7	20.9	3485	55	81	0.29
		1424	Cut and Leave Thinning	27.8	34.2	3323	38	44	0.55
		1529	Cut and Leave Thinning	59.3	103.5	3418	41	57	0.33
		1636	Cut and Leave Thinning	12.7	13.1	4063	41	71	0.26
		1653	Cut and Leave Thinning	16.8	26.9	3944	43	39	0.05
		2041	Cut and Leave Thinning	52.3	59.5	4163	29	24	1.00

Obj#	Primary Objective	Analysis Unit Num.	Action Methods	Action Acres	Total Unit Acres	Median Elevation [ft]	Mean Canopy Height [ft]	Mean Canopy Cover [%]	rel. Objective Achievement
12	**Ungulate Habitat Lower Elevation**	119	Cut and Leave / Planting	10	155.1	1325	102	23	0.00
		319	Cut and Leave / Slash	10	15.9	1361	124	82	0.00
		745	Thinning/Machine Yarding	21.4	60.0	813	121	85	0.39
		779	Cut and Leave / Slash	10	10.6	1408	125	87	0.00
		981	Cut and Leave / Slash	10	41.2	1154	126	88	0.00
		1551	Cut and Leave / Slash	12	12.1	981	72	91	0.00
		1915	Thinning/Machine Yarding	13.6	37.6	838	125	79	0.27
		2063	Thinning/Machine Yarding	3	80.1	1624	116	98	0.00
14	**Wildfire Defensible Space**	123	Thinning /Machine /Fuels	7.6	7.6	1403	82	95	0.35
		502	Thinning /Machine /Fuels	11.5	11.5	974	129	96	0.36
		539	Thinning /Machine /Fuels	8.9	8.9	609	135	76	0.03
		651	Thinning /Machine /Fuels	21.1	21.1	929	103	77	0.55
		709	Thinning /Machine /Fuels	14.6	14.6	1451	84	90	0.69
		754	Thinning /Machine /Fuels	6.8	6.8	1420	113	87	0.76
		1071	Thinning /Machine /Fuels	5.7	5.7	613	122	69	0.15
		1113	Thinning /Machine /Fuels	34.3	34.3	547	100	46	0.60
		1115	Thinning /Machine /Fuels	14.6	14.6	677	115	80	0.36
		1170	Thinning /Machine /Fuels	18.9	18.9	710	115	82	0.36
		1366	Thinning /Machine /Fuels	72.1	72.1	1190	131	92	0.79
		1554	Thinning /Machine /Fuels	12.9	12.9	938	73	39	1.00
		1555	Thinning /Machine /Fuels	8.3	8.3	1574	92	53	0.50
		1579	Thinning /Machine /Fuels	8.7	8.7	941	70	40	0.46

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Table 3.2: Management Objectives, Planned Acres, and Candidate Pools

		Area Allocation (acres)			
Obj#	**Objective**	**Five-Year Plan**	**Year 6-28**	**Total Acres**	**Candidate Pool**
1	Old-Growth Forest	15,005		15,005	15,005
1	Second-Growth Forest	53,624		53,624	72,751
2	Mature Forest Reserve	8,578		8,578	8,578
4	Reserve Unstable Slopes	4,251		4,251	4,251
5	Reserve Hydo Mature	1,275		1,275	1,700
13	Reserve Elk Canopy Cover	1,634		1,634	1,672
3	Late-Seral Forest Thin	230	482	712	11,792
6	Thin Forest Hydrology	0	0	0	1,615
7	Thin/Gap Recharge Basins	148	436	584	4,287
8	Thin/Plant Dry Adapted	59	139	198	548
9	Thin/Plant Warm Adapted	225	346	571	3,429
10	Thin Deciduous Diversity	132	344	476	3,445
11	Thin/Gap Upper Elk Habitat	344	398	742	3,167
12	Thin/Gap Lower Elk Habitat	90	90	180	1,903
14	Defensible Space	246	165	411	1,229

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Table 3.5

Table 3.5: Active Management Units for years six to 28 of the Cedar River Municipal Watershed Forest Management Plan; Analysis unit numbers refer to mapped landscape units; relative objective achievement refers to achievement indicators defined in the Methods Section.

Primary Objective	Analysis Unit Num.	Action Methods	Acres	Total Unit Acres	Median Elevation [ft]	Mean Canopy Height [ft]	Mean Canopy Cover [%]	rel. Objective Achievement
Late-Seral Forest Restore	257	Thinning/Cable Yarding	46.6	109.6	2453	97.0	96.1	0.54
	555	Thinning/Machine Yarding	73.7	109.7	938	126.5	89.8	0.94
	760	Thinning/Cable Yarding	73.7	109.6	2321	127.6	96.4	0.75
	845	Thinning/Machine Yarding	12.2	17.4	1400	110.3	91.2	0.15
	1153	Thinning/Cable Yarding	37.8	66.6	1792	137.0	95.9	0.48
	1865	Thinning/Cable Yarding	32.7	47.8	1863	125.1	97.4	0.46
	1866	Thinning/Cable Yarding	40.8	122.8	1929	130.4	95.8	0.42
	2036	Thinning/Machine Yarding	51.2	73.1	2491	96.8	98.3	0.40
	2045	Thinning/Cable Yarding	34.8	58.9	2248	109.5	96.5	0.09
	2063	Thinning/Machine Yarding	42.5	80.1	1624	116.4	98.5	0.23
	1607	Thinning/Machine Yarding	35.5	53.9	2470	90.9	96.8	0.53
Recharge Basin Hydrology	75	Cut and Leave Thinning	16.1	25.7	3769	58.2	86.5	0.07
	448	Cut and Leave Thinning	41.8	89.9	3059	39.4	71.4	0.10
	493	Cut and Leave Thinning	14.9	22.1	3264	60.2	75.3	0.09
	834	Cut and Leave Thinning	41	95.7	2958	45.7	52.5	0.10
	993	Cut and Leave Thinning	74.3	110.0	3202	44.8	76.5	1.00
	1023	Cut and Leave Thinning	73.2	113.6	3044	67.9	88.6	0.61
	1500	Cut and Leave Thinning	40.8	83.6	3622	39.9	31.5	0.46
	1562	Cut and Leave Thinning	92.3	101.1	3224	42.6	54.8	0.77
	1632	Cut and Leave Thinning	16	53.8	3772	37.0	44.7	0.00
	1869	Cut and Leave Thinning	13.8	21.9	3709	38.8	62.8	0.08
	1870	Cut and Leave Thinning	12	20.7	3615	35.8	42.3	0.08

Primary Objective	Analysis Unit Num.	Action Methods	Acres	Total Unit Acres	Median Elevation [ft]	Mean Canopy Height [ft]	Mean Canopy Cover [%]	rel. Objective Achievement
Climate Resilience Dry Adapted Species	320	Thinning/Machine Yarding	25.8	77.3	679	117.5	76.8	0.60
	615	Thinning/Machine Yarding	6.2	19.7	801	126.1	78.3	0.16
	1446	Thinning/Machine Yarding	41.9	113.3	695	129.8	84.3	0.86
	1910	Thinning/Machine Yarding	27.8	76.7	640	132.8	80.8	0.63
	1911	Thinning/Machine Yarding	37.2	94.7	680	109.8	74.1	1.00
Climate Resilience Warm Adapted Species	218	Cut and Leave / Planting	5.2	97.7	3927	26.9	27.0	0.80
	220	Cut and Leave / Planting	5.3	82.9	3973	30.8	44.9	0.66
	455	Cut and Leave / Planting	7.2	65.3	3623	45.1	71.2	0.45
	458	Cut and Leave / Planting	7.7	101.8	3503	37.9	58.6	0.65
	995	Cut and Leave / Planting	15.8	72.7	3838	44.1	73.2	0.79
	1001	Cut and Leave / Planting	16.1	96.8	3929	33.9	52.8	0.87
	1306	Cut and Leave / Planting	23.1	90.7	3730	38.4	54.6	0.82
	1511	Cut and Leave / Planting	27.2	102.6	3310	46.0	60.0	0.73
	1521	Cut and Leave / Planting	27.6	89.4	3957	26.3	30.6	0.82
	1604	Cut and Leave / Planting	35	74.3	2975	42.2	50.9	0.47
	1641	Cut and Leave / Planting	40.8	87.0	3842	45.9	46.8	0.72
	1777	Cut and Leave / Planting	49.5	81.6	3730	49.7	66.6	0.56
	1778	Cut and Leave / Planting	49.7	38.4	4051	43.6	66.1	0.13
	1615	Cut and Leave / Planting	35.9	51.3	3998	29.8	31.4	0.39
Deciduous Diver-sity	42	Individual Tree Release	57.2	84.8	931	132.7	82.7	0.11
	59	Individual Tree Release	73	109.3	921	136.9	89.5	0.18
	438	Individual Tree Release	66	226.8	744	141.8	86.4	1.00
	617	Individual Tree Release	38.8	55.5	741	122.2	89.2	0.11
	745	Individual Tree Release	39.8	60.0	813	121.3	84.9	0.26
	1908	Individual Tree Release	34.7	49.6	688	135.8	79.5	0.18
	1918	Individual Tree Release	34.7	53.4	803	136.6	86.7	0.33

Primary Objective	Analysis Unit Num.	Action Methods	Acres	Total Unit Acres	Median Elevation [ft]	Mean Canopy Height [ft]	Mean Canopy Cover [%]	rel. Objective Achievement
Ungulate Habitat Upper Elevation	259	Cut and Leave Thinning	45.7	62.4	3810	49.2	45.9	0.15
	456	Cut and Leave Thinning	53	55.1	3742	46.9	74.0	0.79
	637	Cut and Leave Thinning	54	53.5	2253	51.8	86.1	0.47
	1309	Cut and Leave Thinning	73.7	74.9	4086	31.6	28.7	0.41
	1610	Cut and Leave Thinning	65.6	80.6	2709	38.5	52.5	0.87
	1613	Cut and Leave Thinning	31.5	40.4	3753	40.3	50.5	0.51
	1628	Cut and Leave Thinning	74.4	104.2	3702	36.7	33.2	0.09
Ungulate Habitat Lower Elevation	117	Thinning/Machine Yarding	20	86.9	1538	88.9	69.1	0.04
	355	Thinning /Machine /Fuels	19	20.2	1066	85.3	93.5	0.19
	642	Thinning/Machine Yarding	12	41.8	1532	106.1	90.8	0.13
	655	Thinning /Machine /Fuels	7	13.3	941	86.5	92.5	0.05
	675	Thinning /Machine /Fuels	6	6.4	1010	80.7	80.1	0.00
	676	Thinning /Machine /Fuels	6	9.1	839	98.7	92.4	0.27
	1131	Thinning/Machine Yarding	20	50.3	1220	115.8	91.1	0.18
Wildfire Defensible Space	505	Thinning /Cable /Fuels	46.2	46.2	1550	100.4	91.8	0.00
	1036	Thinning /Cable /Fuels	54.7	54.7	1431	102.0	96.3	0.00
	1037	Thinning /Machine /Fuels	55.1	55.1	710	108.5	83.8	0.00
	1077	Thinning /Cable /Fuels	9.3	9.3	550	115.1	77.3	0.00

Table 3.7

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Table 3.7: Annual budget for the first five years of the Forest Management Plan by objective and budget category; Work phases include the following tasks: Planning - design, permits, layout; Implementation - supervision, compliance, accounting; Administration - program administration, contracts, reporting; Services - appraisal, reports, thinning, planting, fuels treatment; Logging - thinning and logging service cost included in logging revenue #3 and #14, and most #8 and #12.

			Average Annual (5-Year Plan)				Planning and Implementation				Additional Administration and Monitoring				Labor Days Work Phase			
Obj#	**Primary Objective**	**Action Methods**	**Analysis Unit**	**Acres**	**Cost**	**Est. Revenue**	**Budget Category (P&I)**	**Planning Cost**	**Implement. Cost**	**Services Cost**	**Budget Category (Admin)**	**Admin. Cost**	**Budget Category (Monitoring)**	**Monitoring Cost**	**Planning**	**Implement.**	**Program Admin.**	**Monitoring**
HCP Budget																		
3	Late-Seral Forest Restore	Thin/Plant	2.8	45.96	$34,470	$88,194	HCP-Cost Com.	$14,477	$8,617	$11,375	O&M	$13,623	O&M	$4,302	13.1	7.8	19	6
7	Recharge Basin Hydrology	Thin/Gap	1.4	29.68	$14,417	$-	HCP-Cost Com.	$5,767	$1,442	$7,209	O&M	$3,585	O&M	$5,736	5.2	1.3	5	8
8	Dry Climate Adaptation	Thin/Plant	0.6	11.72	$8,639	$17,501	HCP-Cost Com.	$3,616	$2,064	$2,959	O&M	$5,736	O&M	$6,274	3.3	1.9	8	8.75
9	Warm Climate Adaptation	Thin/Plant	1.4	44.96	$30,311	$-	HCP-Cost Com.	$12,124	$3,031	$15,155	O&M	$7,170	O&M	$6,740	11.0	2.7	10	9.4
10	Deciduous Diversity	Girdle	1	26.38	$7,917	$-	HCP-Cost Com.	$3,167	$792	$3,959	O&M	$3,585		$-	2.9	0.7	5	
O&M Budget																		
11	Ungulate Habitat Summer	Cut and Leave	2	68.74	$32,352	$-	O&M	$12,941	$3,235	$16,176	O&M	$7,170	O&M	$7,600	18.0	4.5	10	10.6
12	Ungulate Habitat Winter	Thin Yard / Fuels	1.6	18	$20,977	$39,797	O&M	$6,030	$4,844	$10,102	O&M	$7,887	O&M	$7,600	8.4	6.8	11	10.6
14	Wildfire Defensible Space	Thin Yard / Fuels	2.8	49.2	$27,210	$59,813	O&M	$11,428	$6,803	$8,979	O&M	$11,472	O&M	$1,076	15.9	9.5	16	1.5
15	Slash Management	Fuels	4	45.4	$31,780	$-	O&M	$3,178	$3,178	$25,424	O&M	$1,434		$-	4.4	4.4	2	
Total			17.6	340.0	$208,073	$205,306		$72,728	$34,006	$101,338		$61,662		$39,327	82.3	39.6	86.0	54.9

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Table 4.4

Table 4.4: Monitoring Goals and Objectives

Obj #	Objective	Action	Monitoring Program		Monitoring Goals: Action Effectiveness	Monitoring Goals: Objective Achievement
1	**Late-Seral Forest Reserve**	Reserve	Long-term Forest Monitoring	Existing HCP Program		Forest Development
3	**Late-Seral Forest Development**	Thin	Long-term Forest Monitoring	Existing HCP Program	Regeneration and growth	Forest Development
4	**Forest Cover on Unstable Slopes**	Reserve	Remote Sensing/ Disturbance Monitoring	Existing HCP Program		Forest Cover
5	**Hydrologically Mature Forest**	Reserve	Remote Sensing/ Disturbance Monitoring	Existing HCP Program		Forest Cover
6	**Young Stands for Hydrology**	Co-Benefit	Forest Hydrology	New		
7	**Young Stands in Recharge Basins**	Thin	Forest Hydrology	New	Wetland hydrology	Biotic community stability
8	**Climate Resilience Dry Adapted Species**	Thin/Plant	Climate Resilience	New	Planted survival and growth, invasive species	Plant community change
9	**Climate Resilience Warm Adapted Species**	Thin/Plant	Climate Resilience	New	Planted survival and growth, invasive species	Plant community change
10	**Climate Resilience Deciduous Diversity**	Thin	Climate Resilience	New	Vigor of released deciduous trees	Persistence of deciduous trees in conifer forest
11	**Elk Habitat Upper Elevation**	Thin/Gap	Ungulate Habitat	New	Forage plant cover and effects on other wildlife species	Improvement of elk forage habitat
12	**Elk Habitat Lower Elevation**	Thin/Gap	Ungulate Habitat	New	Forage plant cover and effects on other wildlife species	Improvement of elk forage habitat
13	**Elk Habitat Reserve Winter Cover**	Reserve	Remote Sensing/ Disturbance Monitoring	Existing HCP Program		Forest Cover
14	**Defensible Space**	Thin/Fuels	Fuel Hazard Management	New	Change in fuels structure	
15	**Fuel Hazard Management**	Fuels	Fuel Hazard Management	New	Change in fuels structure	

Table 4.5

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Table 4.5: Monitoring parameters and response models for monitoring management actions for different management objects of the Forest Management Plan.

Object	Action	Parameter	Response	Baseline	Effect Scale	Response Time	Variability	Co-Variables
Ungulate Forage (Objectives 11 and 12)	Thinning, gaps	Forage species productivity	forage species increase in cover proportional to thinning intensity	pre-thinning	project site, sample plots	5-10 years	overstory distribution	site quality, competing vegetation
	Thinning, gaps	Plant community	Greater relative abundance of forage species following treatment	pre-thinning	project site, sample plots	5-10 years	succession, climate	
	Thinning, gaps	Animal community	Increase in ungulate use	pre-thinning	project site	5 years		
Wildfire Fuel Structure (Objective 14)	Fuel removal, piling	Dead fuel loading	load decreases with removal	pre-treatment	project site	1 year	removal pattern, thinning pattern	thinning pattern
	Fuel removal, piling	Dead fuel distribution	increased variability with removal and piling	pre-treatment	project site	1 year	removal pattern, thinning pattern	thinning pattern
	Thinning	Live fuel loading	live fuels decrease with thinning intensity	pre-thinning	project site	1 year	removal pattern, thinning pattern	thinning pattern
Catchment Hydrology (Objective 7)	Gaps, thinning	Wetland hydrology	Later snow disappearance date in canopy openings, wetland summer water table increases with canopy removal	Control catchment	Wetland	1-5 years	Annual/decadal climate	Climate, surface geology, vegetation
	Gaps, thinning	Plant community	wetland indicator species persist in treated catchments	Control catchment	Wetland	10-15 years	Seasonal phenology, decadal climate	Climate, vegetation zone, surface hydrology
Climate Resilience (Objectives 8 and 9)	Planting	Plant survival	Planting established desired species	post-treatment	seedling, project	5-10 years	climate, site, species	Site quality, competition, browse
	Planting	Plant growth	Planted trees increase in height and leaf area over time	post-treatment	seedling, project	5-10 years	climate, site, species	Site quality, competition, browse
	Thinning and planting	Community composition	Tree species diversity increased following planting	post-treatment	project site	10-20 years	Site, planting pattern, succession	Species composition
	Thinning and planting	Invasive species cover	Invasive species do not colonize site	post-treatment	project site	1-10 years	Seed source	Competing vegetation

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Table 5.2

Table 5.2: Optimization Model Achievement and Value Indices, including calculated co-benefits for optimization model. Possible negative effects were not included in the model.

Goal	Objective	No.	Achievement Index	Value Index	Co-Benefits	Possible Negative Effects
Late-Seral Forest Habitat	Protect old-growth forest and mature forest	1	Old-Growth, Mean Height / Norm Site Index	Norm Site Index * 1-Climate Exposure		
	Protect mature forest in climate refugia	2	Canopy height / (1.2 * site index)	Topographic Position	Obj#5	
	Restore late-seral forest characteristics	3	Value * Site Index * Operational Acres	1 - Distance to Old-Growth	Obj#12	Obj #1 (canopy cover)
Forest Hydrology	Retain forest cover on unstable hillslopes	4	Percent canopy cover* Acres*Value	Percent unstable slope		
	Protect hydrologically mature forest in valley locations	5	Canopy height / site index	Topographic Position * Site Index	Obj#2	
	Thin young productive forest in valley locations	6	Thinned Acres * Site Index	Mean site Index	Obj#3, 11	
	Thin/gap forests in groundwater recharge basins	7	Value * Thinned Area * (1- Canopy Rumple)	Distance to hydrological feature	Obj#11, 6	Obj #1 (canopy cover)
Climate Resilience	Thin and plant drought affected forest with dry adapted species/genotypes	8	Value * Operational Area * Canopy Loss	Climate Exposure/Max Exposure	Obj #12	Obj #1 (canopy cover)
	Thin/plant young exposed stands with warm adapted species/genotypes	9	1-Deciduous Cover * Operational Acres * Obj. Value	Climate Exposure/Max Exposure	Obj#3, 11	
	Release individual deciduous trees to promote species diversity	10			Obj#12	
Ungulate Habitat	Thin young stands to increase forage plant cover in upper elevations	11	Gain in Elk Forage Index	Gain in Elk Forage Index	Obj#6, 7	Obj #1 (canopy cover)
	Thin second-growth forest to increase ungulate forage in lower watershed	12	Gain in Elk Forage Index	Gain in Elk Forage Index	Obj# 10, 3	
	Retain canopy cover for ungulate winter habitat	13	Canopy Cover	Percent Steep Slope	Obj #5	
Fire Hazard Mitigation	Create defensible space around at-risk infrastructure	14	Canopy Height	Distance to Infrastructure		Obj #1 (dead wood)

Table 5.3

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Table 5.3: Cost of action objective combinations. Costs are shown as administration/implementation service/revenue from surplus timber sale. Revenue calculations are shown in Table 5.7. Co-benefits from actions were calculated in optimization model. Thinning acres are 70% of accessible analysis unit acres. Planting acres are 50% of thinning acres. Thin-Ground is based on ground-based logging equipment. Thin-Cable is based on cable-yarding logging equipment. No cost is associated with Reserve status or passive restoration.

		Actions										
Obj#	**Objectives**	**Reserve**	**Thin-Ground**	**Thin- Cable**	**Thin/Down Wood**	**Thin Young**	**Thin Young / Plant**	**Plant**	**Fuels**	**Thin Young / Fuels**	**Thin-Ground / Fuels**	**Thin-Cable /Fuels**
1	**Passive Restoration**	Yes	-	-	-	-	-	-	-	-	-	-
3	**LSF Thinning**	-	500/250/variable	500/250/ variable	250/250/0	Co-benefit	Co-benefit	-	-	-	-	-
4	**Unstable Slopes**	Yes	-	-	-	-	-	-	-	-	-	-
5	**Hydrologically Mature**	Yes	-	-	-	-	-	-	-	-	-	-
6	**Forest Hydrology Valleys**	-	-	Co-benefit	-	250/250/0	-	-	-	-	-	-
7	**Forest Hydrology Catchments**	-	-	-	-	250/250/0	300/500/0	-	-	-	-	-
8	**Climate Resilience Lower**	-	500/250/variable	-	-	-	-	250/350/0	-	-	-	-
9	**Climate Resilience Upper**	-	-	-	-	-	300/500/0	250/350/0	-	-	-	-
10	**Deciduous Tree Diversity**	-	-	-	150/150/0	-	-	-	-	-	-	-
11	**Ungulate Habitat Upper**	-	-	-	-	250/250/0	Co-benefit	-	-	250/1000/0	-	-
12	**Ungulate Habitat Lower**	-	Co-benefit	Co-benefit	Co-benefit	-	-	-	-	-	-	-
13	**Ungulate Winter Cover**	Yes	-	-	-	-	-	-	-	-	-	-
14	**Defensible Space**	-	-	-	-	-	-	-	500/1100/0	-	500/250/ variable	500/250/ variable

Figure 2.1

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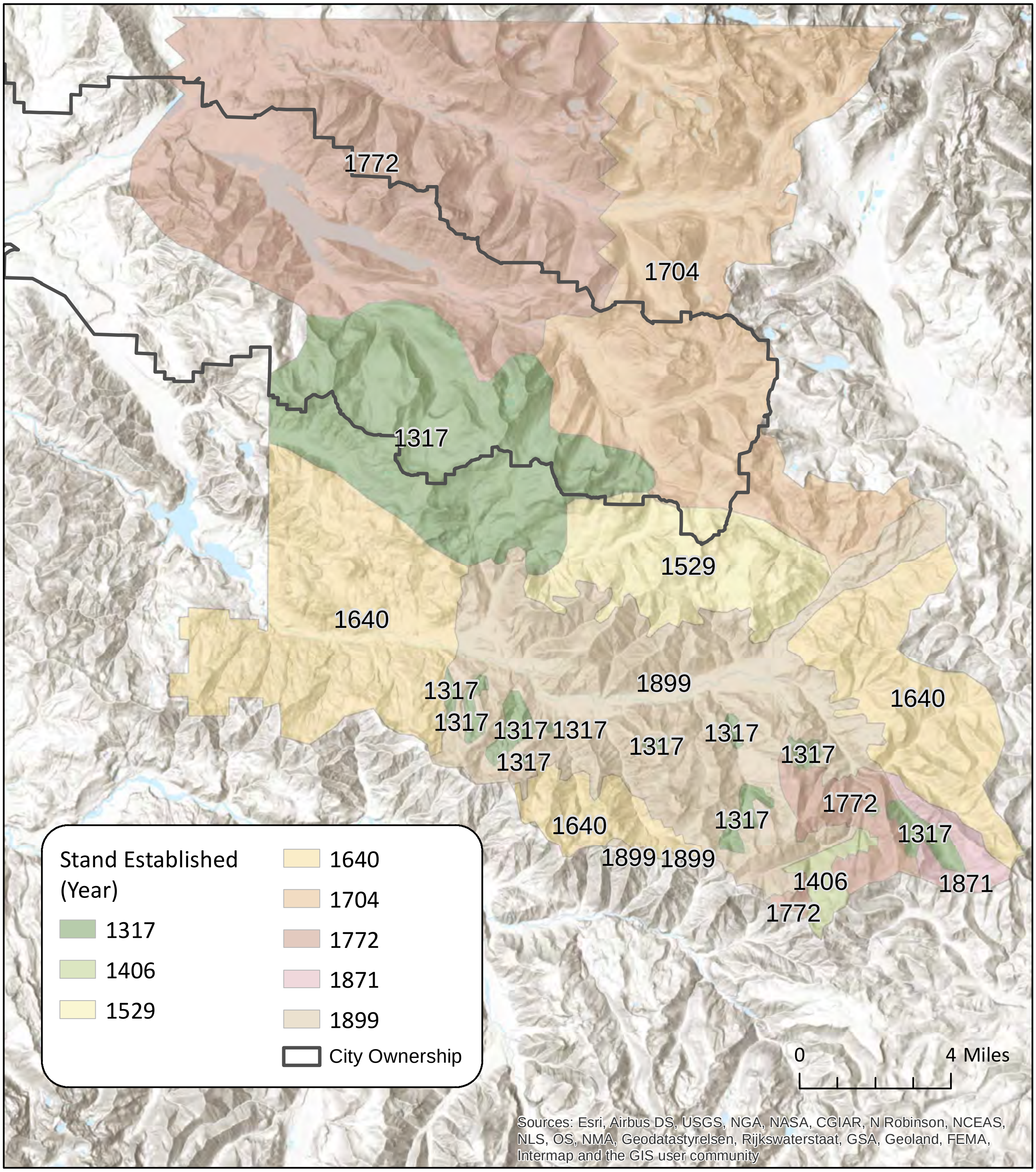
Figure 2.1: Fire History of Cedar and Green River Drainages



CEDAR RIVER WATERSHED FOREST MANAGEMENT PLAN

Figure 2.1: Fire History of Cedar and Green River Drainages; data from Henderson and Peter 1981; Map shows years of forest stand establishment from tree ring records, indicating stand replacing fire history.

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Figure 4.1

Figure 4.1: Example of Monitoring Schedules for different Forest Management Plan Objectives