AN ABSTRACT OF THE THESIS OF

Trevor Grandy for the degree of Master of Science in Water Resources Policy and Management presented on March 13, 2018.

Title: Saving Darlingtonia: Pumping, Pollution, Public Participation, and Perceived Impacts to a Carnivorous Pitcher Plant: Darlingtonia State Natural Site, Florence, Oregon

Abstract approved:

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W. Todd Jarvis

Oregon's coast draws millions of visitors every year to witness the natural wonders of one the world's most vibrant and publicly accessible areas where mountain forests meet sandy beaches and the sea. Communities along the Oregon coast are restricted to narrow stretches of developable land overlying sand deposits between the ocean and Oregon's Coastal Range. Population on the coast varies tremendously, particularly during the dry summer season when the human population can increase up to 500% due to tourism. Within one of these narrow sand deposits is the North Florence Dunal Aquifer, an EPA-recognized sole source aquifer supplying thousands of citizens in the city of Florence, Oregon with water in addition to dozens of groundwater dependent ecosystems (GDE) among the dunes and forests. One of these GDE is a fen within the Darlingtonia State Natural Site, a recreation site managed by the Oregon Parks and Recreation Department (OPRD) to protect and showcase a community of rare, carnivorous pitcher plants, the *Darlingtonia californica* (*Darlingtonia*). Increased human-related activities present a plethora of risks to this GDE including groundwater drawdown, salinity intrusion, nitrate contamination, among other source water quality and quantity concerns. In accordance with the call from GDE scholars to increase monitoring activities and model the hydrogeology of

GDE, this study developed a groundwater monitoring program and performed a hydrogeologic analysis of the site to develop a better understanding of necessary groundwater boundary conditions for the health and vigor of the *Darlingtonia* population. A pressure transducer was installed in a geotechnical boring on-site to monitor the water table and samples were collected monthly for 12 months to establish the baseline conditions for the site and determine potentially adverse inputs. Results reveal a lack of pumping-induced groundwater drawdown and minimal influence from likely contaminant sources (septic systems, runoff, etc.). Source water temperature, however, is a serious concern for the *Darlingtonia* community within the fen as literature suggests their shallow root systems need a constant supply of cool groundwater to maintain health and vigor. This study also examines current GDE policy and management practices within and around Darlingtonia State Natural Site while exploring GDE policy and management mechanisms from around the world to determine how management and public participation in GDE protection can be improved at the site.

Saving Darlingtonia: Pumping, Pollution, Public Participation, and Perceived Impacts to a Carnivorous Pitcher Plant: Darlingtonia State Natural Site, Florence, Oregon

by
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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Trevor Grandy, Author

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This one's for the greatest state in the world… O-H!

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1. INTRODUCTION

> *"I found myself confronted by a community of strange, sweet-smelling tube-shaped plants. They grew in upthrusting clusters of six or eight, like little green families, with the oldest attaining a height of three feet and the youngest no bigger than a child's crooked finger. Regardless of size, and except for the broken-backed unfortunates, they were all identical in shape, starting narrow at the base and tapering larger toward the neck like a horn, except instead of the horn's blossoming bell, they turned at the last moment, bowing their necks, looking back to their base. Imagine an elongated comma, sleek, green, driven into the purple mud with its straightened tip; or picture half-notes for vegetable musicians, thicker at the neck than at the base, with the rounded oval head a swooping continuation of the neckline; and it is still unlikely that you have the picture of these plants. Let me say only that they were and artist's conception of chlorophyll beings from another planet, stylized figures half humorous, half sinister. Perfect Halloween fare…*
>
> *…I plucked one of the plants from its family to examine it more carefully and found that under the comma's loop was a round hole resembling a mouth, and at the tapered bottom of the tube, a clogging liquid containing the carcasses of two flies and a honey bee, and I realized that these odd swamp plants were Oregon's offering in the believe-it-or-not department of unusual life forms: the Darlingtonia. A creature trapped in that no-thing's land between plants and animals along with the walking vine and the paramecium, this sweet and sleek carnivore with roots enjoyed a well-rounded meal of sunshine and flies, minerals and meat. I stared at the stalk in my hand and it stared blindly back."*
>
> - Ken Kesey: "Sometimes a Great Notion"

While Ken Kesey provides an uncanny personification of the *Darlingtonia californica* (Figure 1) from the perspective of a first encounter with these carnivorous flowering plants, in our non-fiction, twenty-first century world the cobra lily is a sensitive and rare species (Kagan et al., 2016) on Oregon's coast, hence, one should observe without disturbing it, unlike Kesey's character, Leeland Stamper. Oregon's Parks and Recreation Department (OPRD) have dedicated an eighteen-acre site, three miles north of Florence to protect and prominently display one of the state's largest known populations of Oregon's only pitcher plant species (Richard, 2015). Darlingtonia State Natural Site is one of only six natural sites in Oregon and is the only state park solely dedicated to protecting a single plant species (OPRD, 2017), and for good reason. One feels like the flies or honey bee Kesey describes while walking down the natural site's boardwalk for the first time entranced by the sweet and musty smell of the flowering plants, the ominous yet benign trepidation of the dark, murky fen water, and the curious nature of the delicate, meat-eating cobra lily themselves.

Figure 1 – Darlingtonia californica (OPRD, 2017)

Darlingtonia reside in fens along the Pacific Coast and as far inland as the Sierra Nevada Range (Figure 2) (Crane, 1990). Fens, like that of Darlingtonia State Natural Site, are groundwater-dependent

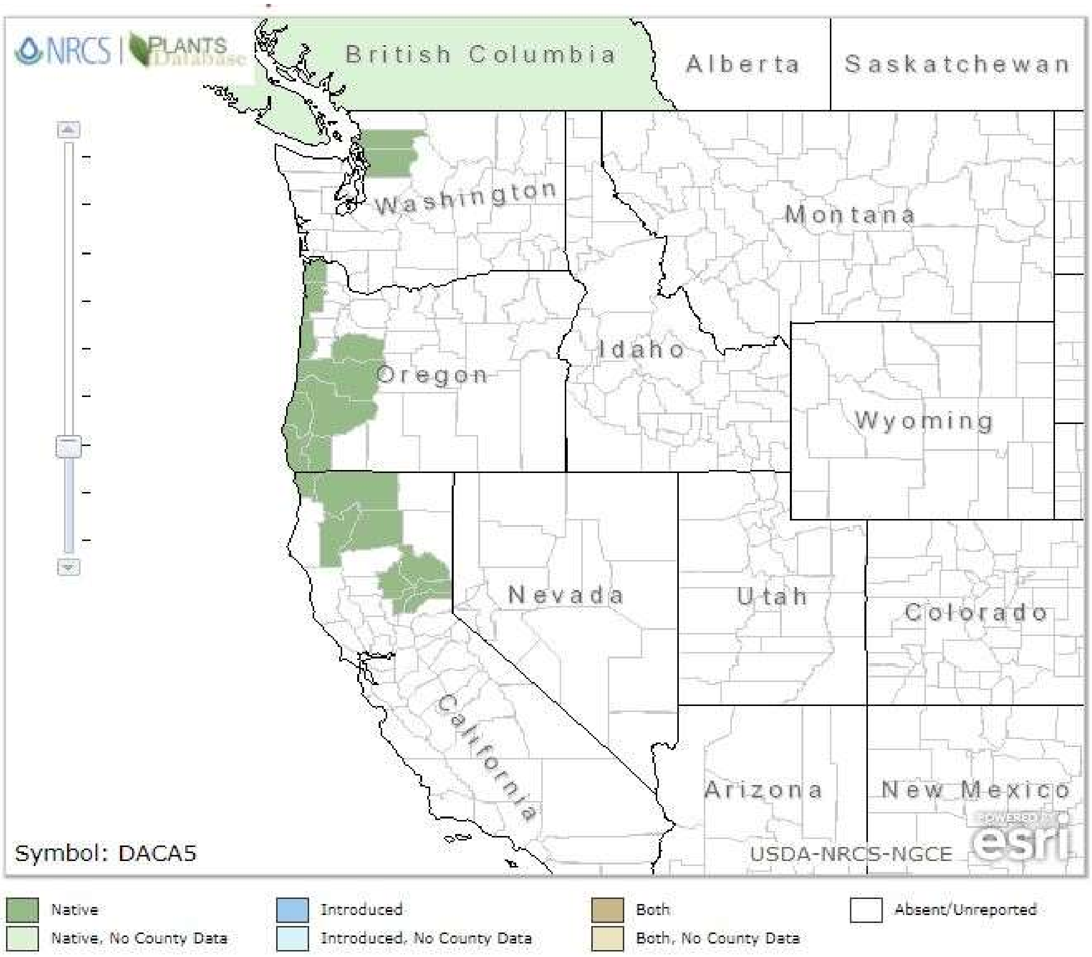

Figure 2 - Range of D. californica (USDA, 2017)

ecosystems (GDE) with an unusual water chemistry that often supports a rare flora species (Brown et al., 2011). Mineral-rich, consistently water-logged fens with peaty, slightly alkaline soil provide the ideal environment for the proliferation of *Darlingtonia* communities (BSA, n.d.). One of the most important factors that supports *Darlingtonia* growth is the presence of flowing water, which keeps their root system cool and functional (Crane 1990). Loss of groundwater supply could denote dire consequences for the sustainability of a *Darlingtonia* population. Such is the concern of OPRD. Site managers have witnessed a loss in "abundance and vigor" in the *Darlingtonia* community over the past decade and a half and requested assistance from students and faculty at Oregon State University to investigate reasons for these changes. Researchers developed the situation map depicted in Figure 3 to illustrate the plethora of issues that may be affecting the abundance and vigor of the *Darlingtonia* population at Darlingtonia State Natural Site. This study focuses on the hydrology-related issues that may be affecting the Darlingtonia State Natural Site GDE.

1.1 Management Research Question and Objectives

The purpose of this study pursues to answer the following research question:

Are anthropogenic activities in the vicinity of Darlingtonia State Natural Site affecting the quality and quantity of the North Florence Dunal Aquifer supplying groundwater to the fen and community of *Darlingtonia californica* therein?

The research addresses four alternative hypothesis about nearby anthropogenic activities that may be affecting the abundance and vigor of *Darlingtonia* at the site. A colleague (Chellew, 2017) investigated potential for influence of shade as a factor. The four hypotheses include:

Hypothesis 1: Altered flow of surface water through the site due to culvert installment on U.S. Highway 101has resulted in the decline

Hypothesis 2: Altered groundwater table owing to groundwater well development in region has resulted in the decline

Hypothesis 3: Increased nitrate concentrations in groundwater (potentially from leaking septic systems nearby) has resulted in the decline

Hypothesis 4: Reasons other than those suggested above

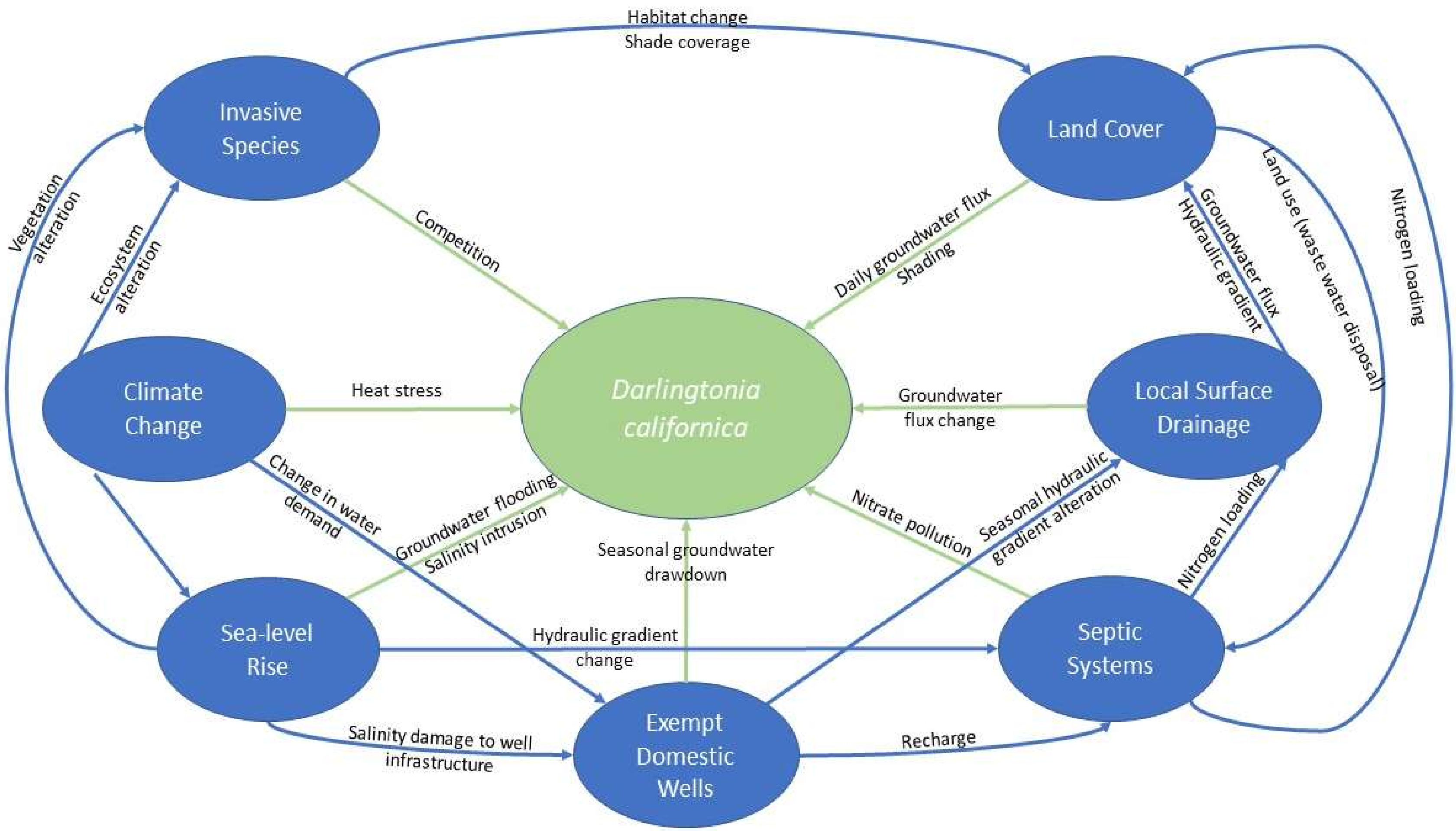

Figure 3 - Situation map depicting the some of the issues affecting the Darlingtonia population at the Darlingtonia State Natural Site GDE

Two objectives need to be addressed to answer this question concerning the characteristics of the North Florence Dunal Aquifer and the quantity and quality of the groundwater underlying Darlingtonia State Natural Site.

1.1.1 Objective 1: Hydrogeological Analysis

The first objective is to extensively study the North Florence Dunal Aquifer to determine aquifer characteristics including hydraulic conductivity, hydraulic gradients, and local flow paths. Developing a conceptual hydrogeologic model of the aquifer displaying the hydrogeology and flow characteristics within and around Darlingtonia State Natural Site is necessary to visualize potential impact of surrounding anthropogenic activity on the groundwater supplying the site's GDE.

1.1.2 Objective 2: Groundwater Monitoring

Groundwater monitoring of the site can reveal vital quality and quantity information about the water directly supplying the *Darlingtonia* community. Quality will be determined through ion chromatographic spectroscopy anion analysis to determine whether constituents, such as high levels of nitrate, harmful to the fen community are present. Quantity will be monitored by constant measurement of the groundwater table relative to the site's surface. These data will be paired with observation of the *Darlingtonia* community within the park (by colleagues with expertise in biogeography) to investigate trends in both.

1.2 Policy Research Question and Objective

Groundwater dependent ecosystems are both important and face growing risks to their survival. Policy and management efforts specific to GDE are a relatively new phenomenon over the past decade and a half; however, some early efforts at protection exist. Determining policy and management practices that can conserve threatened GDE can aid in the effort to protect rare ecosystems, biodiversity, and groundwater. This leads to the following research question:

> What are the current policy and management mechanisms protecting groundwater dependent ecosystems (Darlingtonia State Natural Site) and how can they be improved?

1.2.1 *Objective 3: GDE Policy and Management Review*

The third objective includes reviewing and analyzing state, national and international policy governing groundwater dependent ecosystems to determine best management practices to protect GDE. This analysis will include current national, state, and local GDE policy pertinent to Darlingtonia State Natural Site and the GDE therein. The review also examines policy tools being used around the world to protect and conserve groundwater dependent ecosystems.

1.3 Outline for the study

This study will begin by exploring GDE protection policy and management mechanisms employed around the world and highlight the importance of protecting GDE. Environmental and human development organizations recognize the importance of GDE making their protection and conservation an integral part of sustainability missions (Foster et al., 2005; Martin-Bordes, 2010; Ramsar, 2014). Aquifers around the world are threatened by a variety of anthropogenic activities making GDE vulnerable to the degradation of source water quality and/or quantity (Klove et al., 2011). Pollution from localized point sources (wastewater and industrial effluent, underground storage tanks) or from widely distributed non-point sources (agriculture/urban runoff) percolates into aquifers changing the chemistry and temperature of groundwater potentially limiting its function to dependent ecosystems (Hardisty & Ozdemiroglu, 2005). Pumping water from the ground for domestic and municipal water users, as well as irrigators, can have pervasive and lasting consequences for all aquifer stakeholders, including GDE (Bartolino & Cunningham, 2003). Studies utilizing data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites reveal that about one-third of regional groundwater basins in the world are under stress due to anthropogenic consumption (Figure 4) (Richey et al., 2015). Pumping and pollution combined with altering atmospheric conditions threaten to alter historic aquifer recharge values and carrying capacities (Taylor et al., 2013), while further increasing pollution risks due to more frequent flooding events (Habel et al., 2017).

General aquifer stressors vary by region and locality. The North Florence Dunal Aquifer, the supply for the fen at Darlingtonia State Natural Site and U.S. EPA-recognized Sole-Source Aquifer for the greater Florence area, faces risks common to shallow, coastal groundwater resources. Residences in the rural setting of northern Florence rely on isolated septic systems for

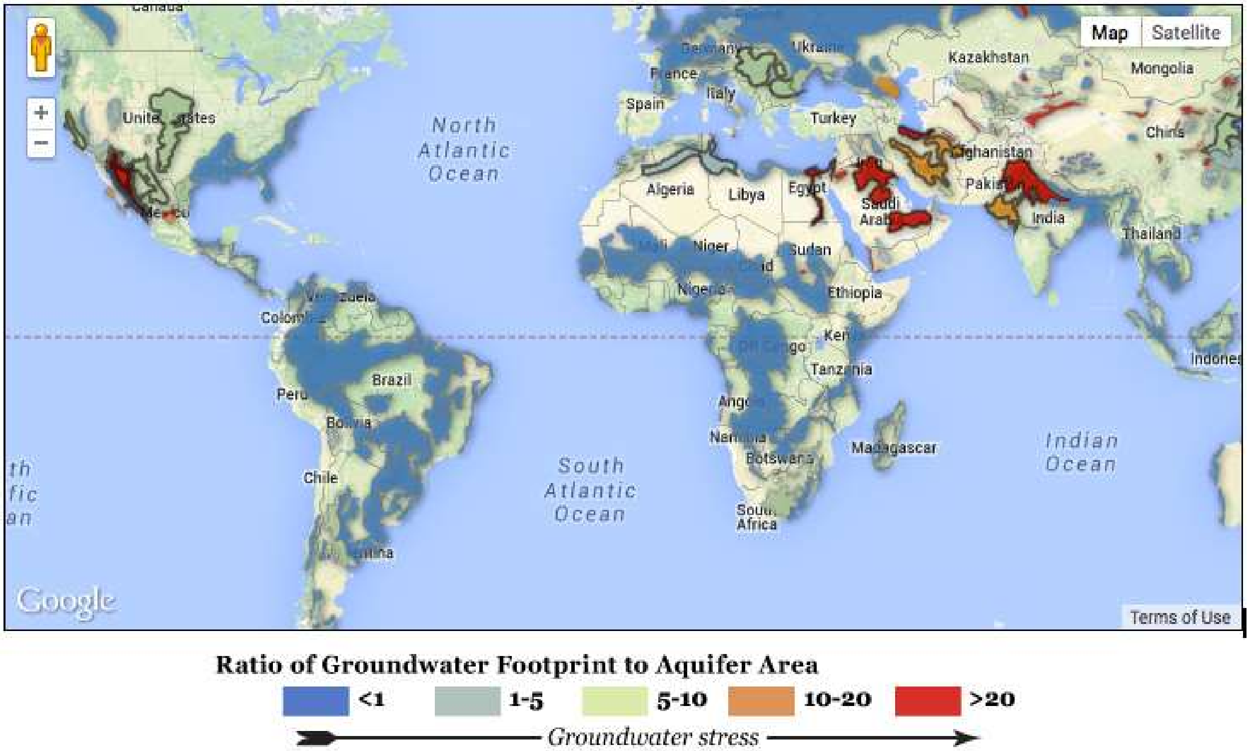

Figure 4 – Global groundwater stress measured by volume of withdrawals compared to aquifer recharge surface area (Water Footprint Network, 2014)

wastewater treatment which can cause nitrate leaching into the aquifer (Hardisty & Ozdemiroglu, 2005). This study investigates anthropogenic activities and the quality/quantity patterns of the North Florence Dunal Aquifer. By modeling the aquifer and monitoring the groundwater on-site, this study provides park managers with data on source water pressures to the Darlingtonia State Natural Site GDE. Methods for this investigation and results are presented in turn.

Finally, the implications of these findings and recommendations for Darlingtonia State Natural Site GDE management will then be discussed. There are a number of management mechanisms in the northern Florence area affecting the site providing the site's GDE with protection. I will evaluate the robustness of the GDE protection based on the findings of the GDE protection policy and management literature review.

2. LITERATURE REVIEW

2.1 Groundwater Dependent Ecosystem Policy Review: Inventory of Protection Mechanisms

Wetlands, springs, and other GDE are highly valued resources in the United States and efforts to preserve these ecosystems have been emphasized beginning in the late twentieth century at the national level with the 1972 Clean Water Act (Votteler & Muir, 2002). The motivation for this movement stems from the desire for clean drinking water and pollution abatement, but has expanded to include more values, such as ecosystem services and habitat protection, as research into GDE has promoted understanding and recognition of the services they provide. Several states have adopted more comprehensive protections, with varying enthusiasm depending on civic recognition of the importance of GDE (Votteler & Muir, 2002).

While some states assign high value to GDE, management challenges remain for all resource stakeholders. Knuppe and Pahl-Wostl (2011) point out that GDE management challenges "are more frequently associated with failures of governance than with the actual resource base" (p.3389). Until recently, groundwater resource laws have primarily focused on human uses (Aldous & Bach, 2011) with little regard for GDE, threatening long-term groundwater sustainability. Scholars and governing institutions began recognizing the need to address GDE conservation through policy at the recent turn of the century (Foster et al., 2006). Historically, policy has separated surface and groundwater allocation/protection though the two are undisputedly physically linked (Beseki & Hodges, 2006; Rohde et al., 2017). In fact, groundwater resource management is highly fragmented in many governmental and agencies and state policies with few mechanisms to promote cooperation between scientists, managers, and stakeholders (Knuppe & Pahl-Wostl, 2011).

Effective management of groundwater and GDE require a social-ecological system approach in which the needs for human and bio-physical stakeholders are interwoven during development of management solutions. Ostrom's principles to counteract the 'tragedy of the commons' applies to the governance of GDE granting the flexibility of managing the resource to the community of stakeholders; however, stakeholders should be supplied with the best knowledge of bio-physical constraints and monitoring systems for collective management decisions (Foster et al., 2010). Ostrom's (1990) principles include clearly defined boundaries, collective arrangements for participation, and low-cost conflict resolution mechanisms.

These prerequisites to successful management of social-ecological system resources parallel the requirements GDE scholars have outlined as vital to GDE conservation. Seven categories of management actions required for GDE protection emerged from the policy literature review: 1) identification and mapping GDE including identifying and quantifying threats, 2) allocating adequate high-quality groundwater to support GDE, 3) spatial planning, 4) high-resolution groundwater quality and quantity monitoring, 5) adaptive management, 6) restoration, and 7) public participation/awareness. The importance of these management actions is further described and discussed below.

2.1.1 Identifying and mapping GDE

Step one of natural resource management is understanding the geographical extent of the resource. GDE scholars identify clearly defining the boundaries of groundwater systems as vital to GDE management, including the biophysically and socially dependent components:

> "The first step is to identify the nature, extent, and degree of dependency of [groundwater dependent] ecosystems. It is impossible to characterize the degree of groundwater reliance, and therefore ecological response to change, without first understanding where ecosystems occur" (Hoyos et al., 2016, p.2).

Once data are available, spatial analysis tools, like Geographic Information Systems (GIS), can provide a useful framework for a spatial database with which water managers can determine boundaries and all forms of groundwater dependent use in one place. Identifying highly impacted GDE can prove difficult requiring a case-by-case approach. Griebler, et al. (2010) recommend classifying ecosystems with 3 spatial units: 1) habitat/ecosystem unit at the local scale, 2) the aquifer type at the regional scale, 3) and landscape unit at the regional scale.

The Global Water Partnership's 2003 Integrated Water Resources Management plan recommends protecting ecosystems on a catchment basis by identifying minimum requirements dependent on ecosystem needs. The plan states "mapping vital ecosystems in different regions is needed as a means for better protection" (GWP, 2003). California, the only state in the United

States to specifically recognize GDE in groundwater policy via the Sustainable Groundwater Management Act of 2014 (SGMA), began mapping GDE in the mid-2000s. These maps are valuable resources for Groundwater Sustainability Agencies which the SGMA requires to identify and consider impacts on GDE every 5 years (Rohde et al., 2017).

Hydrologists generally agree on classifying GDE based on ecohydrogeology to understand human impacts and connectivity to other ecosystems (Tomlinson, 2010). Governing bodies have begun to follow suit. State governments in Australia began calling for management of GDE that maintained ecological processes and biodiversity in the early 2000s, a charge requiring the determination of baseline conditions and characteristics (Griebler et al., 2010). The European Union (EU) also recognized the importance of identifying GDE impact by measuring GDE characteristics and ecological change due to hydrologic impact (Klove et al., 2014). Both institutions essentially call for the classification of GDE biophysical and social boundaries and impacts. From these monitoring and classifying standards, guidelines for GDE management policy can be derived (Tomlinson, 2010, p.944).

Hydrology plays a large role in GDE classification. Western states developing GDE management policy need to determine aquifer characteristics for aquifers in widely varying settings. Payne and Woessner (2010) have developed a tool for just that purpose based on previous USGS classification systems. Their model suggests accounting for 1) the geologic framework (aquifer medium), 2) hydrology (or aquifer productivity), 3) groundwater quality (based on specific conductance), and 4) groundwater/surface water exchange (depth to groundwater). Payne and Woessner developed a simplified code to identify and serve as shorthand for an aquifer and all of its pertinent characteristics (Figure 5)

GIS is a useful spatial tool for maintaining GDE databases. Hoyos, et al. (2016) reviewed just how practical these tools are when mapping and characterizing GDE. One of the most practical measurement methods includes field surveys taking hydrometric measurements (water table depth, discharge, hydraulic conductivity, etc.) to calculate water budgets on a local level. The authors also recommend Leaf Area Index surveys to help determine evapotranspiration and whether larger-scale methods, like remote sensing, are practical for a particular study site (Hoyos et al., 2016). Remote sensing data may come from methods like Land Satellite (LANDSAT)

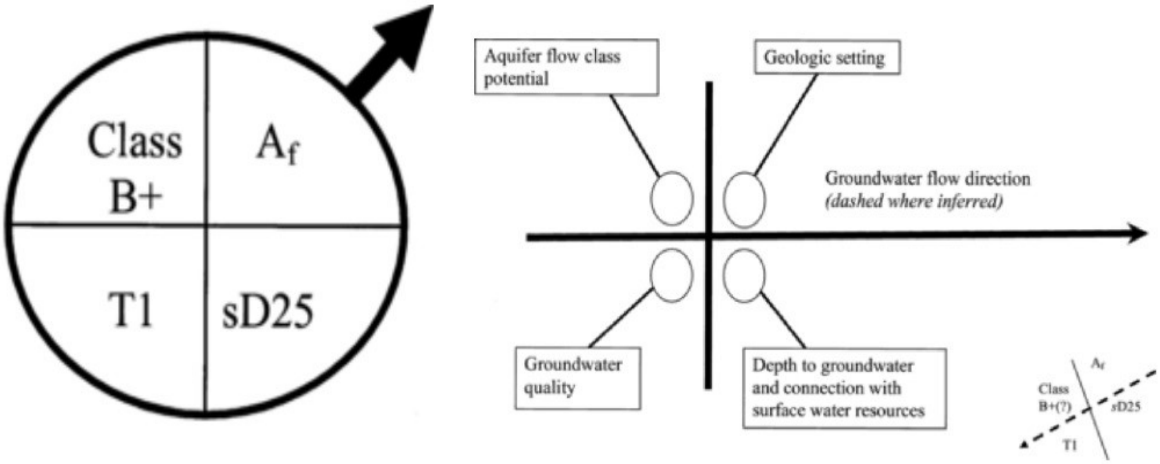

Figure 5 - Payne and Woessner's (2010) Aquifer Classification Mapping Framework symbol displaying aquifer flow class, geologic setting, groundwater quality, depth to water and flow direction.

measurements, aerial photographs, and Light Detection and Ranging (LiDAR). Data from the Gravity Recovery and Climate Experiment (GRACE) satellite measure changes in Earth's gravitational field revealing changes in terrestrial water storage (Sun, 2013) potentially revealing GDE source water storage and depletion. Both field measurements and remote sensing methods have limitations, thus Hoyos, et al. (2016) recommend integrating the two by synthesizing field data with regional remote sensing data for a more robust GIS spatial analysis.

Statewide GDE mapping and classification in Oregon has commenced thanks to the efforts of The Nature Conservancy. Research by The Nature Conservancy has provided data with significant policy and management implications. Nearly half of all watersheds in Oregon contain two or more types of GDE (Brown et al., 2011) providing significant ecosystem services for communities throughout the state.

2.1.2 Allocating groundwater for GDE

One of the provisioning ecosystem services of GDE is aquifer recharge; however, often groundwater recharge depends on a healthy, functional surface ecosystem for infiltration and recharge via a stream or wetland (MacKay, 2006). Ensuring ample water supply for GDE not only protects sensitive ecosystems from harm, but prevents a negative feedback loop by providing water for ecosystems and dependent stakeholders reliant on the same aquifer. Integrated Water Resources Management (IWRM) requires a coordinated development of land

and water resources to optimize equitable economic, social, and natural systems welfare (GWP, 2003). Managing water resources to maintain and restore GDE health is a vital sustainability consideration for water managers.

The European Union Water Framework Directive (WFD) requires member states to develop management plans for surface and groundwater mandating water managers to consider the whole, above/below-ground reality (Acs et al., 2013). These plans resemble comprehensive river basin management plans in their scope and require nations to maintain water quantity and quality to maintain the health of terrestrial ecosystems dependent on groundwater (Rohde et al., 2017, p.294). South Africa passed the National Water Act of 1998 utilizing “resource directed measures” (RDMs) to guarantee water supply for GDE (Rohde et al., 2017). RDMs are intended to determine the optimal range of consumptive and non-consumptive uses to prevent the degradation of social-ecological systems (Seward, 2010). Australia’s federal government, via the National Water Initiative of 2004, requires state entities to identify and protect GDE (Griebler et al., 2010; Rohde et al., 2017) and develop management plans that do not allocate more than 50% of a sustainable yield (Klove et al., 2014). Several states throughout the U.S. have policy mandating the protection of GDE including Florida’s Water Resources Act (1972) which set up review processes for groundwater withdrawal permits to determine the impact to vegetation, aquatic species and wetlands. Rhode Island’s Fresh Water Wetlands Act (1956) requires groundwater permit applicants requesting to withdraw more than 10,000 gallons per day to collect and analyze data determining the impact to nearby wetlands before permits are even submitted (Aldous et al., 2011).

Iran faces a unique challenge as an arid nation reliant on GDE and groundwater-dependent infrastructure for community water allocation. Stakeholders have begun working with agencies to develop environmental water requirements to ensure the health and vitality of lakes, streams, and wetlands to protect biophysical components, ecological processes and ecological services (Sajedipour et al., 2016). Iranians, particularly in urban areas, rely on groundwater dependent qanāts, or subterranean channels used to transfer snowmelt to populated areas/zones of economic interest (Motiee et al., 2007). Qanāts have been used throughout the country as early as 500 BC, though several of these ancient systems are experiencing depletion. Stakeholders invest in the analysis of infrastructure efficiency and allocation requirements to reverse depletion patterns for long-term sustainability on a local basis.

Market-based mechanisms for allocating water quantity for ecological purposes is another mechanism for managing GDE supply. Water markets throughout the western United States recognize in-stream water rights with the sole purpose of providing water for fish, amphibians, habitat, etc. (Megdal et al., 2015). While in-stream water rights are explicitly surface water provisions, the hydraulic connection indirectly provides groundwater quantity protections via GDE (streams) (Aldous et al., 2011). Surface water protection is an important policy tool as a survey of water managers from every state revealed that a small minority of state policies consider the needs of GDE and only half of the states explicitly recognize the connection of surface and groundwater (Megdal et al., 2015). Oregon explicitly recognizes this connection via in-stream leasing, transfers, and state land allocations are a regular practice. Most of these mechanisms are voluntary ways for water rights holders to leave water in-stream. Australia's Murray-Darling Basin Authority has been buying water rights from farmers for nearly a decade in effort to leave water in-stream and in the ground for GDE functions (Aldous et al., 2011).

Australia's water rights buyback program is a response measure attempting to reverse decades of groundwater exploitation. Market-based policies encouraging withdrawals are starting to receive scrutiny in less-developed nations. Policies in South Asia and Mexico provide subsidies for electricity costs associated with groundwater pumping for irrigation (Klove et al., 2014). Subsidies for water-intensive crops in arid areas can lead to similar overexploitation including areas in the western United States (House & Graves, 2016). Policies with direct and indirect effect on deforestation or forest recovery also effects the health and supply of water to GDE recharge and quality. Supplying agencies with the tools to properly value groundwater, pumping costs and the ecosystem services provided by GDE will inform market-based policy of the actual costs of groundwater exploiting practices. Economists Koundouri and Pashardes (2003) encourage caution in use of hedonic price analyses for water resource policy as "it is possible for these techniques to give rise to misleading conclusions about the effect of an environmental attribute on producers' welfare if potential biases from inappropriate sample selection criteria are ignored" (p.54).

The nature of U.S. water allocation policy creates fragmented and incomprehensive GDE protection. The McCarran Amendment (1952) yields water allocation sovereignty to the states, many of which merely use indirect GDE allocation measures, if any. South Africa, Australia and the EU have developed comprehensive and mandatory GDE allocation requirements through their recent water management legislation which take precedent over consumptive uses. However, many states fail to account for all environmental groundwater needs serving "well-established consumptive-use sectors – agriculture, industry, and drinking water supplies – at the expense of the environment and ecosystem services" (Megdal et al., 2015, p.682). State agencies ought to employ a variety of methods and models to determine the amount of groundwater necessary for dependent species and their vegetative habitats (Orellana et al., 2012).

2.1.3 Spatial planning

A variety of GDE spatial planning strategies are used to protect ecosystems throughout the world. MacKay (2006) advocates for incorporating spatial planning into water resource planning processes, "ensuring that scoping studies are carried out at regional levels to identify potential occurrence and vulnerability of groundwater-dependent ecosystems" (p.236). Regional GDE data and spatial considerations can aid in determining water allocation needs to promote GDE vigor while identifying potential impacts from nearby anthropogenic withdrawals.

Florida's Water Resources Act of 1972 established regulation of water use in the state through permits that demonstrate use is beneficial, will not interfere with existing uses, and is consistent with the public interest. Some of the water management districts within the state use the review process to deny withdrawals resulting in drawdown near wetlands, lakes, and other GDE recognizing the public interest in protecting groundwater dependent natural resources (Aldous & Bach, 2011). OWRD's water rights review has a similar process. Other states conduct spatial planning for municipal groundwater resources. Minnesota and Indiana expanded the scope of the Safe Water Drinking Act within their respective states by requiring all groundwater-based municipal water providers to draft Wellhead Protection Plans. The plans require water utilities to delineate a Wellhead Protection Area, to identify/inventory potential sources of contamination, develop a contaminant isolation zone, and develop/report pumping plans (IDEM, 2017; MDA, 2017). Residents within the delineated protection areas are informed of their spatial status and encouraged to take extra caution when disposing of waste or engaging in activities potentially impacting the aquifer. In the region of our study site, the City of Florence maintains a robust Aquifer Protection Plan complete with contaminant exclusion zones and pumping models predicting consequential drawdown from municipal pumping (City of Florence Oregon, 2013). The plan serves as a spatial-planning resource for development.

Delineating vegetated buffer zones around GDE into land-use requirement codes is another form of spatial planning used by resource managers. Vegetated buffer zones are strips of vegetated land maintained in locations where they are able to protect vulnerable resources from runoff pollution down-gradient of industrially/agriculturally active land. Maintaining riparian buffer strips is an effective, low-cost mechanism for reducing contamination risks (Klove, 2011). The European Union currently uses vegetated buffer zones to reduce nitrate impact from agricultural practices and mitigate off-site pesticide runoff (Klove et al., 2014). The EU Common Agricultural Policy requires farmers to devote 5% of their land "to ecological focus areas" (Klove et al., 2014, p.1079) which includes vegetated buffers to mitigate runoff pollution (European Commission, 2017). China actively manages spatial coastal planning by considering freshwater inflow impacts to lagoons and other marine GDE due to groundwater withdrawal from coastal development (Zhu et al., 2012).

Pumping-restricted buffer zones are another spatial-planning tool that can be used for GDE conservation and protection. Otago, New Zealand issues groundwater withdrawal rights based on distance to GDE and discharge rates. The state's water agency uses the Jenkins solution for drawdown to delineate GDE interference zones:

> $q = erfc\ [r/(4tT/S)^{0.5}]$ where q is stream depletion (L^3/T), Q is pumping rate (L^3/T), erfc is the complimentary error function, r is the distance between the pumping well and stream (L), t is time (T), T is transmissivity of the aquifer (L^2/T), and S is storativity of the aquifer (unit-less)

Groundwater pumping applicants within the GDE interference zones need to prove their withdrawals will not significantly affect a neighboring stream or GDE (Beseki & Hodges, 2006). This innovative interference zone approach still allows stakeholders to apply for water rights within the buffer, but the size of the water right is a serious consideration for the agency. Otago uses the Jenkins solution to determine the combination of “5 L/s [of stream interference], 90% confidence, and 30 days of continuous pumping as the upper limit for an acceptable risk for stream depletion” (Beseki & Hodges, 2006, p.1699). Delineating interference zones that restrict groundwater pumping provide GDE with the necessary water supply in addition to downstream surface water rights while still allowing for responsible consumptive use of the aquifer. Other authors, such as Treidel et al. (2012) recommend GDE preservation by decreasing withdrawals affecting GDE supply and even relocating wells currently interfering with GDE.

Other spatial planning innovations include designating lands for conservation and recreation like the Danube Alluvial Zone National Park downstream of Vienna, Austria. The park’s primary purpose is to restore the hydraulic connection between the river and the historic floodplain (Tockner et al., 1998). Regulatory measures employed include the prohibition of new well borings as well as other GDE protection strategies. National, state/provincial, and municipal parks around the world act as mechanisms for GDE conservation, if groundwater extraction within park boundaries is regulated or prohibited.

2.1.4 Monitoring quality and quantity for GDE

The importance of sufficient programs for GDE monitoring and reporting is a consensus among GDE scholars and resource managers (Rohde et al., 2017). Recognition of the mechanisms and baseline conditions of a GDE allow managers to determine thresholds and build appropriate protection practices. Determining the ecohydrology through conceptual models and quantitative assessments of how groundwater interacts with GDE is a crucial step of baseline modeling (Klove et al., 2011). Hoyos et al. (2016) define ecohydrology as the “description of hydrological mechanisms that underlie ecological patterns and processes” (p.3), in other words, the baseline groundwater conditions necessary for ecological interaction.

Some monitoring programs were outlined in the *Identifying and mapping GDE* section of this chapter including California’s 5-year Groundwater Sustainability Plans. The second of the three basic concepts underpinning South Africa’s RDMs is determining and policing the thresholds at which consumptive uses adversely affect GDE. The EU’s WFD outlines the needs and availability required for GDE and directs states to determine and monitor quantitative threshold values for terrestrial ecosystems (Klove, 2014). The WFD also requires monitoring for groundwater quality and levels at which GDE would be adversely affected.

Griebler et al. (2010) and Klove et al. (2014) outline a series of assessments to determine baseline GDE conditions, broken into two parts: hydrogeologic and ecological assessments. The hydrogeologic assessment includes traditional hydrometric methods including piezometers, seepage meters, aerial photographs, etc. in addition to surface water measurements. Determining flow patterns through tracers or modeling allows managers to determine potential sources of contamination and the amount of time before a GDE will be impacted following the release of a contaminant. Temperature analysis also reveals important baseline flow patterns and water quality parameters. Ecological assessments include a before-after-control-impact design testing the change in response to a controlled site and adversely affected site. Traditional bio-assessments of taxa expected to taxa observed is another monitoring mechanism that can display whether the biodiversity of a GDE is an indicator of hydrologic stress. Similarly, assessing ecosystem processes (decomposition, production, etc.) serves as another potential indicator. Klove et al. (2014) recommend predictive ecosystem integrity monitoring related to hydraulic conditions as integrated conceptual models of GDE are a critical means of understanding GDE requirements. Ultimately, Klove et al. (2011) call for “[local] studies to assess [GDE] should include multi- and interdisciplinary knowledge on hydrogeology, geochemistry, and ecology to avoid wrong decisions” (p.779).

Following these baseline assessments, the Millennium Ecosystem Assessment asks managers to define quantitative environmental flow and water level values for each specific GDE (Brauman, 2007), as the plans of California, South Africa, and the EU do. A specific example comes from a study of central Oregon fens where the healthy threshold depth to water range was explicitly stated as 0.35-13.7 inches (Aldous & Bach, 2014). Orellana et al. (2012) quantified vegetation groundwater use in GDE as a tool to determine minimum flows. Their methodology included variably saturated models, saturated groundwater models, fully distributed and coupled hydrologic models, and lumped models. Lowry and Loheide (2010) introduce the term ‘groundwater subsidy’ as “the difference in the volume of water extracted per unit area through root water uptake with shallow water table conditions as compared to that extracted groundwater under drainage conditions [free of vegetation]” (p.1-2). Modeling these depth-to-water requirements for GDE vegetation vigor aids in putting a price on the benefit of ecosystem services from maintaining minimum groundwater levels.

However it is accomplished, monitoring groundwater quality and quantity thresholds are an important practice for GDE protection. According to Megdal et al. (2015), large governance mechanisms in the U.S. lack this important regulation which is necessary for protection of the large number of GDE at risk of water supply loss or contamination (Brown et al., 2011).

2.1.5 Adaptive management

Developing groundwater management systems that use the best commercial and scientific data available to protect GDE then continually revising those plans based on results and new scientific data is the approach considered most likely to succeed in providing for stakeholders and ecosystems. Adaptive management is the "process for improving management policies and practices by systemic learning from the outcomes of implemented management strategies and by considering changes in external factors in a pro-active manner" (Pahl-Wostl et al., 2010, p.573). Water managers need not have the perfect management plan to protect GDE initially, but ought to implement a well-researched management strategy, learn from it, and adapt. This approach highlights the importance of continued research and monitoring with local data as a best management practice (Klove et al., 2014).

Adaptive management approaches have become the default GDE governance mechanism used throughout the world, including in Australia (Rohde et al., 2017), South Africa (Seward, 2010), and California (Megdal et al., 2015). Ostrom et al. (2003) emphasized the importance of adaptive management designed to handle imperfect data in groundwater resource management in the commons. Incoming refined data is used to reconcile conflicts, link across spatial and temporal scales while acclimating to fluctuations (Megdal et al., 2015). Local data should model climate change implications for long-term efficacy. These implications include expected changes from base conditions as well as projected groundwater withdrawal for domestic needs, in addition to the agricultural and industrial groundwater withdrawal fluctuations (Triedel et al., 2012). Current climate and meteorological models are an excellent starting point for this type of analysis, which focuses on GDE subsystem requirements as the model's boundaries.

Northwestern China is an arid region where communities are highly dependent on GDE with widely varying ecosystem conditions which vary throughout the year reflecting temporal precipitation patterns. Scientists have developed baseline data sets over periods of several years to determine how to manage these ecosystems during dramatic weather periods (Liu et al., 2017). Stakeholders dependent on the transboundary Guarani Aquifer System in South America rely on international cooperation to sustainably manage groundwater resources, a process which has undergone several episodes of adaptation due to varying physical conditions, regional development, and political will (Villar, 2016). Behailu et al. (2016) completed an institutional analysis case study of water management in several Ethiopian communities finding adaptive capacity to be inadequate. The author recommends incorporating traditional indigenous practices into GDE sustainability efforts.

Integrated Water Resources Management (IWRM) is the adjustment of regulatory frameworks, economic management instruments, conjunctive management of GDE and groundwater, land use regulations, and social participation to optimize water management for social and natural systems (GWP, 2003; Klove et al., 2013). At its core, IWRM is adaptive management: adjusting several inputs of the system to adapt to a catalyst or changing goals. Of the variables outlined in IWRM, social learning/public participation are often the least developed (Kastens & Newig, 2008; Marín, 2014). Adaptive management is one of the two pillars in the Management and Transition Framework for groundwater governance structures (Knüppe & Pahl-Wostl, 2011). Foundations for this approach are based on the Social Learning and Regime Transitions theories in addition to Institutional Analysis and Development (Ostrom, 2003). Discovering inclusive limitations within an institution and working to foster public participation is an essential dimension of adaptive management.

2.1.6 Restoration

An important and frequently used GDE management tool is restoration. The EU WFD calls for an ambitious restoration effort for groundwater bodies of poor status (nitrate levels greater than 50 mg/L) (Klove et al., 2014). Historically, GDE restoration has been accomplished as a response in the United States to abide by requirements of the Clean Water Act (Aldous & Bach, 2011). Some proponents of IWRM call for the revival of lost ecosystems with an emphasis on ecosystems benefitting vulnerable populations (GWP, 2003). GDE remediation efforts restore biodiversity, improve nearby marine habitats, and sequester carbon while often producing a positive feedback to make nearby systems more resilient (Bullock et al., 2011). Understanding hydrogeological boundaries is necessary for proper restoration. Orellana et al. (2012) note the importance of evaluating water budget parameters, like groundwater and transpiration, of an ecosystem prior to restoration efforts.

Aquifer recharge (AR) and aquifer storage and recovery (ASR) are increasingly popular methods used for GDE restoration in arid regions. Artificial recharge and storage improvements provide an engineered means for aquifer depletion mitigation (Megdal et al., 2015). There are over 1200 operable ASR and AR wells in the United States, mainly concentrated in the western-third of the country (Figure 6) (EPA, n.d.). Australian communities use AR and ASR to secure domestic and agricultural water resources. Restoration of ecosystem services from GDE is a well-cited benefit for Australian stakeholders considering these projects (Molloy et al., 2009).

Figure 6 - Distribution of ASR wells by national EPA regions (EPA, n.d.)

2.1.7 Public participation and collaboration

Many authors consider public participation and collaboration as critical elements of GDE protection and management. The third of South Africa's three RDM principles is public participation in allocation and optimal threshold decisions (Rohde et al., 2017). Ostrom's principles to counteract the 'tragedy of the commons' by creating formal avenues for collaborative resource management decisions are cited throughout groundwater governance literature from The World Bank, United Nations, and other human development agencies (Foster et al., 2010). A governance framework analysis revealed a lack of explicit collaborative mechanisms in the Upper Guadiana Basin of Spain, a basin ripe with stakeholder strife because of rigorous groundwater use. This is an example of how problems in water management can arise when important actors are excluded from the management process (Knüppe & Pahl-Wostl, 2011). A second, more integrated process resulted in greater cooperation and wider acceptance of a strategic management plan. Iranian water management agencies underwent comprehensive change throughout the early twenty-first century to shape GDE governance to be more reflective of traditional qanāt management structures in which communities worked cooperatively to maintain groundwater dependent infrastructure (Reza Balali et al., 2009; Yazdanpanah et al., 2013). Public participation also aids in the alignment of a shared vision among groundwater resource stakeholders, another requirement of the IWRM (GWP, 2003).

Yet, to achieve public participation, “we need to foster a greater awareness of the role of GDE in the landscape among key stakeholders” (Aldous & Bach, 2011). The greatest challenge facing public participation is developing public awareness and education about GDE. Positive implications of natural resource education include:

> “cognitive development and personal empowerment at the level of local resource communities; simplification of the often complex discourse encountered in resource management; reduction in feelings of powerlessness often experienced by members of the public in environmental assessment scenarios; a reduction of ignorance and indeterminacy regarding resource management issues; conflict resolution at the cognitive level; and, clarification of the opposing values, interests or actions at the heart of a conflict” (Diduck, 1999, p.85).

Foster et al. (2010) outline the following principles for an effective public engagement campaign: transparency, effective communication, participatory management, and honesty including frankness about ‘business as usual,’ acknowledging capacity limitations, and challenging macro-policies. Greater involvement in public decision leads to greater ownership in the management of natural resources promoting the spirit rather than simply the letter of GDE management law (Knüppe & Pahl-Wostl, 2011). Incorporating traditional indigenous management mechanisms diversifies collective creativity in GDE and water management, while providing examples of previously successful social-ecological system resource management strategies that have transcended millennia (Behailu et al., 2016).

Presently, there is a serious lack of foundational groundwater education in the United States as evidenced by the Dickerson and Dawkins (2004) assessment of eighth-grade students' groundwater knowledge. The issue does not stop in high school, as most adult men and women, regardless of socio-economic status, do not understand groundwater systems or the role of GDE (Dickerson & Callahan, 2006). Herein lies a serious gap in groundwater policy: education and public outreach programs. The work presented here is an attempt to fill this gap in the Florence, Oregon region.

2.1.8 Ramsar Convention on Wetlands

To illustrate a holistic example of the GDE protection management categories outlined, the Ramsar Convention on Wetlands encourages listed sites to use the categories outlined throughout the literature review. The international wetland treaty organization boasts 169 contracting parties, member countries, containing nearly 2,300 listed wetlands of international importance (Finlayson, 2014). To receive a designated listed status, wetland stakeholders need to *identify* and report the ecologic, botanical, and hydraulic properties of the site which make it vital to the international community (Ramsar, 2014). Stakeholders also need to develop plans to *monitor* bio-diversity and hydraulic conditions while planning *restoration* activities to revive the ecosystem to its maximum ecologic potential. Data from the monitoring is expected to inform *adaptive management* plans particularly if the ecological character of the site alters. Ramsar also encourages public outreach and *stakeholder involvement* in wetland resource management with an emphasis for aboriginal input. Ramsar-designated sites have a successful track record as a multilateral environmental agreement providing data and lobbying power to influence policy at the local and state levels of governance surrounding the sites (Mauerhofer et al., 2015). Policies include *spatial planning* and *water allocation* considerations. Above all, Ramsar's greatest success comes in the form of portraying wetlands as important components of the landscape, providing critical ecosystem services rather than a nuisance to development (Ferrajolo, 2011).

2.2 Current Groundwater Dependent Ecosystem Policy

Megdal et al. (2015) define groundwater governance as the overarching framework of groundwater use laws, regulations, customs, and the processes of engaging the public and private sectors as well as civil society. Groundwater governance dimensions include political-institutional, sociocultural, economic, and ecological (IWRM, 2003). The following sections document the U.S. Federal and Oregon state policy mechanisms influencing GDE management.

2.2.1 Groundwater Policy in the United States

Surface water policy in the United States is divided into two doctrines: *Riparian* and *Prior Appropriation*. Water is considered a public resource and part of the corpus of the Public Trust Doctrine which places the fiduciary responsibility on the state government to responsibly manage the resource for current and future citizens (Sax, 1969). *Prior Appropriation* has been the surface water doctrine of the western U.S. since established by the California Supreme Court in the 1855 case Irwin v. Phillips in which two mining operations engaged in a battle of water diversions before the court ruled the party to first establish the diversion had the right. This "first in time, first in right" notion is the central tenant of western U.S. water law. Fertile land and economic opportunities were limited in the arid and rugged landscape. Granting surface water rights on a first-come, first-serve basis enticed western migration while rapidly establishing Euro-American economic presence and precedent for water allocation policy in the west.

Policy and laws concerning groundwater allocation were largely undeveloped until the late 1930s when high intensity turbine pumps were invented. Until this point, groundwater was perceived as a bottomless resource (Dellapenna, 2007) providing additional water for junior surface water rights holders or stakeholders in arid regions where surface water supply is inconsistent. The limited dimensions of groundwater were revealed through advances in pumping technology creating demand for legal mechanisms to govern allocation (Kemper, 2004). Groundwater governance in the United States is fragmented and does not reflect the east-west split of surface water allocation policy. Rather, groundwater allocation is far more complex across, and even within states (Table 1) (Megdal et al., 2015), and legislation is generally underdeveloped leading to clashes between agencies and rights holders (Leshy, 2008).

	Yes	No	No Response
States have groundwater laws (formal or informal)	50	0	1
State law recognizes the connection between surface water and groundwater	25	23	3
State law recognizes groundwater quality	43	5	3
State law recognizes groundwater conservation	36	12	3
State law recognizes groundwater-dependent ecosystems	25	21	5
State agencies have groundwater oversight and enforcement authority	48	0	3
Local agencies have groundwater oversight and enforcement authority	31	1	19
Different state agencies oversee water quantity and water quality	36	15	0
State agencies have sufficient capacity to carry out responsibilities	25	23	3
Respondents have observed substantial changes in groundwater management	35	15	1

Table 1 - Survey results from the Megdal et al. (2015) study of groundwater governance where a state groundwater agency official from each state was interviewed

Dellapenna (2007) divides U.S. groundwater allocation policy into six prevailing categories. The *Absolute Dominion* doctrine grants a landowner complete rights to the water underlying their property if the water is captured before it leaves the land. This rule developed in higher courts prior to scientific understanding of groundwater resources. *Reasonable Use* rules developed as hydrologists' expertise trickled into the courts and legislative assemblies. Using water beneficially and on the overlying land are two basic prerequisites of reasonable use which attempt to prevent large water users from adversely affecting the supply of neighboring small well owners. *Correlative Rights* are based on a "common yardstick of common need" for competing users of a shared aquifer. The common yardstick is often based on historic uses, a static governance system that can create a "race to the bottom" among stakeholders attempting to establish their allocation rights. *Appropriative Rights* reflect Prior Appropriation surface water doctrine, in which a groundwater user who is first in time is first in right. This approach allows state agencies to track groundwater withdrawals through the issuance of permits and rights, though few states comprehensively use appropriation for both surface and groundwater allocation. *Regulated Riparianism* has emerged in eastern states where users may withdrawal reasonable amounts of water from beneath their owned land but are required to establish their use via permit. Several states use riparian permits to establish a conjunctive use scheme, though western states maintain Prior Appropriation for surface water with Regulated Riparian groundwater policy (Oregon exempt wells). The final category, *Prescriptive Rights* are established upon long-term continued use. The main difference between this doctrine and the rest is that Prescriptive Rights establish a groundwater right by first time of use as opposed to date of dispute (Correlative Rights) or disregarding any date as a precedent (Absolute Dominion).

If an aquifer crosses state lines, the federal government steps in to resolve allocation disputes between states as sovereign entities. Three well-developed inter-state groundwater resolution mechanisms exist: 1) interstate compacts consented by Congress, 2) Supreme Court allocation via the “equitable apportionment” doctrine of federal common law, and 3) Congressional legislation that supersedes existing interstate compacts (Leshy, 2008). The final of these three mechanisms bypasses states as the sovereign water allocation party and includes the Clean Water Act, the Safe Drinking Water Act and Endangered Species Act. Primarily, these superseding legislative actions are concerned with groundwater quality, fragmenting the primary forms of groundwater quantity and quality governance between federal and state governments.

The Clean Water Act protects wetlands, as the statute explicitly expresses the value of wetlands to human systems by providing natural remediation for contaminated water (Aldous & Bach, 2011). Recently, the Supreme Court limited the scope of the Clean Water Act, weakening its power as a GDE protector. Wetland management is primarily left to communities and states which widely vary from environmentally conscious states in the northwest, to development-focused communities like Houston (Satija, et al., 2015). The Safe Drinking Water Act provides secure, direct groundwater quality protection standards to GDE as part of a community’s drinking water system. Aldous and Bach (2011) display that this application of the act has a limited practical scope as it protects 18% of identified GDE in Oregon. The Endangered Species Act also provides protection for GDE by mandating quality standards and minimal flows into ecosystems hosting the habitat of one or more listed species’. Though an indirect mechanism, the Endangered Species Act protects many GDE from groundwater drawdown and degradation.

Legal frameworks provide rights and obligations to governing bodies and citizens while achieving sustainable resource utilization. Federal policy has historically protected drinking water quality, which may include minimal quantities to abate contamination, but there is a failure at the federal level to address ecological needs for GDE (Megdal et al., 2015), (Brown et al., 2011). Federal groundwater policy in the U.S. yields quantity allocation to the states, yet includes a complex set of legislative actions to mandate minimum quality standards. The hydraulic connection between surface and groundwater calls for a conjunctive governance approach to these water resources (Mechlem, 2016); however, there are several dimensions within groundwater governance that require local, state, and national levels of government institutions for effective management (Varady et al., 2016).

2.2.2 Groundwater Policy in Oregon

Oregon's Groundwater Act of 1955 established state government authority for groundwater resources management. The act directs the state of Oregon to determine rights of groundwater use that most closely reflect an *Appropriative Rights* doctrine (Dellapenna, 2007). Oregon has adopted an exempt well policy for domestic users reflecting a *Regulated Riparian* doctrine: household well owners need not maintain pumping records or report withdrawal amounts to the state. These exempt domestic wells can pump up to 15,000 gallons per day (OWRD & OHA, 2015), a large amount of water for a household, with no practical oversight. Exempt wells are required to test water quality only in the event of a property transaction. All wells built for economic purposes (agricultural, industrial, etc.) are subject to the appropriation process and are required to produce pumping records and report well-related activities to the state (OWRD, 2013). The state compiles and actively maintains data regarding the capacity, shape, and hydraulic characteristics of all aquifers underlying Oregon explicitly recognizing the hydraulic connection between surface and groundwater resources (Iverson & Bateman, 2016).

The Oregon Department of Environmental Quality (ODEQ) oversees programs concerning groundwater quality within the state issuing waste permits, remediation requests, and basin-wide quality reports (Oregon DEQ, 2009). The ODEQ coordinates with the OWRD on groundwater quantity issues that require greater allocation for remediation and have the authority to claim water rights for pollution abatement in-stream or in an aquifer. ODEQ is responsible for maintaining minimal groundwater quality standards outlined by federal legislation (Clean Water Act, Safe Drinking Water Act, etc.) and even stricter standards outlined by Oregon's legislature.

Ultimately, groundwater policy in Oregon is divided between two state agencies: quality policy is regulated by the ODEQ, and groundwater quantity allocation and monitoring are handled by the OWRD. Because of this division of jurisdiction, there is potential for a significant fragmentation and gaps in protection for GDE under current groundwater policy in the United States and Oregon that properly accounts for the protection of GDE.

2.3 Groundwater Resources

There are wide spread misconceptions about groundwater throughout the United States and the world. Dickerson and Dawkins (2004) collected qualitative data on eighth graders' groundwater science comprehension, an educational level where students should have basic understanding of groundwater concepts according to the National Science Education Standards. The study found the subjects "hold naïve conceptions concerning groundwater, although the natures of those conceptions are not easily recognized because of both scientific vocabulary and vernacular used in explanation of groundwater concepts" (p. 180). These misconceptions have implications for groundwater management decisions around the world. Groundwater management scholars recognize these misconceptions and cite the importance for adequate understanding of hydrogeological relationships and science-based groundwater data to inform water managers and stakeholders (Baldwin et al., 2012; Gerakis, 1998).

Less than 1% of the earth's water being fresh is a frequently cited statistic, but misleading. Around 2.5% of the water on earth is fresh, of which glaciers currently hold 68% and over 30% is located beneath the surface (USGS, 2016; Gleick, 1993). The fact is, over 98% of Earth's usable freshwater is groundwater and accounts for over half of the world's drinking water. A 2010 study by the United States Geological Survey (USGS) determined 34% of public-supply withdrawals came from groundwater sources equaling 15.7 billion gallons of fresh groundwater per day. The study also reveals that groundwater is the source for 98% of the United States domestic water supply (private wells), or 3.54 billion gallons per day. Irrigators rely on aquifer yields pumping 49.5 billion gallons per day, a large portion of the United States' total groundwater withdrawals, 79.3 billion gallons per day. Figure 7 displays groundwater withdrawals by state.

As of 2016, groundwater provides 31.7% of Oregon's freshwater supply including nearly 90% of individual household supply and 36.3% of irrigation supply (NGWA, 2016). 40% of regional Oregon watersheds contain two or more groundwater dependent ecosystems (GDE) (Brown et al., 2011) emphasizing the importance of these ecosystems to the overall health of

Figure 7 – Daily groundwater withdrawals by state (USGS, 2010)

aquifers and local watersheds. The 40% GDE figure is derived from incomplete maps that do not include springs or some lakes, thus this figure could be far greater. Oregon's water agencies recognize the hydraulic connection between surface and groundwater as new groundwater right applications are analyzed to protect senior surface water rights, including in-stream water rights fulfilling environmental needs (Megdal et al., 2015).

Most groundwater management research in defines groundwater as a *common-pool resource*. Common-pool resources, as defined by Ostrom et al. (1994), are "resource systems… where excluding potential appropriators or limiting appropriation rights of existing users is nontrivial (but possible) and the yield of the resource system is subtractable" (p. 4). In other words, aquifers contain water as its core resource from which agents can extract for use, but is limited by nature, which makes the resource vulnerable to exploitation or degradation.

Consequences of groundwater resource degradation are not limited to human institutions. Over-pumping from domestic wells leads to drawdown and poses risks to aquifer water quality and ecosystems dependent on shallow groundwater, a concern the World Bank has identified as a priority (Foster et al., 2005). This study adopts the Klove et al. (2011) definition of groundwater dependent ecosystems: "ecosystems for which current composition, structure and function are reliant on a supply of groundwater" (p.771). These ecosystems include communities of plants, animals and microorganisms where the availability of groundwater is critical to the type and quantities of flora and fauna as well as the activity (photosynthesis, pollination, etc.) of the residents (plants and animals) of said communities (Hoyos et al., 2016). Because of the human and ecosystem reliance on and interaction with groundwater resources, this research labels groundwater as a *social-ecological system*. The term social-ecological system has been used in academic research to emphasize the interconnectedness of social and ecological systems (Berkes et al., 2001). This study defines a social ecological-system as a set of critical natural resources whose distribution and availability are regulated by complex and adaptable human and biophysical factors that are naturally sustainable (Machlis et al., 1997).

Groundwater moves along flow paths from recharge areas and percolates within geologic and soil formations beneath earth's surface to discharge areas within GDE (Klove et al., 2011). Saturated zones are the subsurface formations that contain water. The movement is very slow, typically mere inches to a few feet per day, a velocity dependent on hydraulic conductivity (Heath, 2004), because the water must move through the voids of a solid medium. The slow nature of groundwater movement and protection from soil/geologic media provide groundwater with a natural resistance to pollution compared to surface water, hence, its popularity among municipalities for domestic supply. Recharge occurs when precipitation or runoff enters the ground. Water usually moves through the unsaturated zone before reaching the saturated aquifer (Klove et al., 2011), hence, recharge is slowest in arid regions with surface layers of low hydraulic conductivity. Aquifer size varies from local to regional systems depending on topography, geology, and climate (Figure 8) (Heath, 2011). Local groundwater flow occurs at depths near the surface over short distances, often interacting with surface environments (GDE, root systems, etc.) recharging and discharging on a shorter time scale. Large-scale, regional aquifers have deeper flow patterns occurring over greater distances. Regional aquifers with vast depths can hold water for up to thousands of years. This water is often referred to as fossil water and, like fossil fuels, once withdrawn, full recharge will not occur within a reasonable human time-scale (Foster & Loucks, 2006). Discharge typically occurs as the water table changes suddenly dispelling groundwater into surface water bodies.

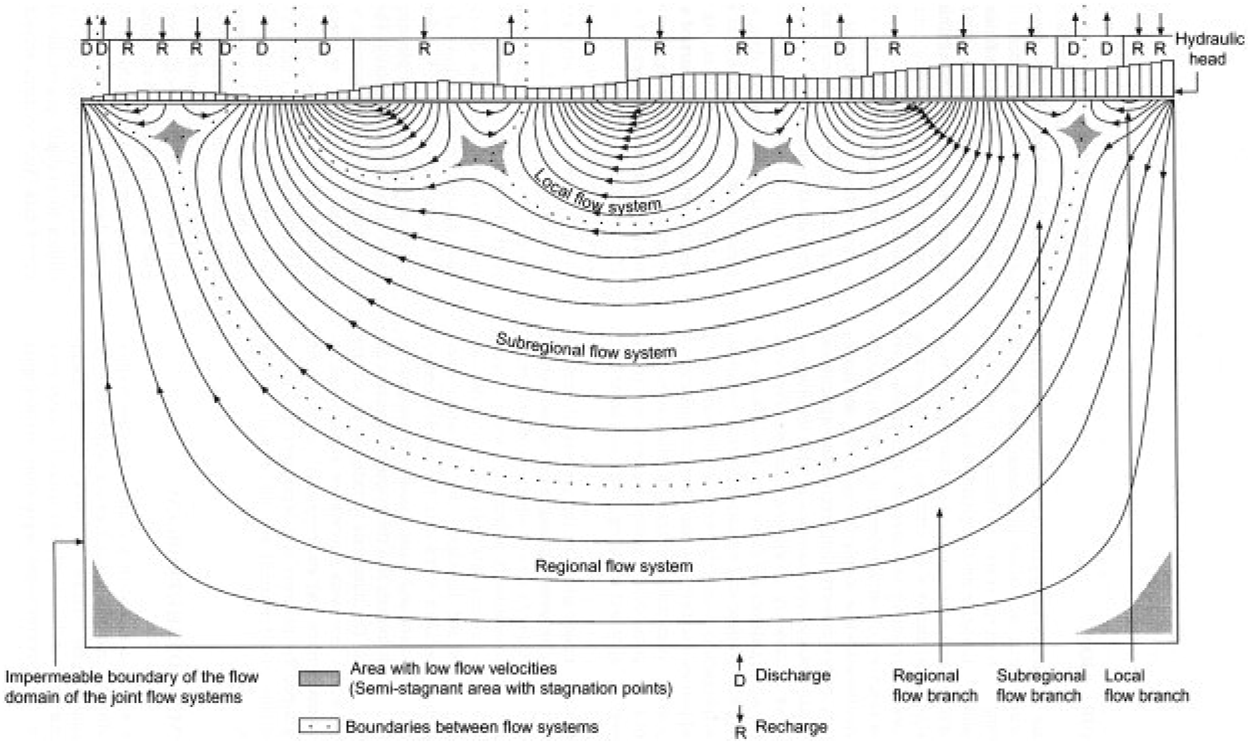

Figure 8 – Idealized nested groundwater flow systems model (Toth, 1963) courtesy of Zhou & Li, 2011

The dynamic equilibrium of the hydrologic cycle often promotes a fallacious assumption of renewability (Thomas & Leopold, 1964). Renowned hydrologist, C. V. Theis (1940), disputes this notion claiming groundwater is mined every time a pump is turned on, and once withdrawn, the water is eventually discharged into the oceans, consumed, and/or contaminated losing its value as a freshwater resource. Additionally, when net groundwater storage loss due to withdrawals exceeds recharge, aquifer storage and recharge capabilities can be permanently impaired. The physical presence of sub-surface water provides pressure essential for the aquifer matrix. If the water is removed, the pressure drops allowing sediments to compact and fill the empty space left by the withdrawn water causing land to subside and aquifer storage capabilities to dwindle (Smith et al., 2017). Land subsidence is physically visible from the surface and garnered national attention during California's 2011-2017 drought (Figure 9). This research considers groundwater as a *semi-renewable resource*: neither completely renewable nor non-renewable (Gleick & Palaniappan, 2010). The level of renewability is largely dependent on the recharge timescale which ranges from a few months to millions of years, the size of the groundwater system, and hydrologic connectivity to surface water systems (Gleeson et al., 2016).

Figure 9 – Land subsidence due to groundwater withdrawals in San Joaquin Valley, CA (USGS, 2015)

The resilience of groundwater to contamination does not make it immune to potential pollution sources. Nolan and Hitt (2006) investigated the vulnerability of shallow groundwater and drinking water to nitrate pollution in the United States. Several sources, including agriculture and waste management, have the potential to contaminate shallow aquifers. Residential communities can also serve as potential sources of contamination to aquifers (Rodriguez del Reya et al., 2012) and domestic wells can act as conduits for pollution sources reaching aquifers of all depths (Steichen et al., 1988). The remediation of shallow and intermediate aquifers affected by the industrial sector has become a stable source of business for environmental consulting firms. Remediation often occurs over a long-term period taking up to several decades due to the dispersive and slow nature of groundwater flow. Drawdown combined with sea-level rise can cause salinity intrusion into coastal aquifers compromising the chemistry of extractable freshwater.

Lack of hydrologic awareness, human and ecological dependence on groundwater systems, and aquifer vulnerability to exploitation and contamination highlight the importance of groundwater systems management research. An all-inclusive approach to groundwater management that accounts for the best interests of all stakeholders regarding socio-economic development and protection of ecosystems and services that ecosystems provide which have been identified as critical for water managers. Diplomatic groundwater sustainability efforts will depend on such an approach (Klove et al., 2014). Recently, several groundwater scholars have called for an approach to groundwater management with generational and socioeconomic equity that balances environment, society, and the economy (Gleeson et al., 2010; Klove et al., 2014).

2.4 Groundwater Dependent Ecosystems and Ecological Services

This research attempts to advance inclusive groundwater management strategies by investigating groundwater dependent ecosystems, the vital interface connecting subsurface water to diverse ecological communities that provide dynamic biophysical services (MacKay, 2006). The importance of conserving and protecting GDE has been acknowledged by the World Bank, (Foster et al., 2006), the United Nations Educational Scientific and Cultural Organization (UNESCO) (Martin-Bordes, 2010), and the World Conservation Union (Bergkamp & Cross, 2006). When developing theoretical guidelines for groundwater governance structures, Knuppe and Pahl-Wostl (2011) determined an ecosystem services approach as one of two pillars in their Management and Transition Framework (MTF). Adaptive management is the second pillar. The Ramsar Convention on Wetlands, an international treaty for the conservation and sustainability of wetlands, began listing wetlands of international importance in 1971 following the inaugural convention in Ramsar, Iran. The treaty maintains a database of nearly 2,300 listed GDE that host vulnerable flora, fauna, and fowl species requiring listed organizations to promote stakeholder involvement in adaptive resource management (Ramsar, 2014).

GDE are often points of discharge for subsurface water as it percolates via hydraulic flow paths. Research reveals seven distinct categories of GDE (Eamus & Froend, 2006; Brown et al., 2011; Klove et al., 2011): *springs, streams*, *lakes*, *wetlands*, *wet forests (phreatophytic zones)*, *coastal lagoons, and subterranean ecosystems*. Figure 10 from Foster et al. (2006) illustrates the interaction between several GDE categories and groundwater. Ecosystem communities evolve to the abiotic conditions of the environment including the climate, aquifer characteristics, as well as geologic and geomorphic structures (Klove et al., 2011). Hoyos et al. (2016) term these boundary conditions as *ecohydrology*, or "the description of the hydrological mechanisms that underlie ecological processes" (p.3). GDE hydrology includes four major aspects: 1) the water table *level* as its depth varies within the system, 2) groundwater discharge *flux* into and out of the system, 3) *pressure* associated with the potentiometric head of the aquifer supplying groundwater to the system, and 4) water *quality*, or chemical characteristics.

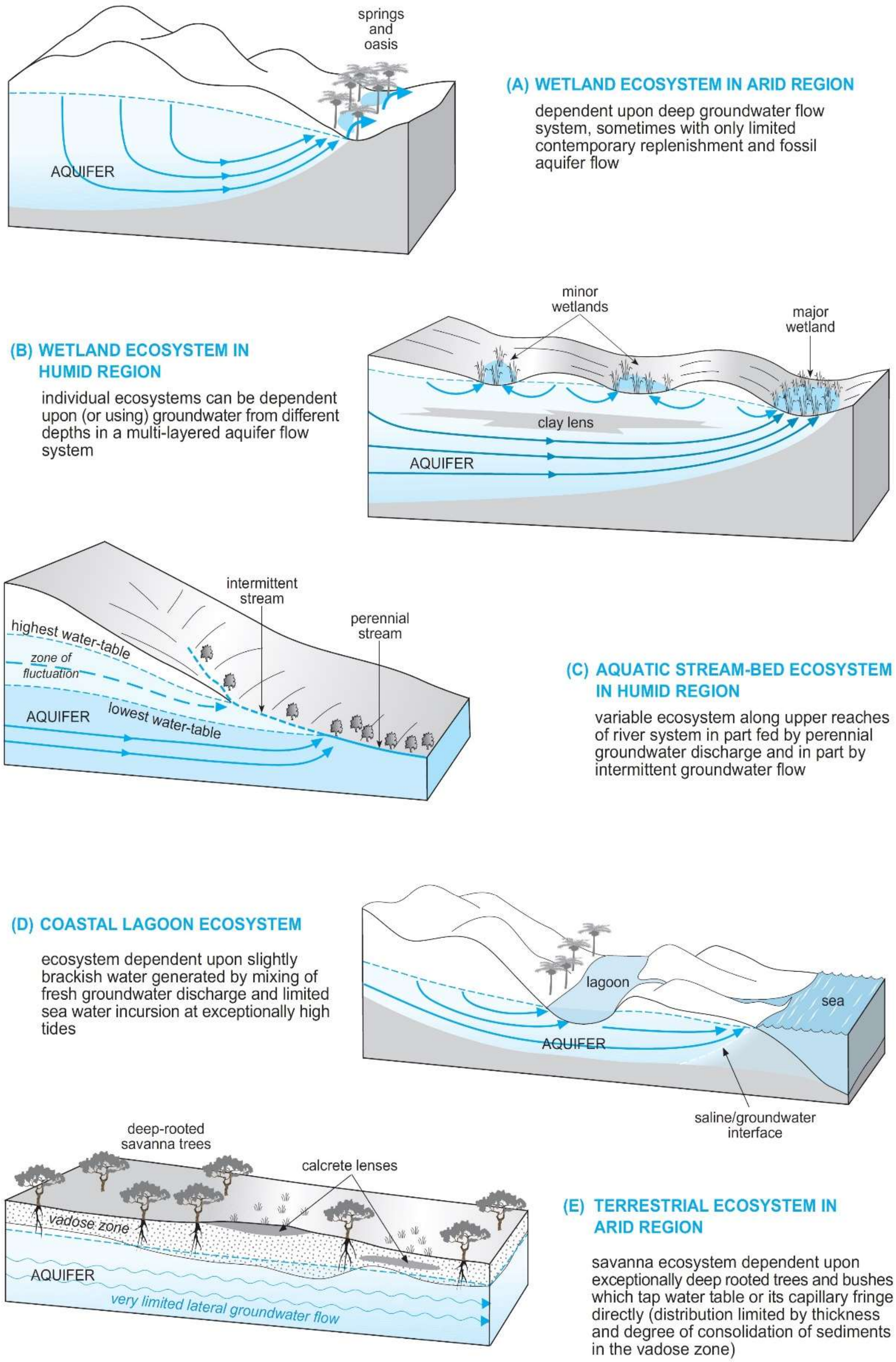

Figure 10 - Conceptual model of the main categories of GDE (Foster et al., 2006)

hydraulic conductivity occasionally running dry as the aquifer drains rapidly, while fens and peatlands rely on stable water table levels receiving consistent recharge from precipitation, surface flow, and groundwater. Klove et al. (2011) suggest utilizing *hydroperiods,* or timing and duration of groundwater discharge as influenced by aquifer characteristics and multi-scale flow patterns, as a starting point for classifying GDE. They identify four types of hydroperiods: 1) *periodic*, a seasonal climate-influenced pattern, 2) *intermittent* which yields great variability in flow, 3) *episodic*, or irregular flow exclusively present during high water levels in the aquifer, and 4) *perennial*, a continuous source (Klove et al., 2011). The fen at Darlingtonia State Natural Site, for example, has a *periodic* hydroperiod influenced by seasonal weather patterns. Other water sources, such as precipitation and surface flow, also influence the water levels, flux, and pressure of GDE. For instance, low-lying wetlands or springs in arid regions likely rely solely on groundwater as opposed to a temperate lagoon which receives water from a variety of sources including the ocean, rain, and runoff as well as groundwater.

Variability in water sources also influence the chemical characteristics of the water within a GDE. Groundwater quality is primarily influenced by soil composition, geochemistry of the site, ratio of surface water to groundwater within a GDE, and scale/hydroperiod of the aquifer on which the GDE is dependent (Klove et al., 2011). Water chemistry in turn influences the biodiversity within an ecosystem, changing the interactive functions that varying species have with the water system influencing the abiotic characteristics of the ecosystem (Hoyos et al., 2016). Water content within vegetation and soil has been extensively measured and understood to be a critical feedback mechanism for the health of GDE communities (Wildung et al., 1975; Clausnitzer & Hopmans, 1994; Kumar et al., 2013; Quijano et al., 2013). Of the seven types of GDE, surface water sources are the most dependent (Beseki & Hodges, 2006). The hydraulic connection between groundwater maintains water levels and discharge rates for ecosystems and communities dependent on the life-sustaining ability of said source.

Shallow GDE are often extremely important to regional biodiversity. The vadose zone and surface water interface zones connect surface terrestrial systems (Tomlinson, 2010 p.939) promoting dynamic, highly-specialized, and eclectic biologic communities that reflect the site's ecohydrology (Klove, 2011).

The widely cited Millennium Ecosystem Assessment (2005) outlines four categories of ecosystem services: 1) provisioning, 2) supporting, 3) regulating, and 4) cultural. Australian researchers used this report to define the four categories of ecosystem services as they pertain to groundwater and the importance of GDE to maintain groundwater systems (Tomlinson & Boulton, 2010). *Provisioning*, the first and most obvious service is human dependence on groundwater as a source for municipal use, irrigation, etc. GDE serve as important points for aquifer recharge and subsequent storage/use as the hydraulic interface between surface and subsurface waters. Healthy ecosystems help allow for more consistent recharge (MacKay, 2006) as deforestation can reduce dry-season surface flows and subsequent aquifer storage (Bruijnzeel, 2004).

Supporting ecosystem services include bioremediation functions, ecosystem engineering, and water quality indicators (Tomlinson & Boulton, 2010). A wide array of research demonstrates the bioremediation capabilities of GDE, particularly wetlands. Various forms of wetland vegetation are well-known contaminant removal agents and used as a natural form of wastewater treatment around the world (Vyzmazal, 2010; Spenser, 1993). GDE also act as ecosystem engineering tools regulating recharge, discharge, and water table depths for flora, fauna, and aquatic communities (Aldous & Bach, 2014). Finally, GDE communities act as water quality indicators: as water quality or quantity degrades, sensitive sentinel species within wetlands, like the *Darlingtonia*, provide an early warning for the chemical and hydrologic changes.

Some of the *regulating* groundwater ecosystem services relate to the properties of supporting services. For example, as recharge regulators, GDE partially absorb strong run-off events preventing flash-floods or damaging high-flow events down-gradient. Phreatophytes, or vegetation with deep root systems which draw their water supply from a shallow water table, within GDE play a major role in run-off management services. Cities, like Houston, have long ignored natural flood control value associated with GDE filling in crucial wetlands for development (McGuire, 2016). The Houston region has now experienced catastrophic flood events in the years 2015, 2016 and 2017 with the recent Hurricane Harvey costing billions in property damage and dozens of human lives (Smith et al., 2017). Beyond flood control, this groundwater-dependent vegetation regulates local climates and prevents significant soil erosion events (Orellana et al., 2012) adding value to the land surrounding the GDE. Loss of regulating GDE services would result in a negative hydraulic redistribution feedback loop where freshwater would be more difficult to recover for use by ecological or human communities before discharging into the oceans.

Finally, the *cultural* ecosystem services provided by groundwater include spiritual, scientific, and other human-related values associated with GDE (Tomlingosn & Boulton, 2010). Hot springs may be the most widely recognized spiritually significant GDE as humans have been flocking to the geologically-heated waters seeking spiritual refuge for centuries (Crittenden, 2013). First-nation cultures throughout the world place spiritual significance in the sustainability of natural resources derived from streams, lakes, and other hydraulically-linked surface ecosystems as displayed by the Māori of New Zealand who fought for 140 years to grant the North Island's Whanganui River the same rights as a Kiwi citizen (Roy, 2017). Other cultural uses include recreational, aesthetic, and economic value as flora, fauna and aquatic species develop for human use or interaction (Hoyos et al., 2016). Economic ecosystem services supplied by GDE to aquifer and surface water systems have gained increasing salience since the turn of the millennium. Scholars have begun to realize that ecosystems are not the only groundwater-dependent agencies of the world, but communities around the globe have groundwater-dependent economies (Llama & Martinez-Santos, 2005).

Many of these services described above aptly describe significant ecosystem services relevant to sustainable economies including water recharge and storage for municipal, agricultural, and other uses. Fisheries and aquaculture industries take advantage of the productive and dynamic services provided by coastal lagoons (Gonenc & Wolfin, 2005). Supply and other supporting services, like pollution control and natural purification, are vital to public health in communities reliant on aquifers for municipal use. Residents of Florence, Oregon, the closest municipality to the study site, benefit from these natural public health services as their municipal supply comes from 1 of 80 Sole Source Aquifers in the United States and the sole Sole Source Aquifer in Oregon (EPA, 1997). A Sole Source aquifer is recognized by the EPA as an aquifer that "supplies 50 percent of the drinking water for its service area" while "there are no reasonably available alternative drinking water sources should the aquifer become contaminated" (EPA, n.d.). GDE overlying Sole Source Aquifers have important implications for the economic and physical well-being of the communities the aquifers serve. The North Florence Dunal Aquifer also lies beneath Darlingtonia State Natural Site, supplying the fen hosting the *Darlingtonia* plant.

Another source of economic significance from GDE is tourism. Streams and lakes are continually a popular choice for fishermen, boaters, and adventure seekers. The vast biodiversity of wetlands and other hydraulically connected ecosystems draw flora and fauna lovers of all types to spend money in and around GDE throughout the world. Oregon's coast is no exception. According to the Oregon Tourism Commission (2017), there were 17.2 million overnight visitors in the Oregon coast region in 2016 pumping nearly $2 billion into the rural economies. In addition to managing the vast majority of Oregon's beaches, Oregon State Parks has 57 parks and 2 natural sites in the coastal region. Darlingtonia State Natural Site is one of these natural sites. The protected, groundwater-dependent fen is a major draw for curious individuals and families from around the world with the desire to witness hundreds of carnivorous plants increasing the amount of time and money visitors spend in the greater Florence area.

2.5 Darlingtonia californica

Darlingtonia californica (syn. *Chrysamphora californica*) is a carnivorous plant native to northern California and Oregon. *Darlingtonia* is a monotypic genusand the only member of the *Sarracinaceae* family found west of the Rocky Mountains. It was discovered in a marsh adjacent to an upper Sacramento River tributary and recognized by John Torrey as a distinct pitcher plant, who named it for his dear friend and botanist William Darlington (*Darlingtonia*), and the location of its discovery (*californica*) (Lloyd 1942). *Darlingtonia* are considered a rare find in the wild; there are few known populations within its limited geographic range.

Darlingtonia plants maintain a distinctive shape including a ballooned head with external fishtail appendages and outer-flower nectar ports, as well as a tubular leaf that tapers to a strong perennial rootstock, supporting a rosette of old and young ramets (Figure 1) (Adalassnig et al. 2005). *Darlingtonia* grows in a colonial fashion and frequently colonizes in open areas exposed to sunlight. It is considered an early to mid-seral bog species, and likely to be a poor competitor without fire or additional disturbance in later successional stages (Ellison et al. 2005; Ellison et al. 2012). *Darlingtonia* grows from sea level to approximately 8,500 feet (2,600 meters) in altitude. They are commonly associated with *Sphagnum* moss and Labrador tea in poorly drained (coastal) fens or basins where lodge pole pine dominates the canopy with few other stunted trees and shrubbery. Round-leaved sundew is another carnivorous plant that can be found in this ecological association.

One of the most important factors that supports *Darlingtonia* growth is the presence of flowing water, which keeps their shallow root system cool and functional (Crane 1990; Oregon.gov 2004). The *Darlingtonia* have a prolific, shallow root system typically reaching depths of less than a foot. The roots make the plants resistant to fire and the presence of heavy metals, like iron, in the surrounding soil (Adlassnig et al., 2005). However, the temperature sensitivity of *Darlingtonia* roots is important. Cool running freshwater is necessary to keep the roots exposed to temperatures around 10 °C. Adlassnig et al. (2005) observes: "cultivation experiments show that the roots have an absolute requirement for this low temperature; they die if exposed to temperatures above 10 °C for a prolonged period of time, and seedlings are even more sensitive (as cited in Slack, 2000)" (p.133). Average annual temperature highs along the mid-Oregon coast varies from 18-20 °C but can reach up to 35 °C (NOAA, n.d.) accentuating the importance of continuous cool groundwater flow at the site.

This pitcher plant fills and maintains internal water levels with its own root system, distinguishing *Darlingtonia* from open-mouthed pitcher relatives that rely on rainfall or other above ground sources. *Darlingtonia*'s unique plant anatomy has earned it the common name 'cobra lily' and countless comparisons to reptilian or extra-terrestrial life (Ellison et al. 2005; Ellison et al. 2012; Adlassnig et al. 2005). The *Darlingtonia* vessel sports many chlorophyll-free (transparent) leaf fenestrations or areolae, to transmit light and confuse insect prey. Internalized stiff, down-tracking hairs encourage insects towards a basal pool of water for digestion via mites, bacteria and enzymes, leaving only skeletal remains (Fashing 2004).

Figure 11 - Darlingtonia flower (Magic of Life Trust, 2007)

Large, showy and fragrant flowers bloom in spring (April-August depending on altitude): each flower arises from a separate stalk per plant, with five crimson-purple petals concealing androecium and gynoecium (reproductive organs) (Figure 11). The petals are surrounded by yellow-green narrow oval-shaped sepals. Floral anatomy relies on insect interaction with abundant pollen and nectar production, suggesting bees as a potential pollinator. Mature capsules develop post fertilization and produce approximately 2,000 seeds each (Meidl et al. 2011). A population study at Darlingtonia State Natural Site conducted by students in the College of Earth Ocean and Atmospheric Sciences at Oregon State University revealed *Darlingtonia* thrive in moderate sunlight, but are temperature sensitive (Chellew et al., 2017). Findings of this study dictate that temperature and sun exposure trade-offs ought to be considered for *Darlingtonia* in a managed site.

2.6 Vulnerability of Shallow Groundwater Dependent Ecosystems

Groundwater close to the surface interact with anthropogenic and natural processes most frequently. These shallow aquifers are often unconfined with an upper boundary defined by the phreatic surface or water table (Heath, 2004). An unconfined aquifer lacks an overlying aquitard, or confining geologic layer, allowing for surface process interaction including GDE supply and easy access to water withdrawals. Shallow groundwater is subject to several pertinent risks related to human activity distressing the health of dependent ecosystems, like the fen in Darlingtonia State Natural Site (Klove, 2014). Potential sources of degradation to the North Florence Dunal Aquifer and other shallow aquifers are divided into three categories: 1) pollution activities, 2) pumping, and 3) climate change related impacts. Potential threats to the Darlingtonia State Natural Site GDE are conceptually illustrated in Figure 12.

Interaction with surface processes includes the usual activities that contaminate surface water sources. Modern agricultural activities not only promote the removal of GDE that serve to recharge shallow aquifers and act as a buffer for groundwater quality, but the activities themselves produce wastes that interfere with surface and groundwater chemistry. Pesticides used for agriculture are laced with chemicals detrimental to biological health/growth carrying the capacity to disrupt ecological processes (Damalas & Eleftherohorions, 2011). The effects of hazardous chemicals in the biosphere, or ecotoxicology (Rattner, 2009), also includes damaging

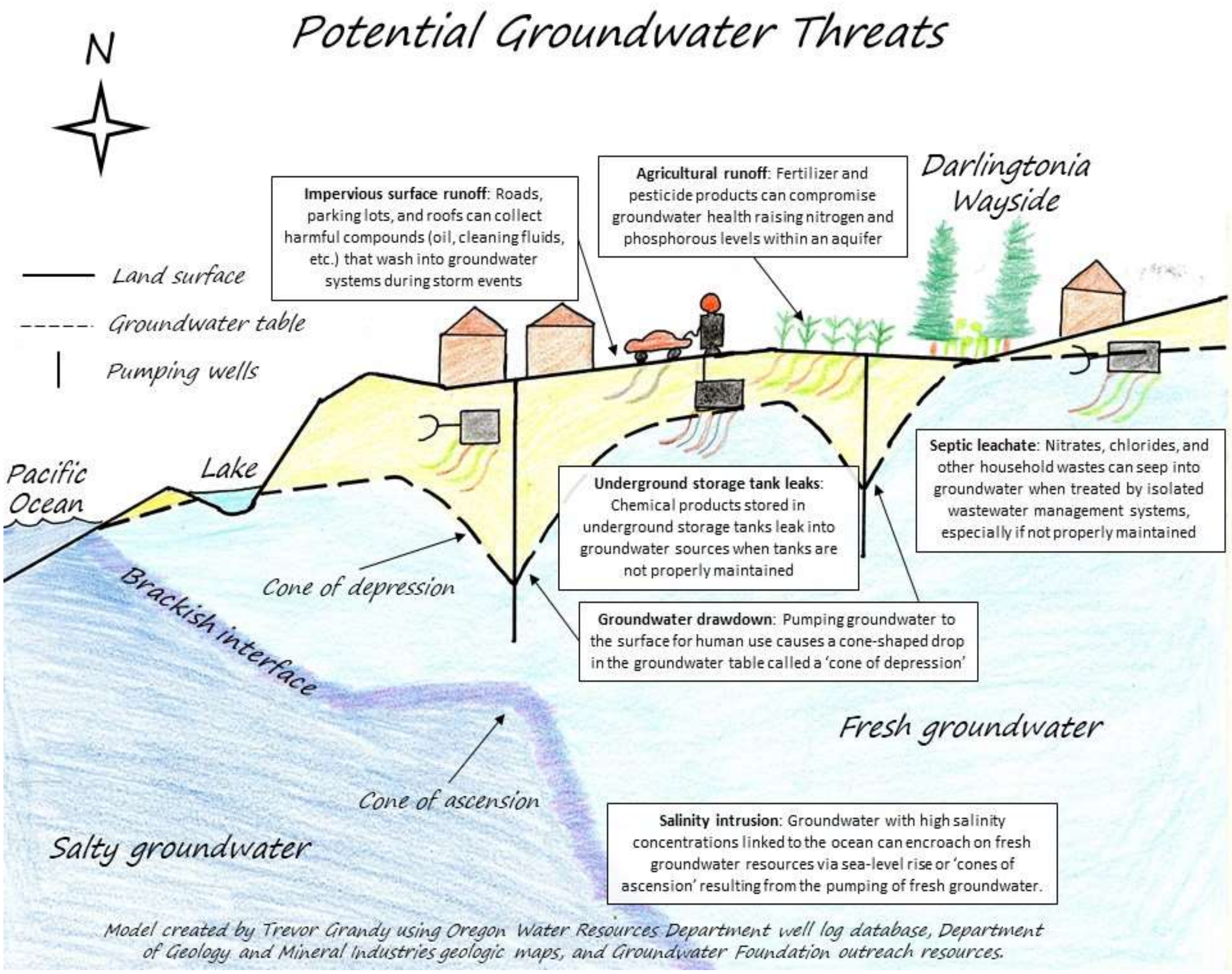

Figure 12 – Activities potentially compromising groundwater quantity and quality in the North Florence Dunal Aquifer

solvents used for industrial purposes. Any agent applied to a farm field or stored underground has the potential to engage groundwater flow through runoff or leaking infrastructure (Hardisty & Ozdemiroglu, 2005). These solvents continue down groundwater flowpaths dispersing down-gradient (Heath, 2004). Agricultural sites also use nitrate-heavy fertilizers to promote crop growth which can runoff with precipitation into surface water bodies or percolate into shallow groundwater systems. Steichen et al. (1988) found nitrate levels above the EPA and USGS recommended maximum contaminant level for safe human consumption (10 mg/L (miligrams per liter)) (Hoppe et al., 2011) in 28% of Kansas farmstead wells. The study examined the correlation between aging groundwater infrastructure and pollutant occurrence as improperly abandoned or damaged wells create a direct conduit for surface pollution to reach aquifers of all depths (Jimenez-Martinez et al., 2011). A 2011 study of domestic well tests required for real estate transactions in Oregon determined that 2.2% of private wells tested contained nitrate concentrations of 7-9 mg/L and 1.7% contained 10 mg/L or greater. High nitrate levels are known to cause serious human health defects (Hudak, 2000) and can also affect dependent ecosystem characteristics (Brown et al., 2011). Waste water treatment is a well-known point source nitrate pollution activity (Chen et al., 2010). Rural areas, like much of Oregon's coast, rely on a domestic septic system for each household or cluster of households which, if not properly maintained, can leach elevated nitrate, chloride, and even caffeine levels into aquifer systems (Rodriguez del Reya et al., 2012). A GDE inventory conducted by Brown et al. (2011) determined that about 30% of Oregon GDE clusters are threatened by nitrates, 30% by industrial chemicals, and 70% by pesticide solvents.

Groundwater extraction is a driving force in water supply for various sectors and regions around the world. For every withdrawal, however, there is consequence to shallow aquifer supply and hydrology. Land subsidence and storage loss is the most visible consequence that can arise from over extraction (Siade et al., 2014), but change in water table elevations and groundwater flow paths are the most pertinent effect of withdrawals (Heath, 2004) and the greatest risk to GDE vitality (Aldous & Bach, 2014). The Brown et al. (2011) Oregon GDE inventory found permitted wells threaten 18% of GDE clusters in the state and high densities of exempt wells threaten 7%. Surface water contributes more water into a GDE water budget over the course of the year, but the timing and chemistry of the groundwater influence have a disproportionate effect on the overall health of the ecosystem (Aldous & Bach, 2014) particularly during dry seasons when demand for groundwater extraction is generally the greatest.

Anthropogenic impacts to atmospheric patterns affect shallow aquifer recharge rates around the world. Water resource climate change studies primarily focus on flow regime and storage changes for surface waters, but groundwater has gained a sharpened focus since 2005. Klove et al. (2014) point out that "unconfined aquifers, especially surficial shallow aquifers are more likely to have renewable groundwater on meaningful time scales and will be particularly sensitive to changes in variability and climatic conditions" (p.253). The primary concern is that changes in precipitation patterns and land area capable of recharge may change seasonal storage and potentially lower water levels and flow patterns. Changes in flow patterns result in temperature and chemistry shifts (i.e. acidification), subsequently impacting species spatial

Potential scenarios and foreseen impacts on groundwater quality due to climate change.

Scenario	Foreseen impact on groundwater	Potential impact on aquifers	Potential impacts on ecosystems	Uncertainty related to impact
Increased leaching due to more intense rainfall	Increased leaching of water soluble contaminants such as nitrates	Increased concentration of pollutants	Potential Impacts on ecosystems – Eutrophication and pollution	Changes in precipitation intensity varies regionally (this change is mainly foreseen for dry and warm climate)
Sea level increase	Salt water intrusion in coastal aquifers	Increased groundwater salinity	More seawater exchange to coastal lagoons. Changes in groundwater flow patterns in coastal ecosystems	The amount of intrusion will depend on coastal aquifer system water level and amount of water extraction
Changed agricultural practice	Increased leaching of water soluble nutrients due to longer growing season and/or intensified irrigation Increased need for pesticides in cold climate	Increase in agriculture can lead to increased pollution. Lower groundwater levels due to higher irrigation may add to the problem	Eutrophication, salinization. Reduced discharge to ecosystems	Increased CO_2 can lead to less transpiration counteracting the irrigation needs and risk of increased leaching
Changed snow accumulation and melt	Increased winter time groundwater recharge in temperate climate with seasonal snow cover. Changes to the timing of snowmelt and corresponding recharge	Increase risk of salt intrusion from road runoff as more salt is use and recharge occur in winter	No direct impacts known on that change water quality in ecosystems	

Table 2 - Potential scenarios and impacts on groundwater quality due to climate change (Klove et al., 2014)

distribution and GDE biodiversity (Heath, 2004). Some of these regime changes are outlined in Table 2. These changes are part of a negative feedback mechanism in which the pollution breakdown functions of GDE become compromised affecting receiving waters and ecosystems down-gradient or down-stream as illustrated by Figure 13. All these changes to recharge and quality will affect the water balance of GDE, particularly wetlands, depending on ecohydrogeology of the ecosystem. Further study is needed for a clear vulnerability picture of GDE on a regional and classification basis (Klove, 2011). Identifying baseline biological and ecological characteristics that, if stressed, reveal a threshold for permanent change to the function and structure of a GDE would aid this effort serving as indicators of strain to the aquifer and ecosystem (Griebler et al., 2010).

2.7 Vulnerabilities of Coastal Aquifers

Aquifers and GDE located near the ocean present a unique set of vulnerabilities when compared to inland aquifers and GDE. Shallow coastal groundwater is hydraulically linked to the ocean and its tidal influence resulting in “sunny-day flooding” events in coastal communities

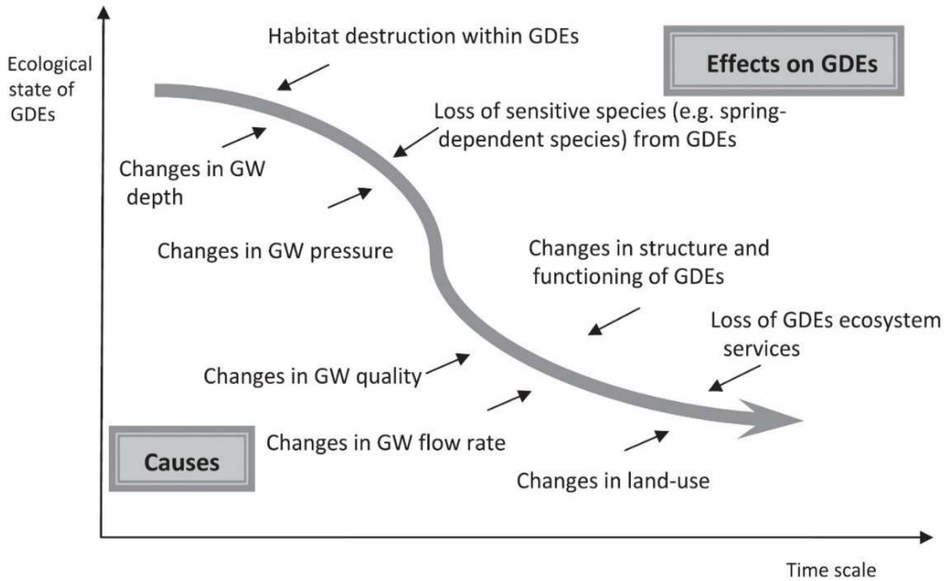

Figure 13 - Conceptual model of ecological changes to GDE with increasing pressure from climate change and anthropogenic activities (Klove et al., 2014)

around the country. Miami is now coordinating city planning efforts in attempt to mitigate the current issue and Washington D.C. is predicted to experience 388 tidal floods per year by 2040 (Spanger-Siegfried et al., 2014). Officials in Honolulu are modelling tidally-induced groundwater flooding to track future public health problems as rising water levels inundate waste water cesspools contaminating aquifer and surface water sources (Habel et al., 2017). Tidal flooding not only causes flooding headaches for vulnerable communities, but contamination concerns as well.

Another unique aquifer contamination distress for coastal stakeholders is saltwater intrusion. Shallow, unconfined aquifers near sources of saltwater interact with the ocean by discharging into lagoons or seawater via the hyporheic zone or underwater springs (Sophocleous, 2002; Zacharias et al., 2003). Some underwater springs supply unique ocean ecosystems, *hardgrounds*, reliant on mineral-rich, brackish water (Wilson & Palmer, 1992). Saltwater interacts with freshwater beneath the surface as well: dense saltwater naturally sinks below less-dense freshwater creating a brackish water interface where the two waters meet known as the *zone of diffusion* (Heath, 2004) illustrated as the “brackish interface” in Figure 12. Changes in sea level influence the depth of the diffusion zone moving saltwater landward while reducing the amount of shallow freshwater available for ecosystems and communities at the surface, a phenomenon known as *saltwater intrusion* (Ferguson & Gleeson, 2012). All the climate change-related complications discussed for shallow aquifers certainly apply to shallow coastal aquifers as well, though the presence of saltwater further complicates the situation for groundwater and GDE on the coast.

While sea-level rise may be one cause of saltwater intrusion, pumping has a far greater effect to induce salinity contamination (Ferguson & Gleeson, 2012). Developed communities and domestic wells reliant on coastal groundwater withdrawals pull freshwater from aquifers at rates that can exceed recharge. This results in drawdown via a *cone of depression*: a change in hydraulic gradients toward a pumping well causing a change in hydraulic pressure (Theis, 1940). Pressure influence from within an aquifer overlying saltwater creates an equal reaction beneath the well raising the zone of diffusion and saltwater, a phenomenon known as a *cone of ascension* (Figure 11) (Reilly & Goodman, 1987). Essentially, the water pumped is replaced by brackish and saltwater due to greater hydraulic head (pressure) from below. Ferguson and Gleeson (2012) predict groundwater extraction coupled with sea-level rise will induce saltwater intrusion that could affect aquifers with <0.0001 gradient, a shallow figure, up to 1300 feet inland. Ecosystems are subsequently negatively impacted by saltwater intrusion as communities' sensitive to salt experience stress (Klove, 2013). Nitrate pollution, as well as other contaminants, present challenges for coastal GDE as septic and agricultural influences infiltrate aquifer supplies discharging into sensitive fens (Darlingtonia State Natural Site in Figure 11), marshes, and estuaries (Portnoy et al., 1998).

3. METHODS

3.1 Study Site: Darlingtonia State Natural Site and Surrounding Area

Darlingtonia State Natural Site was designated by Oregon State Parks to protect the rare plant species *Darlingtonia californica*. The park is situated roughly 2 miles east of the Pacific Ocean and 3 miles north of Florence, Oregon on U.S. Highway 101 (Figure 14). Oregon's coast is an active reverse plate boundary: The Juan de Fuca Plate subdues eastward beneath the North American Plate from Victoria Island, British Columbia to northern California. Oregon's Coastal Range flanks Darlingtonia State Natural Site about 1 mile east and 2 miles north of the site. The Coastal Range near Oregon's central coast consists primarily of Middle Eocene (37.8 to 47.8 million years ago (mya)) sandstone and siltstone known as the Tyee Formation (Oregon DOGAMI, n.d.). Eocene-aged basaltic intrusions occur throughout the Coastal Range, creating

Figure 14 - Location of Darlingtonia State Natural Site

topographically-dramatic capes all along the coast including Cape Perpetua, located 4 miles north of Darlingtonia State Natural Site. The Tyee Formation arcs eastward, cresting at the Siuslaw River directly east of Florence. Quaternary (2.58 mya to present) beach and eolian sand deposits occupy this arc. Thousands of years of tides, waves, and strong coastal winds have shaped the sands into large dunes and depressions. Freshwater lakes fill several of the larger depressions throughout the sand-filled arc (Figure 15).

Florence, Oregon lies among these dunes adjacent to the Siuslaw River. The community is home to nearly 9,000 Oregonians. Logging, fishing and agriculture were once the mainstays of the city's economy with an increasing focus in tourism. Florence residents and visitors rely on

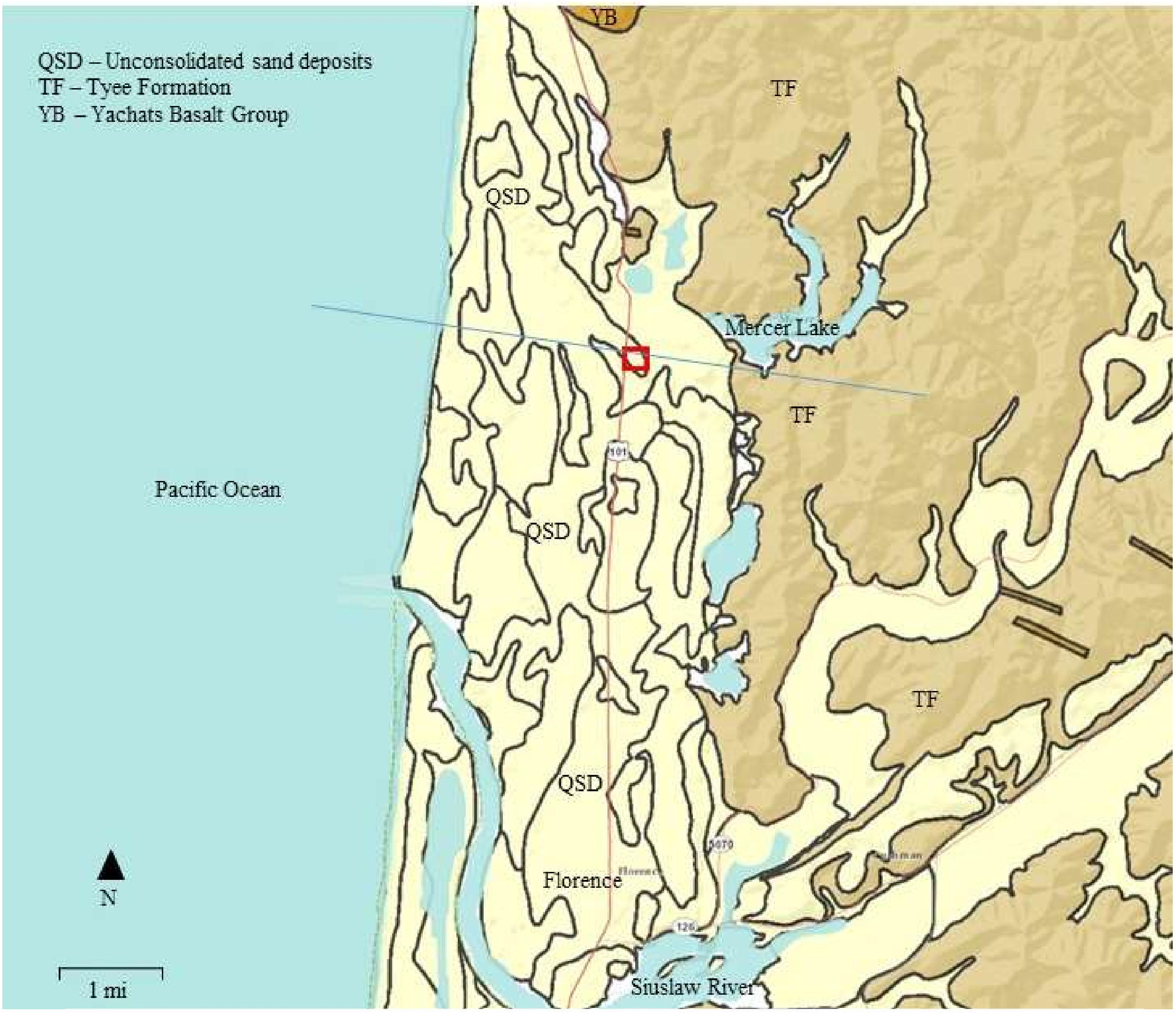

Figure 15 - Geology of Darlingtonia State Natural Site (outlined in red) and surrounding area (Oregon DOGAMI, n.d.). Blue line represents cross section of Figure 18

the sand deposits for their water supply as it serves as the principal aquifer for the area. The North Florence Dunal Aquifer is an EPA-recognized Sole Source Aquifer. This status requires the City of Florence to maintain an up-to-date Groundwater Protection Plan to prevent and plan for contamination events (City of Florence, 2013). Stakeholders primarily withdraw water for municipal and domestic use. Several surface water rights for agricultural use exist in the area as well. The Heceta People's Water Utility District provides water to unincorporated neighborhoods and households north of the Florence boundary with surface water from Clear Lake, a lake dependent on the North Florence Dunal Aquifer for its water (U.S. EPA, 1987). These unincorporated households rely on sub-surface septic systems to store and treat wastewater.

Darlingtonia State Natural Site sits with Florence among the dunes in a topographically low-lying area. Over half of the natural site contains standing water throughout most of the year. This coastal, typically-flooded wetland is in an area fed by groundwater with slightly acidic, peaty soil as reflected by pH data derived from parameters taken during water sampling events which ranged from 5.7 to 6.9. It is, by the definition of the National Forest Service (Weixelman & Cooper, 2009), a fen. Fens are peatlands with continuously high-water levels, more than 15.75 inches (40 cm) of peat soil and water chemistry reflecting the mineral origin of its source water (Bridgham et al., 1996 as cited in Aldous & Bach, 2014).

Vegetation within fens are critical to the maintenance of the ecosystem. Fen vegetation is dependent on local topography as well as groundwater depth, flux and chemistry. Changes to the water chemistry can cause irreversible changes to these GDE (Klove et al., 2011). Presence of groundwater prolongs the period of plant decomposition creating a rich, peaty soil that accumulates on the order of centimeters per thousands of years (Johnston et al., 2012). These unique conditions create a productive environment for rare plant species, resulting in the relatively high native biodiversity of fens compared to other ecosystems of equal size (Weixelman & Cooper, 2012). Shallow groundwater is necessary for the shallow root systems of many of these delicate plant species. Aldous and Bach (2014) found an ideal depth to water range to be 0.35 to 13.7 inches (0.9 to 34.8 cm) for the vigor of wetland fen plants in National Forest land between the Klamath and Deschutes basins. Consistent water levels within fens provide a buffer from extreme weather events for communities within the ecosystem while temperature and chemistry of the groundwater differs from that of the intermittent supply of surface water. Characteristics of the water supply reflect the geology and recharge elevation (Aldous & Bach, 2014).

Other coastal GDE near the Florence coast include shallow sea hardgrounds, estuaries and lagoons, as well as lakes and streams. Groundwater-induced shallow sea hardgrounds occur where the groundwater table is exposed at the ocean floor. Communities of shallow and deep-sea organisms develop around these nutrient-rich sources (Taylor & Wilson, 2003), which serve as a link between coastal aquifers and the ocean. Estuaries and lagoons are shallow water bodies near the ocean with freshwater and saltwater influence. These coastal ecosystems are a prolific habitat and crucial for healthy fishery and aquaculture production. The ratio of saltwater and freshwater is an important input for these ecosystems, thus, a decrease in groundwater inflow is a serious risk to ecosystem vitality (Klove et al., 2011). Freshwater lakes and streams in the Florence area are also dependent on a stable groundwater supply (U.S. EPA, 1987).

3.2 Hydrogeologic Analysis

Hydrogeologic analysis of the shallow, unconfined aquifer north of Florence was completed through the collection of over 600 well logs surrounding the Darlingtonia State Natural Site dating from 1955 to present from the OWRD, and surface geology reports from the Oregon Department of Geology and Mineral Industries (DOGAMI). Data from these sources were compiled into a database that clearly displayed the geologic features of the area in addition to hydrologic conditions of each stratum. These data were used to develop a hydrogeologic site conceptual model and potentiometric surface map of the Darlingtonia State Natural Site area in addition to a spatial display of water table elevation and stratigraphic boundaries developed with ArcGIS software.

Well performance tests from the well logs were used to determine hydraulic conductivities within the principal aquifer and the surrounding formations. Hydraulic conductivity was calculated from the relationship between transmissivity and saturated aquifer thickness derived from Darcy's Law (Heath, 2004):

$\boldsymbol{K = {}^{T}\!/_{b}}$ – K = hydraulic conductivity (ft/min), T = transmissivity (ft^2/day), b = saturated thickness (ft.)

Transmissivity was calculated from the Driscoll (1986) estimation for transmissivity using specific capacity tests in unconfined aquifers:

$\frac{Q}{s} = \frac{T}{1500}$ – Q/s = specific capacity, Q = pumping discharge (ft^3/min), s = drawdown(ft.), T = transmissivity (ft^2/day)

These data in addition to qualitative data derived from extensive site examinations and aerial photography determine key surface water boundary conditions of the local water system. When necessary, the researcher consulted with property owners and stakeholders in the area for pumping data and water levels within existing wells to enhance the resolution of the baseline aquifer conditions.

Ultimately, these data were compiled and computed via ArcGIS software to spatially reveal general groundwater elevations, gradients, flow directions, and transport patterns that have the potential to impact the quality and quantity of the groundwater at Darlingtonia State Natural Site. The Lane County Land Management Division Online Property Records Database provided septic and underground storage tank (UST) property records in the Florence area. Sanitation records were explored to map septic systems near Darlingtonia State Natural Site to spatially analyze potential nitrogen influence with conceptualized flows.

3.3 Groundwater Monitoring

A hand auger was used to dig a 6-inch wide, 9-foot deep geotechnical boring in the Darlingtonia State Natural Site fen on August 14, 2016. Upon completion of the boring, a 1.5-inch PVC casing was installed. The PVC casing is screened from 4 to 9 feet beneath the surface and packed with sand from 3 to 9 feet. Bentonite chips were used to pack the boring from 0 to 3 feet of depth and seal the boring from surface interference. Stratigraphic data at each foot beneath the surface as well as construction data for the boring is available on the well log which was submitted to OWRD on September 9, 2016 (Appendix A). An In-Situ Level Troll 100 pressure transducer was installed 8 feet below the casing and paired with an In-Situ BARO Troll 100 directly beneath the casing which recorded barometric pressure to calibrate groundwater depth readings. Transducers were set to record pressure every hour. The boring is in the northern section of the Darlingtonia State Natural Site fen located on a small, dry hummock about 15 feet from the boardwalk (Figure 16). The pressure transducer began collecting data on the date of installation, August 14, 2016.

Figure 16 – Location of geotechnical boring in Darlingtonia State Natural Site fen

I visited the Darlingtonia State Natural Site monthly throughout the twelve-month study period to collect water level data from the pressure transducer within the existing nine-foot geotechnical boring in Darlingtonia State Natural Site. Data from the transducer were compiled with In-Situ software and Microsoft Excel to establish a baseline groundwater depth trend for the site beginning in the 2016-2017 water year (October 1 to September 30). Data were collected through December 10, 2017. Barometric pressure readings were subtracted from the in-situ pressure data and converted to depth in water column (feet) with the following formula: $WD = P * 0.4335$ (WD = depth of water column (feet), P = pressure (psi)). Measurements of the water table were manually recorded with a tape measure every month and were used to calibrate the depth in water column data to reveal hourly depth-to-water information.

When pressure transducer data revealed apparent pumping-related drawdown (Figure 17), researchers prepared a model via Microsoft Excel to calculate the distance to the pumping source using the Bouwer and Rice (1976) slug test for unconfined aquifers. Drawdown and duration of pumping were derived from 18 apparent pumping events and run through the model in attempt to investigate the source of drawdown at Darlingtonia State Natural Site. Aquifer properties calculated from well log performance tests were used to fulfill other necessary variables for the following equations to reveal pumping radius (AQTESOLV, 2017):

$K = \frac{r_{ce}^2 \ln \frac{R_e}{r_{we}})}{2L_e} \frac{1}{t} \ln\left(\frac{H_o}{H_t}\right)$: K = hydraulic conductivity (ft^3/day), r_{ce} = well and casing radius (feet), R_e = effective pumping radius (feet), r_{we} = borehole radius, L_e = , t = recovery time (seconds), H_0 = initial head (feet), H_t = head after full recharge (feet).

$r_{we} = r_w\sqrt{\frac{K_z}{K_r}}$: r_w = well radius (feet), K_z = vertical hydraulic conductivity (ft/day), K_r = horizontal hydraulic conductivity (ft/day).

$r_{ce} = \sqrt{(1 - n_e)r_c^2 + n_e r_w^2}$: n_e = effective porosity (unit-less), r_c = nominal casing radius (feet)

After running the model, the City of Florence Public Works returned a phone call (after several weeks) providing information about precipitation data which made the model obsolete. More information on this precipitation data is provided in the Results chapter.

Groundwater sampling procedures were completed in conjunction with a coastal stream survey study managed by Feiten and Santelmann (2018). Field personnel collected water samples

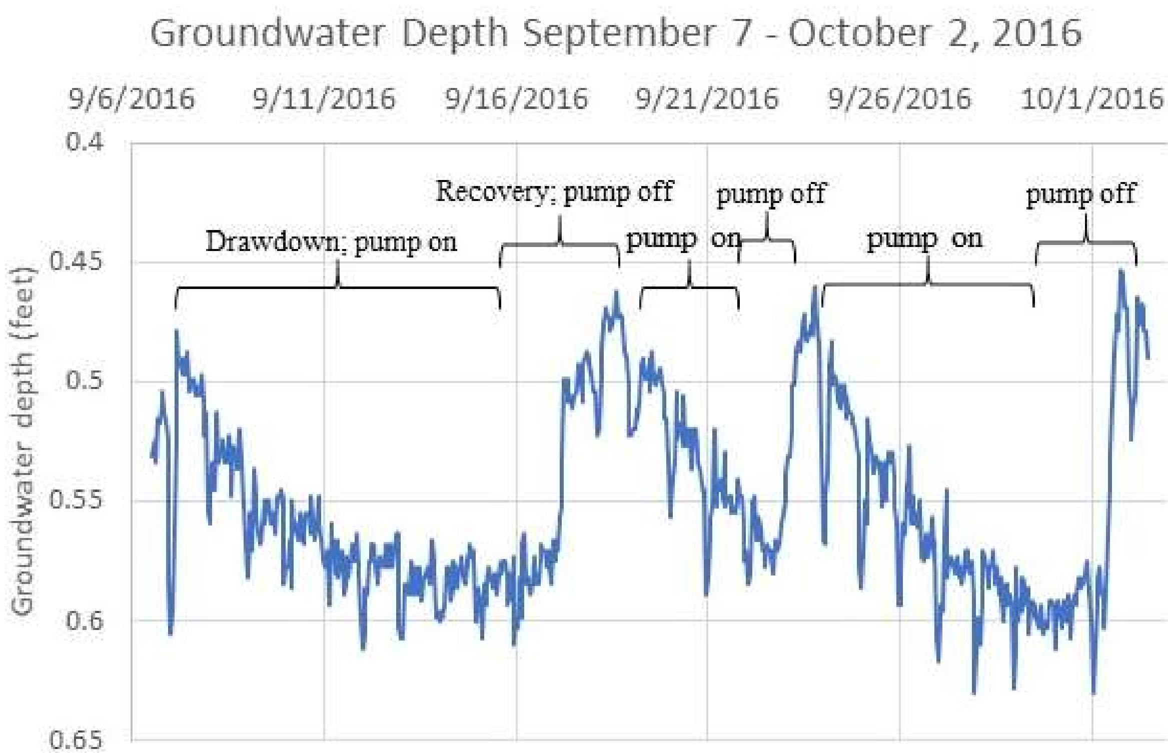

Figure 17 - Groundwater depth at Darlingtonia State Natural Site during pumping episode

from the boring to test inorganic ion levels (nitrates, chloride, sulfate, etc.) via anion chromatography analysis in accordance with EPA method 300.0 (determining inorganic anions by ion chromatography) (Motter & Jones, 2015) in the Institute for Water and Watersheds Collaboratory at Oregon State University in Corvallis, Oregon. Sampling procedures, laboratory calibration, as well as quality assurance and control measures are summarized in Appendix B.

Previous studies from the Oregon Parks and Recreation Department (OPRD) included groundwater data from similar GDE along the Oregon coast which were analyzed for the effects groundwater had on overlying vegetation community. Researchers also searched for previous and concurrent data that have cataloged the *Darlingtonia* population to analyze other potential catalysts of the plant population's abundance and vigor. OPRD provided old photographs of the site for visual analysis of historic water levels in the Darlingtonia State Natural Site fen. These data were studied to determine the correlation between groundwater conditions and the historic health of the *Darlingtonia* community at Darlingtonia State Natural Site.

3.3.1 Groundwater and Soil Moisture Temperature Survey

Undergraduate students participating in a summer internship with the School of Chemical, Biological, and Environmental Engineering at Oregon State University volunteered to conduct groundwater and surface water sampling in addition to shallow soil temperature probing at various points around Darlingtonia State Natural Site. The students performed nitrate analyses on surface and groundwater samples from the site for further quality control and assurance. The students also used a temperature probe to survey groundwater and soil moisture temperature depths of 1 and 6 inches throughout the Darlingtonia State Natural Site fen. Temperature survey data were taken on the afternoon of August 5, 2017 (Appendix C). Temperature data from the In-Situ pressure transducer were also recorded and analyzed for groundwater temperature data collected at roughly 7 feet beneath ground level.

4. **RESULTS**

4.1 Conceptual Model of Site Hydrogeology

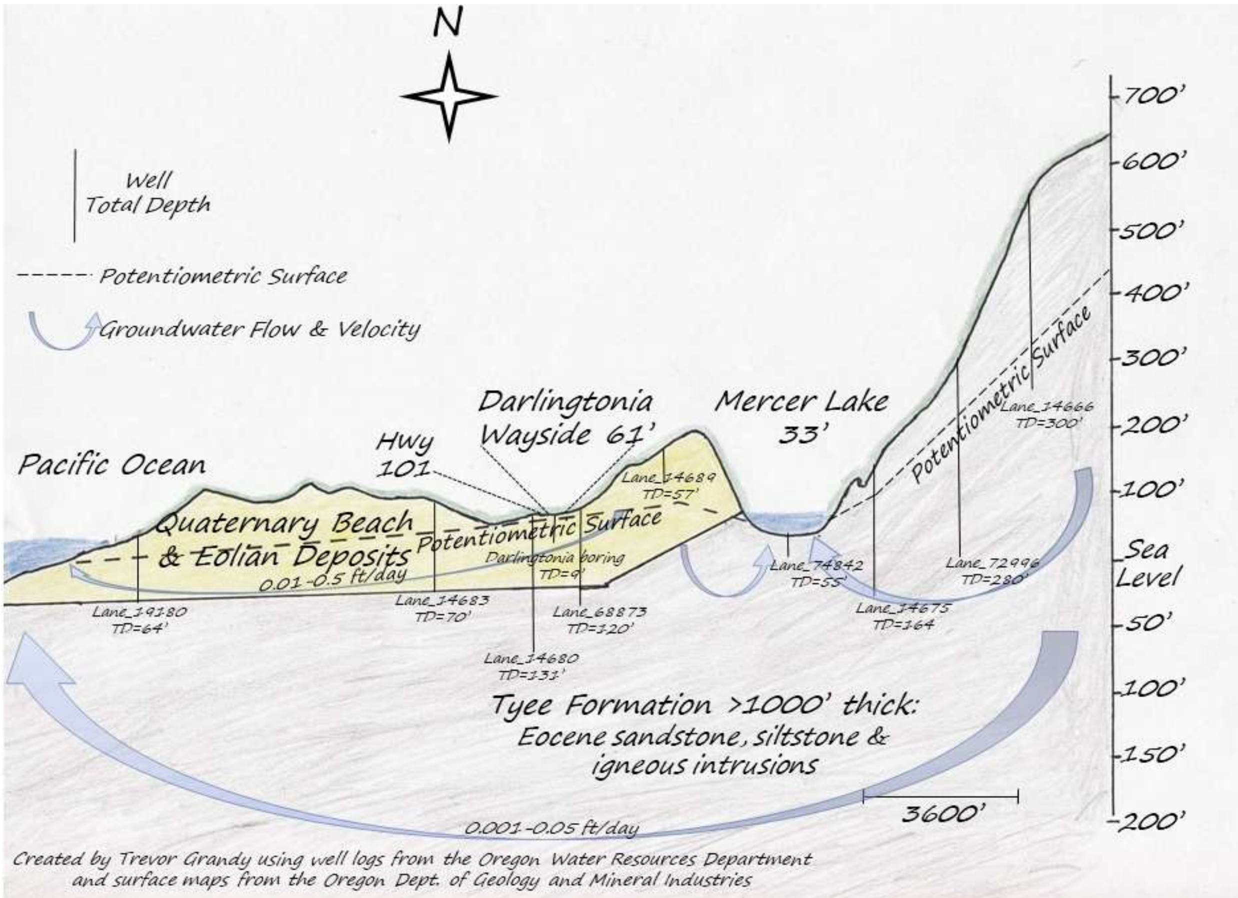

Figure 18 - Hydrogeologic conceptual model of northern Florence, Oregon. Cross section location provided in Figure 19

Of the 600-plus well logs representing borings in the greater Florence area collected, 108 well logs provided adequate and legible location data, geologic stratigraphy, and groundwater elevation information to create a conceptual model. Data from these sources were compiled into a database that clearly displayed the geologic features of the area in addition to hydrologic conditions of each stratum. Surface geology maps made publicly available by DOGAMI were used to identify the geologic formations revealed in the well logs. The database contents were translated to a geologic site conceptual model (Figure 18) and potentiometric surface map of the North Florence Dunal Aquifer around Darlingtonia State Natural Site in addition to a spatial display of local water table elevation calculated by hand and digitized into an ArcGIS geodatabase (Figure 19).

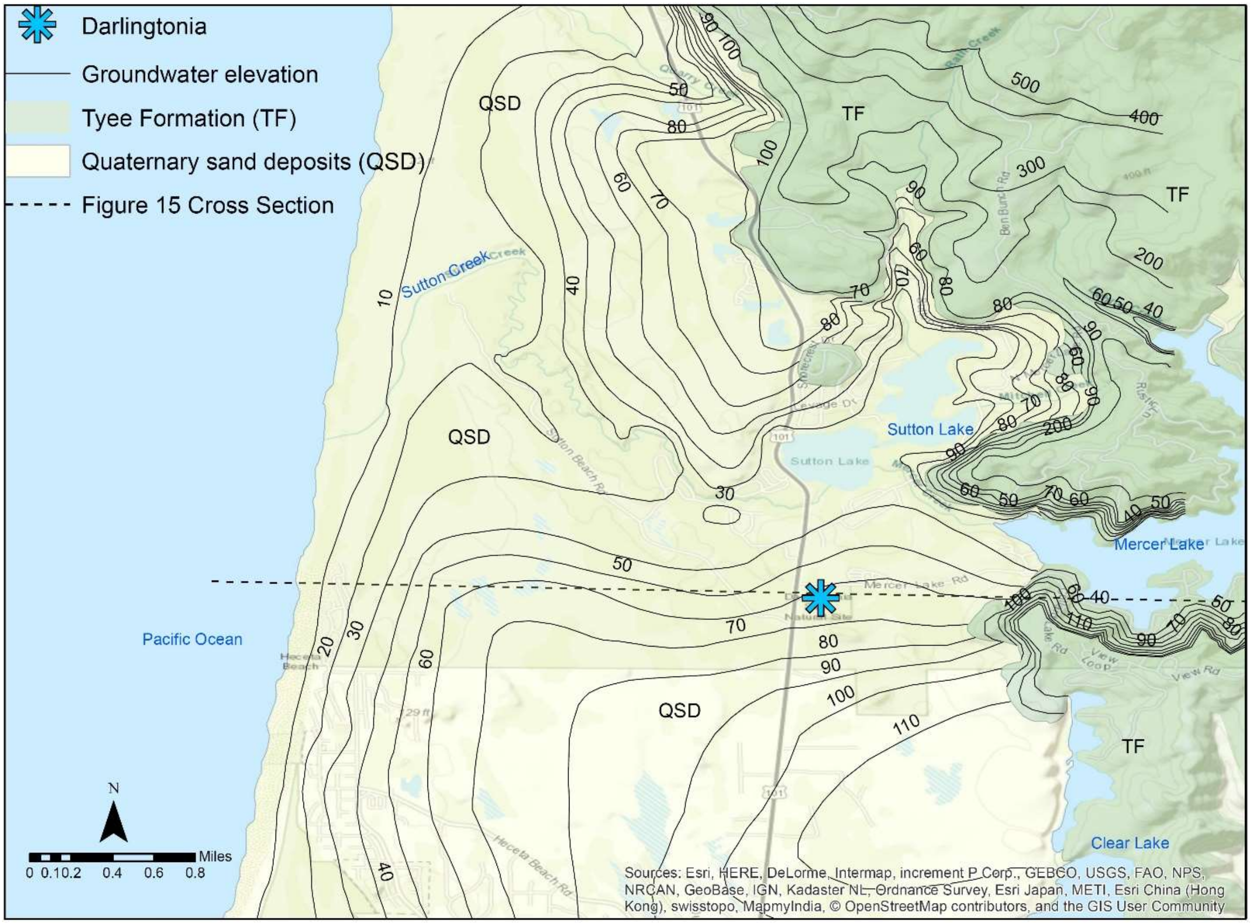

Figure 19 - Static groundwater elevation of the North Florence Dunal Aquifer

Well performance tests from the well logs were used to determine hydraulic conductivities within the principal aquifer and the surrounding formations (Tables 3 & 4). These data in addition to qualitative data derived from extensive site examinations and aerial photography determine key surface water boundary conditions of the local water system. When necessary, the researcher consulted with property owners and stakeholders in the area for pumping data and water levels within existing wells to enhance the resolution of the baseline aquifer conditions. Ultimately, these data were compiled and computed via ArcGIS software to reveal general spatial patterns of groundwater elevations, gradients, flow directions, and transport patterns that have the potential to impact the quality and quantity of the groundwater at Darlingtonia State Natural Site (Figure 20). Septic system and UST locations derived from the Lane County Division of Land Management property records were included in the ArcGIS geodatabase. These data revealed minimal potential influence from domestic septic systems or underground storage activity (Figure 21).

Quaternary Sand Deposit Aquifer Parameter Calculations

Well ID	Aquifer	Test discharge	Test duration	Drawdown (ft)	Transmissivity (ft^2/min)	Aquifer thickness (ft)	Hydraulic conductivity (gpd/ft^2)	Hydraulic Conductivity (ft/day)
LANE_14683	Sand	22 gal/min	1hr	8	4125	70	58.9	7.89
LANE_68873	Sand/Tyee	7.5 gal/min	1hr	89.75	125	79.8	1.57	0.210
LANE_19180	Sand	2.78 gal/min	3hr	6	695	24	29.0	3.88
LANE_14674	Sand	4.67 gal/min	2.5hr	2	3503	47	74.5	9.98
LANE_14677	Sand	35 gal/min	1hr	20	2625	70	37.5	5.02
LANE_75045	Sand/Tyee	15 gal/min	2hr	60	375	105	3.57	0.478
LANE_14685	Sand	5.83 gal/min	2hr	5	1749	70	25.0	3.34
LANE_14699	Sand	14 gal/min	1hr	25	840	70	12.0	1.61
LANE_14673	Sand	5 gal/min	1hr	15	500	70	7.14	0.956
LANE_24314	Sand	3 gal/min	1hr	14	321	70	4.59	0.615
LANE_19163	Sand	13 gal/min	1hr	40	488	110	4.43	0.593
LANE_19164	Sand	10 gal/min	1hr	24	625	160	3.91	0.523
LANE_19167	Sand	5 gal/min	1hr	20	375	120	3.13	0.418
LANE_19175	Sand	6 gal/min	1hr	12	750	124	6.05	0.810
LANE_57493	Sand	15 gal/min	1hr	30	750	138	5.43	0.728
LANE_69540	Sand/Tyee	4.2 gal/min	1hr	111	56.8	93	0.610	0.0817
LANE_19179	Sand	50 gal/min*	3.5hr	10	7500	58	129	17.3
LANE_19178	Sand	5 gal/min	1hr	10	750	60	12.5	1.67
LANE_19181	Sand	3.33 gal/min	5hr	10	500	60	8.33	1.11
		*Writing illegible						
AVERAGES					1403		16.5	2.217

Table 3 - Aquifer property calculations for the North Florence Dunal Aquifer; data derived from well performance tests on OWRD well logs

Tyee Formation Aquifer Parameter Calculations

Well ID	Aquifer	Test discharge	Test duration	Drawdown (ft)	Transmissivity (ft^2/min)	Aquifer thickness (ft)	Hydraulic conductivity (gpd/ft^2)	Hydraulic Conductivity (ft/day)
LANE_74148	Tyee	15 gal/min	1hr	123**	183	240	0.762	0.102034153
LANE_14680	Tyee	no						
LANE_72441		no						
LANE_72440		no						
LANE_14668	Tyee	5 gal/min*	10 min	30 (ran dry)	250	188	1.33	0.178
LANE_14667	Tyee	10 gal/min*	1hr	90	167	165	1.01	0.135
LANE_14671	Sand/Tyee	4 gal/min*	1hr	208	28.8	129	0.224	0.0299
LANE_2858	Tyee	5 gal/min	1hr	110**	68.2	190	0.359	0.0480
LANE_24315	Sand/Tyee	200 gal/hr*	4hr	dry				
LANE_14666	Tyee	60 gal/min	1hr	90	1000	297	3.37	0.451
LANE_63029	Tyee	76 gal/hr?	1hr	57**	33.3	116	0.287	0.0385
LANE_5038	Tyee	2 gal/min	1hr	156**	19.2	196	0.0981	0.0131
LANE_14661	Tyee	10 gal/min	1hr	93**	161	153	1.05	0.141
LANE_5037	Basalt	40 gal/min	1hr	54** (basalt)	1111	93	11.9	1.60
LANE_4911		no						
LANE_4876	Tyee	20 gal/min	1hr	70**	429	210	2.04	0.273
LANE_2763	Tyee	10 gal/min	1hr	82**	183	256	0.715	0.0957
LANE_65729	Sand/Tyee	no						
LANE_14662	Tyee	2.5 gal/min	1hr	288** (clay)	13.0	301	0.0433	0.00579
LANE_14664	Sand	33 gal/min*	2.5hr	6	8250			
LANE_57720	Tyee	13 gal/min	1 hr	249	78.3	299	0.262	0.0351
LANE_74436	Tyee	5 gal/min	1.5hr	281**	26.7	279	0.0957	0.0128
LANE_74372	Tyee	5 gal/min	1.5hr	218**	34.4	250	0.138	0.0184
LANE_52262	Tyee	5 gal/min	1hr	182	41.2	228	0.181	0.0242
LANE_14658	Sand	13 gal/min	5.5hr	12	1625			
		*bailer test		**SWL-drill stem				
AVERAGES					751		1.41	0.188

Table 4 - Aquifer property calculations for the Tyee Formation; data derived from well performance tests on OWRD well logs

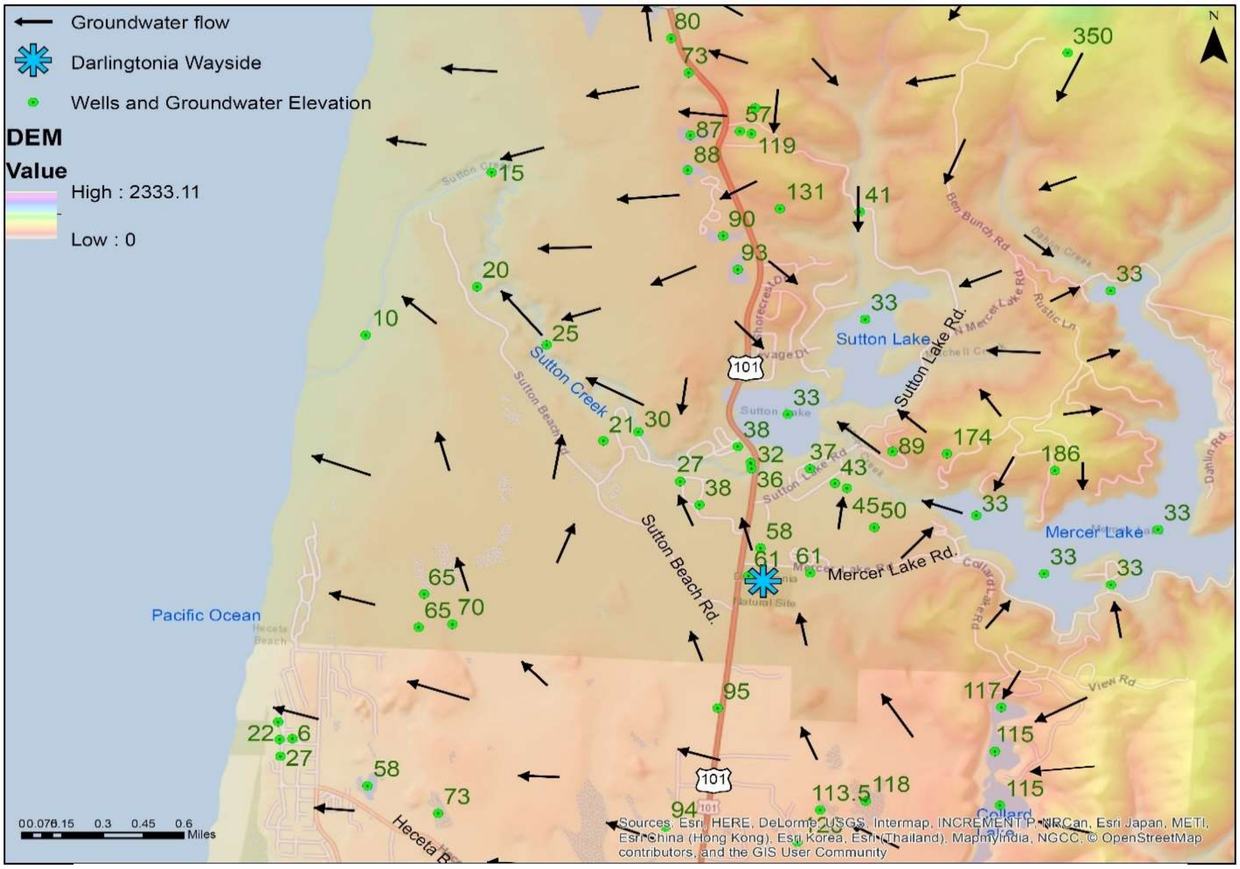

Figure 20 – Conceptualized groundwater flows near Darlingtonia State Natural Site

Analyses of well log data confirmed the North Florence Dunal Aquifer is largely comprised of unconsolidated ocean and eolian sand deposits. These unconsolidated sands range from 50 feet of thickness near the shore of the Pacific Ocean to over 200 feet beneath the larger dunes located by Mercer Lake and Sutton Lake. Well logs demonstrate the thickness of sand deposits at Darlingtonia State Natural Site to be about 70 feet. Spatial analysis of water table measurements reveals the piezometric surface is largely dependent on local topography with groundwater mounds under dunes and local streams, while lakes and the Pacific Ocean serve as hydraulic sinks. In other words, groundwater elevations are higher near dune formations and closely reflect local surface water elevations. The piezometric trend of the North Florence Dunal Aquifer is highest at the eastern boundary juxtaposing the Tyee Formation with low to moderate gradients (0.0066 to 0.00877) extending to the Pacific Ocean, the aquifer's western boundary. Analysis of well performance tests reveals a high hydraulic conductivity of 2.3 feet/day in the unconsolidated sands where porosity was estimated at 0.29 (Table 5). With these parameters, groundwater velocity moving through the site was calculated at an average of 0.046 feet/day.

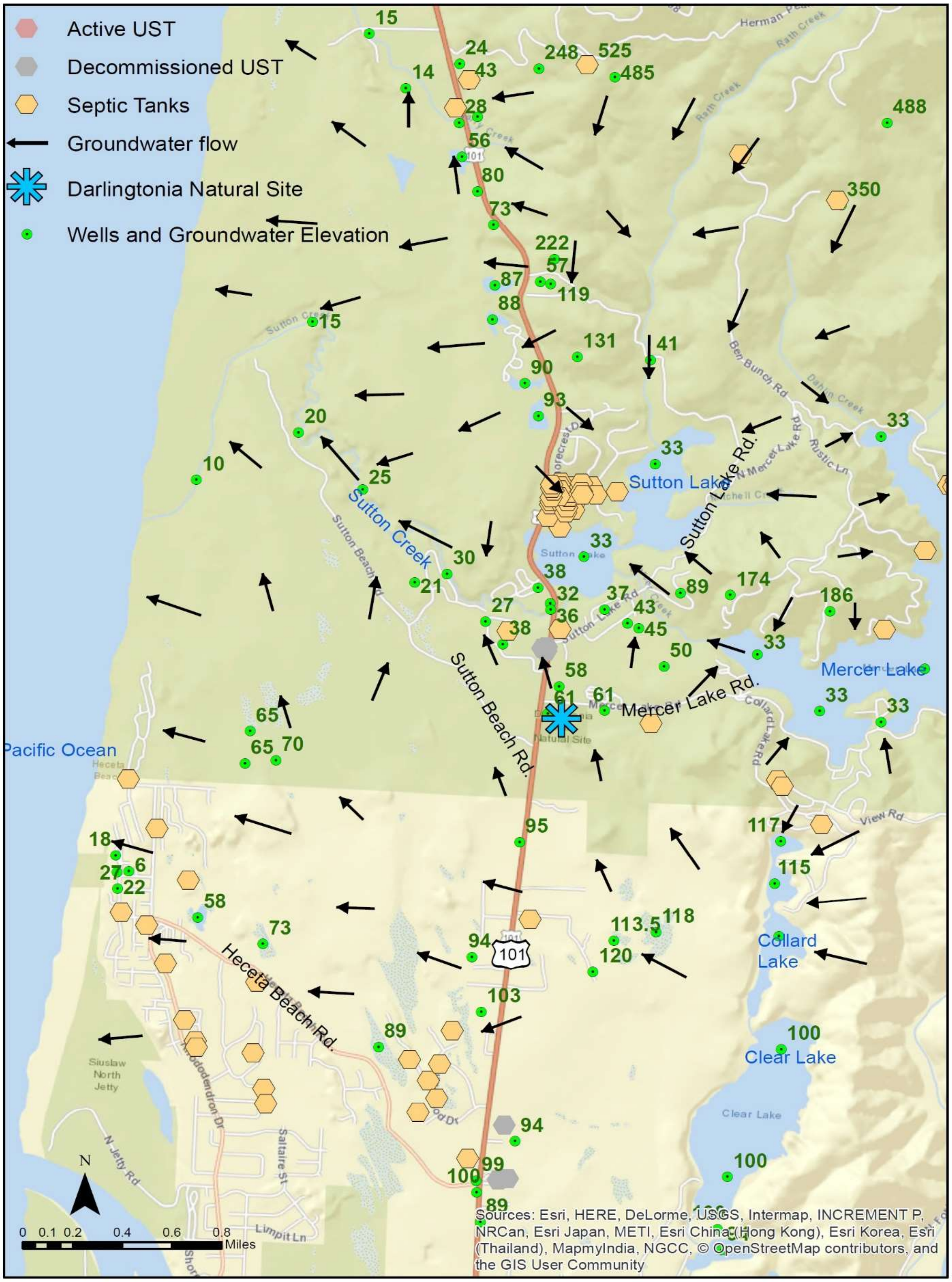

Figure 21 - Conceptual groundwater flow patterns of the North Florence Dunal Aquifer and septic inventory map near Darlingtonia State Natural Site

Calculated Groundwater Velocities in Sand Deposits				
-	Hydraulic conductivity (ft/day)	Gradient	Porosity	Velocity (ft/day)
Maximum	9.97	0.00877	0.26	0.336
Minimum	0.210	0.00660	0.50	0.00277
Mean	2.30	0.00660	0.33	0.0460
Median	0.858	0.00660	0.33	0.0172
Close to site	0.418	0.00660	0.33	0.00836
Close to site	5.02	0.00877	0.33	0.133

Table 5 - Groundwater velocities of the North Florence Dunal Aquifer

Well logs largely reveal a hard, dark/grey sandstone beneath the yellow unconsolidated sands, which the Oregon DOGAMI identifies as the Tyee Formation. The Tyee Formation is largely sandstone and siltstone with igneous intrusions (USGS, 2015). This formation serves as an effective underlying boundary, or aquitard, to the North Florence Dunal Aquifer 70 feet below the study site. Well performance tests recorded by well logs reveal a hydraulic conductivity of 0.188 feet/day for the Tyee Formation (Table 4), a figure much lower than the unconsolidated sand of the overlying aquifer (Table 3). Flow velocities are slower while hydraulic gradients greatly vary depending on the local topography. The discrepancy in aquifer characteristics effectively disconnects the hydrology between the Tyee formation and sand deposits.

Groundwater flowing into the Darlingtonia State Natural Site (61 feet above sea level) enters from the southeast via a hydraulic high near Collard Lake (115 feet above sea level). Flow generally moves through the site in a northerly/northwesterly direction toward the lower-lying surface water boundaries of Mercer Lake and Sutton Creek (~33 feet above sea level) (Figure 20). There is a small creek running from east to west through the site north of the fen and south of the parking lot draining shallow groundwater at the site. However, the resolution provided by the limited number of wells logs does not reveal a trend at this fine a resolution.

Beyond the natural surface water boundaries, U.S. Highway 101 runs north-south west of the site where a small drainage swale is also receiving shallow, local flow. Again, this flow influence is not detected by static water levels determined by well log data. At a regional scale, there is a hydraulic low about 0.5 miles northwest of Darlingtonia State Natural Site near the Sutton Creek by the Sea sub-division, and by the Sutton Campground, managed by the U.S. Forest Service (Figure 19). Spatial analysis reveals that flow is marginally influenced by this hydraulic low, potentially affecting water table elevations.

4.2 Groundwater Monitoring

4.2.1 Pressure Transducer Monitoring

The monthly groundwater monitoring program was successfully conducted from November 2016 to December 2017. Pressure transducer data were collected through December 10, 2017. Water levels derived from the transducer data revealed the following temporal patterns: consistently high (near the surface) during the winter months, while gradually lowering throughout the summer months into late September and October (Figure 22). Figure 23 displays precipitation and barometric pressure recorded at the Florence Public Works Weather Station (KORFLORE23), approximately 2.5 miles southeast of Darlingtonia State Natural Site, throughout the study period. As precipitation rates increased during the autumn months, groundwater levels gradually rose. This trend continues into the winter. While water levels

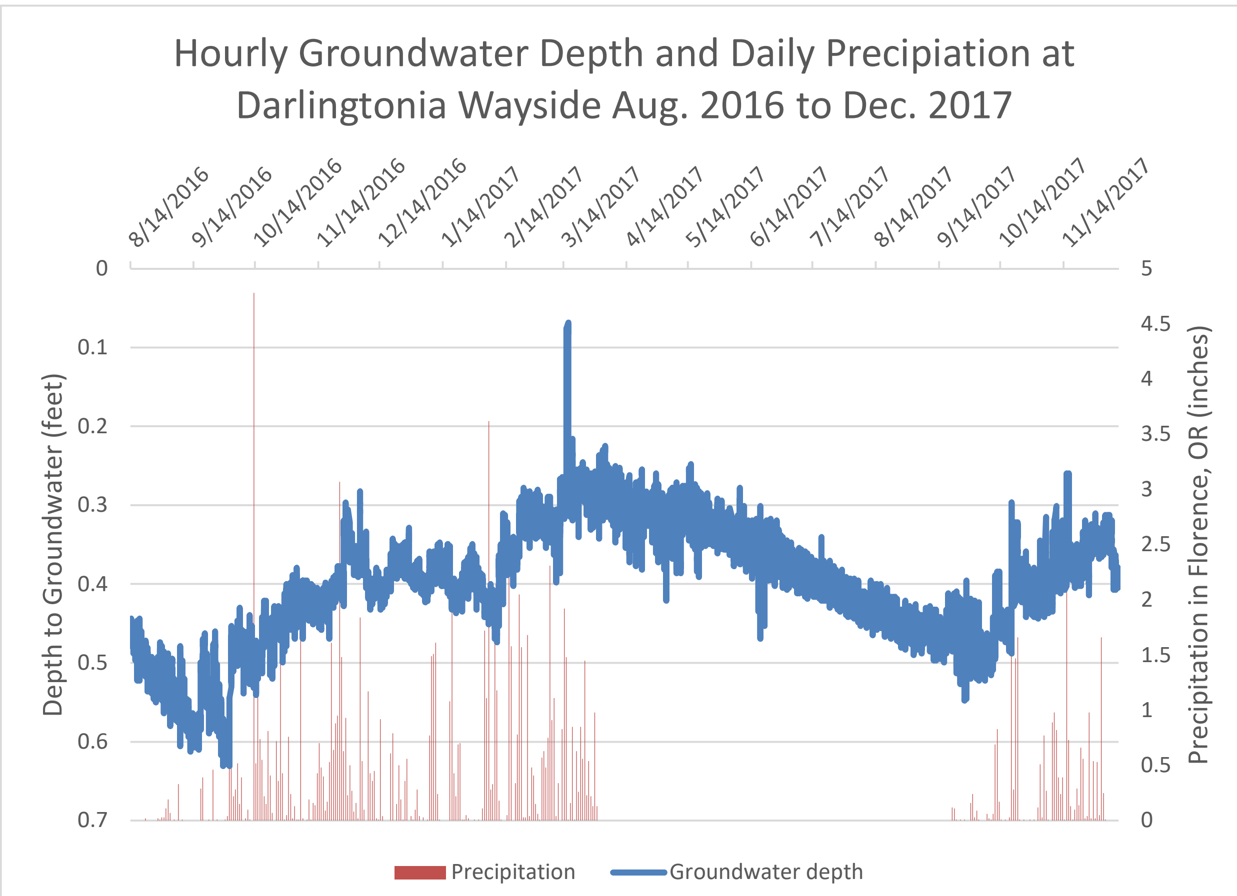

Figure 22- Graph of groundwater depth and precipitation data at Darlingtonia State Natural Site throughout the study period

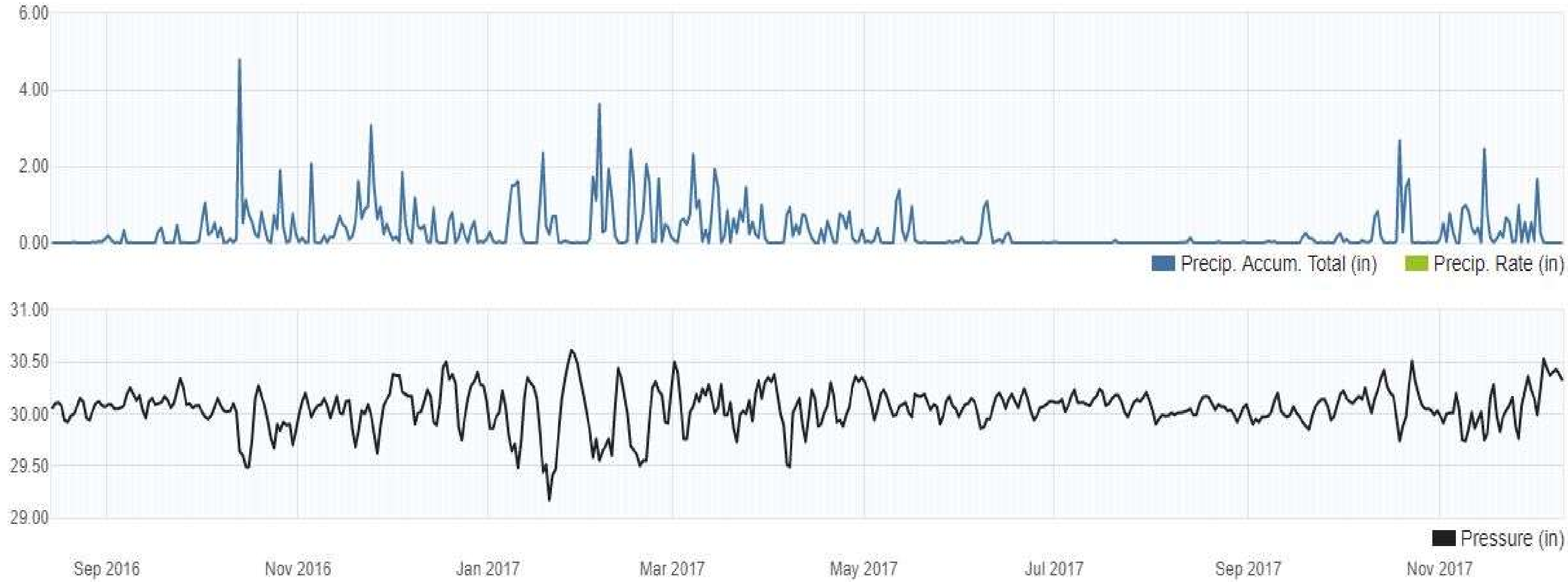

Figure 23 - Temperature and precipitation data for Florence, Oregon from August 14, 2016 to December 10, 2017. Data provided by Weather Underground

varied throughout the year, it is important to note differences in depth to water is on the magnitude of inches: from 0.10 feet (1.2 inches) in mid-March 2017 to 0.63 feet (7.5 inches) in the early October 2016. Water depths were calibrated to ground level at the site of the boring and confirmed with reference to a staff gage on site. Short-term variations also appear in the pressure transducer data. The hourly pressure recordings provided resolution fine enough to display bi-daily tidal influences, daily variations in evapotranspiration rates associated with surrounding vegetation, and groundwater table spikes during precipitation events (Figure 24).

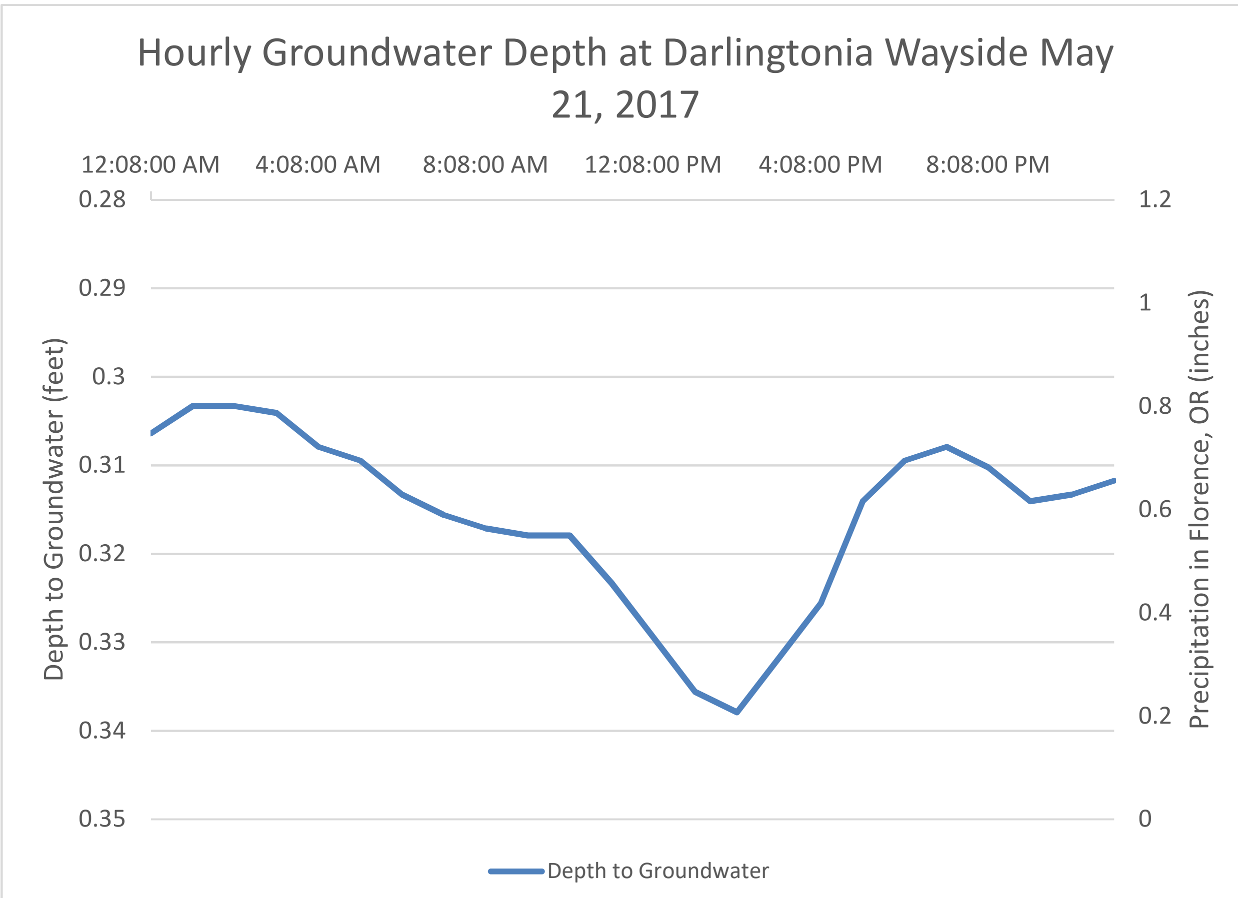

Figure 24 - Hourly groundwater depth data for 24-hour period on May 21, 2017

Water table level variations in September and early October 2016 reveal unique drawdown/recharge episodes differing from seasonal or daily tidal patterns. Water levels generally appear to drop at a rapid rate initially, as much as 0.13 feet (1.6 inches) over 3 to 5 days. The drawdown rate tapers off over the next 2 to 3 days before water table levels rapidly increase to the approximate value prior to the 5 to 10-day event (Figure 25). This pattern was

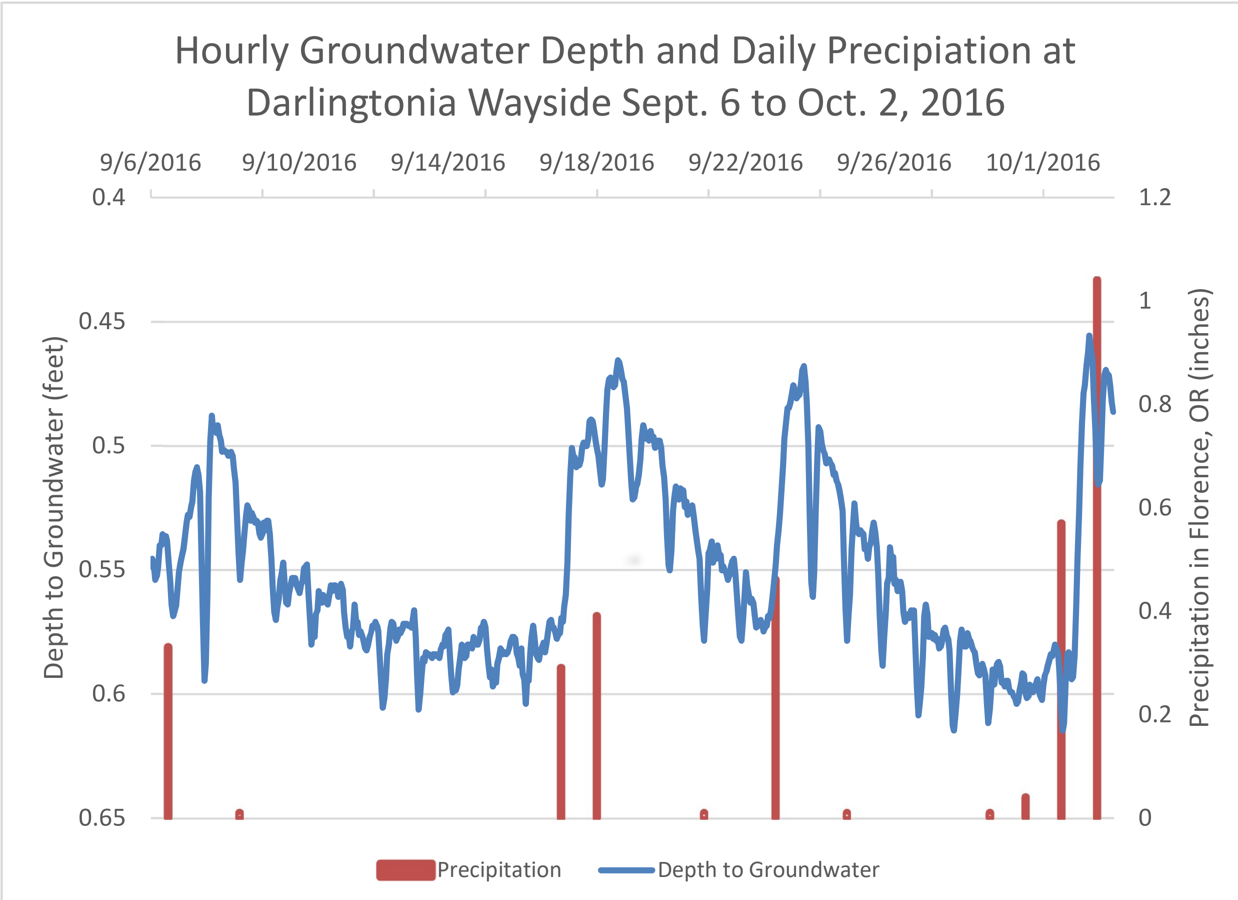

Figure 25 - Groundwater level and precipitation data at Darlingtonia State Natural Site

initially thought to resemble a pumping influence: drawdown occurs at a rapid rate as the pump is initially turned on, water levels begin to level out as the hydraulic cone of depression associated with the pumping grows away from the well, then water levels quickly recover as the pump is turned off leveling out as the aquifer equilibrates to the steady state without withdrawal. A model was developed to calculate distance to the pumping radius and 18 apparent pumping events were run through the model. Water table fluctuation at the end of the dry season is consistent with the hypothesis that the seen response is associated with groundwater extraction from nearby wells, however, we were not able to find any nearby evidence of pumping. The water table pattern was also consistent with influence of local precipitation events as determined when a colleague with the City of Florence provided high-resolution precipitation data from the Florence Public Works weather station revealing recharge coincided with late dry season precipitation events (Figure 25). Further investigation into causes behind this water table pattern are beyond the scope of this study but could be addressed in future research.

4.2.2 Groundwater Quality Sampling Results

Water quality parameters measured at the time of sampling are displayed in Table 6. Results from the monthly IWW Collaboratory anion analysis are displayed in Table 7. Chloride was the only consistent anion detected throughout the year of sampling varying from 12.7 to 14.3 mg/L. The surface water sample taken and processed in November 2017 revealed a chloride concentration of 9.4 mg/L. Nitrate, the anion of greatest concern, was detected at minimal levels throughout the study period. Laboratory analysis from Edge Analytical in July and October 2017 generally correlated with results from the IWW Collaboratory; chloride around 14.3 mg/L and nitrate at undetectable amounts (Appendix D). Other analyses performed by Edge Analytical revealed iron concentrations between 1.28 and 1.35 mg/L and silica concentrations of 13.0 and 15.0 mg/L, both above the maximum concentration limits established by the EPA.

Date	Time	Temp (°C)	pH	Cond. (μS/cm)	Salinity (ppt)	TDS (mg/L)
6-Nov-16	1453	13.1	5.85	54.5	0.0	n.a.
7-Dec-16	1308	9.6	5.80	51.5	0.0	47.3
16-Jan-17	1430	10.4	5.90	54.7	0.0	49.2
12-Feb-17	1335	11.6	5.90	55.2	0.0	48.4
12-Mar-17	1315	12.3	5.73	55.9	0.0	48.0
2-Apr-17	1300	13.2	5.73	60.2	0.0	50.3
14-May-17	1210	12.3	5.85	59.2	0.0	50.4
14-Jun-17	1300	12.4	n.a	56.0	0.0	47.9
11-Jul-17	1335	14.9	6.91	60.9	0.0	48.9
10-Aug-17	1230	13.9	6.94	68.8	0.0	64.0
19-Sep-17	1345	13.8	6.72	67.1	0.0	55.6
22-Oct-17	1210	13.1	6.71	64.4	0.0	54.2
Surface Water	-	-	-	-	-	-
19-Nov-17	1215	9.0	6.68	38.9	0.0	36.6

Table 6 - Field parameters taken at sampling events at Darlingtonia State Natural Site

Date	Chloride (mg/L)	Bromide (mg/L)	Sulfate (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)
November 6, 2016	13.9	0.034	0.335	0.024	n.a.	n.a.
December 7, 2016	12.7	0.049	0.926	n.a.	n.a.	n.a.
January 16, 2017	14.0	0.040	0.912	0.045	n.a.	n.a.
February 12, 2017	13.4	n.a.	0.011	0.017	0.048	n.a.
March 12, 2017	13.1	0.243	0.335	0.029	n.a.	0.038
April 2, 2017	14.3	0.001	0.267	0.051	n.a.	0.009
May 14, 2017	13.5	0.044	0.152	0.042	n.a.	0.019
June 14, 2017	13.2	0.075	0.187	n.a.	n.a.	n.a.
July 11, 2017	13.2	0.282	0.251	0.041	n.a.	n.a.
August 10, 2017	13.5	0.088	0.251	n.a.	0.137	n.a.
September 19, 2017	15.0	0.043	0.251	0.025	n.a.	n.a.
October 22, 2017	16.1	0.027	0.083	0.015	n.a.	n.a.
Surface Water	-	-	-	-	-	-
November 19, 2017	9.45	0.013	1.95	n.a.	n.a.	n.a.
n.a. - denotes ion not analyzed due to concentrations being below IC spectroscopy detection limits						

Table 7 - Spectral chromatography anion analysis from Darlingtonia State Natural Site boring; one surface water sample result

In addition to my monthly sampling of groundwater from the boring on site, undergraduate conducted nitrate analyses producing a report provided as Appendix C. Their sampling revealed similar results: low nitrate levels within the fen. Samples from the stream north of the fen revealed nitrate concentrations as high 0.34 mg/L. These streams are down-gradient from the Darlingtonia State Natural Site parking lot and restroom which has a sub-surface waste storage vault.

These undergraduate students also surveyed the shallow soil moisture temperature at depths of 1 and 6 inches at various locations around the Darlingtonia State Natural Site fen. Probing was conducted in the afternoon on August 5, 2017. Temperature probe analysis revealed high soil moisture temperatures throughout the fen ranging from 12.2 to 24.5 °C at a 1-inch depth and 11.4 to 17.5 °C at a 6-inch depth (Appendix C). Analysis of the temperature data displays an elevated soil moisture temperature at 1 and 6 inches of depth where tree canopy is sparse and the fen is exposed to solar radiation during the late morning and afternoon.

Temperature data recorded by the In-situ® pressure transducer are consistent with the probe data. Groundwater temperature was recorded about 7 feet below ground-level and ranged from 10.6°C (February 2017) to 13.1°C (September 2016) and averaged 11.7°C throughout the study period (Figure 26). Groundwater temperatures were greater than 11°C, 1 degree greater than the temperature threshold identified in the literature as the maximum for ideal *Darlingtonia* conditions (Crane, 1990), for 325 days of the 484-day study period. For one 365-day water year (October 1, 2016 to September 30, 2017), groundwater exceeded 11°C for 206 days and averaged 11.5°C. Ambient air temperature averages at Darlingtonia State Natural Site ranged from -1.8°C (January 2017) to 19.8°C (September 2017) with an overall average of 11.4°C (Figure 27). Air temperatures were greater than 11°C for 279 days out of the 484-day study period and consistently cooler than 11°C from mid-November to early May. Daily air temperature averages for a water year exceeded 11°C on 204 days and averaged 11.2°C

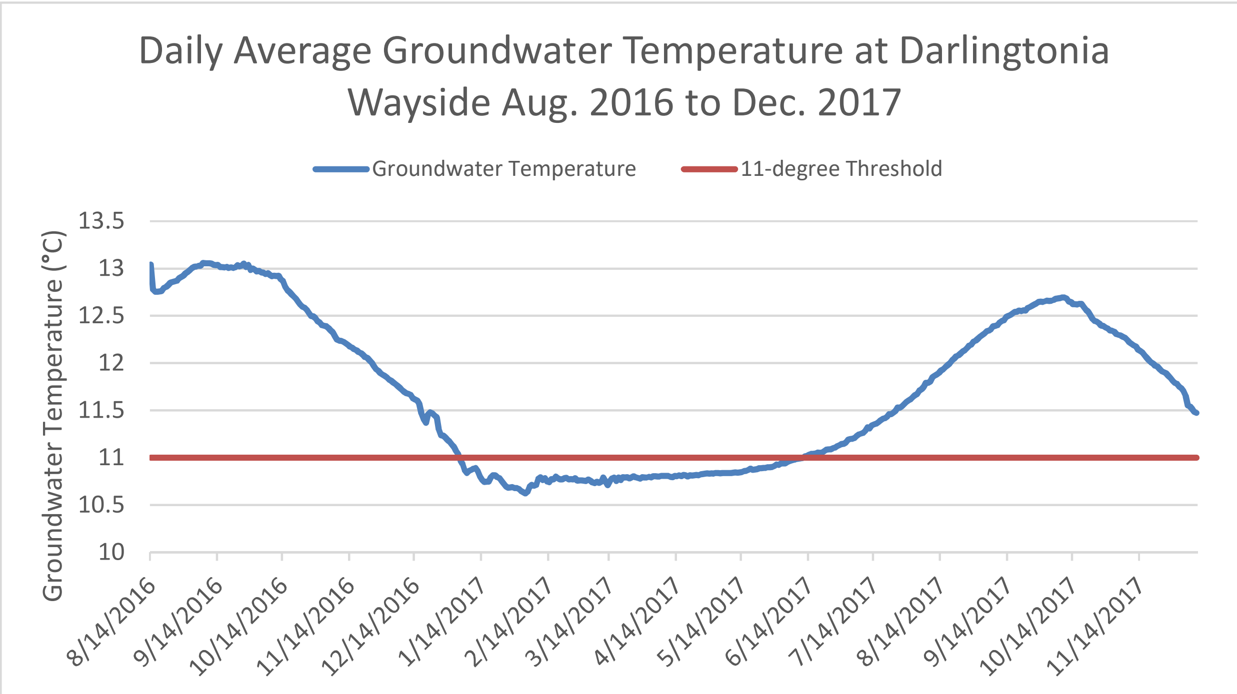

Figure 26 - Darlingtonia State Natural Site boring groundwater temperature approximately 7 feet below the ground surface

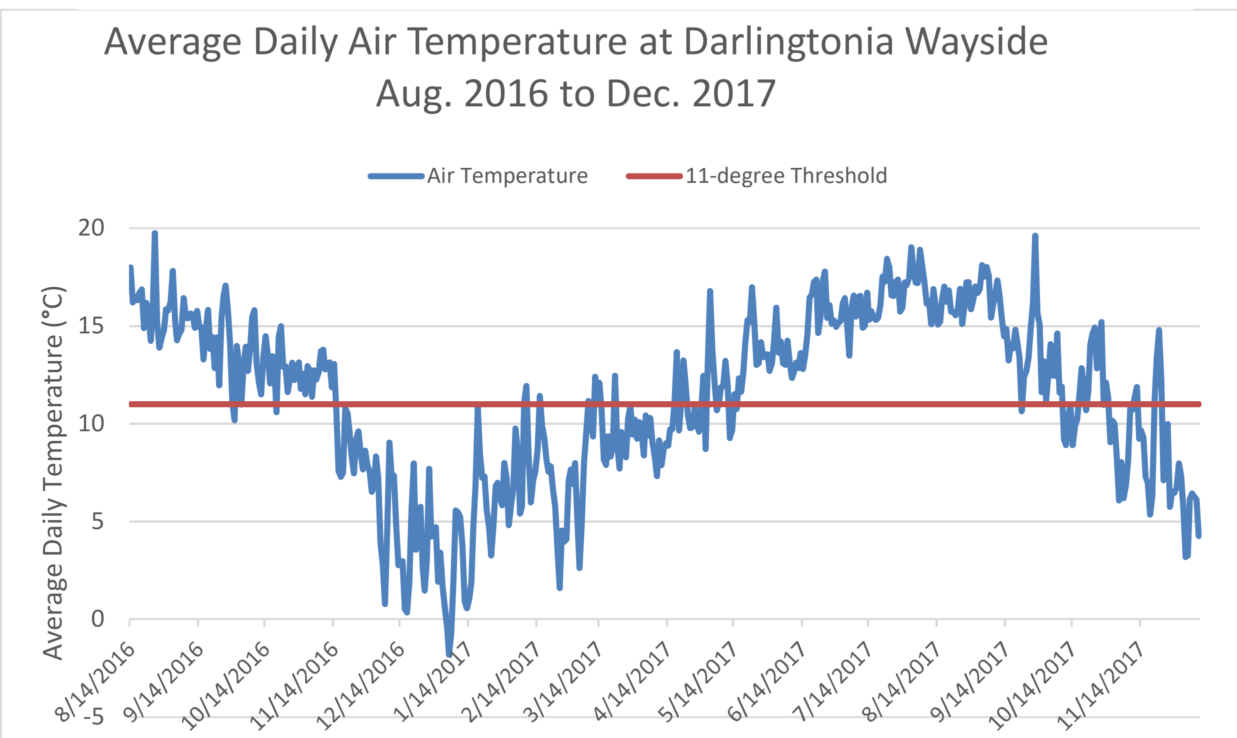

Figure 27 - Daily air temperatures at Darlingtonia State Natural Site recorded by barometric pressure transducer in borehole

5. DISCUSSION

5.1 Darlingtonia State Natural Site Hydrogeologic Analysis

5.1.1 Water Chemistry

Anion chromatography analysis of groundwater samples from the Darlingtonia State Natural Site geotechnical boring demonstrate that the fen's source water has minimal concentrations of nitrogen-related compounds, the element of greatest concern to the *Darlingtonia* community (Table 7). Water sample analyses submitted to Edge Analytical for quality assurance and control are consistent with findings from the baseline analysis (Appendix D). Spatial analysis of the North Florence Dunal Aquifer hydrogeologic conceptual flow model and inventory of potential sources of contamination reveals low risk for septic influence (Figure 21). Contamination risk from industrial compounds at Darlingtonia State Natural Site is also low. Spatial inventories of underground storage tanks and water rights point of withdrawal locations overlain on the hydrologic conceptual flow patterns reveals minimal potential sources of contamination south and southeast of Darlingtonia State Natural Site, the source of the fen's incoming groundwater flow. In fact, largely undeveloped wooded areas, barren sand dunes, and freshwater lakes occupy much of the land up-gradient.

Laboratory analysis of the water samples reveal that chloride was the only anion measured with levels consistently greater than 1.0 mg/L (Table 7) (Appendix D); however, literature on the species did not provide a concentration of chloride that would impact the health and vigor of the *Darlingtonia*. Saltwater and septic influence are the two most considerable explanations for chloride presence in the groundwater. The analysis provided by Edge Analytical revealed 11.6 mg/L of sodium in July and 11.0 mg/L of sodium in October, both times a groundwater sample cation analysis was run by the laboratory (Appendix D). Whether or not saltwater intrusion is occurring (Figure 12) requires further study. Over pumping can cause saltwater intrusion degrading the water quality of the North Florence Dunal Aquifer, an important consideration for stakeholders of the aquifer. The Heceta Water District (now known as the Heceta People's Water Utility District) began supplying residents north of Florence with water from Clear Lake (about 1.5 miles southeast of Darlingtonia State Natural Site) in 1969 (HWPUD, n.d.) relieving saltwater upwelling potential from exempt domestic pumping wells dispersed throughout the aquifer as the utility service district expanded throughout the northern Florence area into the twenty-first century.

While water quality metrics were within CWA standards for surface water bodies throughout this study, current water conditions are always subject to future change. To mitigate future risks, park managers may consider employing an educational program at Darlingtonia State Natural Site for stakeholders and park visitors. Septic systems dominate the wastewater treatment mechanisms in the vicinity of the North Florence Dunal Aquifer, making nitrogen loading a potential threat to the Darlingtonia State Natural Site fen source water over the long-term. Informal discussions with park visitors, residents, and park staff revealed that many residents up-gradient from the site use the Darlingtonia State Natural Site parking lot to send text messages and make phone calls before heading back into neighborhoods with "spotty cell coverage." Perhaps a reminder in the parking lot to stay up to date on septic maintenance would prove beneficial to aquifer water quality.

5.1.2 Groundwater Supply

The groundwater monitoring program comprised of tracking water table level using pressure transducer data and monthly sampling and analysis of well water has provided an empirical baseline with which park managers can use to track changes to water table levels and groundwater chemistry within the Darlingtonia State Natural Site fen. Water table trends throughout the year follow a predictable temporal pattern of shallower depths to water during the wet winter season and deeper depths to water throughout the dry summer months. Variation does not exceed more than 0.55 feet (6.6 inches) and depths do not exceed more than 0.64 feet (7.7 inches) beneath the surface at the site of the boring in the northern section of the fen (Figure 22). Literature suggests the roots of carnivorous plants, including the *Darlingtonia*, reach depths up to a foot (Adlassnig et al., 2005). While the rooting zone is shallow, groundwater monitoring revealed that the roots were not subject to subterranean conditions too dry for survival during this study. Depth to water levels varies throughout the site, however, as the surface is dominated by small-scale topographic crests and troughs varying up to a foot or two throughout the fen. Troughs in each of the four study sectors contained standing water year-round, while crests were usually dry.

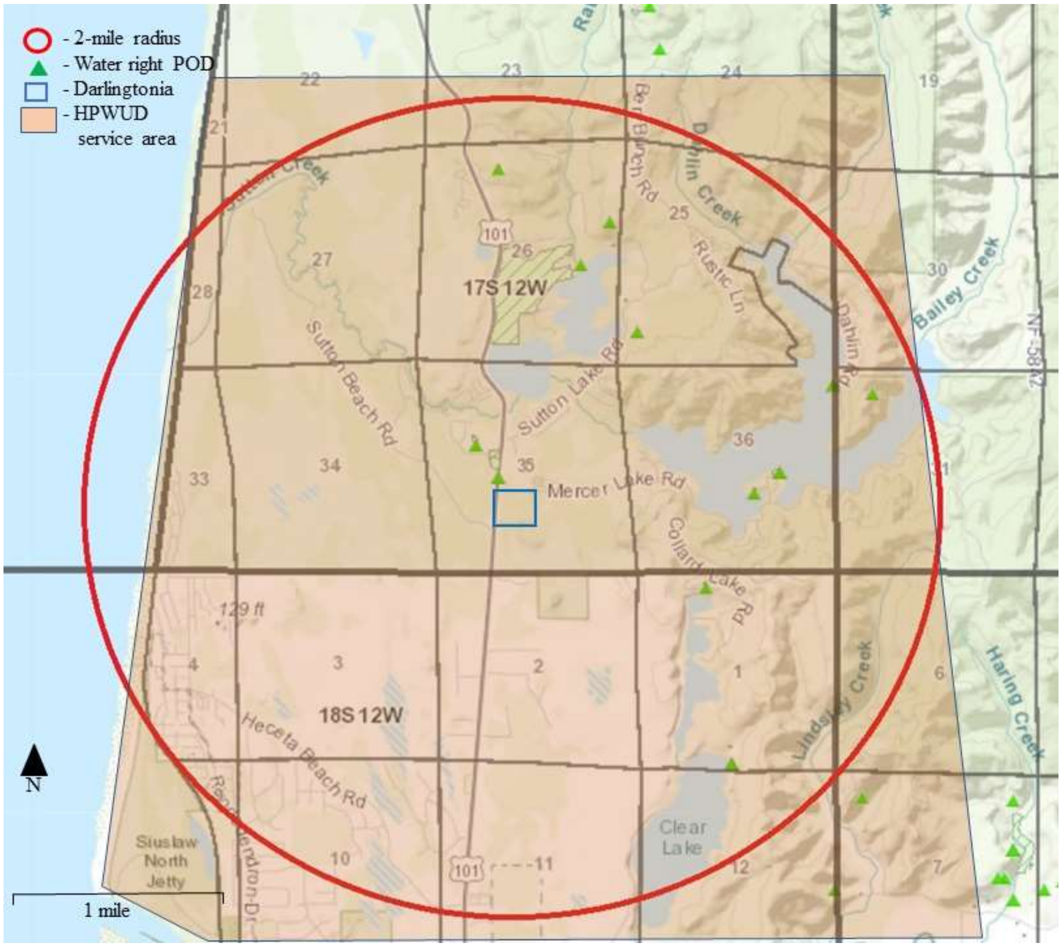

Figure 28 - Map of approximate Heceta Water People's Utility District service area and water rights certificates within 2-mile radius of Darlingtonia State Natural Site. Note: Water rights permits not shown

Examination of pressure transducer and precipitation data indicated that there is no apparent pumping activity affecting the Darlingtonia State Natural Site fen groundwater supply (Figure 25). Most residents, RV parks, and campsites receive their water supply from the Heceta Water People’s Utility District. The water utility service area covers stakeholders from the northern urban growth boundary of the City of Florence to subdivisions north of Sutton Lake (OAWU, 2014). The Heceta Water People’s Utility District holds 4 active surface water rights allowing total withdrawals up to 6.25 cubic feet per second (cfs) from Clear Lake for domestic use (Table 8). As of 2012, the district was withdrawing an average of 0.55 cfs or 9% of their total water allowance. A query of water rights cataloged by the OWRD reveals fifteen active surface water right certificates and permits within 2 miles of Darlingtonia State Natural Site (OWRD, n.d.) (Table 9 & Figure 28). There are no active groundwater rights or permits within several

Table 1-1: Water Production / Rights Relationship:					
Intake Name	Water Right Permit	Certified	Water Allowance (cfs)	Actual Usage (cfs)	% of Total Water Right
Clear Lake	S - 33171	56356	1.55	0.55	35
	S - 37524	80690	1.50	0.00	0
	S - 50036	NA	2.25	0.00	0
	S - 52090	NA	0.95	0.00	0
Total			6.25	0.55	09

Table 8 - List of water right permits held by the Heceta Water People's Utility District. Point of diversion is approximately 2 miles southeast of Darlingtonia State Natural Site (OAWU, 2014)

miles of Darlingtonia State Natural Site listed by the OWRD. However, policy in Oregon does allow for exempt domestic wells to pump up to 15,000 gallons per day without applying for a water right permit, thus, the potential for groundwater pumping from exempt wells within the vicinity of the site cannot be ruled out.

Changes to surface hydrology patterns have the OPRD concerned about Darlingtonia State Natural Site's water supply. Shrubs and trees with deeper root systems than *Darlingtonia* encroaching on the fen could increase transpiration rates which are believed to be limiting water supply within the fen. The OPRD began removing vegetation from the fringes of the fen in 2010

Application #	Use	Source	POD distance to site	Max. withdrawal
P82002	Storage/fire protection	runoff - Buck Lake/Dune Lake	1.60 miles	-
P82846	Storage	Unnamed stream - Sutton Creek	0.60 miles	-
S18733-14283	Irrigation .7 acres	Mercer Creek - Sutton Lake	0.10 miles	0.01 cfs
S18733-14682	Irrigation 1.8 acres	Mercer Creek - Sutton Lake	0.10 miles	0.03 cfs
S28149	Irrigation .76 acres	Mercer Creek - Sutton Lake	0.25 miles	0.01 cfs
S31599	Domestic	Kilmer Spring - Mitchell Creek	1.45 miles	0.01 cfs
S32384	Domestic	Rath Creek - Sutton Lake	1.20 miles	0.06 cfs
S39936	Domestic	Unnamed stream - Mitchell Creek	1.00 miles	0.05 cfs
S44622	Irrigation .5 acres	Mercer Lake - Mercer Creek	1.25 miles	0.01 cfs
S49174	Irrigation .2 acres	Mercer Lake - Mercer Creek	1.60 miles	0.005 cfs
S46104	Irrigation .1 acres	Mercer Lake - Mercer Creek	1.00 miles	0.01 cfs
S58423	Domestic	A spring - Rath Creek	1.65 miles	0.01 cfs
S49941	Domestic	A spring - Collard Creek/Lake	1.00 miles	0.00 cfs
S83372	Domestic	Clear Lake - Ackerly Lake	1.60 miles	0.01 cfs
S48678	Domestic	Unnamed spring - Dahlin Creek	1.85 miles	0.005 cfs

Table 9 - List of water right certificates and permits within 2 miles of Darlingtonia State Natural Site

and continue to actively remove vegetation throughout the year (OPRD, n.d.). Culverts, water mains, and other infrastructure installed by the Oregon Department of Transportation (ODOT) and Heceta Water People's Utility District have also concerned park managers. OPRD worked with ODOT and the U.S. Forest Service in 2010 to install sand bags and log dams to slow water flow through the site (Landscope America, 2011). These damming techniques may slow hydrologic flow, but require active maintenance and future project consideration among stakeholders (ODOT, USFS, water utilities, etc.) for long-term wetland sustainability. Park managers acknowledge the hydraulic connection between surface and groundwater flow by addressing the fen's water supply through these comprehensive conservation techniques.

Continuing the pressure transducer monitoring program will prove beneficial to park managers in several ways. Several years' worth of data will enhance the resolution of the water table baseline figures providing new insights on seasonal patterns. Park managers could use the data to develop education and outreach programs emphasizing groundwater science and its connection to GDE, like the fen at Darlingtonia State Natural Site. It also gives park managers a subsurface perspective to determine if pumping activities in the park's vicinity are affecting the water table. Though there is no current evidence groundwater pumping is affecting Darlingtonia State Natural Site, data from the transducer can provide information to investigate the distance to possible sources of withdrawal if this trend changes. Park managers ought to coordinate with stakeholders, like the Heceta Water People's Utility District, to track surface water withdrawal rates to determine if the baseline data is affected by increased surface water usage rates, a likely occurrence as the population of northern Florence area continues to grow and develop.

5.1.3 Water Temperature

The greatest cause for concern with the respect to the vigor of the *D. californica* population at the site may be the elevated temperatures of groundwater and soil moisture within the Darlingtonia State Natural Site fen. Literature suggests that the shallow root system of *Darlingtonia* requires temperatures around 10 °C (Adlassnig et al., 2005; Slack, 2000). Summer soil moisture temperatures within the unshaded fen reach as high as 24.5 °C at a 1-inch depth and 17.5 °C at a depth of 6 inches (Appendix C), well above the temperature outlined in the literature. Soil moisture temperatures followed a spatial pattern wherein the moisture in portions of the fen unshaded by the surrounding canopy was nearly 10 °C warmer than shaded portions at a 1-inch depth, and 5-6 °C warmer at a 6-inch depth. The In-situ® pressure transducer, which records temperature data hourly about 7 feet beneath the surface, also revealed groundwater temperatures above the 10 °C threshold throughout the study period and exceeded 11 °C for more than 56% of the 12-month water year (Figure 26).

There is a positive correlation between water temperature and hydraulic conductivity. In other words, the greater the water temperature, the greater the flow velocity of groundwater through an aquifer/soils (Hillel, 2008). Temperature negligibly affects the density and viscosity of water between its freezing and boiling points. These changes influence hydraulic conductivity could theoretically increase the flow of groundwater as it leaves the Darlingtonia State Natural Site fen after being warmed by the unshaded portions of the site.

5.1.3.1 Limitations of the Temperature Study

There are several limitations associated with this initial study in soil and groundwater temperatures. Shallow soil moisture temperature probing was completed once in early August. Quarterly or monthly soil temperature probing would provide baseline data for temperature stress the *Darlingtonia* experience throughout the year. And while soil temperature may provide an accurate representation of moisture temperature near the surface, groundwater flowing beneath the six-inch depths may be cooler providing reprieve for *Darlingtonia* root systems that reach up to a foot deep.

While the In-situ® pressure transducer provides over a year's worth of hourly resolution temperature data, the quality of this data may be compromised for several reasons. First, the pressure transducer, while effective, is not easily calibrated once in service, thus, is not the most accurate tool for water temperature measurement. Second, water in a geotechnical boring tends to become stagnant despite the transducer sitting within the screened portion of the well. Water temperature can increase, and water chemistry may even differ from the actual groundwater flowing through the aquifer. Therefore, sampling procedures included a three-well volume purge to remove stagnant water prior to taking a sample. Temperature, among other quality parameters, was measured after the three-well volume purge with a YSI EC300 providing more accurate groundwater temperature data 5 to 9 feet below the surface. This was used to compare to transducer temperature recordings; however, this purging method has limitations as well. Air temperature begins influencing the water sample temperature immediately after the water is pulled from the boring. This change in temperature was particularly apparent during the summer sampling visits when the temperature reading on the YSI EC300 increased every 10 to 30 seconds.

Measurements of soil moisture and groundwater temperature were not initially within the scope of this study; however, evidence and research reveal the importance of continued monitoring. A cost-effective method that would enhance fen temperature resolution is a year-long deployment of temperature sensors logging temperature every hour. TidbiT v2 temperature loggers (Figure 29) are a small and unobtrusive means of procuring a baseline temperature data set throughout the fen. Quality of the hourly TidbiT temperature readings can be assured by a combination of the three methods used in this study: 1) quarterly temperature probing, 2) in-situ pressure transducer data logging, and 3) quarterly temperature readings following a three-boring volume purge. These methods would provide a 3-dimensional temperature spatial analysis of Darlingtonia's groundwater sources. Sampling procedures are simple enough that park managers could incorporate this monitoring program into a citizen science outreach program. The data derived from this monitoring program provides direction for canopy and shade management in and around the Darlingtonia State Natural Site fen throughout the year. The Oregon Climate Change Research Institute (Dalton et al., 2017) projects temperatures throughout Oregon to rise 2 to 11 °F through 2080, affecting the chemistry of the fen's water supply as well as its ability to refresh and keep *Darlingtonia* root systems cool.

Figure 29 - A TidbiT v2 Water Temperature Data Logger to scale (Forestry Suppliers, 2017)

5.1.4 Management Implications for the Darlingtonia State Natural Site

The interdependence of groundwater chemistry, quantity, and temperature creates unique conditions influencing the ecology of the Darlingtonia State Natural Site fen. Management strategies currently employed by the OPRD influence ecosystem conditions within the fen affecting the health and vigor of the *Darlingtonia* population. Researchers of this study developed a three-pronged conceptual model illustrating the connection between land management strategies and surface/subsurface conditions. The model is displayed in Figure 30. The model does not quantify ideal conditions for the *Darlingtonia* population in the fen, rather it displays a qualitative theoretical 'sweet-spot', derived from literature and past population studies (Appendix E) (CEOAS, 2017) at which the carnivorous plant population can thrive.

Fens require slightly acidic, cool source water with low levels of natural metals like iron and manganese (Johnston et al., 2012). Water chemistry can be influenced by changes in

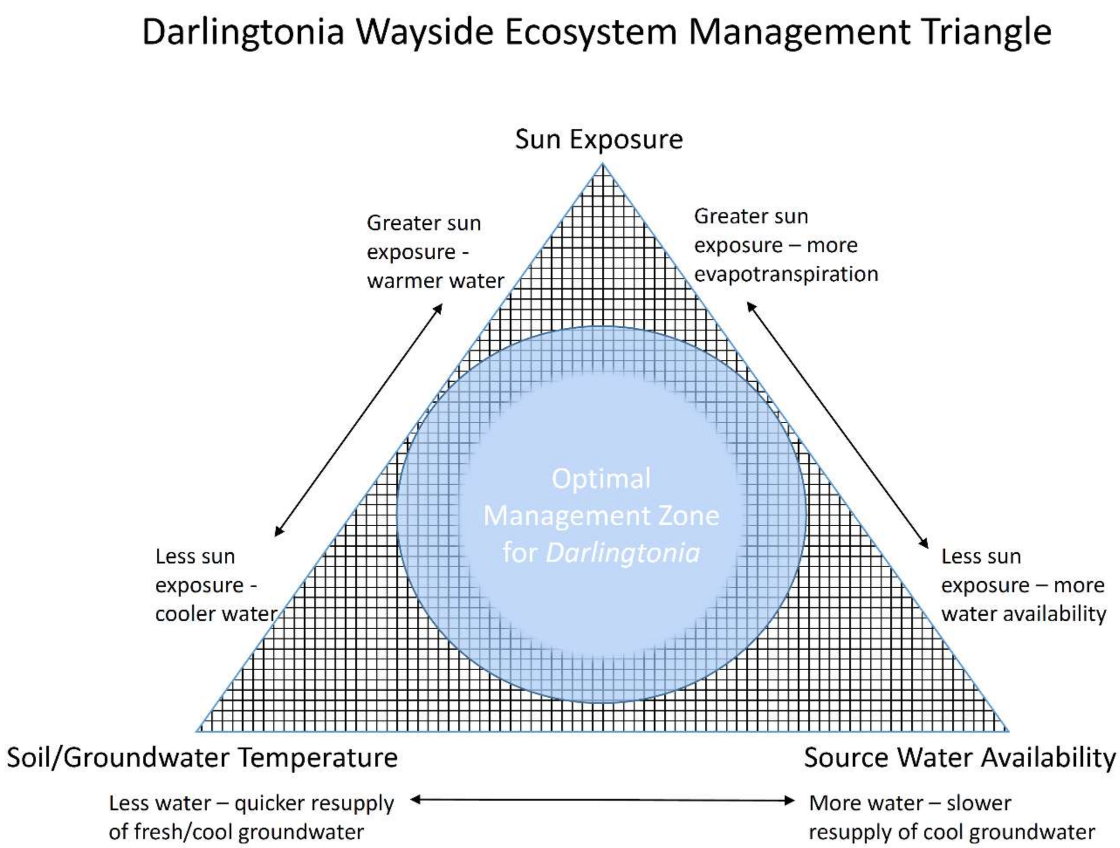

Figure 30 - Theoretical Darlingtonia State Natural Site management model considering sun exposure, water temperature, and water quantity within the site

temperature; however, significant chemical changes are unlikely since Darlingtonia State Natural Site receives water flow from the North Florence Dunal Aquifer at a relatively consistent temperature. The *Darlingtonia* population is influenced by increasing water temperatures within the fen as the water becomes exposed to surface ambient temperatures and sunlight. Reducing canopy shade to increase *Darlingtonia* exposure and reduce *Darlingtonia* competition with encroaching vegetation will increase surface water and soil moisture temperatures within the fen. Increasing water temperature within the fen increases the hydraulic conductivity theoretically increasing the rate at which the water moves through the site (Hillel, 2008) reducing water availability. However, moving warm, stagnant water through the site more rapidly allows for greater inflow from cooler, fresher groundwater up-gradient. Increasing sun exposure also increases evaporation rates reducing water availability while increasing groundwater velocity allowing for greater inflow influence. Park managers ought to consider these interdependent relationships in their land management strategies, and use continued research and monitoring to develop an adaptive management approach that can optimize water quantity, temperature and solar exposure.

As a carnivorous plant, *Darlingtonia* has unique strategies for meeting its resource needs. Digesting insects supplies most of the nitrogen the plants need. While competition for sunlight and water may be a concern for the *Darlingtonia*, Crane (1990) suggests their unorthodox methods for obtaining nutrients minimizes concern for nutrient competition as long as insects are drawn to the fen. In fact, some botanists hypothesize that low nutrient availability gives carnivorous plants a competitive advantage over other plant types.

Among encroaching vegetation are invasive species, another cause for concern. Grasses and blackberry shrubs have been increasing in abundance at the Darlingtonia State Natural Site fen, competing with *Darlingtonia* for sunlight and water (Chellew et al., 2017). Human interference with the delicate fen ecosystem is another cause for concern as Darlingtonia State Natural Site is, after all, a public park. However, the raised boardwalk and railings on site effectively mitigate incidental interference by park visitors hoping to experience the *Darlingtonia* up-close. The OPRD also assigns a ranger to survey park conditions for vandalism and clean any litter within the fen on a daily basis.

5.2 Darlingtonia State Natural Site GDE Policy and Management Analysis

The *Darlingtonia* community at Darlingtonia State Natural Site may be experiencing abundance and vigor fluctuations because of sun/shade exposure and elevated water temperatures, but local and regional groundwater management strategies in the region surrounding the GDE is generally are generally strong. The literature review of GDE policy and management research revealed seven GDE protection strategy categories including 1) identification and mapping, 2) water allocation, 3) spatial planning, 4) groundwater monitoring, 5) adaptive management, 6) restoration, and 7) public involvement. This study reviews policy at the national, state, county, and local level in addition to land and resource management practices executed by the stakeholders of the North Florence Dunal Aquifer region, including the OPRD, to evaluate the robustness of GDE protection at Darlingtonia State Natural Site in each category. Many of the management practices used in the region have been identified as useful protection mechanisms. While these mechanisms were not instituted for the specific purpose of protecting the fen at Darlingtonia State Natural Site, they still contribute to the protection of this GDE.

5.2.1 Identification and Mapping

In the spring of 2016, the OPRD contracted CEOAS at Oregon State University to conduct baseline population studies for the *Darlingtonia* community within the fen at Darlingtonia State Natural Site. This initial study led to a comprehensive groundwater monitoring program and study of the North Florence Dunal Aquifer. The geologic site conceptual model and conceptual groundwater elevation and flow maps have been developed from this study. These models provide pertinent information about influences on incoming groundwater quality and quantity. Wells, water rights, septic systems, underground storage tanks, and other potential sources of drawdown and contamination are spatially cataloged providing OPRD managers with a regional overview of potential groundwater impacts. Aquifer characteristics and boundaries were derived from state geologic maps and well logs recording well performance tests as well as soil and geologic facie characteristics. Hydraulic properties provide insight into the current capacity at which the aquifer supplies the fen at Darlingtonia State Natural Site illustrating potential strategies to adapt flow patterns within and around the park to ensure ample groundwater supply for the health and vigor of the *Darlingtonia* population.

Applying Payne and Woessner's (2010) aquifer classification system to the findings of this study produces the classification shown in Figure 31:

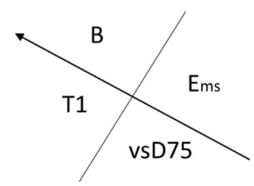

Figure 31 - A classification of the North Florence Dunal Aquifer using the Payne and Woessner (2010) identification framework

The arrow indicates that groundwater moves through the Darlingtonia State Natural Site fen in a west-north-westerly direction toward Mercer Creek and eventually the Pacific Ocean. The B in the top left corner indicates the aquifer sustains intermediate flow characteristics characterized by a hydraulic conductivity around 1-5 feet/day and transmissivity rates between 100 and 1000 ft^2/day. The E_{ms} in the top right corner indicates an eolian geologic setting primarily composed of medium-grained, unconsolidated sand. The T1 in the bottom left corner indicates good groundwater quality as conductivity is less than 1000 mS/cm and the water is used for municipal, domestic, commercial, and irrigation purposes throughout the aquifer area with cost-effective treatment. Finally, the vsD75 in the bottom right corner indicates a very shallow depth to groundwater with a high contribution rate (>75%) from the aquifer to surface water systems.

Other North Florence Dunal Aquifer stakeholders, including the City of Florence, the EPA, the USGS, and Heceta Water People's Utility District have conducted aquifer identification and mapping studies which are available to the public. The North Florence Dunal Aquifer has received extensive study as 1 of 80 Sole Source Aquifers in the United States contributing to the extensive activity of this GDE management category for this aquifer.

5.2.2 Water Allocation

Results from this study indicate the current water supply at Darlingtonia State Natural Site is ample for the health and vigor of the fen's current ecosystem community. Well logs from the OWRD were initially a cause for concern as at least 250 exempt wells were developed for domestic use throughout the northern Florence area. Exempt wells in Oregon can pump up to 15,000 gallons per day with minimal agency oversight to monitor withdrawals. This danger for drawdown dwindled as the Heceta Water District began supplying domiciles with treated water from Clear Lake throughout the northern Florence area in the late 1960s and early 1970s (HWPUD, n.d.). Withdrawals from the up-gradient surface water source has the potential to affect the local water table and hinder groundwater flowing into Darlingtonia State Natural Site; however, a single source of withdrawal is far more efficient for preventing groundwater drawdown than dozens to hundreds of wells supplying individual homes throughout the area. The service boundaries of the Heceta Water People's Utility District have effectively created a domestic pumping buffer zone surrounding Darlingtonia State Natural Site, a highly effective management mechanism to ensure GDE water supply (Klove et al., 2014; Beseki & Hodges, 2006; Rohde et al., 2017).

Other small surface water rights for various uses, mainly irrigation, exist around the site which also have the potential to affect the water table at Darlingtonia State Natural Site. However, the pressure transducer data reveal no effective influence other than natural processes, such as tides, precipitation, etc. Recent modifications to drainage culverts and stream diversions concern park managers about the hydrology surrounding the site and ensuing the retention of water within the fen for the *Darlingtonia* population. OPRD managers can make small, on-site modifications to enhance water retention, though coordinating with stakeholders when development may alter hydrology could be far more effective.

5.2.3 Spatial Planning

The Sole Source Aquifer status of the North Florence Dunal Aquifer has provided justification for extensive spatial studies by several stakeholders. The City of Florence maintains catalogs of potential sources of contamination in addition to zones of sensitivity for their drinking water source (City of Florence, 2013) and must consider the impacts of development on the North Florence Dunal Aquifer while planning for the protection of the groundwater resource. The jurisdiction of this spatial planning resource is limited to Florence city limits, 2 miles south of Darlingtonia State Natural Site, though the aquifer protection plan provides spatial planning data north of the city limits. The U.S. EPA provides an extra layer of oversight for all federally funded projects overlying the aquifer (U.S. EPA, 1997). The Heceta Water People's Utility District monitors water resources and potential sources of contamination near its diversion source, Clear Lake (OAWU, 2014).

The U.S. Forest Service manages the land surrounding Darlingtonia State Natural Site as the Siuslaw National Forest occupies the coast from the southern border of Yachats to approximately 1.5 miles north of Florence, or about 1000 feet south of Darlingtonia State Natural Site. OPRD works with the USFS to maintain forest resources in this area which provide a buffer to restrict the presence of potential contaminants (Brown et al., 2011; Aldous & Brown, 2011) while naturally remediating compromised water quality (Hardisty, Ozdemiroglu, 2005; Klove et al., 2014). The greatest hazard to groundwater quality at Darlingtonia State Natural Site is the presence of on-site septic systems and wastewater storage tanks. Fortunately, conceptual flow mapping reveals minimal septic influence as groundwater flowing into the site generally flows beneath forested lands and isolated sand dunes with minimal development. Managing wastewater on land up-gradient from Darlingtonia State Natural Site should be a spatial planning priority if and when development of the northern Florence area occurs in the future.

5.2.4 Groundwater Monitoring

Groundwater experts recommend consistently gathering local data from GDE to monitor long-term variations in groundwater quality and quantity to adequately inform effective adaptive management decisions (Griebler et al., 2010; Orellana et al., 2012). OPRD funding for the *Darlingtonia* baseline population and groundwater studies were spent installing the geotechnical boring and pressure transducer used to monitor groundwater in this study. Over 16 months of pressure transducer data and 12 months of groundwater quality parameter and anion analysis data have currently been compiled and reported to the OPRD establishing a temporal frame of reference for groundwater quality and quantity at Darlingtonia State Natural Site. Darlingtonia State Natural Site park managers and researchers from CEOAS have access to these tools to continue refining the groundwater baseline to analyze long-term trends to the hydrology of the fen. Thus far, this study has identified the need to monitor spatial and temporal temperature trends within and below the Darlingtonia State Natural Site fen to ensure the *Darlingtonia* community is receiving water cool enough to refresh the shallow root systems. This study recommends continuing the monitoring program by collecting pressure transducer data and water quality samples on a quarterly basis while establishing a year-long spatial temperature baseline with hourly temperature sensor recordings.

The Safe Drinking Water Act requires sole source aquifers to maintain an adequate standard of quality for cost-effective treatment and municipal use by the communities relying on said aquifer (U.S. EPA, 1997). The City of Florence extensively monitors water quality and produces annual state of the aquifer reports for the U.S. EPA and water utility customers. Projects overlying the aquifer boundaries receiving federal funding undergo additional review from the U.S. EPA to minimize the potential for groundwater contamination. The U.S. EPA recognizes the coastal aquifer risks associated with the North Florence Dunal Aquifer, like saltwater intrusion, when reviewing federally funded projects (U.S. EPA, 1987).

5.2.5 Adaptive Management

Adaptive management is a common policy and management tool recommended for social-ecological systems and common pool resources, like groundwater (IWRM, 2003; Rohde et al., 2017). Gathering data from GDE is an important component of the adaptive management process (Klove et al., 2014) to enhance systemic learning and improve management practices (Pahl-Wostl et al., 2010). Recent research has provided a current baseline for plant population, sun/shade, and groundwater conditions, and can inform park directors with data to enhance the effectiveness of Darlingtonia State Natural Site management decisions. Prior to this study, the OPRD began adjusting sun and shade exposure in the fen in an attempt to reduce shade and improve the health and vigor of the *Darlingtonia* population. Further study has revealed water temperature in the fen is a serious consideration when adjusting canopy cover for sunlight exposure. The OPRD also coordinated with ODOT and the Heceta Water People's Utility District when park managers first suspected water infrastructure and drainage culverts were altering the hydrology of the fen. Darlingtonia State Natural Site park managers have displayed an extensive adaptive capacity and willingness to modify conservation mechanisms as GDE conditions have changed.

5.2.6 Restoration

Extensive restoration has not been necessary for the Darlingtonia State Natural Site GDE as the fen has maintained its carnivorous vegetative population since the park was purchased from various owners between 1946 and 1964 (OPRD, 2017). The baseline population and groundwater studies show a willingness of the OPRD to mitigate potential degradation of the fen. Darlingtonia State Natural Site managers began actively changing sun and shade exposure of the fen by removing infringing brush and canopy cover around the edges of the fen in attempt to restore the apparent "declining of health and vigor" *Darlingtonia* population (CEOAS, 2017). The OPRD has also attempted to mitigate hydrology alterations caused by drainage swale development by placing sand bags along the swale edge to slow water flowing out of the fen (OPRD, n.d.).

The North Florence Dunal Aquifer's hydraulic connection to the Pacific Ocean presents a risk of saltwater intrusion into the fresh groundwater supply (Ferguson & Gleeson, 2012). Rising sea levels are a contributing factor to this intrusive phenomenon; however, excessive groundwater pumping is the most prominent culprit contributing to saltwater intrusion in coastal aquifers around the world. Freshwater injection wells are a saltwater intrusion restoration tool used throughout coastal aquifer-dependent communities from Orange County, California (Hammer & Gordon, 1980) to the Syrian coast (Khomine, 2012). Injecting water creates a hydraulic barrier between the freshwater aquifer reserves and the intruding seawater (Figure 32). Groundwater injection technology has taken off since its origins in the late 1970s as Orange County, California's state of the art Groundwater Replenishment System can treat 70 million gallons of wastewater for groundwater injection and

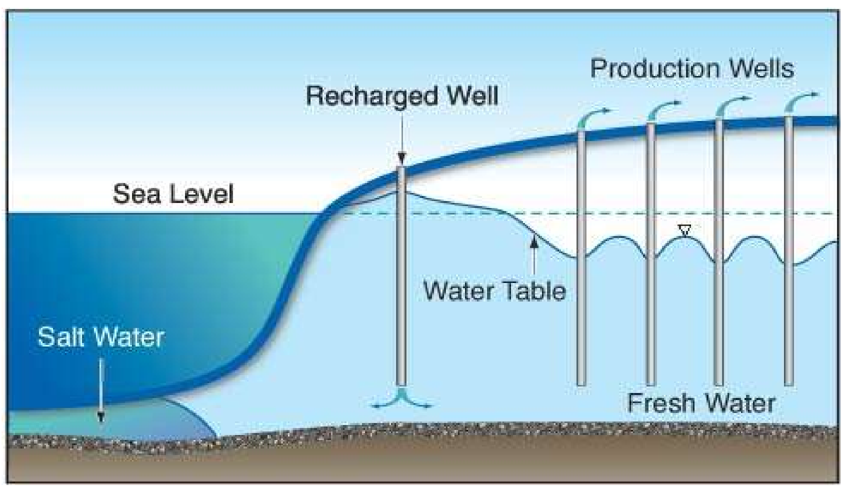

Figure 32 - Conceptual model of an artificial recharge well (Recharged Well) creating hydraulic barrier between saltwater and freshwater in a shallow coastal aquifer (Solinst, n.d.)

replenishment per day (Cutler, 2008). Obviously, this extensive artificial recharge restoration scheme is currently unnecessary for the North Florence Dunal Aquifer, but is a costly option for stakeholders if future development and water demand proliferate to this point.

5.2.7 Public Involvement

Darlingtonia State Natural Site invites public involvement as a state-managed public recreation site. The site boasts several informative signs about the *Darlingtonia* population educating visitors about Oregon's unique carnivorous plant. The boardwalk allows visitors to experience the *Darlingtonia* up-close without disturbing the intricate ecosystem within the fen. The OPRD also has the unique opportunity to educate visitors about groundwater. The average adult in the United States lacks a fundamental comprehension of groundwater concepts (Dickerson & Callahan, 2008; Gerakis, 1998). Groundwater education experts recommend providing educational opportunities where groundwater is accessible at the surface (Foster et al., 2010; Fugate, 1993; IWRM, 2003). The hydraulic connection between unique GDE and groundwater is an ideal site for such an endeavor.

The International Association for Public Participation has developed a spectrum for public involvement ranging from informing to empowering (IAP2, n.d.). The issues surrounding the Darlingtonia State Natural Site GDE are largely a technical problem requiring management decisions from a state agency. In the case of Darlingtonia State Natura Site, public participation is most appropriate at the informing level to keep stakeholders updated on groundwater issues.

Through the groundwater monitoring and conceptual models executed in this study, a sign was developed for the OPRD to install at Darlingtonia State Natural Site (Appendix F). The sign, currently under an extensive review process with the State of Oregon, provides park visitors with insightful knowledge about the North Florence Dunal Aquifer and its significance to the GDE within Darlingtonia State Natural Site. The sign also provides aquifer stakeholders with resources to aid in the maintenance of domestic waste management systems and proper abandonment of aging groundwater infrastructure.

Through the simple, ongoing groundwater monitoring system at Darlingtonia State Natural Site, park managers have a unique opportunity to develop a unique citizen science program. Monthly or quarterly monitoring events can be carried out by students from local schools or during times of high visitor traffic at the park. Park managers could allow guests to participate in the relatively simple procedures of groundwater sampling and pressure transducer recordings. Research programs that involve citizens and park visitors have considerable educational impact on participants while strengthening stakeholder support for GDE protection policy and management (Everard, 2015; Thornton & Leahy, 2012). Sustainable coastal tourism calls for programs that foster environmental sustainability and encourage visitors to consider the health of the ecosystems on which they recreate (Ghosh, 2012). Participating in environmental monitoring programs accomplishes both of these sustainable coastal tourism objectives.

6. CONCLUSION

The research questions addressed in this study required the observation of the physical hydrology of Darlingtonia State Natural Site and a comprehensive overview of the current policy and management of Oregon's coastal GDE in addition to GDE management strategies used throughout the world. The concluding chapter evaluates the objectives of this study to determine if the research questions were adequately answered. Recommendations for future study and brief GDE management recommendations for the OPRD are provided in the final section. Study limitations are discussed throughout this concluding chapter.

6.1 Research Questions

1. Are anthropogenic activities in the vicinity of Darlingtonia State Natural Site affecting the quality and quantity of the North Florence Dunal Aquifer supplying groundwater to the fen and community of *Darlingtonia californica* therein?

Two objectives were developed and executed to answer the first research question: A hydrogeological analysis of the North Florence Dunal Aquifer and a groundwater monitoring program at Darlingtonia State Natural Site.

Current indications are that no, these actions are not affecting the aquifer or fen. Results from the hydrogeologic analysis revealed key aquifer parameters including hydraulic conductivity, groundwater flow directions, and groundwater velocities. Well logs gathered from the OWRD well log database revealed the fen at Darlingtonia State Natural Site may be subject to water table drawdown from local domestic wells. Pressure transducer data recorded hourly from the geotechnical boring at Darlingtonia State Natural Site paired with precipitation data provided by the City of Florence revealed minimal to no anthropogenic interference with the local groundwater levels around Darlingtonia State Natural Site. The development of the Heceta Water District in the late 1960s and continuous expansion to private domiciles, public campsites, and RV parks over the past 50 years diminishes the need to pump groundwater for domestic use in the northern Florence area. Seasonal variations in aquifer recharge and surface evapotranspiration rates are apparent in the pressure transducer data and are still a concern for the source water quantity of the fen. Infrastructure development around the site has park managers concerned for the hydrologic patterns within the fen; however, this study cannot determine how past changes to highway drainage swales affect the current groundwater quantity of Darlingtonia State Natural Site as no baseline data were established prior to the alterations. Pressure transducer data supplied from this study have established an initial baseline for park managers to observe future water table fluctuations as land uses in northern Florence evolve in the future.

Further study into whether stormwater drainage infrastructure adjacent to U.S. Highway 101 is warranted. Data from this study did not include a baseline from before the culvert was installed. Placing a pumping well near the culvert and conducting slug tests would help determine the effect of the culvert. The slug tests would also provide insight as to whether there is a constant pumping source affecting the site since before the installation of the geotechnical boring and pressure transducer in the fen.

Initial water quality concerns at Darlingtonia State Natural Site included nitrogen loading from domestic septic systems, salinity associated with saltwater intrusion and other contaminants associated with various human activities (i.e. agricultural runoff, UST leaks, etc.). Monthly anion chromatography analysis, in accordance with EPA sampling method 300.0 (Motter & Jones, 2015), of samples taken from the geotechnical boring at Darlingtonia State Natural Site revealed an insignificant nitrate presence. This result was confirmed by two analyses completed by an independent, contracted laboratory, Edge Analytical in Corvallis, and an analysis completed by undergraduate interns testing for nitrate, nitrite and ammonia. Hydrogeologic and conceptual groundwater flow analyses support the notion of minimal septic influence as Lane County Land Management records reveal no septic systems up-gradient from the GDE at Darlingtonia State Natural Site to transport nitrogen-laden compounds.

Chloride was the anion with the greatest concentration in addition to a sodium presence from the Edge Analytical cation analysis, completed in accordance with EPA sampling method 200.7 (Martin et al., 1994), suggesting the presence of saltwater in the North Florence Dunal Aquifer and fen at Darlingtonia State Natural Site. Further investigation beyond the scope of this study is necessary to confirm if saltwater intrusion is present. Groundwater sampling analyses reveals that other contaminants are of little concern to the site. This is supported by the conceptual flow analysis which reveals little development up-gradient from Darlingtonia State Natural Site and that vastly wooded areas, exposed sand dunes, and freshwater lakes are the main surface features.

Water temperatures within the fen became a concern following the soil moisture temperature analysis completed by undergraduate interns in early August 2017. Spatial analysis of soil moisture probes at depths of 1-inch and 6-inches revealed temperatures greater than the threshold for the health of *Darlingtonia californica* root systems as outlined by the literature. This notion is supported by groundwater temperatures as measured by the pressure transducer in the geotechnical boring which revealed temperatures above the threshold for well over half of 1 water year. Results from this brief study indicate that shaded areas of the fen maintain cooler moisture and water temperatures within the fen. This is a major implication for the OPRD to consider in moving forward with Darlingtonia State Natural Site land management as cutting back canopy to provide sunlight for the *Darlingtonia* community has been a standard practice for the park over the past 15 years. Fen water temperatures require a more extensive spatial and temporal monitoring program before park managers ought to consider revising current land and canopy management practices.

2. What are the current policy and management mechanisms protecting groundwater dependent ecosystems and how can they be improved at Darlingtonia State Natural Site?

A comprehensive literature review of documents pertinent to current GDE protection policy/management affecting Darlingtonia State Natural Site and policy/management tools used throughout the world to protect GDE was the third, and final, objective to answer the second research question for this study.

Water resources are a highly regarded resource, the universal need for which has established collaborative mechanisms that allow most stakeholders to draw from the well, quite literally. GDE were not explicitly addressed as a resource for which water management agencies needed to account until the “green revolution” era in the United States. Various statutes, like the Clean Water Act and Safe Drinking Water Act, implicitly recognized the importance of GDE for the vitality of water resources throughout the United States. These statutes led to the establishment of new management practices like the EPA's Sole Source Aquifer Program which provides an extra level of federal oversight for the protection of the North Florence Dunal Aquifer. Other federal and Oregon groundwater allocation and protection policy was reviewed in addition to other northern Florence management implications (i.e. park management) to determine the current state of GDE protection capacity for Darlingtonia State Natural Site.

Literature concerning GDE policy and management from around the world was compiled and reviewed to establish a basis through which the GDE protection status of the northern

GDE Protection Mechanism	Darlingtonia Score	Comments
Identification & Mapping	5	GDE and aquifer extensively mapped and spatially analyzed through this study and as a result of Sole-Source Aquifer program.
Water Allocation	4	HPWUD provides inhabitants near GDE with water mitigating the need for groundwater extraction. Stormwater infrastructure affects current surface hydrology of the GDE.
Spatial Planning	4	HPWUD service area serves as an effective pumping radius. No groundwater rights in the area, but groundwater extraction still possible through Oregon's exempt well policy. Groundwater flowing into site influenced by undeveloped National Forest Service land.
Groundwater Monitoring	5	Monitoring program for GDE set up through this study providing park managers with baseline water quality and quantity data.
Adaptive Management	4	Parks actively attempting to mitigate issues with *Darlingtonia* plant population through canopy shade management and hydrology alterations. Study now provides robust data with which managers can base land management decisions.
Restoration	3	Received neutral score because restoration activities have been unnecessary for GDE to this point. Parks have attempted to restore *Darlingtonia* population through canopy shade and hydrology management.
Public Involvement	2	The OPRD has worked with agencies when water infrastructure development may affect the site. However, biggest room for improvement as park could actively engage public with groundwater and GDE outreach and education opportunities.

Table 10 - Darlingtonia State Natural Site GDE management protection strategy scores: 5 being robust and 0 being non-existent

Florence area can be compared. This literature revealed seven categories of GDE protection strategies. Table 10 provides a score for the current level of capacity for each mechanism category for Darlingtonia State Natural Site. Each category is discussed at length in chapter 5, the Discussion section, of this report, and recommendation to maintain or improve protection of the GDE at this site are reported in column 3 of the table.

6.2 Recommendations for Future Research and the OPRD

Darlingtonia State Natural Site managers have expressed previous concern about changes to the hydrology of the fen because of alterations to stormwater infrastructure along U.S. highway 101 directly west, and down-gradient, of the site. Unfortunately, the pressure transducer was installed on-site after these alterations were complete. Thus, it is not possible to assess the effect before installation of the stormwater management infrastructure. Continuing the monitoring program is recommended, as continued monitoring enhances the resolution of the temporal groundwater table baseline while potentially revealing future changes to hydrology as stormwater infrastructure alterations occur in the future.

Elevated levels of chloride and sodium from the water sample results suggest there may be saltwater intrusion affecting the North Florence Dunal Aquifer. Sodium and chloride concentrations can occur in groundwater via natural mechanisms including the erosion of salt deposits or sodium-baring minerals (Perlman, 2016). Other human activities may also increase sodium and chloride concentrations in groundwater, though the conceptual flow analysis suggests runoff from agriculture and septic leachate influence are unlikely for this site. A future groundwater study testing for major anions and cations in previously established borings throughout the aquifer would help assess sodium and chloride concentrations and gradients throughout the aquifer, for a clearer analysis of where saltwater and brackish water occurs within the aquifer.

Water temperatures within and around the fen are the most pressing concern for the community of *Darlingtonia* at Darlingtonia State Natural Site revealed from this study. As recommended in chapter 5 of this report, a comprehensive spatial and temporal temperature study of the fen at Darlingtonia State Natural Site would present a useful 3-dimensional model of temperature trends within the fen better informing canopy and land management decisions made by the OPRD.

GDE protection policy and management analysis revealed generally favorable trends for Darlingtonia State Natural Site. The category receiving the lowest score was public involvement. While park managers have worked with other stakeholders in the northern Florence area to promote the health and vigor of the GDE and the park is inherently publicly inclusive, the OPRD can capitalize on a much larger GDE education opportunity. Currently, the park displays ample information about the vegetation within the park's ecosystem highlighting the rare, carnivorous pitcher plant community. Additional programming highlighting the significance of the hydrogeologic environment which provides water for this rare GDE is an important opportunity for promoting increased understanding of groundwater and GDE in the public (Dickerson & Callahan, 2006; Klove et al., 2014; Rohde et al., 2017). Incorporating signs, citizen science programs, and presentations about the world beneath Darlingtonia State Natural Site is a unique chance to inform a citizenry that is historically hydrologically uniformed.

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7. APPENDICES

APPENDIX A: Geotechnical Boring Summary and Well Log

Darlingtonia State Natural Site: Geotechnical Hole Excavation Summary

Performed: 8/14/2016
Present: Joe Kemper (OSU), Travis Grohman (OSU), Justin Helberg (OSP)

Location

- The well is located on the north side of the boardwalk on a slight topographical rise (see image below).

Drilling Log

- 0-1 feet. Dark brown mud and roots
    - Dug with shovels. Very wet. Water pooling in hole.
- 1-2 feet. Dark brown mud with sand.
    - Dug with shovels. Very wet. Water pooling within 0.5 ft of surface
    - At two feet, a 3 ft length of 6 inch pvc pipe was inserted into the hole to prevent surface material from entering the excavation.
- 2-4 feet
    - Dug with hand auger.
    - Medium fine sand with dark brown mud.
    - Saturated. Water would drop when digging and then fill to within 0.5 ft of surface
    - Dark brown mud is likely from material remaining in hole from top 0-2 feet.
- 4-7 feet
    - Dug with hand auger
    - Medium fine sand – mud has been cleared from excavation
    - Standing water will drop while digging and then rebound to within 0.5 feet of surface.

    - Hand auger unable to reach depth greater than 6.5 feet because saturated sand caved and filled any deeper depth. 3 ft length of 6 inch pvc is replaced with 7 ft length of 6 inch pvc. Static water returns to within 0.5 feet of surface after approximately 10 minutes.
- 7-9 feet
    - Dug with hand auger
    - Medium fine sand.
    - Caving recurring at 9 feet when digging below the bottom of 6 inch pvc.
    - Hand auger is removed and quickly replaced with 1.5 inch casing. Silica packing sand is deposited inside 6" pvc gradually as the 6" pvc is slowly removed. Bentonite is installed from 0-3 feet inside the borehole.

Construction Details

- Well Head is 1.25 feet above land surface
- Well is cased from 0-9 feet below land surface.
- Well is slotted from 4-9 feet below land surface.
- Padlock was installed on twisting cap. One copy of the key was giving to State Park Service to be kept at Honeymann State Park.

Transducer Details

- In Situ Level Troll 100 is installed 8 ft below top of casing.
- In Situ BARO Troll 100 is installed directly underneath the well cap.
- Transducers are set to record measurements every hour. To download the data, a student will need to 1) install WinSitu 5 from In Situ along with the BaroMerge plugin on a field laptop, 2) obtain the transducer dock with USB plugin, 3) bring e-tape to field verify depth to water in the geotechnical hole. Contact Joe Kemper (joseph.kemper12@gmail.com) for details.

LANE 74747

STATE OF OREGON
GEOTECHNICAL HOLE REPORT
(as required by OAR 690-240-0035)

LANE 74747

(1) OWNER/PROJECT

Hole Number ______

PROJECT NAME/NBR: Darlingtonia Wayside

First Name Sherri Last Name Laier
Company Oregon Dept. of Parks and Recreation
Address 89814 Cape Arago Hwy
City Coos Bay State OR Zip 97420

(2) TYPE OF WORK

[X] New [ ] Deepening [ ] Abandonment
[ ] Alteration (repair/recondition)

(3) CONSTRUCTION

[ ] Rotary Air [X] Hand Auger [ ] Hollow stem auger
[ ] Rotary Mud [ ] Cable [ ] Push Probe
[ ] Other ______

(4) TYPE OF HOLE:

( ) Uncased Temporary (•) Cased Permanent
( ) Uncased Permanent ( ) Slope Stablity
( ) Other
Other: ______

(5) USE OF HOLE

Observe static water level fluctuations.

(6) BORE HOLE CONSTRUCTION

Special Standard [ ] (Attach copy)

Depth of Completed Hole 9 ft.

BORE HOLE Dia	From	To	SEAL Material	From	To	Amt	sacks/ lbs
6	0	7	Bentonite Chips	0	3	2	S
2.5	7	9					

Backfill placed from ______ ft. to ______ ft. Material ______
Filter pack from 3 ft. to 9 ft. Material Sand Size 10 x 20

(7) CASING/SCREEN

Casing	Screen	Dia	+	From	To	Gauge	Stl	Plstc	Wld	Thrd
(•)	( )	1.5	[ ]	0	4		( )	(•)	[ ]	[X]
( )	(•)	1.5	[ ]	4	9		( )	(•)	[ ]	[X]
( )	( )		[ ]				( )	( )	[ ]	[ ]
( )	( )		[ ]				( )	( )	[ ]	[ ]
( )	( )		[ ]				( )	( )	[ ]	[ ]

(8) WELL TESTS

( ) Pump ( ) Bailer ( ) Air ( ) Flowing Artesian

Yield gal/min	Drawdown	Drill stem/Pump depth	Duration(hr)

Temperature ______ °F Lab analysis [ ] Yes By ______

Supervising Geologist/Engineer ______

Water quality concerns? [ ] Yes (describe below)

From	To	Description	Amount	Units

(9) LOCATION OF HOLE (legal description)

County LANE Twp 17.00 S N/S Range 12.00 W E/W WM
Sec 35 NE 1/4 of the SW 1/4 Tax Lot 2400
Tax Map Number ______ Lot ______
Lat ° ' " or 44.046899 DMS or DD
Long ° ' " or -124.097928 DMS or DD
(•) Street address of hole ( ) Nearest address

Darlingtonia State Botanical Wayside, Florence, OR 97439

(10) STATIC WATER LEVEL

	Date	SWL(psi)	+	SWL(ft)
Existing Well / Predeepening			[ ]	
Completed Well	08-14-2016		[X]	.25

Flowing Artesian? [ ]

WATER BEARING ZONES Depth water was first found .25

SWL Date	From	To	Est Flow	SWL(psi)	+	SWL(ft)
					[ ]	
					[ ]	
					[ ]	
					[ ]	

(11) SUBSURFACE LOG

Ground Elevation ______

Material	From	To
Dark mud, organics	0	1
Mud with sand	1	2
Sand with mud	2	4
Sand	4	9

Date Started Aug. 14, 2016 Completed Aug. 14, 2016

(12) ABANDONMENT LOG:

Material	From	To	Amt	sacks/ lbs

RECEIVED BY OWRD
SEP 28 2016
SALEM, OR

RECEIVED BY OWRD
SEP 09 2016
SALEM, OR

Date Started ______ Completed ______

Professional Certification (to be signed by an Oregon licensed water or monitoring well constructor, Oregon registered geologist or professional engineer).

I accept responsibility for the construction, deepening, alteration, or abandonment work performed during the construction dates reported above. All work performed during this time is in compliance with Oregon geotechnical hole construction standards. This report is true to the best of my knowledge and belief.

License/Registration Number E 1364 Date Sept. 7, 2016
First Name W. Todd Last Name Jarvis
Affiliation Oregon State University

ORIGINAL - WATER RESOURCES DEPARTMENT
THIS REPORT MUST BE SUBMITTED TO THE WATER RESOURCES DEPARTMENT WITHIN 30 DAYS OF COMPLETION OF WORK

Form Version: 0.96

LANE 74747

GEOTECHNICAL HOLE REPORT -
Map with location identified must be attached and shall include an approximate scale and north arrow

Map of Hole

APPENDIX B: Groundwater Sampling Procedures, Laboratory Calibration, QA/QC

Samples were collected with a three-quarter-inch polyethylene bailer following a three-boring volume purge to remove all stagnant water within the casing before collection. Samples were kept on ice until analysis when they were removed and brought to room temperature. Stock standard solutions are bought at high concentration and diluted in the laboratory following standard procedure. An NSS standard was run prior to samples with a dilution sequence order of 0.2 M, 0.5 M, 1.0 M, 2.0 M, and 5.0 M. Samples were run in 5 mL vials with a blank and standard run every 10 samples. 5 mL samples were processed and samples with concentrations that were beyond detection limits for the instrument were diluted (1 mL sample and 4 mL of DI water) for further analysis. Analysis of ions was completed using a Dionex Ion Chromatograph for anion concentrations within a 48-hour timeframe of sampling. Duplicate water samples were taken in July and October 2017 and delivered to a contracted, third-party laboratory, Edge Analytical in Corvallis, Oregon, for analysis quality assurance and control. Edge Analytical also completed cation and heavy metal analyses in accordance with EPA method 200.7 for determining metals and trace elements by inductively coupled plasma-atomic emission spectrometry (Martin et al., 1994).

Basic water chemistry parameters were taken during sample collection via outlined EPA/OSU procedures. Parameters include conductivity, salinity, total dissolved solids, temperature and pH. Measurements were taken by placing the probes into an acid-washed 500 mL polyethylene bottle following the three-boring volume purge. Data for pH were collected using an Extech Heavy Duty pH meter (model 407227). The pH readings often took longer to stabilize, and pH values for the site were recorded when stable (difference in readings of less than 0.03 units, and no trend in change) for 2 successive 30-second periods. A YSI EC-300 meter was used to collect data for temperature, conductivity, salinity and TDS. Two measurements for conductivity were recorded including temperature corrected conductivity and non-temperature corrected conductivity.

Sample bottles were washed prior to sampling by rinsing the polyethylene bottles with deionized water four times. The bottles were filled with 10% hydrochloric acid solution, capped, and left to soak overnight. The acid was then poured back into the acid storage container and the bottles were rinsed 4 times with deionized water. The bottles were then filled with deionized water and 25% of bottles were randomly selected for conductivity measurements. All readings were observed and recorded under 0.8 μS/cm. Standard procedure requires all pre-tested bottles exhibit less than 1 μS/cm per liter of conductivity. The bottles were then allowed to soak in deionized water overnight. At this time, pre-tested bottles were retested to confirm conductivity did not vary more than 0.8 μS/cm per of conductivity. After conductivity confirmation, all bottles were rinsed a final four times with deionized water and left to dry for 48 hours. Dried bottles were capped and stored in plastic bags to prevent contamination before field sampling.

A 500 mL field blank was collected during each sampling event by pouring deionized water into clean bottleware at the site. A 500 mL filter blank was also prepared in the lab prior to sampling by running deionized water through the filtration system used for samples. All samples were filtered with a Whatman 45μ glass filter. Both blanks were processed, preserved, and analyzed using the same procedures and at the same time as the groundwater samples taken from Darlingtonia State Natural Site. Filters were rinsed with deionized water and baked in an oven for five days to remove all liquid before being packaged in aluminum foil and a plastic bag.

APPENDIX C: Johnson Undergraduate Internship Temperature and Nitrogen Report

Temperature and Nitrogen Sampling at Darlingtonia State Natural Site

Dr. Christine Kelly
Samantha Carrothers and Fox Avery

Darlingtonia State Park is the only Oregon State Park established for the preservation of a single species: the carnivorous plant *Darlingtonia californica*. However, the plants have recently been experiencing a noticeable decline in health. While the direct cause is still unknown, two possibilities include either increased temperature within the root systems or elevated concentrations of nitrogen species from nearby septic systems. A thermometer with a modified probe was taken to Darlingtonia State Park and used to record temperature at both 1" and 6" beneath the soil surface. Water samples were also collected from around the park for nitrate and ammonia measurements. No nitrate was observed in the sample; however, ammonia was found to exist at higher concentrations than expected at three park location. More concerning to the plant, the temperature never fell within the ≤10°C range needed by *Darlingtonia californica* to maintain optimal health. Review of temperature data over the past year from an on-site piezometer revealed that 196 days were spent above this range. Data indicates nitrogen species are not the cause of the deteriorating health, but temperature may be a concern.

Darlingtonia State Natural Site was established with the intent of preserving the area specifically for the carnivorous plant species *Darlingtonia californica*, the only state park in Oregon to do so(http://oregonstateparks.org/index.cfm?do=parkPage.dsp_parkPage&parkId=81). The Darlingtonia plant itself requires very specific conditions in order to survive including shallow water to continually run over their root system. Even more so, it was discovered that the plants are extremely temperature sensitive and will begin to die "...if exposed to temperatures above 10°C for a prolonged time" (Adlassnig, Wolfram. "The Roots of Carnivorous Plants ." *Plant and Soil* (2005): 127-40. *ResearchGate).* In addition, the Darlingtonia are extremely sensitive to salt and nitrogen species in the soil since they receive their required amount through the insects they consume (http://water.oregonstate.edu/sites/water.oregonstate.edu/files/highlight/grandy_darlingtonia.pdf).

Recently, the plants have been experiencing a rapid decline in health. Initially, it was believed that the plants were competing for resources with trees growing in the fen. The trees were subsequently cut down to remedy this, however no signs of improvement followed. A piezometer was installed at Darlingtonia in order to record water conditions as well as other external features such as salinity, pressure, and temperature. As demonstrated in Figure 1., the piezometer is located just off the boardwalk of the park where it can asses the aquifer without disturbing the plants. It is now believed that either deviation in temperature from the plants' preferred range of ≤10°C or excess nitrogen in the soil is the cause of the plants' deteriorating health.

Figure 1. A satellite photo from Google Images that shows the boardwalk at Darlingtonia State Park. The red dot indicates the location of the piezometer.

To better understand possible sources of contamination, a one mile radius was established from the Darlingtonia site, and local buildings were examined. Initial research into the surrounding area lead to the discovery of two campsites, a resort location, and a home directly upstream from the state park. The locations were then mapped out on a topographical imagery of the site and compared to the site as well as streamflow for possible contamination as seen in Figure 2.

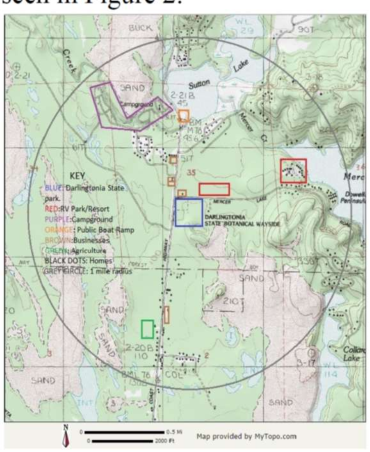


Figure 2. Map of the area surrounding Darlingtonia State Park, located 5 mile North of Florence, OR. The red indicates the Elks RV Park and Mercer Lake Resort from left to right while private businesses and homes are indicated in brown.

All businesses and homes were then investigated further with regards to wastewater disposal. The closest possible source for large scale contamination, the Elks Lodge RV Park, has space for 40 RVs, a waste dumping station connected to a storage tank, and another underground tank for waste storage. Both tanks on the property are serviced once a year. The water used at this site is provided by the City of Florence and is treated in an off-site septic system. Another possible source of contamination, Sutton Campground, is owned by the U.S. Forest Service and operated by American Land and Leisure hosts. This campground has 79 designated RV locations but does not have a dump station. In addition, there are 80 tent sites, 2 large group sites which can serve about 100 people, and one smaller camp site that can service about 30 people. The facilities include 6 flush toilet restrooms (which store waste in holding tanks that are pumped regularly), 19 water stations, and 2 grey water dump stations with unknown drainage systems. Water for this campground comes from Heceta Water People's Utility District. The last possible large source is Mercer Lake Resort located 0.8 miles away from Darlingtonia on Mercer Lake. This resort has 7 cabins with bathroom facilities, 3 cabins without, and 24 RV sites with one dump station. Further information such as wastewater treatment and water use could not be obtained due to difficulty in communicating with the resort. There is also a home just east of the Darlingtonia site, however it is unknown whether or not this home uses a septic system for wastewater treatment. It is possible that the effluent points in any of these systems may reach a juncture in the water table and thus enter the aquifer that feeds into the Darlingtonia's root system.

In order to assess whether or not the water table had been contaminated, colorimetric assays for both ammonia and nitrate were conducted. However, before actual water samples could be processed, preliminary testing was necessary to test the integrity of the tests. As a result, new standard curves were created, the detection limits were tested for both high and low concentrations to examine the behaviors of both assays, and interference tests were run to examine how results may change when in the presence of other nitrogen species or soil.

Standard curves were first created with the synthesis of the reagents necessary for each of the assays. For the Ammonia assay, a new standard curve had to be created with each new batch of reagent. Three standard curves were created over the duration of the project as the 2-Phenylphenol-Nitroprusside Reagent would undergo a color change depending on the age of reagent. Each standard curve improved in accuracy while the third and final standard curve exhibited the most accurate triplicate values while also having an R^2 value of 0.9988 (Figure 3.).

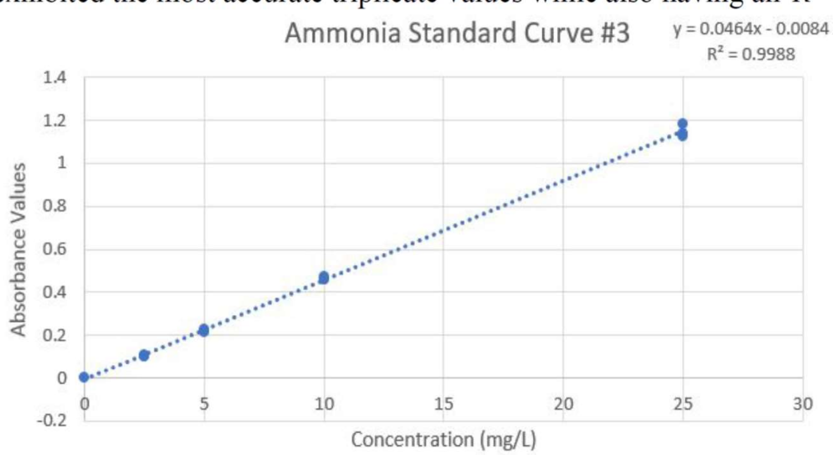


Figure 3. The third standard curve for the ammonium assay which has an R^2 value of 0.9988: an acceptable amount of accuracy. The assay was performed in triplicate as directed by the Standard Operation Procedure.

However, the nitrate standard curve did not require the same level of upkeep with regards to standard curves. Once the initial standard curve was created (Figure 4.) it was deemed to have a sufficiently high R^2 value and stable enough reagents that another standard curve was not necessary.

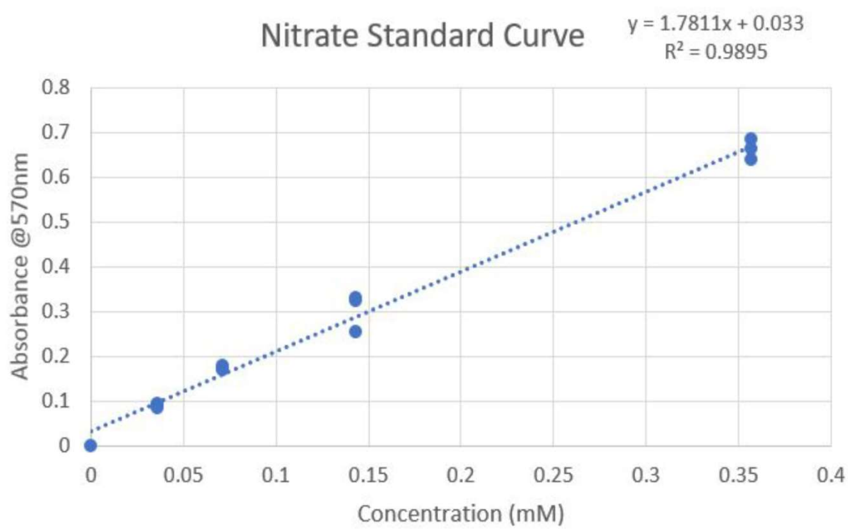


Figure 4.The standard curve for the nitrate assay which has an R2 value of 0.9895 which is an acceptable amount of accuracy. The assay was performed in triplicate as directed by the Standard Operation Procedure.

Following the creation of the standard curves, standards exceeding the limits of the assays were created to test the detection capabilities of the assays. Since the ammonia assay has a detection limit of 0-25mg/L, lower standards of 0.5,1.0,and 2.0mg/L and higher standards of 30.0 and 50.0 mg/L were created in excess of typical standards to ensure the graphed behavior would remain linear with regards to the created standard curve. Not only did all triplicate measurements remain accurate with regards to the given amount in all three trials, but all points remained linear with the initial standard curve. However, the nitrate assay did not remain as consistent. While the lower standards of 0.018, 0.009, and 0.004mM remained linear with the standard curve, the high standards of 0.5355mM and 0.714mM did not exhibit linear behavior. Rather, true deviation began at around 0.350mM. These results are consistent with the 0.0-0.323mM range established in the standard operating procedure of the nitrate assay. By confirming the established ranges from the SOPs, data can be considered more accurate when experimental samples are tested in the assays.

The final preliminary test involved testing the interference by either nitrogen species or soil particulate on the amount of ammonia and nitrate. That is, observing how nitrate, ammonia, or nitrite may prevent the accurate reading of one another in the assays. In order to test how nitrogen species act, control samples of ammonia and Di water, nitrate and DI water, and nitrite and DI water were tested with mixtures of nitrate:nitrite, nitrite:ammonia, ammonia:nitrate, and mix of all three species to determine exactly which may interfere with another. While the nitrogen species interference test with regards to ammonia shows trace amounts of nitrate and nitrite detected (Figure 5.), they occur in such negligible amounts that no interference is said to occur.

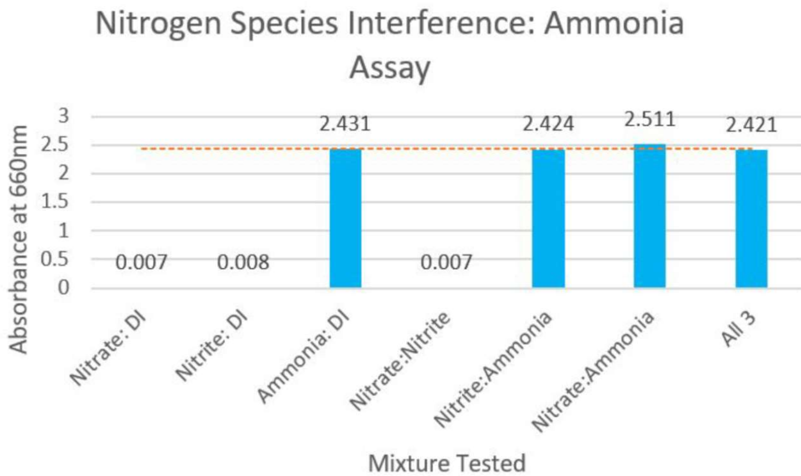


Figure 5. All samples tested containing ammonia remain within acceptable error amounts from the ammonia baseline absorbance value of 2.431. Nitrate and nitrite show no detection in either the controls or within the mixtures confirming no interference in the assay.

However, when all of the samples were performed in the nitrate assay, a considerable amount of nitrite was detected; 0.066 absorbance to nitrate's 0.274 absorbance value (Figure 6.).

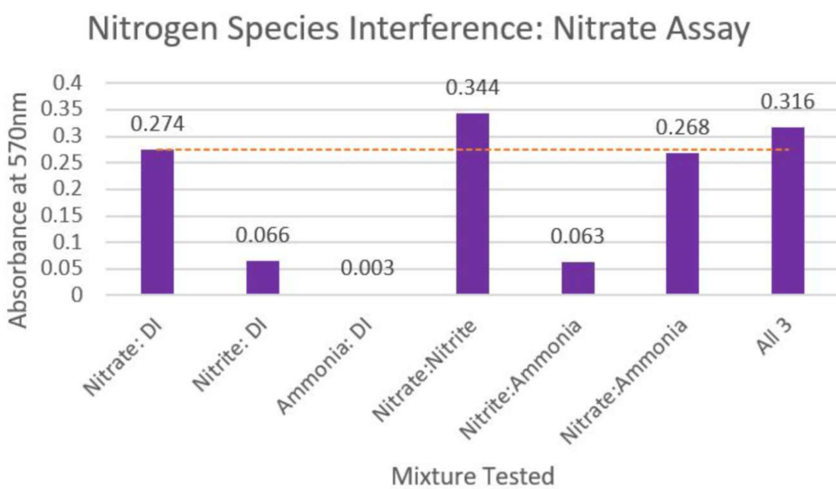


Figure 6. The nitrogen species interference test for nitrate detected a considerable amount of nitrite within the control, indicating that nitrite causes interference when trying to get an accurate reading on nitrate absorbance. Ammonia is undetected within this assay and causes no interference.

The nitrate:nitrite sample only further proved the interference when the absorbance value read back as 0.344, the sum of control nitrate and nitrite values. Therefore, it can be concluded that nitrite does cause interference with nitrate. That being said, it is not cause for concern as because of the rapidly occurring nitrification process where nitrite present in soil and river samples is transformed into nitrate. Even though the nitrite does cause some interference, it is not necessarily detrimental to the as the presence of nitrite with nitrate gives a clearer understanding of the amount of nitrate present with the amount soon to be present.

Despite not being tested for by itself, nitrite was tested for interference in order to get a complete picture of nitrogen species behavior. Nitrate and ammonia exhibited negative absorbance values that proved consistent throughout all tested samples, Figure 7. As nitrite concentration is not a primary concern of the experiment, the minimal amount of interference does not matter.

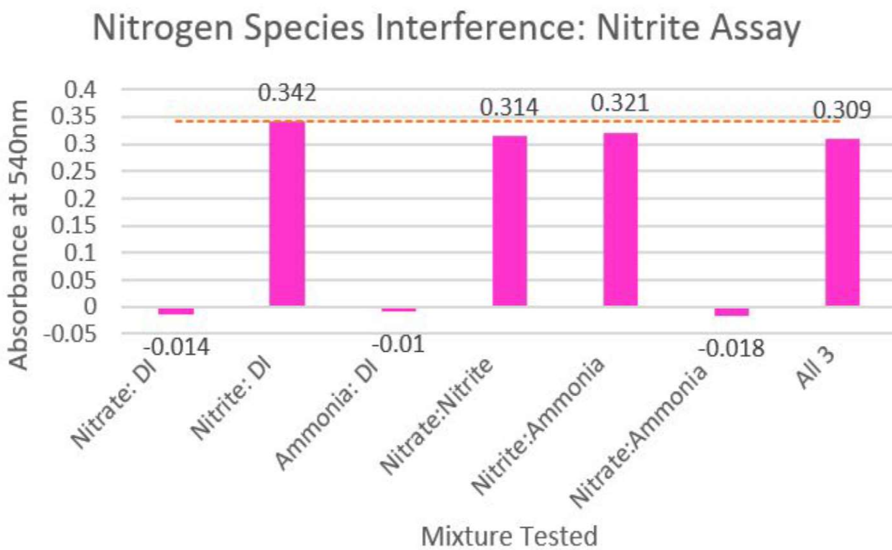


Figure 7. The nitrogen species interference test with regards to nitrite shows negative absorbance amounts of nitrate and ammonia detected. However, these are consistent throughout the assay and cause no immediate cause for concern.

Having examined how nitrogen species interact with one another, the final preliminary test for the assays was the determination of interference by soil. Interference would arise from either soil particulate or fertilizers added to the soil that may affect the chemical composition. Soil was obtained and samples including of a control standard, DI water and soil, standard and soil, and a 1:1 mixture of DI water and a standard mixed with soil were prepared. The samples were created for both ammonia and nitrate and allowed to sit once created to ensure that the soil was thoroughly mixed. The samples were then centrifuged to obtain clear water samples. The nitrate assay showed minimal interference in that the samples containing soil prevented all of the nitrate present from being detected (Figure 8).

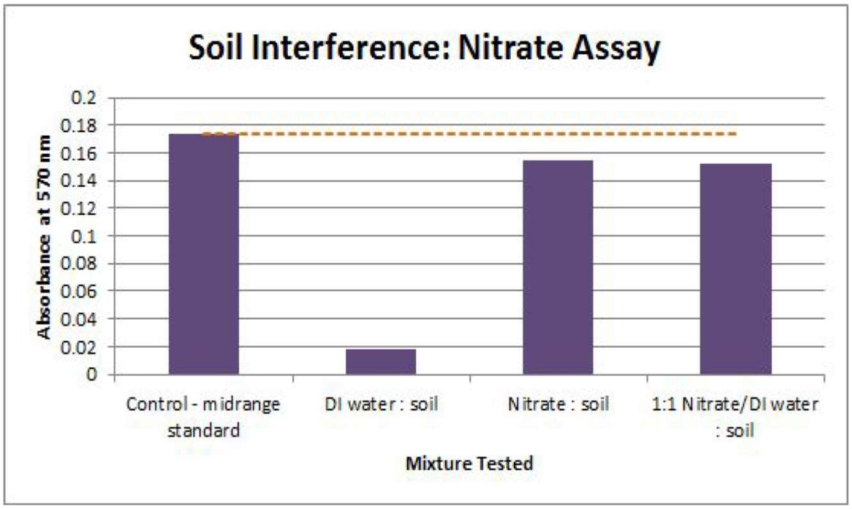


Figure 8. Soil interference prevented the full amount of nitrate to be recorded in the assay by a value of about 0.020.

On the other hand, the soil interference test for the ammonia assay revealed that soil greatly interfered with the amount absorbed. On average, there was a 0.1447 difference in what was expected and what was absorbed, Figure 9.Therefore it is vital that all samples obtained from the Darlingtonia site be free of soil particulate.

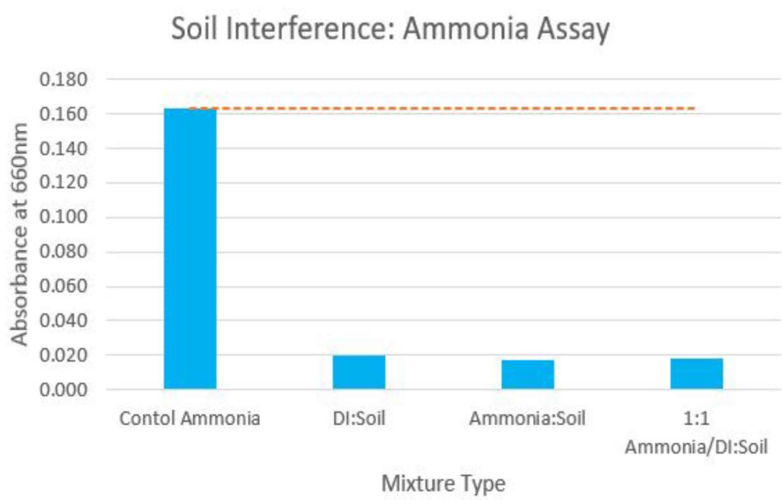


Figure 9. Soil interference test results with regards to the ammonia assay. Any time soil is present, absorbance decreased significantly from expected values.

Having completed all of the preliminary testing, the Kelly research group traveled to Darlingtonia State Natural Site on August 5th, 2017. While there, water samples were taken from 11 sample sites including the piezometer and stream, temperature readings were recorded at depths of 1" and 6" from 16 sites, and general notes about the overall health and appearance were recorded. The water samples were then taken back to the lab to undergo nitrate and ammonia colorimetric assays while the collected temperature data went under immediate analysis along with the past data collected from the pressure transducer in the piezometer.

While performing the colorimetric assays, nitrate yielded negative absorbance values leading to negative concentrations after computation with the standard curve. Therefore, it can be assumed to have a value below the detection limit of the assay or simply zero. On the other hand, when first performing the ammonia assay, the concentrations came out much higher than expected (Figure 10.).

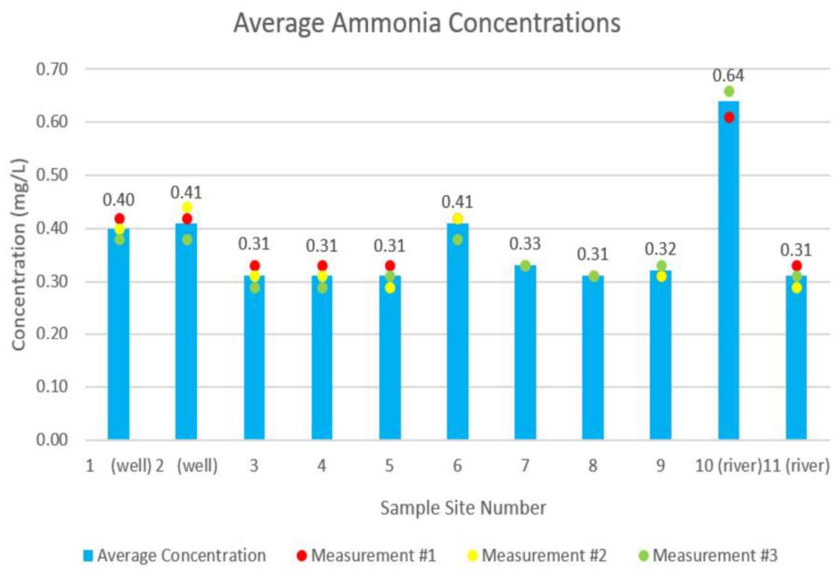


Figure 10. Final concentration in mg/L of water samples taken at Darlingtonia State Natural Site.

In order to confirm that the amounts were correct, the assay was run with many different water samples including three Darlingtonia samples, samples from a nearby creek and river, a known concentration of ammonia, and a deionized water sample. While the samples returned the exact same values as before, the deionized water sample returned a value of 0.30. It was then concluded that 0.30 is actually the lowest determinable amount and should therefore be treated as a zero value. The final results of the assays were then adjusted with this new zero value for both the Darlingtonia concentrations (Figure 11.) and the final confirmation test (Figure 12.).

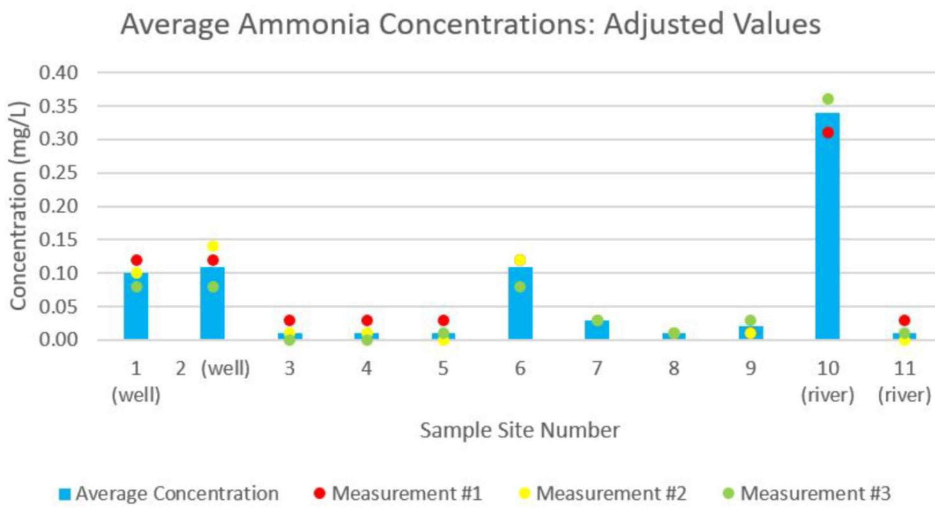


Figure 11. Final concentration in mg/L of water samples taken at Darlingtonia State Natural Site with the adjusted 0.30 mg/L zero value.

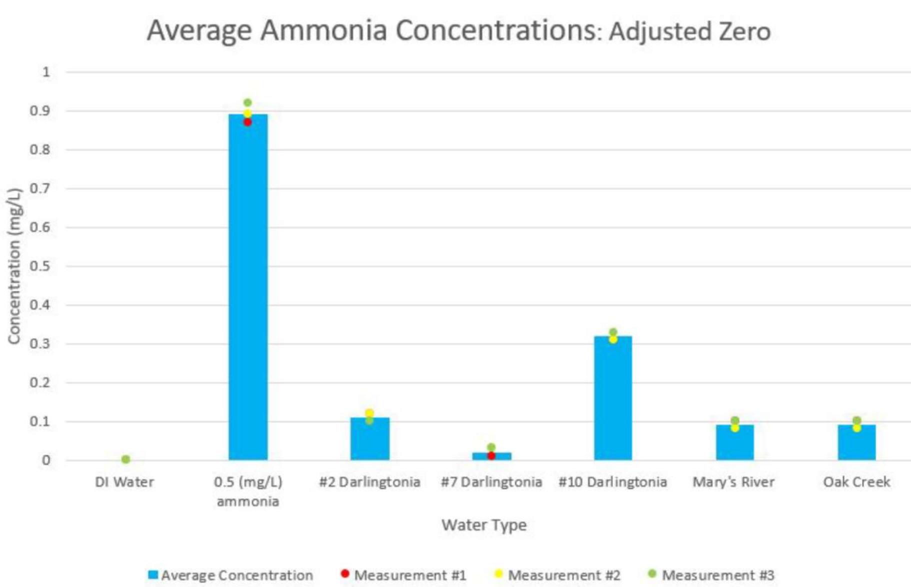


Figure 12. Final confirmation test with DI standard, 0.5mg/L standard, Darlingtonia standards, and local river and creek standards.

After adjusting the results for the new zero, it is clear to see from the confirmation tests that the results are accurate between multiple runs and likely reflect the true concentrations. While most of the Darlingtonia samples occur in small enough concentrations to not be the likely cause of deterioration in plant health, the water sample taken downstream has a significantly higher amount than the rest of the samples. Location suggests that a leak in the vault toilet may lead to the inflated concentration of ammonia but further research would be necessary to establish any concrete reasoning.

The temperature data taken from the park was immediately mapped to represent both 1" below the surface (Figure 13.) as well as 6" (Figure 14.) to gain a better understanding of the relationship between temperature and perceived plant health.

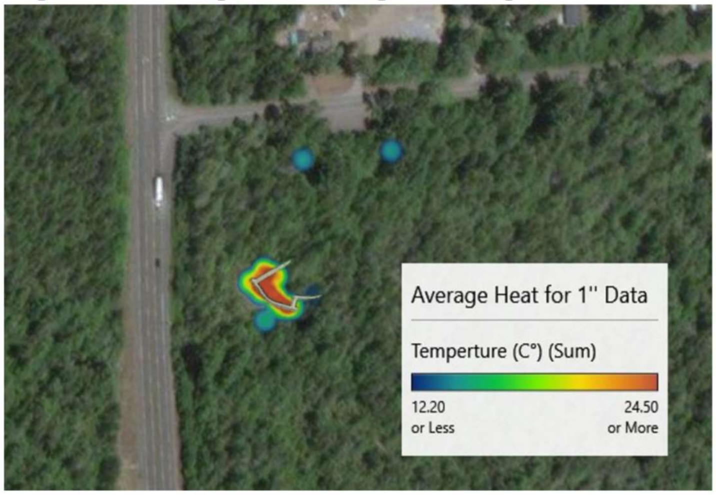


Figure 13. Map reflecting soil temperature at a depth of 1" based off of measurements taken at Darlingtonia State Park with respect to the board walk.

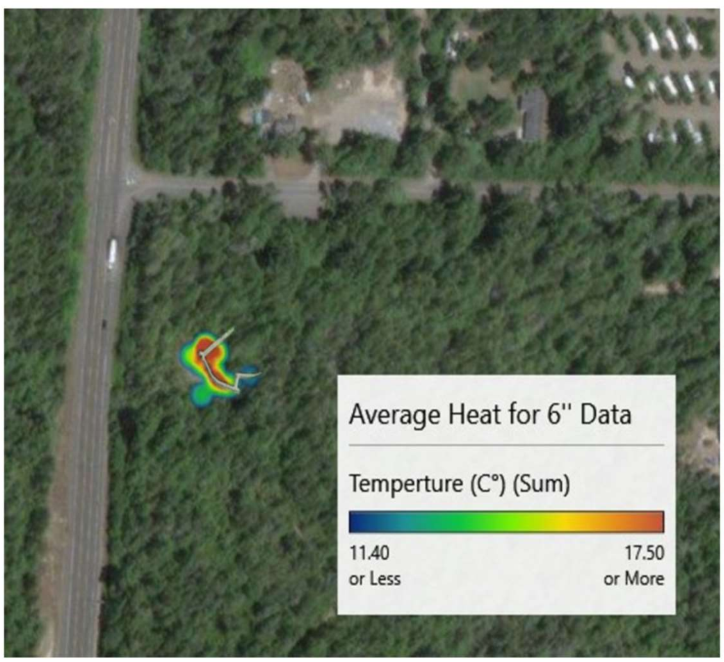


Figure 14. Map reflecting soil temperature at a depth of 6" based off of measurements taken at Darlingtonia State Park with respect to the board walk.

While it is important to note that temperatures were taken in the hottest part of the afternoon, the temperature never reached the desired 10°C range that is preferred by the plant for optimal growth. In fact, review of the temperature data collected from the pressure transducer shows that of the past 357 days, 196 have daily averages that surpass this range (Figure 15.) as well as half of the monthly averages (Figure 16).

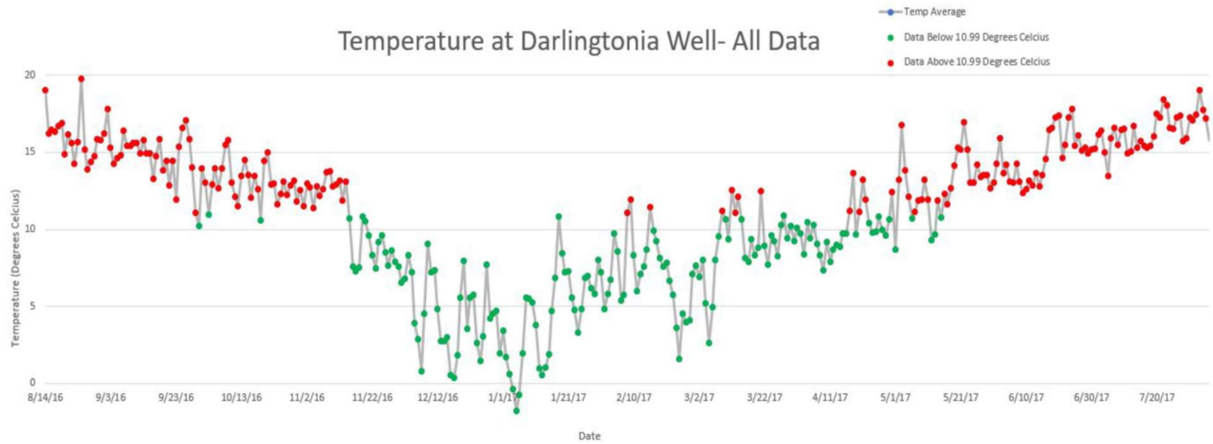


Figure 15. Data points depicting daily temperature averages over 357 days based off of piezometer data. Temperatures in green indicate days with an average less than 10.99°C while red points indicate days that exceed temperatures above 10.99°C.

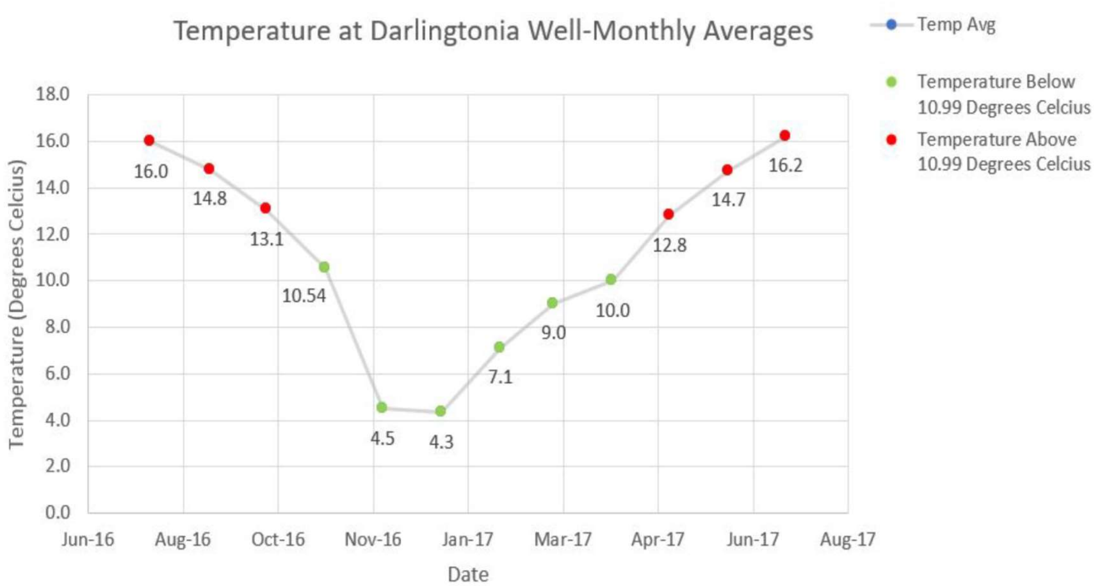


Figure 16. Calculated monthly averages based on piezometer data indicate where the average temperatures for each month fall within the ideal range (green) and when they exceed it (red).

However, all data taken from the pressure transducer may not be the best representation of temperature throughout the park as it is just one location on one side, and the water has a tendency to become stagnant in the well itself. That being said, with the large periods of time where the temperature exists over the desired range, temperature is a cause for concern with regards to overall plant health. Having performed the colorimetric assays of the water samples and in-depth analysis of the temperature, it can be concluded at this time that contamination by nitrogen species is not the likely cause of health issues while temperature is something of concern and should be monitored more closely in the future.

APPENDIX D: Water Sample Analysis Reports from Edge Analytical

EDGE ANALYTICAL

Burlington, WA *Corporate Laboratory (a)*
1620 S Walnut St - Burlington, WA 98233 - **800.755.9295** • 360.757.1400

Bellingham, WA *Microbiology (b)*
805 Orchard Dr Ste 4 - Bellingham, WA 98225 - 360.715.1212

Portland, OR *Microbiology/Chemistry (c)*
9150 SW Pioneer Ct Ste W - Wilsonville, OR 97070 - 503.682.7802

Corvallis, OR *Microbiology/Chemistry (d)*
540 SW Third Street - Corvallis, OR 97333 - 541.753.4946

Bend, OR *Microbiology (e)*
20332 Empire Blvd Ste 4 - Bend, OR 97701 - 541.639.8425

Drinking Water Report

Client Name: OSU - Institute for Water & Watersheds
1442 NW Dixon St
Corvallis, OR 97330

Reference Number: **17-16425**
Report Date: 7/20/17
Approved By: anp,bj,kdf,lrs
Authorized by: Sarah P Miller

Sarah P Miller
Lab Manager, Corvallis

Project: Darlingtonia
Field ID: Well #1
Sample Description: Darlington State Wayside
Sample Date: 7/11/17 13:45

Lab Number: 046-37377
Date Received: 7/11/17
Sampled By: Trevor Grandy
Sampler Phone:

CAS Number	Analyte	Result	MCL	Pass	Lab	QL	Units
E-10184	ELECTRICAL CONDUCTIVITY	**77.5**			a	10	uS/cm
14797-55-8	NITRATE-N	**ND**	10	Pass	d	1.0	mg/L
7440-70-2	CALCIUM	**1.53**			a	0.5	mg/L
7439-95-4	MAGNESIUM	**1.29**			a	0.5	mg/L
7440-09-7	POTASSIUM	**0.65**			a	0.5	mg/L
7440-23-5	SODIUM	**11.6**			a	0.5	mg/L
7439-89-6	IRON	**1.35**	0.3	Fail	a	0.05	mg/L
7439-96-5	MANGANESE	**0.012**	0.05	Pass	a	0.01	mg/L
7631-86-9	SILICA	**15.0**			a	0.05	mg/L
16984-48-8	FLUORIDE	**ND**	4	Pass	a	0.5	mg/L
16887-00-6	CHLORIDE	**14.3**			a	0.2	mg/L
NA	CARBONATE	**ND**			a		mg/L
NA	BICARBONATE	**ND**			a	5.0	mg/L
14808-79-8	SULFATE	**0.6**			a	0.4	mg/L

otation:
CL = Maximum Contaminant Level, maximum permissible level of a contaminant in water established by EPA; Federal Action Levels are 0.015 mg/L for Lead and 1.3 mg/L for Copper. Sodium has a commended limit of 20 mg/L. A blank MCL value indicates a level is not currently established.
. = Quantitation Limit is the lower calibration cpncentration.
) = Not detected above the listed specified reporting limit (QL).
AS Number = Chemical Abstract Service Number is an unique identifier of the chemical tested.

EDGE ANALYTICAL

Burlington, WA	Corporate Laboratory (a)	1620 S Walnut St	Burlington, WA 98233	800.755.9295 • 360.757.1400
Bellingham, WA	Microbiology (b)	805 Orchard Dr Ste 4	Bellingham, WA 98225	360.715.1212
Portland, OR	Microbiology/Chemistry (c)	9150 SW Pioneer Ct Ste W	Wilsonville, OR 97070	503.682.7802
Corvallis, OR	Microbiology (d)	540 SW Third Street	Corvallis, OR 97333	541.753.4946

NELAP ACCREDITED TNI LABORATORY

Data Report

Client Name: OSU - Institute for Water & Watersheds
1442 NW Dixon St
Corvallis, OR 97330

Reference Number: **17-29886**
Project: Darlingtonia

Report Date: 11/6/17

Date Received: 10/23/17
Approved by: bj,hkl,lrs,spm,tbp
Authorized by:

Sarah P Miller
Lab Manager, Corvallis

Sample Description: Darlingtonia St Botanical - MW-1 | Sample Date: 10/22/17 12:30 pm
Lab Number: 64861 | Sample Comment: | Collected By: Trevor Grandy

CAS ID#	Parameter	Result	PQL	MDL	Units	DF	Method	Lab	Analyzed	Analyst	Batch	Comment
7440-70-2	**CALCIUM**	1.51	0.5	0.009	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
7439-89-6	**IRON**	1.26	0.05	0.0012	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
7439-95-4	**MAGNESIUM**	1.33	0.5	0.001	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
7439-96-5	**MANGANESE**	0.012	0.01	0.0002	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
7440-09-7	**POTASSIUM**	0.59	0.5	0.1	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
7631-86-9	**SILICA**	13.0	0.05	0.003	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
7440-23-5	**SODIUM**	11.0	0.5	0.05	mg/L	1.0	200.7	a	10/31/17	ANP	200.7_171031a	
16887-00-6	**CHLORIDE**	15.5	0.2	0.0223	mg/L	1.0	300.0	a	11/4/17	HKL	I171103A	
16984-48-8	**FLUORIDE**	ND	0.5	0.0072	mg/L	1.0	300.0	a	11/4/17	HKL	I171103A	
14808-79-8	**SULFATE**	0.46	0.4	0.0497	mg/L	1.0	300.0	a	11/4/17	HKL	I171103A	
NA	**BICARBONATE**	11.1	1.3		mg CaCO3/L	1.3	SM2320 B	a	11/4/17	SRS	ALK_171104	
NA	**CARBONATE**	11.1	1.3		mg CaCO3/L	1.3	SM2320 B	a	11/4/17	SRS	ALK_171104	
E-10184	**ELECTRICAL CONDUCTIVITY**	76.5	10		uS/cm	1.0	SM2510 B	a	11/4/17	SRS	EC_171104	
E-10173	**TOTAL DISSOLVED SOLIDS**	57	10		mg/L	1.0	SM2540 C	a	10/26/17	HKL	TDS_171026	
14797-55-8	**NITRATE-N**	ND	1.0	0.072	mg/L	1.0	SM4500-NO3 D	d	10/24/17	RAP	DNO3_171024B	
14797-65-0	**NITRITE-N**	ND	0.005	0.0014	mg/L	1.0	SM4500-NO3 F	c	10/25/17	CPO	CNO3_171025	

Notes:
ND = Not detected above the listed practical quantitation limit (PQL) or not above the Method Detection Limit (MDL), if requested.
PQL = Practical Quantitation Limit is the lowest level that can be achieved within specified limits of precision and accuracy during routine laboratory operating conditions.
D.F. - Dilution Factor

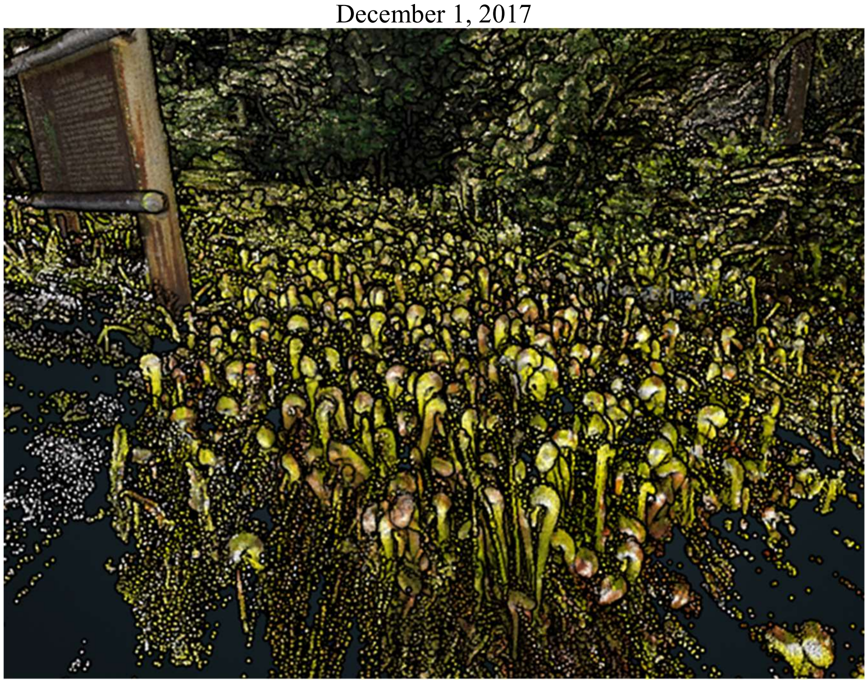
APPENDIX E: 2016 and 2017 *Darlingtonia* Population Study Results

Darlingtonia Botanical Wayside Monitoring Project
Interim Report 2017

Prepared by Trevor Grandy, Megan Chellew, Mary Santelmann, and Joseph Kemper

Submitted to Oregon State Parks

December 1, 2017



Ground-based LiDAR image of *Darlingtonia californica* at Darlingtonia Wayside State Park

Introduction

Darlingtonia californica (syn. *Chrysamphora californica*) is a carnivorous plant native to northern California and Oregon. *D. californica* is monotypic and the only member of the *Sarracinaceae* found west of the Rocky Mountains. It was discovered in a marsh adjacent to an upper Sacramento River tributary and recognized by John Torrey as a distinct pitcher plant, who named it for his dear friend and known botanist William Darlington (*Darlingtonia*), and the origin of its discovery (*californica*) (Lloyd 1942). *D. californica* are considered a rare find in the wild; there are few known concentrations within its limited geographic range of Oregon and California. The population at Darlingtonia Wayside, a small state park located on the Pacific coast is of particular interest due to the size and vigor of the population (Figure A-1). This botanical preserve is the only state park in Oregon dedicated to the protection of a single plant (History of Oregon State Parks).

D. californica plants maintain a distinctive shape including a ballooned head with external fishtail appendages and extrafloral nectaries, as well as a tubular torsioned leaf that tapers to a strong perennial rootstock, supporting a rosette of old and young ramets (Adalassnig et al. 2005). *D. californica* grows in a clonal fashion and frequently colonizes open, sunny areas. It is considered a seral bog species, and are likely to be poor competitors without fire or additional disturbance in later successional stages (Ellison et al. 2005; Ellison et al. 2012). *D. californica* occur from sea level to approximately 2,600 meters in altitude. They are commonly associated with *Sphagnum* moss and *Ledum glandulosum* (Laborador tea) in poorly drained (coastal) fens or basins, where *Pinus contorta* dominates the canopy with few other stunted trees and shrubbery; *Drosera rotundifolia* is another carnivorous plant that can be found in this ecological association. One of the most important factors that supports *D. californica* growth is the presence of flowing water, which keeps their root system cool and functional (Crane 1990; Oregon.gov 2004).

This pitcher plant fills and maintains internal water levels with its own root system, distinguishing *D. californica* from open-mouthed pitcher relatives that rely on rainfall or other above ground sources. *D. californica* unique plant anatomy has earned common names like the ‘cobra lily’ and comparison to reptilian or extra-terrestrial life (Ellison et al. 2005; Ellison et al. 2012; Adalassnig et al. 2005). The *D. californica* vessel sports many chlorophyll-free leaf fenestrations or areolae, to transmit light and confuse insect prey. Internalized stiff, down-tracking hairs encourage insects towards a basal pool of water for digestion via mites, bacteria and enzymes, leaving only chitinous remains (Fashing 2004). Large, showy and fragrant flowers bloom in spring (April-August depending on altitude): each flower arises from a separate stalk per plant, with five crimson-purple petals concealing androecium and gynoecium. The petals are surrounded by yellow-green lanceolate sepals. Floral anatomy is melittophilic with abundant pollen and nectar production, suggesting bees as a potential pollinator. Mature capsules develop post fertilization and produce approximately 2,000 seeds each (Meidl et al. 2011).

The Darlingtonia Wayside State Park and Botanical Preserve is located adjacent to U.S. Highway 101, five miles north of Florence, Oregon (in Lane County). An original purchase of 16.54 acres in 1946 and a subsequent purchase of an additional 1.38 acres in 1963 were completed to preserve and feature the special plants as a natural attraction (History of Oregon State Parks). Recent concern over the maintenance and protection of *D. californica* at Darlingtonia Wayside has led to consideration of site hydrology. Over time, as more trees and woody shrubs are recruited, the wetland may dry out and the over-story will shade out carnivorous plants of interest, which have comprised the majority of the herbaceous understory in past. Current management strategies have included tree removal and sandbag/log dams to retain soil moisture, slow transpiration, and halt forest encroachment. It is not clear at this time if these strategies for hydrologic restoration and fen preservation will yield desirable outcomes. It is known that *D. californica* tends to occur and thrive with full sun exposure and moist, nitrogen/phosphorus-poor soil, though further research is required to describe the precise conditions for optimal habitat at Darlingtonia Wayside.

Due to concerns for the sustainability of the *D. californica* population, Oregon State Parks, in collaboration with a team of scientists from OSU established a program to monitor the *D. californica* population at Darlingtonia Wayside and determine if *D. californica* is increasing in abundance, decreasing in abundance, or maintaining a stable population size. Initiating this multi-year study of Darlingtonia Wayside will establish a framework to answer the following questions:

1. How does survival and growth of *D. californica* in shaded (forest) areas compare to *D. californica* in open sunny areas?
2. What is the current level of abundance and status of the *D. californica* population at Darlingtonia Wayside?
3. Is *D. californica* abundance and plant population demography changing over time at Darlingtonia Wayside? (note, this will require continued monitoring these populations over time)
4. What factors appear to be influencing the cover, abundance, and vigor of *D. californica* at Darlingtonia Wayside?

Our strategy for answering these research questions includes establishing long-term monitoring plots in shaded and open exposure areas within Darlingtonia Wayside fen. Plots were carefully established to be accessible from either the perimeter of the fen or areas adjacent to the existing boardwalk to minimize site disturbance or damage to existing clumps of *D. californica*. Ground based LiDAR imagery was captured for exploratory analysis and investigation of using remotely sensed imagery to monitor *D. californica* population size over time at the scale of the entire site occupied by *D. californica* at Darlingtonia Wayside.

Initial results and baseline data on the relative abundance and vigor of *D. californica* under conditions of sun, shade, and site wetness are presented in this interim report based on sampling conducted in summer 2016. Ongoing monitoring for multiple years of will be required to identify patterns and trends in the population and provide estimates on population size and survivorship. This interim report to Oregon State Parks outlines our initial findings.

<u>Study Area & Methods</u>

Establishment of Darlingtonia Wayside Monitoring Plots and Field Sampling Methodology

Sampling was done using a stratified-random plot selection design. We divided the fen into four sections based on location of the section relative to the boardwalk (Figure A-2, Table A-1 and Table A-2). The 'Contained Fen' is the section enclosed by the boardwalk on 3 sides of the interior (deck sections 1, 2, 3). The 'Central Fen' section includes all areas from the right side of the Darlingtonia informational sign, to the nearest edge of the boardwalk; the 'Central Fen section is directly perpendicular to deck section 2 (11.01 meters). The 'South Fen' (at the south end of the site, to the left of the Darlingtonia informational sign as one faces the sign), is adjacent to deck sections 4, 5, 6, 7. The 'South Fen' section is perpendicular to the aforementioned decks. Lastly the 'North Fen' (to the right of the Darlingtonia sign and the 'Central Fen', facing the sign), is encompassed only by deck section 1. Most plots are demarcated with a numbered metal tag attached to a PVC post (Table A-3) for relocation. It was not possible to collect GPS points for each plot as there was poor signal within the fen, and thus insufficient accuracy and resolution. Instead, we located plots using tape measure and compass directions to identify and establish plots at randomly-selected grid coordinates on our visualized grids for each section (Figure A-2, Figure A-3, Table A-2, and Table A-3).

We designated three sun and three shade plots within each of the four sections of fen for a total of 12 plots in sun and 12 plots in shade (Table A-2, Table A-3). The sun plots are all located in closer proximity to the boardwalk in open sunny areas (no tree coverage), while the shade plots are farther from the boardwalk in comparison, usually closer to the forested edge of the fen (tree coverage). A rangefinder was used to determine the proportion of hours from 7 am to 7 pm that each plot has shade or sun coverage. We noted that the Central Fen will need to be sampled for six additional shade plots in future years; owing to the position of trees on the western, but not southern side of these plots, the currently designated shade plots have longer time periods of greater sun exposure in summer than other shade plots (Figure A-5).

As noted above, we established a grid for each section, and plot locations were chosen randomly within the grid, using a random number generator for plot grid coordinates. All grids were established 1 to 2 meters out from the boardwalk, and placed to avoid areas without *D. californica* coverage. If a plot coordinate intended for a sun plot landed in the shade or vice versa, the plot category was reassigned in that case. If a randomly-selected plot coordinate fell less than 1 meter away from an established plot, the coordinate in question was resampled. We made an exception for the distance threshold where *D. californica* patches in a particular subsection of fen were limited, and there were fewer areas to sample; in the case where there are few sunny or shady sections of *D. californica* in a particular part of the fen, or the plot is difficult to access without excessive disturbance or trampling then plots may be placed only 1 m apart. We made this exception a total of four times, once in each fen subsection (for the contained fen the exception was made for a shade plot, for the other three fen subsections all exceptions were made for sun plots) (Table A-3). The primary objective of this methodology was to acquire sufficient sample plots in each portion of the fen to identify trends in vigor and abundance, while minimizing site disruption and to have an equal number of plots for each category.

To randomly select a location for a plot, one must visualize the square meter grid with a rangefinder and meter tape for appropriate meter resolution and accuracy (use the grid dimensions provided in the table above, for each section). Then (x, y) coordinates are chosen with a random number generator (based on the x, y dimensions of the grid) and the southwest corner of the plot is marked with a tagged PVC pole, 10 cm above ground. It is crucial to record the tag number associated with the plot. Note, if obstructions within the site prevent the use of the SW corner, the SE corner or other may be used, and must be noted.

Each plot is surveyed by laying a PVC meter square (four PVC pipes attached with elbow or 'L' pieces) over the plot, matching the SW corner of the meter square to the tagged PVC pole marking the plot. The PVC square enables a more precise visual estimation and record for percent cover of bare soil or exposed water within the plot. Within the meter square one must identify and note percent coverage of non-*D. californica* plants as well. Incremental markings on meter square are helpful with estimates. For repeat sampling, we suggest noting the compass orientation of the plot parallel and perpendicular to the boardwalk and the coordinate distance between the plot and the boardwalk. Finally, data collectors should measure canopy coverage with a densitometer extended over the center of the plot (facing North, South, East, West and averaging the measurements). For each periodic round of data collection, it is necessary to also collect sun shade coverage for the entire fen throughout the day, on the hour (from 7 am to 7 pm)

(Figures A-4 & A-5). This is ideally completed on a day with open sky and no clouds. The purpose of sun coverage data is to capture the proportion of time in a given day (close to summer solstice) that the plots are sunny or shaded, in order to understand how much daily exposure *D. californica* individuals receive within the plot.

Each plot should have a count of the number of *D. californica* ramets per discrete cluster, within the plot. The ramet count is to be based on age class (Table A-4) and the number of flowers present should be recorded (dead or alive). Measure the two tallest ramets/shoots within the plot with a PVC pole or meter stick (measure length if they are not erect). As part of the data record for each plot, one should photograph it with the meter square.

LiDAR Acquisition and Visualization

We were able to successfully obtain imagery of the fen on June 28th, utilizing two Riegl 400 terrestrial laser scanners on the corners of the boardwalk. Data (in the form of a point cloud) were obtained with a several sensor scans, and were processed (using Cloud Compare) into a DSMs (Digital Surface Model) of different file formats (.bil, .las, .tiff). These data were used to manually count *D. californica* ramets captured from the imagery throughout the fen, using a virtual reality system (VRUI) in the OSU GeoMat Research Lab.

Installation of Geotechnical Boring and Groundwater Monitoring

As mentioned in previous reports, a geotechnical boring with the purpose of measuring water table height and for collection of water samples from the subsurface was installed on August 14, 2016 by Joe Kemper (OSU), Travis Grohman (OSU), with Justin Helberg (OSP) present. The geotechnical borings located on the north side of the boardwalk on a slight topographical rise (Appendix B). An In Situ pressure transducer and paired barometric pressure transducer were installed within the geotechnical boring and set to record hourly pressure readings to be calibrated to reveal the depth to the groundwater table. Data from the transducer and water samples provide “eyes beneath the ground” to keep record of subsurface flow patterns to determine if adequate water is quenching *D. californica* root systems year-round.

A monitoring plan was developed and included monthly visits by two field personnel throughout the year-long study period to collect water level data from the pressure transducer within the nine-foot geotechnical boring in Darlingtonia Wayside. Data from the transducer was compiled to establish a baseline groundwater depth trend for the site beginning in the 2016-2017 water year (October 1 to September 30). We analyzed groundwater depth data for external forces impacting groundwater availability at the site including tidal influences, precipitation events and groundwater pumping activity within the zone of influence.

We collected water samples from the boring to test inorganic ion levels (nitrates, chloride, sulfate, etc.) via anion chromatography analysis (EPA Method Number 300.0) in the Institute for Water and Watersheds (IWW) Collaboratory at Oregon State University in Corvallis, Oregon every month. Two samples were sent to Edge Analytical, a commercial laboratory in Corvallis for Quality Assurance/Control. Samples were collected with a three-quarter-inch polyethylene bailer after purging 2.5 gallons to remove all stagnant water within the boring before collection. Basic water chemistry parameters, pH, temperature, total dissolved solids, and conductivity (Table C-2), were taken during sample collection. Previous studies from Oregon State Parks included groundwater data from similar Groundwater Dependent Ecosystems (GDE) which were analyzed for the effects groundwater had on overlying vegetation community. We also searched for previous and concurrent studies that have cataloged the *D. californica* population to analyze other potential catalysts of the plant population’s abundance and vigor.

Local and regional trends within the North Florence Dunal Aquifer can reveal information about the flow of groundwater influencing Darlingtonia Wayside. Modeling the flow through the measurement of the piezometric surface and aquifer characteristics around the site vicinity reveals potential contaminant transport origins and sources of drawdown. Well logs made electronically available to the public through the Oregon Water Resources Department contain information about well installations, lithology and pumping tests for the North Florence Dunal Aquifer dating back to the 1940s. Researchers compiled these data to spatially analyze hydraulic conductivity and gradients, flow velocities, and medium-grained sand stratigraphy.

We spoke informally with residents at the Darlingtonia Wayside and Florence Farmers Market. Researchers shared local hydrologic information, to increase awareness of the groundwater risks associated with coastal aquifers, and listen to stakeholder concerns as a form of public outreach. Resources developed through the first two objectives of this study, which include groundwater elevation maps and conceptual models (Figures C-5, C-6, C-7, C-8), were provided for participants. These resources were made available to illustrate the 'sense of place' awareness between the shallow coastal aquifer and its stakeholders (making the unseen seen). Meetings also included information about resources the Lane County Public Health Authority and Oregon Domestic Well Protection Program have made available to residents.

Results

Darlingtonia Monitoring Plots

Sun and shade coverage data suggest that within the summer season, our designated sun plots spend most daylight hours with predominant to full sun exposure, while designated shade plots send the majority of daytime in at least partial shade (Figure A-5). Table A-7 and Table A-8 display the data from plots established this year at Darlingtonia Wayside. This year marks the second round of data collection for an experimental design intended to extend for several years. In each of the plots, the number of young (still growing and developing), mature (tall and morphologically developed, with a fully ballooned head, bright green color and fenestrations), senesced (mature individuals that have partially desiccated, turned brown, yellow, or red), and dead (fully desiccated individuals that have fallen and/or broken) *D. californica* were recorded. Number of flowers (green upright stalks with petals and/or inflorescence intact) and number of dead flowers (desiccated brown or black stalks that may be broken, with flower parts missing) were also recorded. The tallest individuals in each plot were measured as well. These data will provide an opportunity to compare and detect patterns between *D. californica* plants in plots that are primarily in shade or sun, over time.

Table A-10 indicates the results from one way paired sample t tests. Paired sample t tests investigate differences between the mean values for two sample populations. One tailed t tests were applied to compare shade populations to sun populations. The one tailed t tests examine sample differences in one direction (either greater or smaller), thus employing a larger window and more opportunity to detect subtler variation. Our *a priori* hypothesis stated the expectation that *D. californica* would fare better in sun compared to shade; the one tailed t-test examines the directionality of our prediction. All t tests have been considered in the context of a P value being significant if it is less than or equal to 0.05. None of the comparisons within individual categories (live ramets, dead ramets, or flowering shoots, Table A-10) were significantly different. This includes total number of *D. californica* shoots using a one tailed t test for all data categories (live, dead, flowers) shows no significant difference ($p = 0.45$) between *D. californica* in sun plots and shade plots; the number of *D. californica* ramets growing in sun and in shade a relatively similar.

Table A-9 indicates the one-way Analysis of Variance (ANOVA) test to compare different sections or blocks of the fen by *D. californica* vigor. We compared all data categories (live, dead, flowers, as defined in Table A-10) between the North, South, Central, and Contained fens. The ANOVA compares mean averages of multiple (3 or more) samples. The null hypothesis for an ANOVA test would be that two or more samples have the same mean values. Our one-way ANOVA for the fen blocks indicates a statistically significant interaction, thus two or more fen sample means are significantly different from one another ($p < 0.05$). Post-hoc t-tests (both one tailed and two tailed) made direct comparisons between all possible pairings (Table A-11) to see which fen blocks were different from each other. The South, Central, and Contained fen demonstrated no significant differences for any of the post hoc tests (Table A-11). However, there is a strong significant difference between the North fen and all other fen blocks (for both one tailed and two tailed t tests); there are fewer counts of *D. californica* in North fen (Table A-11). This outcome suggests certain environmental conditions at Darlingtonia Wayside may have an impact the pattern of *D. californica* survival and reproduction. We hypothesize that hydrology and moisture may be related to this difference, as the North fen was observed as the driest and least populated portion of Darlingtonia Wayside.

Digital imagery

Processing and analysis of the digital imagery obtained with LiDAR and exploration of its utility in monitoring *D. californica* plants at the site has been completed, and an initial visualization of the 3-dimensional images is included here in Appendix A. Owing to the limited collection of LiDAR data from only two sampling points, the data are relatively coarse and there are areas in which some plants blocked returns from other plants in their “shadow”. While it is possible to use these data for counts, many more sampling locations would be required to prevent the “shadowing” effect. Digital photos from permanent sampling points from multiple angles and locations in the fen might provide a better set of digital imagery to use in image processing for this type of counting.

Groundwater Monitoring

The groundwater monitoring program outlined in the Methods was successfully executed monthly from November 2016 to October 2017. Pressure transducer data was collected through December 2017. Water levels derived from the transducer data revealed the following temporal patterns: consistently high (near the surface) during the winter months, while gradually lowering throughout the summer months into late September and October (Figure C-3). As precipitation rates increased during the autumn months, groundwater levels gradually raised to the higher winter levels (Figure C-3). While water levels varied throughout the year, it is important to note differences in depth to water is on the magnitude of inches: from 0.10 feet (1.2 inches) to the water table in mid-March to 0.63 feet (7.5 inches) in the early October. Water depths were calibrated at the site of the boring. The boring is located in the north fen on a small, dry hummock (Figure B-1).

Short-term variations also appear in the pressure transducer data. The hourly pressure recordings provided resolution fine enough to display bi-daily tidal influences and groundwater table spikes during precipitation events. Precipitation data are provided by the Oregon Parks and Recreation Department collected from a rain gauge at Jessie M. Honeyman Memorial State Park 3 miles south of Florence.

Water table level variations in September and early October 2016 reveal a unique time frame differing from temporal, tidal, or precipitation patterns. Water levels generally appear to drop at a rapid rate initially, as much as 0.13 feet (1.6 inches) over 3 to 5 days. The drawdown rate tapers off over the next few days before water table levels rapidly increase to the approximate value prior to the 5 to 10-day event (Figure C-4). This pattern resembles a pumping influence: drawdown occurs at a rapid rate as the pump is initially turned on, water levels begin to level out as the aquifer equilibrates to the new steady-state of withdrawal, then water levels begin quickly recharge as the pump is turned off leveling out as the aquifer equilibrates to the steady state without withdrawal. An investigation into potential pumping sources is ongoing. Possible distances to the source of pumping are calculated from aquifer characteristics derived from public well logs and groundwater models (Table C-2 and C-3) and drawdown data derived from the pressure transducer (Figure C-3 & C-4).

Results from the monthly IWW Collaboratory anion analysis are displayed in Table C-1. Chloride was the only consistent anion detected throughout the year of sampling varying from 12.7 to 14.3 ppm (parts per million). Nitrate, the septic-associated anion of greatest concern, was detected at minimal levels. Laboratory analysis from Edge Analytical in July and October 2017 generally correlated with results from the IWW Collaboratory; chloride around 14.3 ppm and nitrate at undetectable amounts. Other analyses performed by Edge Analytical revealed elevated iron and silica concentrations, an expected result from a coastal aquifer with unconsolidated sand as a medium.

Undergraduate students participating in a summer internship with the School of Chemical, Biological, and Environmental Engineering at Oregon State University volunteered to conduct groundwater and surface water sampling in addition to shallow soil temperature probing at various points around Darlingtonia Wayside. The report produced from the analysis is provided as Appendix D. Sampling followed the same procedures outlined in the Methods section and revealed similar results: low nitrate levels within the fen. However, surface water samples taken from the downstream location of the creek running between the parking lot and fen revealed ammonia concentrations of 0.34 mg/L (Appendix D, Figure 11).

Temperature probe analysis revealed high soil temperatures throughout the fen ranging from 12.2 to 24.5 °C at a 1-inch depth and 11.4 to 17.5 °C at a 6-inch depth (Appendix D, Figures 13 & 14). Probing was conducted in early afternoon on August 5, 2017. Spatial analysis of the temperature data displays a trend of elevated soil temperatures at both 1 and 6 inches of depth where tree canopy is sparse and the fen exposed to solar radiation throughout the late morning and afternoon. Temperature data recorded from the in-situ pressure transducer supports the probe data. Monthly groundwater temperature averages in the boring ranged from 4.3 °C (December) to 16.2 °C (July) (Figure D-16). Temperatures were consistently less than 11 °C for less than half of the year, from mid-November to early May (Figure D-15).

Site Hydrogeologic Conceptual Model

Hydrogeological analysis of the shallow, unconfined aquifer north of Florence was completed through the collection of over 600 well logs representing wells surrounding the Darlingtonia State Botanical Wayside from the Oregon Water Resources Department, and surface geology reports from the Oregon Department of Geology and Mineral Industries. Data from these sources were compiled into a database that clearly displayed the geologic features of the area in addition to hydrologic conditions of each stratum. These data were used to develop a geologic site conceptual model (Figure C-5) and potentiometric surface map of the Darlingtonia Wayside area in addition to an ArcGIS spatial display of water table elevation (Figure C-6).

Pumping tests from the well logs were used to determine hydraulic conductivities within the principal aquifer and the surrounding formations (Tables C-2 & C-3). These data in addition to qualitative data derived from extensive site examinations and aerial photography determine key surface water boundary conditions of the local water system. When necessary, the researcher consulted with property owners and stakeholders in the area for pumping data and water levels within existing wells to enhance the resolution of the baseline aquifer conditions. Ultimately, these data were compiled and computed via ArcGIS software to spatially reveal general groundwater elevations, gradients, flow directions, and transport patterns that have the potential to impact the quality and quantity of the groundwater at the site (Figure C-7).

Analyses revealed the medium of the North Florence Dunal Aquifer is largely unconsolidated ocean and Aeolian (wind) sand deposits. These unconsolidated sands range from 50 feet of thickness near the shore of the Pacific Ocean to over 200 feet beneath the larger dunes located by Mercer and Sutton Lakes. Well logs demonstrate the thickness at site to be roughly 70 feet. Spatial analysis of water table measurements reveals the piezometric surface is largely dependent on local topography with groundwater mounds found under dunes and local streams, lakes and the Pacific Ocean serving as hydraulic sinks. In other words, groundwater elevations are higher near dune formations and closely reflect local surface water elevations. The general piezometric trend of the North Florence Dunal Aquifer is highest at east boundary with the Tyee Formation with low to moderate gradients (0.0066 to 0.00877) extending to the Pacific Ocean, the western boundary. Analysis of pumping tests revealed a high hydraulic conductivity of 2.3 feet/day within the unconsolidated sands where porosity was estimated at 0.29 (Table C-2). With these parameters, groundwater velocity moving through the site was calculated at an average of 0.046 feet/day (0.552 inches/day).

Well logs largely reveal a hard, dark/grey sandstone beneath the yellow unconsolidated sands, which the Oregon Department of Geology and Mineral Industries identifies as the Tyee Formation. The Tyee Formation is largely sandstone and siltstone with igneous intrusions (USGS, 2015). This formation serves as an effective underlying boundary, or aquitard, to the North Florence Dunal Aquifer 70 feet below the study site. Pumping tests recorded by well logs reveal a hydraulic conductivity of 0.188 feet/day, a figure much lower than the unconsolidated sand of the overlying aquifer (Table C-3). Flow velocities are much slower while hydraulic gradients greatly vary depending on the local topography. The discrepancy in flow characteristics effectively disconnects hydraulic flow between the two formations.

Groundwater flowing into the Darlingtonia State Botanical Wayside (61 feet above sea level) enters from southeast of the site from a topographic high near Collard Lake (115 feet above sea level). Flow generally moves through the site in a northerly/northwesterly direction toward the lower-lying surface water boundaries of Mercer Lake and Sutton Creek (~33 feet above sea level) (Figure C-7). There is a small creek running from east to west through Darlingtonia Wayside north of the fen and south of the parking lot draining shallow groundwater at the site. However, the resolution provided by the limited number of wells and the logs does not reveal a trend at this small of a scale.

Beyond the natural surface water boundaries, U.S. Highway 101 runs north and south west of the site where a small drainage swale is also receiving shallow, local flow. Again, this flow influence is not detected due to its small-scale nature. At a much larger scale, there is a hydraulic low about 0.5 miles northwest of Darlingtonia Wayside in the vicinity of the Sutton Creek by the Sea sub-division and the Sutton Campground managed by the U.S. Forest Service (Figure C-6). Spatial analysis reveals flow is marginally influenced by this hydraulic low (Figure C-7) potentially effecting water table elevations.

<u>Discussion & Recommendations for Future Research</u>

Vegetation

Findings from our second year of data collection are not consistent with the hypothesis that *D. californica* is more vigorous and produces more shoots in sun than in shade (Tables A-5, A-6, A-7, A-8, A-9). This finding contrasts last year's study where it was determined there were far more *D. californica* growing in the sun. The winter and spring seasons for 2017 were cooler and wetter than 2016 (Figure A-7 & A-8) which may have impacted the *D. californica* growth patterns at the site. Annual population data collection over time will provide a larger sample size for more robust statistical analysis. Additional years of data collection are also necessary to track patterns. We would recommend that *D. californica* plot data be collected every June (at minimum) for several years (5-10) in order to investigate whether there are patterns or trends in population size and vigor, and to investigate the potential relationships between population vigor and abundance and site characteristics over time.

The objective for this exploratory study is to provide a baseline of plant abundance and vigor at this site. The baseline will enable us to detect patterns or trends at Darlingtonia Wayside population with subsequent rounds of data collection. It is hypothesized that the Darlingtonia Wayside clonal population may have evolved here for centuries (Aaron Ellison, personal communication on site, June 2016). Recent changes in land use and management around this site have generated concern over whether site conditions will continue to sustain a healthy, vigorous population. In addition to efforts towards understanding differences in plant growth in sun and shade, it may be important to investigate the potential impact of development and hydrologic alterations within Darlingtonia Wayside. For example, over the past 20 years of housing development in this area, a number of private wells, septic systems, and town sewer systems have been installed. The Oregon Department of Transportation put in a culvert between the site and U.S. Highway 101 recently. The effect these alterations might have on the hydrology of the site has not been determined; however, it may be possible to expand the current project to investigate site hydrology further.

The consequences of absolute and physical removal of trees and shrubs in the past 5-10 years (intended to prevent loss of *D. californica* from shading and encroachment) illustrates the challenge of managing small populations of rare species. The initial impact of woody removal was loss of *D. californica* individuals from the contained section of the fen to physical disturbance (trampling) and sun damage, and invasion of disturbed areas by *Calamagrostis*. *D. californica* populations in the contained section of the site seem to have rebounded, but may face future challenges without concerted efforts to control invasive species such as *Calamagrostis*; the population may decline owing to competition with *Calamagrostis*, introduced as part of the disturbance associated with tree removal. It may be of interest to core and age remaining trees at this site, in addition to monitoring non-*D. californica* vegetation for invasion. Coring would allow us to investigate changes in vegetation, fluctuations in water and nutrients, as well as environmental conditions.

As discussed in previous reports, a prescribed burn is worth consideration, as it would eliminate the myrtlewood and salal with no risk of trampling, seed tracking or other risks associated with disturbance on foot. Research suggests *D. californica* would respond well to a prescribed burning and may even increase in vigor; a burn could provide the opportunity for *D. californica* to rebound and recover (keeping in mind that *D. californica* are poor competitors and successful early pioneers) (Ellison, personal communication on site, 2016). A burn in August, post seed release, may promote *D. californica* resurgence via the seedbank, after vegetation has cleared. Selective removal of individual trees to modify hydrology (in certain areas of the fen) is another feasible treatment that would be less disruptive than burning and may also be restorative long term. However, it is important to be mindful that tree removal may create opportunity for invasive species or disrupt the fen, tree selection and removal should be considered carefully. Most importantly, it is critical that we continue to observe and monitor this site over time. Gaining a better understanding of how the Darlingtonia Wayside population is changing will enable precise, careful, and vigilant management of this precious Oregon plant community.

Groundwater Monitoring

The groundwater monitoring program comprised of pressure transducer data and monthly sampling has provided an empirical baseline with which park managers can track changes to water table levels and groundwater chemistry within the Darlingtonia Wayside fen. Water table trends throughout the year follows the predictable temporal pattern of highest levels during the wet winter season and lower levels throughout the dry summer months. Variation does not exceed more than 0.55 feet (6.6 inches) while not exceeding a depth greater than 0.64 feet (7.7 inches) at the site of the boring in the North fen (Figure B-1). Literature suggests the roots of carnivorous plants, including the *D. californica*, reach depths of up to a foot (Adlassnig et al., 2005). While this is shallow, groundwater monitoring reveals the roots were not subject to subterranean conditions too dry for survival. Depth to water levels vary throughout the site as the surface is dominated by local hummocks and troughs. Troughs in each of the four study sectors contained standing water year-round, while hummocks in most of the sectors were dry. The North fen is consistently the driest sector within the study area.

Continuing the pressure transducer monitoring program will prove beneficial to park managers in several ways. Several years' worth of data will enhance the resolution of the water table baseline data providing new insights on the temporal patterns. Seasonal groundwater data aids Darlingtonia Wayside land management decisions, i.e. when to let brush grow to provide extra canopy shade to retard evapotranspiration rates in the fen. Park managers could use the data to develop education and outreach programs emphasizing groundwater science and its connection to groundwater dependent ecosystems, like the fen at Darlingtonia Wayside. It also gives park managers a subsurface view to determine if pumping activities in the park's vicinity are affecting the water table. Data from the transducer can provide information to investigate the distance to possible sources of withdrawal. Several campgrounds and RV sites within a mile of Darlingtonia Wayside may be withdrawing groundwater for their tenants. These sites likely maintain pumping records which park managers could review for the purpose of determining whether withdrawals will affect the plant population and overall fen health.

Laboratory analysis of the water samples a general lack of dissolved nitrogen concentrations. Chloride was the lone anion with levels consistently greater than 1.0 ppm (Table C-1); however, literature on the species failed to provide a concentration of chloride that would may impact to the *D. californica*. Salinity or septic influence are the two most considerable explanations for chloride presence in the groundwater. Septic influence is unlikely as nitrate and ammonia concentrations were either not detectable or very low (less than 0.2 ppm). The analysis provided by Edge Analytical revealed 11.6 mg/L in July and 11.0 mg/L in October both times a sample was sent to the laboratory (Figures C-1 & C-2). This suggests the chloride is likely linked to salt from the nearby Pacific Ocean. Whether or not salinity intrusion is occurring (Figure C-8) requires further study.

While water quality proved favorable throughout this study, this may be subject to change in the future. To mitigate future threats, park managers may consider employing an educational program at the site for local stakeholders. Septic systems dominate the wastewater treatment mechanisms within the Darlingtonia Wayside vicinity making nitrogen loading a viable threat. Informal interviews with park goers, residents, and park staff revealed that many residents up-gradient from the site use the Darlingtonia Wayside parking lot to send text messages and make phone calls before heading back into neighborhoods with "spotty cell coverage." Perhaps a reminder in the parking lot to stay up to date on septic maintenance would prove beneficial to aquifer health.

The greatest cause for concern are the elevated groundwater and soil temperatures within the Darlingtonia Wayside fen. Literature suggests the shallow root system of *D. californica* requires temperatures around 10 °C (Adlassnig et al., 2005; Slack, 2000). Soil temperatures within the unshaded fen reach as high as 24.5 °C at a 1-inch depth (Figure D-13) and 17.5 °C at a depth of 6 inches (Figure D-14), well above the temperature outlined in the literature. The in-situ pressure transducer, which records data about 7 feet beneath the surface, also revealed groundwater temperatures above the 10 °C mark for about half of the calendar year (Figure D-15 & D-16).

There are several limitations associated with this initial study in soil and groundwater temperatures. Temperature probing was completed once in early August. Quarterly or monthly soil temperature monitoring would provide baseline data for temperature stress the *D. californica* experience throughout the year. And while soil temperature may provide an accurate representation of moisture temperature near the surface, continuously moving groundwater below the recorded depths may be cooler providing reprieve for root systems around a foot deep.

While the in-situ pressure transducer provides over a year's worth of fine-resolution temperature data, the quality of this data may be compromised. First, the pressure transducer, while effective, is not the best tool for water temperature measurement. Second, water in a geotechnical boring tends to become stagnant, particularly above the screen. Water temperature can increase and water chemistry may even differ from the actual groundwater flowing through the bottom/around the boring. Therefore, sampling procedures included a three-well volume purge prior to taking a sample. Temperature (and other parameters) was measured after the three-well volume purge with a YSI EC300 providing a more accurate groundwater temperature representation around 5 to 9 feet below the surface. However, this method has limitations as well: when air temperature is greater than the groundwater temperature, the liquid immediately begins increasing in temperature as soon as the water it is pulled from the boring.

Soil and groundwater temperature was not initially within the scope of this study; however, evidence and research reveal the importance of continued monitoring. A cost-effective method that provides an adequate picture of the situation is a combination of the three methods used in this study: 1) quarterly temperature probing, 2) in-situ pressure transducer data logging, and 3) quarterly temperature readings following a three-well volume purge. Sampling procedures are simple enough that park managers could incorporate this monitoring program in a citizen science outreach program. The data derived from this monitoring program provides direction for canopy and shade management in and around the Darlingtonia Wayside fen.

We also recommend a comprehensive temperature monitoring program designed to measure temperature throughout a calendar year to establish a temporal baseline for shallow sub-surface temperature trends. To accomplish this, Oregon State researchers will install 24 TidbiT v2 Water Temperature Data Loggers 5 centimeters beneath the surface at each of the vegetation monitoring plots (both sun and shade plots). The TidbiTs are small and unobtrusive (Figure C-9) requiring only two site access events: installation and data collection/decommissioning. Both events will commence during the winter when the health of the *D. californica* population is of least concern. TidbiTs will be set to record temperature on an hourly basis for one year providing a relatively high-resolution baseline of temperature trends within the fen throughout the year.

Conceptual Hydrogeologic Model

Conceptual Hydrogeologic Model derived from well logs, pumping tests/records, and hydrologic calculation provides a map displaying sources of potential contamination and groundwater drawdown based on the general flow of the North Florence Dunal Aquifer. Samples from the monitoring program demonstrates the park's groundwater to have minimal concentrations of compounds potentially harmful to the *D. californica* (Table C-1, Figures C-1 & C-2, Appendix D). Models and maps created through this study displays an up-gradient with minimal sources for potential contamination. The greatest concern is salinity intrusion and nitrogen loading from septic influence (Figure C-8); however, most of septic concentrations do not appear to have influence over the groundwater flowing through Darlingtonia Wayside (Figure C-7).

There remains potential for groundwater drawdown, particularly during the dry summer seasons. While there are no groundwater right permits or certificates near Darlingtonia Wayside, maps show several campsites and RV parks with pumping wells exempt from regulation. Park managers should coordinate with all sites of withdrawal to track pumping records to predict groundwater stress for the site and heat stress for the *D. californica*. Over pumping can cause salinity intrusion (Figure C-8) degrading the water quality throughout the study area of the aquifer highlighting the importance of coordination among stakeholders.

Conclusion

Results from the 2017 monitoring program reveal soil moisture and groundwater temperature to be a serious consideration for site management. There now appear to be three related variables for consideration to promote the abundance and vigor of the *D. californica* population within Darlingtonia Wayside: sun exposure, groundwater availability, and source water temperature. Greater sun exposure may promote photosynthesis within *D. californica*, but promotes evapotranspiration and warms moisture within the fen to a lethal point for the plants. More water on site slows down groundwater velocity stagnating fen moisture to increase temperature with exposure while promoting growth of vegetation that shade out the *D. californica*. To illustrate this connectedness, Figure C-10 displays the three variables on a triangular continuum revealing the optimal condition for *D. californica* health and vigor account for all three variables. There are, of course, external factors, including groundwater pollution and invasive species encroachment, to consider as well. While groundwater pollution appears to be minimal, plot surveys reveal a noticeable presence of *Calamagrostis* and blackberry among the native plants in the fen. Ultimately, the fen at Darlingtonia Wayside requires careful management consideration and robust monitoring of the variables outlined throughout this study.

Acknowledgements

We thank the Oregon State Parks staff for their ongoing support and information about the site history. We thank Dr. Chris Parrish of OSU Civil and Construction Engineering Department and his graduate students for volunteering their time to collect ground-based LiDAR imagery at the Darlingtonia Botanical Wayside site in June, and post-processing of the initial imagery. We thank Dr. Michael Olson in Forest Engineering for the loan of the equipment for acquiring the ground-based LiDAR imagery. We thank Dr. Todd Jarvis and the Institute for Water and Watersheds for providing funds to contract Edge Analytical in Corvallis for water chemistry testing. We thank Dr. Christine Kelly of OSU College of Engineers and her Johnson scholars, Samantha Carruthers and Fox Avery, for providing spatial analysis of Darlingtonia Wayside's shallow soil temperature and water chemistry results. We thank Nicole Feiten for volunteering her time (and patience) to complete the fieldwork necessary to compile the data for the groundwater analysis (and for driving to the ice cream shop following said events).

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Appendix A. Vegetation Monitoring

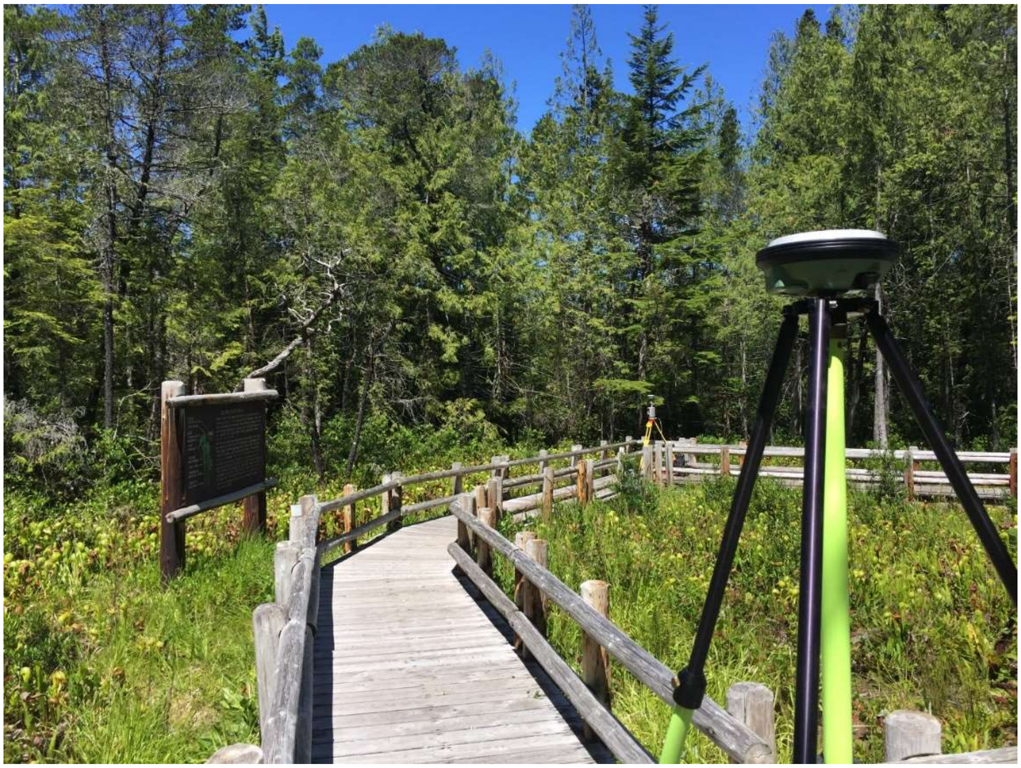


Figure A-1. Images of Darlingtonia Wayside from LiDAR scan perspective on the boardwalk, courtesy of Oregon State Professor, Dr. Chris Parrish (2016).

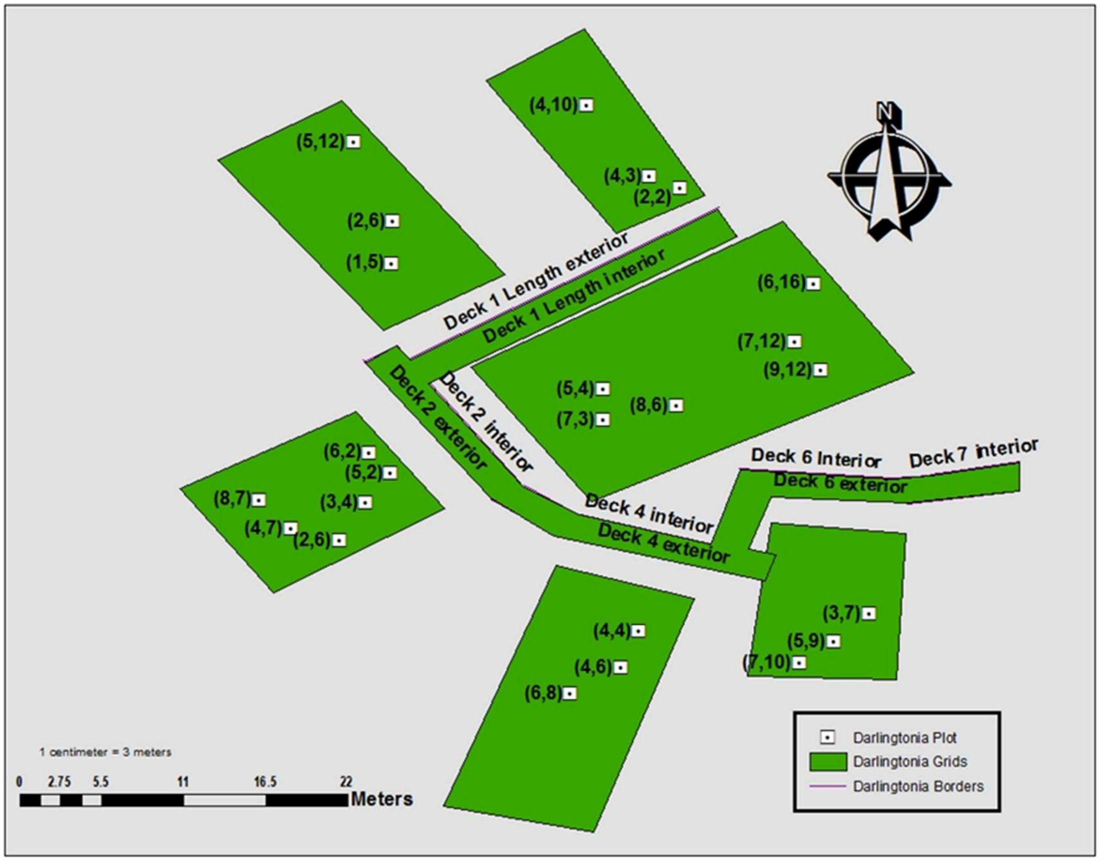


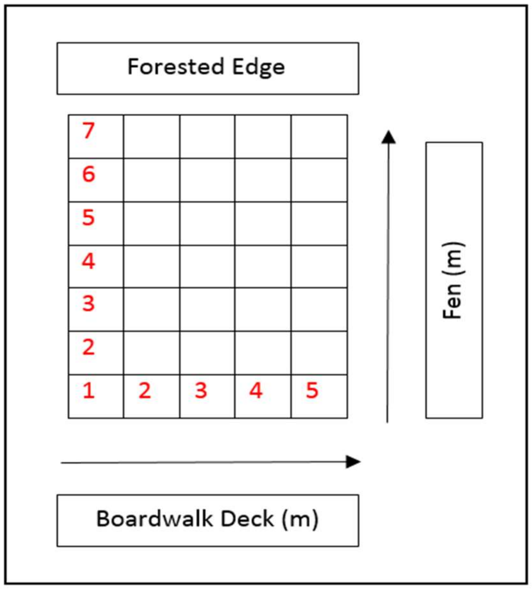
Figure A-2. Site Map with plots and sections labeled. Grids used for random plot placement in each fen are depicted in green. Relative plot locations are marked by a white square with a black circle in the center. The estimates for grid placement were approximated visually in this figure and are not to scale. Interior and Exterior decks used for measurement in Table 1 are labeled. Prepared by Megan Chellew

Table A-1. Boardwalk Deck Section Measurements (prepared by Megan Chellew):

Deck 1: Exterior (22 m) Interior (22 m)	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
Width of Deck: 1.68 m	18 cm to center of post 1 205 … 2 355 … 3 TOTAL: 365 cm	18 cm to center of post 1 205 … 2 355 … 3 TOTAL: 365 cm	Panel 3: 14 … 1 200 … 2 343 … 3 TOTAL = 363 cm	Panel 4: 13 … 1 198 … 2 347 … 3 TOTAL = 358 cm	Panel 5: 13 … 1 203 … 2 349 … 3 TOTAL = 367 cm	Panel 6: 16 … 1 198 … 2 320 … 3 TOTAL = 359 cm

Deck	**Exterior (meters)**	**Interior (meters)**	**Bearing**
1	22	22	222°
2	11.01	8.2	130°
3	3.63	3.1	110°
4	10.6	6.7	90°
5	3.65	5.2	80°
6	9.3	6.7	70°
7	3.65	4.45	46°

Sampling terminology:
Deck- A portion of the boardwalk made up of a various number of panels.
Panels- Three posts with two logs nailed in between
Single- Single upright logs that join horizontal logs into a panel.
Fen Subsection – A portion of the site that is bordered partially or wholly by one or more boardwalk Decks
Grid – A visualized array of meter squares. Used for selecting location of random plots. Coordinates on the grid represent a meter square along the x axis (the boardwalk) by a meter square along the y axis (the fen).



Concept for random plot establishment: Grid visualization for a section of fen. Random numbers were selected for each coordinate, and meter square plots were located along the grid. Coverage (sun or shade) was noted for each coordinate selected.

Figure A-3. Grid Coordinate System for random plot establishment. Prepared by Megan Chellew

Table A-2. Location of grids and plots for each portion of the fen sampled (*N.M. – Not Marked). Provided by Megan Chellew

Fen sub-section	**Associated Deck(s)**	**Grids for Random Sampling**	**Sun plots**	**Shade plots**
Contained	Deck 1, Deck 2 (interior)	11 meters (across boardwalk) by 18 meters (into fen) Deck 2 by Deck 1 (interior).	77, 69, 76	N.M., 70, 68
Central	Deck 2 (exterior)	10 meters (across boardwalk) by 8 meters (into fen). Deck 2	90, N.M, N.M,	95, 78, 93
South	Deck 4 (exterior), Deck 5, Deck 6 (exterior)	Grid A – Shade 7 meters (across boardwalk) by 10 meters (into fen). Deck 6 by Deck 5. Grid B – Sun 7 meters (across boardwalk) by 17 meters (into fen) Deck 4.	96, 98, 97	84, 83, 82
North	Deck 1 (exterior)	Grid A – (Shade, Sun) Close to boardwalk with unmarked plots. 4 meters (across boardwalk) by 5 meters (into fen). Deck 1. Grid B – (Shade, Sun) Closer to the opposite end of Deck 1 and interior Deck 2. 5 meters (across boardwalk towards exit) by 14 meters (into fen)	80, 81, N.M.	79, N.M, 100

Figure A-4. An image of processed LiDAR data at 0.01 m resolution. Below is a screenshot from a 3D point cloud visualization, courtesy of Matt O'Banion.

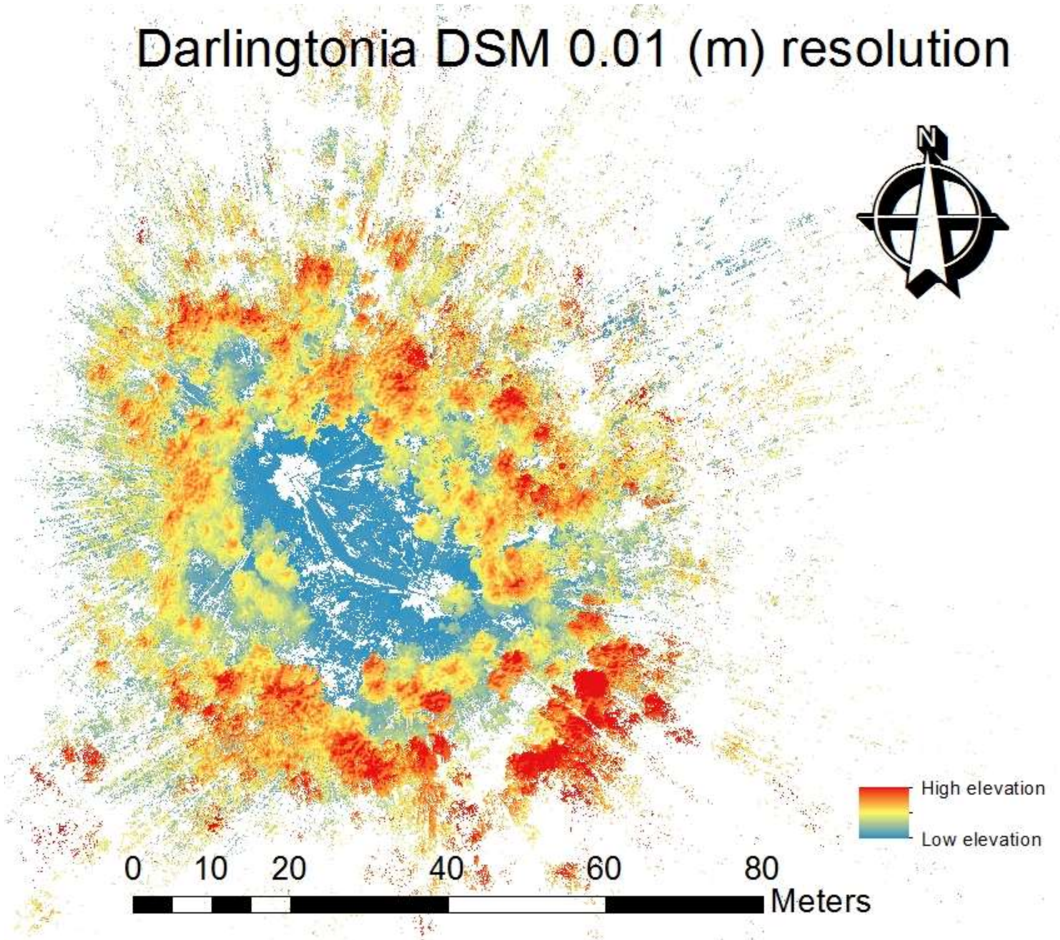


Table A-3. Plot locations by number and fen subsection. Prepared by Megan Chellew

Shade Plot Number	Fen Subsection	Grid Coordinate (m)
70	Contained Fen	9, 12
N.M.	Contained Fen	7, 12

68	Contained Fen	6, 16
95	Central Fen	2, 6
78	Central Fen	8, 7
93	Central Fen	4, 7
84	South Fen	3, 7
82	South Fen	5, 9
83	South Fen	7, 10
N.M.	North Fen	3, 4
100	North Fen	5, 12
79	North Fen	4, 10
Sunny Plot Number	**Fen Subsection**	**Grid Coordinate (m)**
69	Contained Fen	5, 4
77	Contained Fen	7, 3
76	Contained Fen	8, 6
90	Central Fen	3, 4
N.M.	Central Fen	5, 2
N.M.	Central Fen	5, 3
96	South Fen	6, 8
98	South Fen	4, 6
97	South Fen	4, 4
N.M.	North Fen	2, 2
80	North Fen	2, 6
81	North Fen	1, 5

Table A-4. *D. californica* Age Classes. Prepared by Megan Chellew

Age Class	Description
1	young; smaller size, head not fully ballooned, lack of developed fenestrations
2	mature; larger size, head fully ballooned, clear fenestrations
3	senesced; fenestrations are opaque and a red/brown color, leaves are partially dried, balloon may be partially deflated
4	dead - most or all of the shoot is dried, shoot may have fallen over

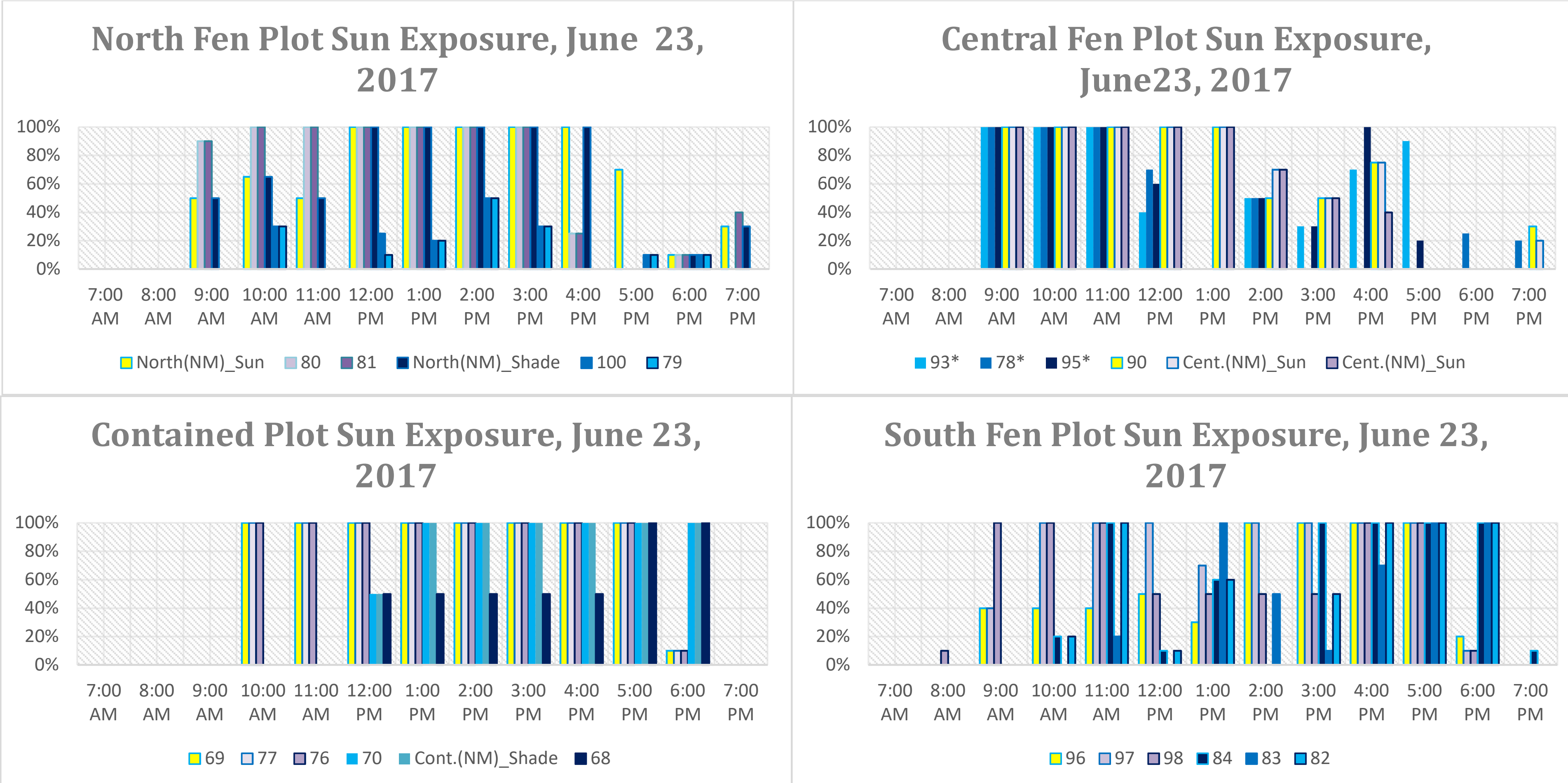


Figure A-5. Estimations of percent sun exposure for each fen block over a 12 hour period. Based on these data, most plots designated as 'shade' plots spend the majority of their day in partial to full shade. The exception are plots in the Central fen area, which are in 60-100% sun for nearly 8 hours during the day. Based on these data, at this time in the summer, most of the plots designated as 'sun' plots spend more than 8 hours of the day with 60-100% sun exposure. Prepared by Trevor Grandy

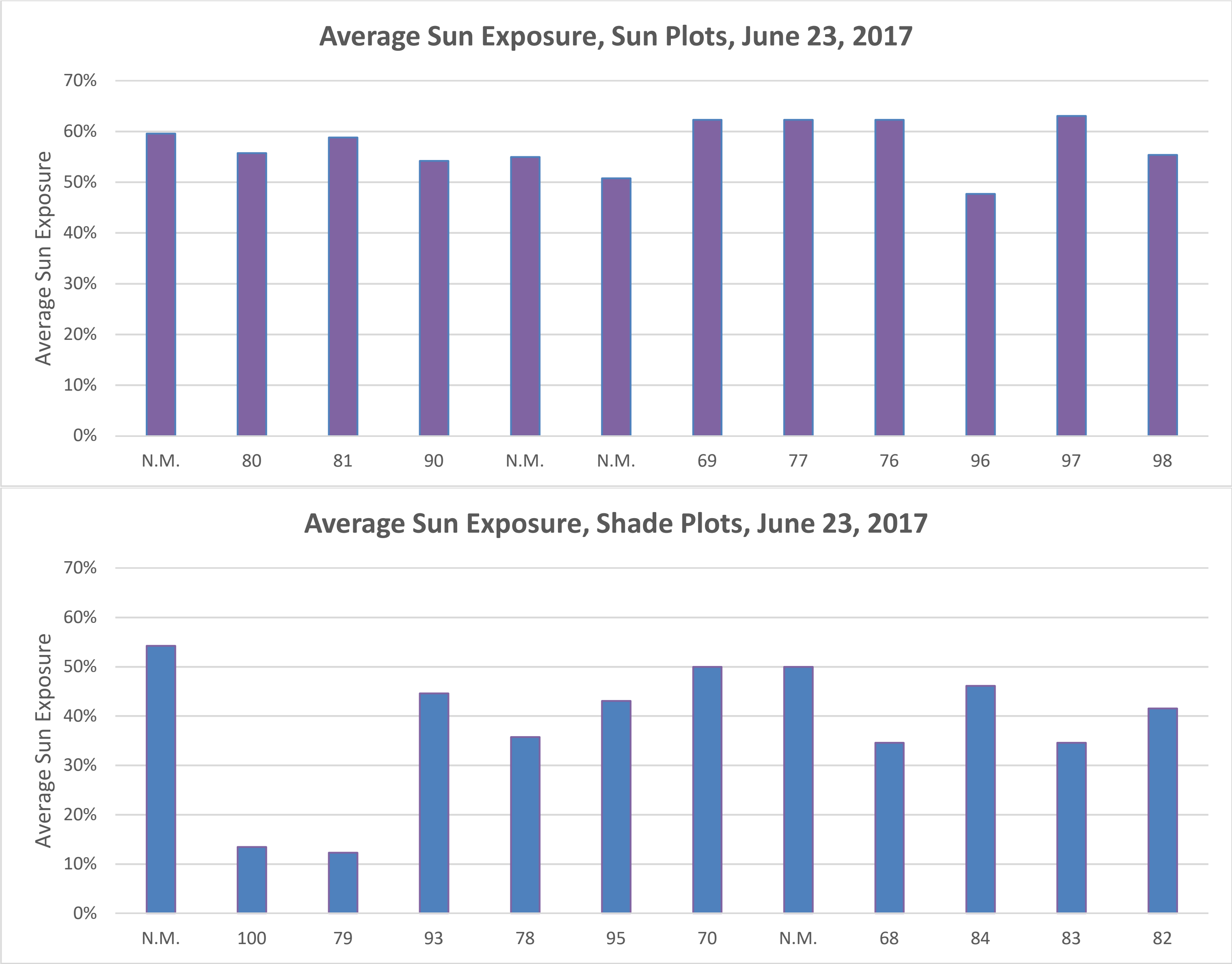
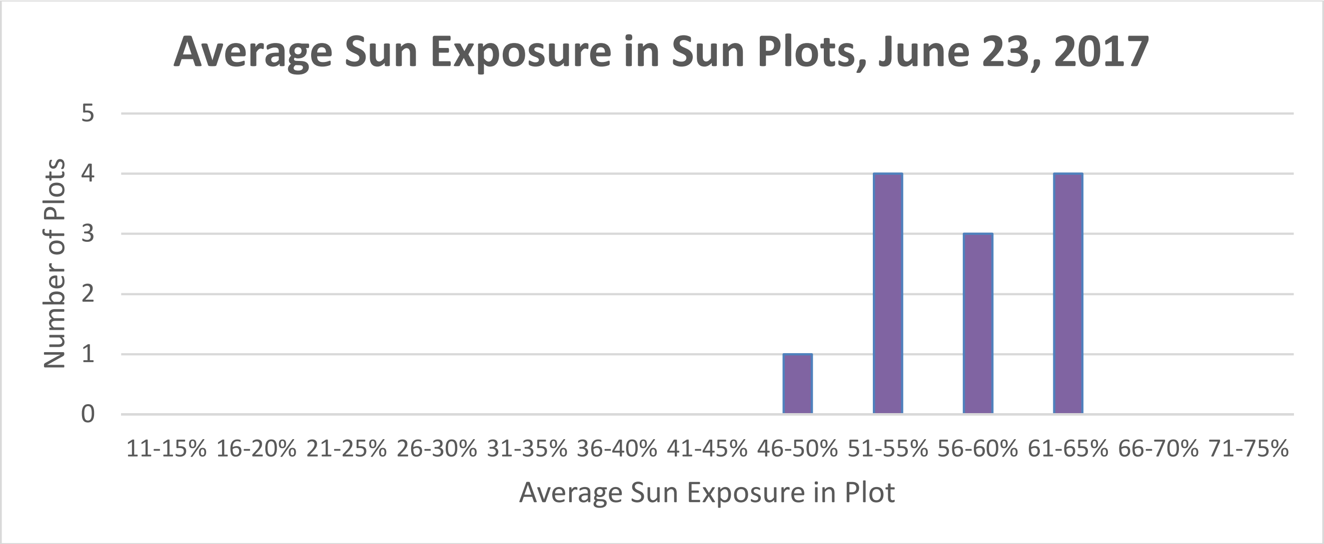
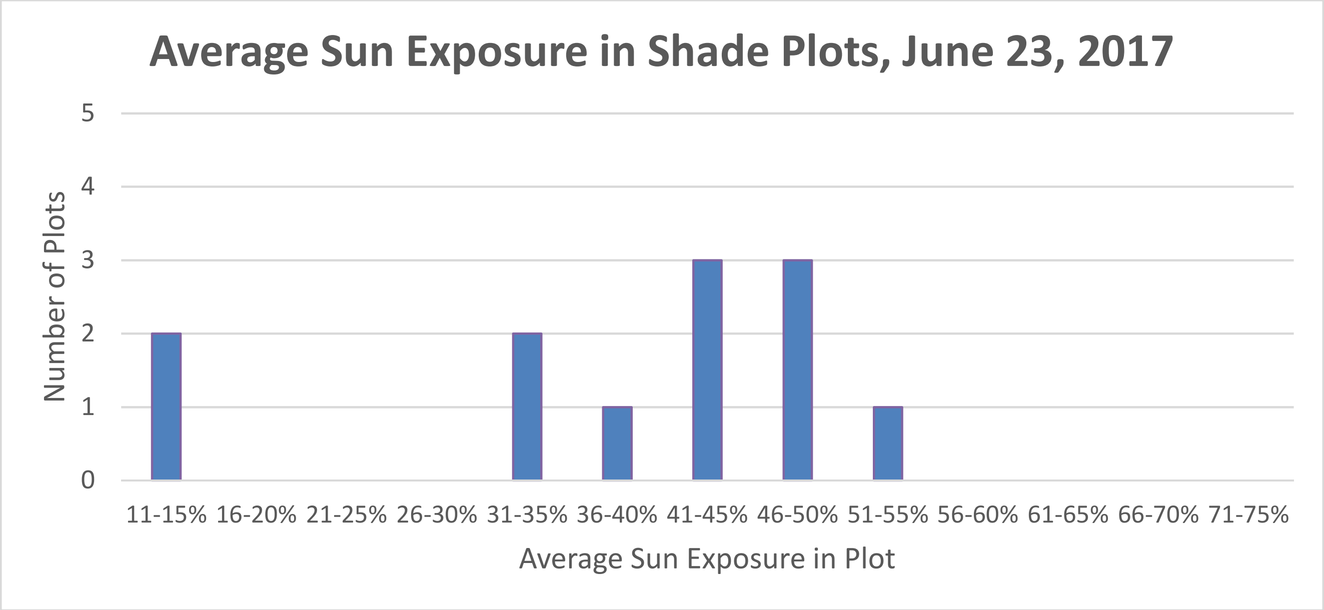


Figure A-6. Average sun exposure for each fen block throughout the 12-hour collection period (0700-1900). Prepared by Trevor Grandy





Column1	Sun Plots	Shade Plots
>50% Sun Exposure	11	1
<50% Sun Exposure	1	11

Figure A-7. Average sun exposure of fen blocks broken down into sun and shade plot histograms. Prepared by Trevor Grandy

Table A-5. Data and Summary Statistics from Shade Plots at Darlingtonia Wayside. Prepared by Trevor Grandy

Fen	Trt.	Plot	No. of Young	No. of Mature	No. of Senesced	No. of Dead	No. of Flowers	No. of Dead Flowers	Ht. of Tallest (cm)
North	Shade	79	15	0	36	35	5	0	70
North	Shade	100	20	0	20	26	1	0	60
North	Shade	RF5	29	4	15	7	0	0	35
South	Shade	84	17	0	46	55	0	3	80
South	Shade	83	27	4	58	44	3	5	50
South	Shade	82	12	1	42	24	0	0	75
Contained	Shade	CoF4	15	1	33	15	5	9	65
Contained	Shade	70	11	2	25	18	7	1	60
Contained	Shade	68	24	0	51	26	4	8	65
Central	Shade	95	8	0	22	36	2	2	60
Central	Shade	78	0	0	8	74	1	0	70
Central	Shade	93	9	1	21	22	1	1	55
		Total	187	13	377	382	29	29	-
		Mean	**15.6**	**1.1**	**31.4**	**31.8**	**2.4**	**2.4**	**62.1**
		St Dev	**8.4**	**1.5**	**15.4**	**18.6**	**2.4**	**3.2**	**12.0**
			Total alive	**200**	**Total dead/dying**	**759**	**Total flowers**	**58**	

Table A-6. Data and Summary Statistics from Sun Plots at Darlingtonia Wayside (*plot treatments reassigned based on measured sun exposure). Prepared by Trevor Grandy

Fen	Trt.	Plot	No. of Young	No. of Mature	No. of Senesced	No. of Dead	No. of Flowers	No. of Dead Flowers	Ht. of Tallest (cm)
North	Sun	80	2	0	3	27	1	2	55
North	Sun	81	4	0	11	13	2	0	55
North	Sun	RF6	5	1	19	22	0	0	40
Central	Sun	90	25	0	48	44	5	2	90
Central	Sun	CF5	35	0	71	56	6	7	70
Central	Sun	CF6	29	1	44	55	9	6	80
South	Sun	96	16	2	39	38	0	0	60
South	Sun	98	11	3	27	25	3	1	50
South	Sun	97	11	3	27	35	1	3	60
Contained	Sun	77	13	1	17	18	3	3	60
Contained	Sun	69	19	4	29	21	3	4	55
Contained	Sun	76	17	0	25	33	7	5	65
		Total:	187	15	360	387	40	33	-
		Mean	**15.6**	**1.3**	**30.0**	**32.3**	**3.3**	**2.8**	**60.8**
		St Dev	**10.2**	**1.4**	**18.4**	**14.0**	**2.9**	**2.4**	**11.6**
			Total alive	**202**	**Total dead/dying**	**727**	**Total flowers**	**73**	

Table A-7: Results of ANOVA comparison of *D. californica* frequency by block (North Fen, South Fen, Contained Fen, Central Fen). Prepared by Trevor Grandy

ANOVA

Single Factor

SUMMARY	Column1	Column2	Column3	Column4
Groups	*Count*	*Sum*	*Average*	*Variance*
North	36	325	9.027777778	124.9420635
South	36	586	16.27777778	322.2063492
Central	36	651	18.08333333	483.7357143
Contained	36	459	12.75	133.6214286

ANOVA	Column1	Column2	Column3	Column4	Column5	Column6
Variation Source	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1733.131944	3	577.7106481	2.170813088	0.094182073	2.669256364
Within Groups	37257.69444	140	266.1263889			
Total	38990.82639	143				

Table A-8. Results of one tailed T-Test comparison of *D. californica* frequency between all Sun and Shade plots.

	One-Tailed T Test
Alive (Comparing total Young and Mature between Sun and Shade)	**0.48658**
Dead (Comparing total Senesced and Dead between Sun and Shade)	**0.38467**
Flowers (Comparing Total number of flowers for Sun and Shade)	**0.19695**
Total (Compare total number of Darlingtonia between Sun and Shade)	**0.45203**

Table A-9. Post Hoc T-Test results (Block v Block comparison) with Bonferroni correction ($p < 0.0125$). Tables prepared by Trevor Grandy

t-Test: Two-Sample Assuming

Equal Variances

North vs. South

	Variable 1	*Variable 2*
Mean	9.027777778	16.27777778
Variance	124.9420635	322.2063492
Observations	36	36
Pooled Variance	223.5742063	
Hypothesized Mean Difference	0	
df	70	
	-	
t Stat	2.057137922	
P(T<=t) one-tail	0.021700259	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.043400518	
t Critical two-tail	1.994437112	

t-Test: Two-Sample Assuming Equal Variances
North vs. Contained

	Variable 1	*Variable 2*
Mean	9.027777778	12.75
Variance	124.9420635	133.6214286
Observations	36	36
Pooled Variance	129.281746	
Hypothesized Mean Difference	0	
df	70	
	-	
t Stat	1.388896699	
P(T<=t) one-tail	0.084633678	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.169267357	
t Critical two-tail	1.994437112	

t-Test: Two-Sample Assuming Equal Variances
North vs. Central

	Variable 1	*Variable 2*
Mean	9.027777778	18.08333333
Variance	124.9420635	483.7357143
Observations	36	36
Pooled Variance	304.3388889	
Hypothesized Mean Difference	0	
df	70	
	-	
t Stat	2.202280465	
P(T<=t) one-tail	0.015470715	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.030941431	
t Critical two-tail	1.994437112	

t-Test: Two-Sample Assuming Equal Variances
South vs. Central

	Variable 1	*Variable 2*
Mean	16.27777778	18.08333333
Variance	322.2063492	483.7357143
Observations	36	36
Pooled Variance	402.9710317	
Hypothesized Mean Difference	0	
df	70	
t Stat	-0.38160161	
P(T<=t) one-tail	0.351956404	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.703912807	
t Critical two-tail	1.994437112	

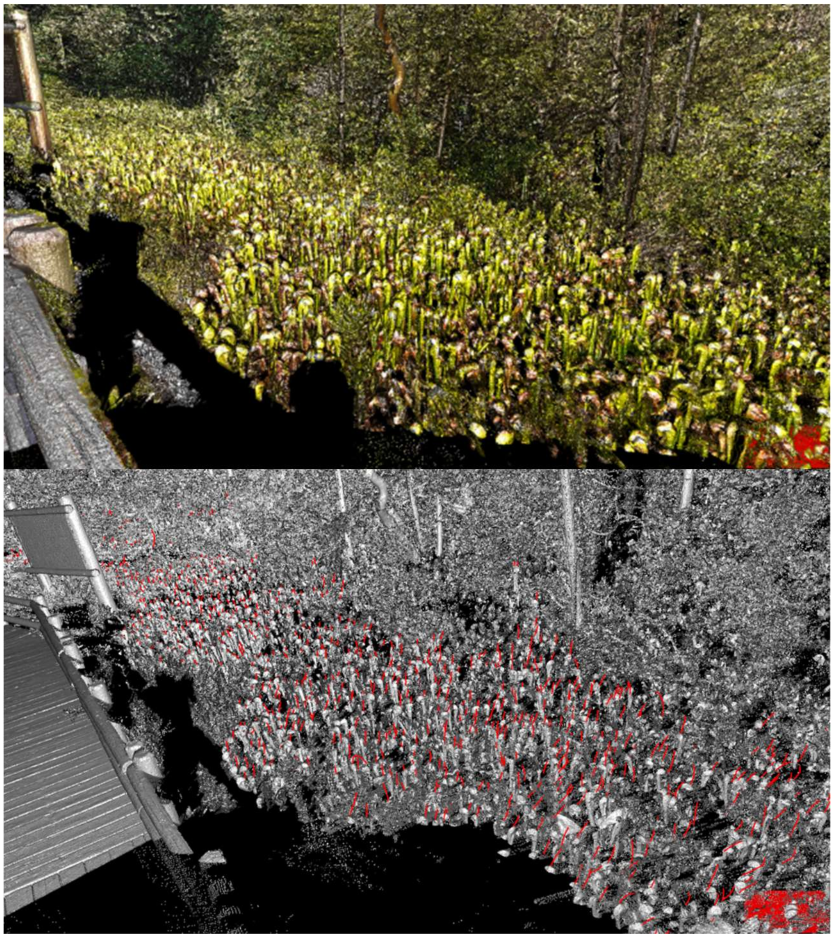
t-Test: Two-Sample Assuming Equal Variances
South vs. Contained

	Variable 1	*Variable 2*
Mean	16.27777778	12.75
Variance	322.2063492	133.6214286
Observations	36	36
Pooled Variance	227.9138889	
Hypothesized Mean Difference	0	
Df	70	
t Stat	0.991407219	
P(T<=t) one-tail	0.162450737	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.324901474	
t Critical two-tail	1.994437112	

t-Test: Two-Sample Assuming Equal Variances
South vs. Contained

	Variable 1	*Variable 2*
Mean	16.27777778	12.75
Variance	322.2063492	133.6214286
Observations	36	36
Pooled Variance	227.9138889	
Hypothesized Mean Difference	0	
Df	70	
t Stat	0.991407219	
P(T<=t) one-tail	0.162450737	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.324901474	
t Critical two-tail	1.994437112	

Figure A-6. Counting individual stems of *D. californica* from Lidar imagery. Top image- colored Lidar image of west side of boardwalk. Bottom – Same image as above in black and white used for counting- once counted, stems receive a red strike through mark. Images provided by Megan Chellew



Counts from Lidar imagery (2016):
South Fen: 1359
Central Fen: 878
North Fen: 700
Contained Fen: 545
Total *D. californica* counted from Imagery: 3482

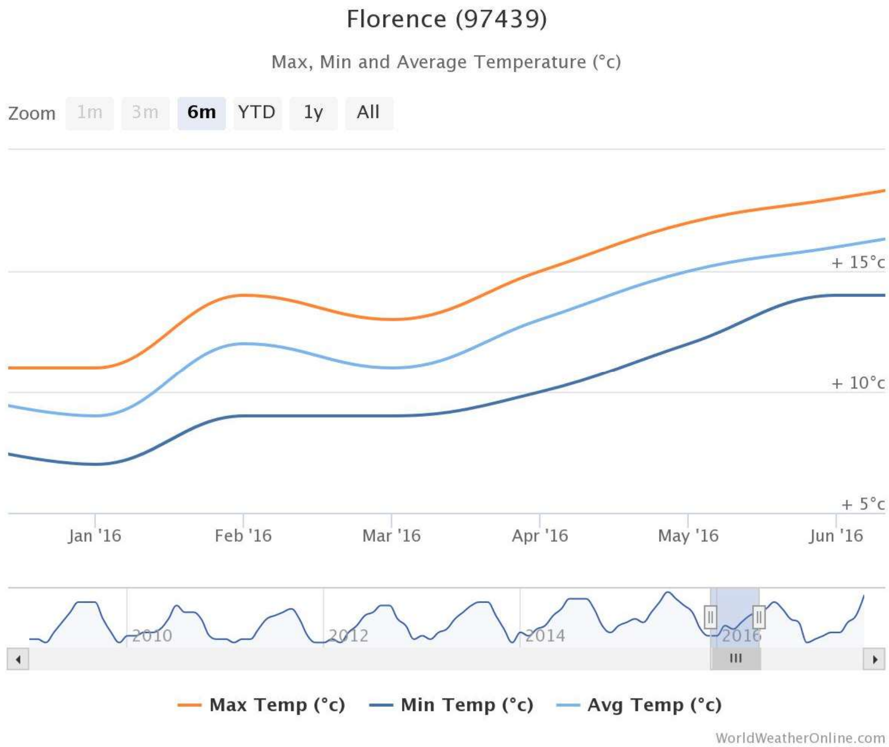
Because the Darlingtonia Wayside imagery is coarse; there are holes in part of the data/image; however, provides an impression of the overall population size

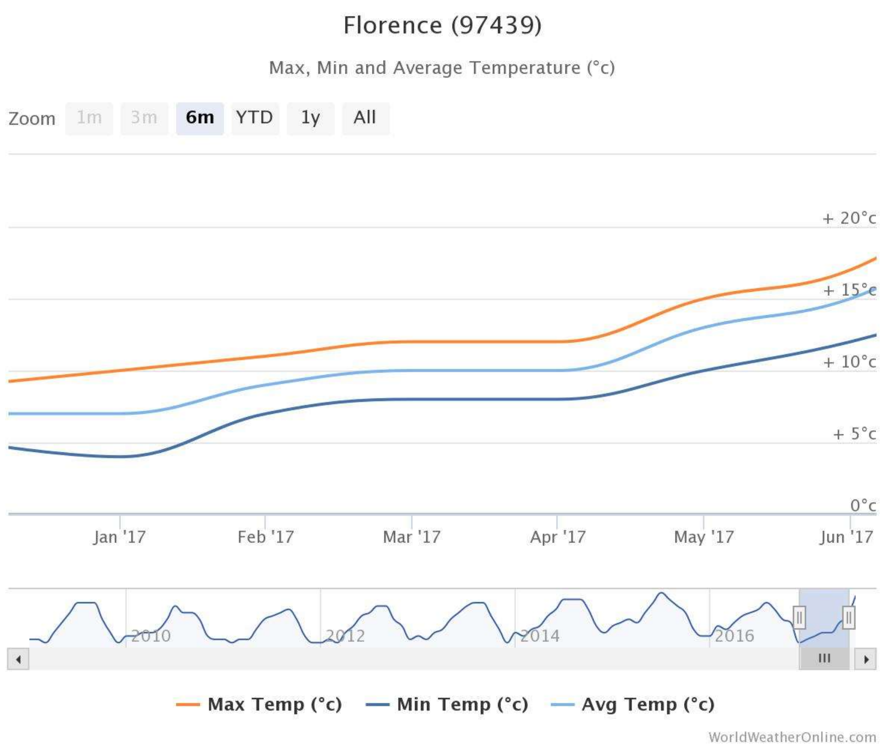
Figure A-7. Monthly precipitation data throughout 2015, 2016, and 2017 at the Florence Public Works Weather Station (KORFLORE23) in Florence, Oregon. Image provided by The City of Florence

Rainfall units are expressed in inches with the current year listed first. Average rainfall for all years is listed at the end of the report. This data is updated by the middle of the current month for the previous month.

Month	2015	2016	2017	Ave Since 1957
January	3.68	12.58	10.31	10.90
February	10.86	6.33	20.18	8.87
March	6.52	10.62	16.92	8.25
April	2.93	2.55	8.04	5.14
May	1.37	0.84	4.38	3.43
June	0.41	1.86	2.92	2.09
July	0.10	1.55	0.06	0.59
August	0.93	0.23	0.25	0.91
September	0.77	3.03	0.96	2.03
October	4.44	15.47	7.40	5.16
November	7.61	14.45		10.58
December	24.09	8.75		11.96
Annual Rainfall	63.71	78.26	71.42	69.54

Figure A-8. Comparison of temperature averages throughout winter/spring 2016 and 2017 at the Florence Public Works Weather Station (KORFLORE23) in Florence, Oregon. Images provided by World Weather Online





APPENDIX F: Project Sign for Darlingtonia State Natural Site

Darlingtonia Botanical Wayside: A Groundwater Dependent Ecosystem

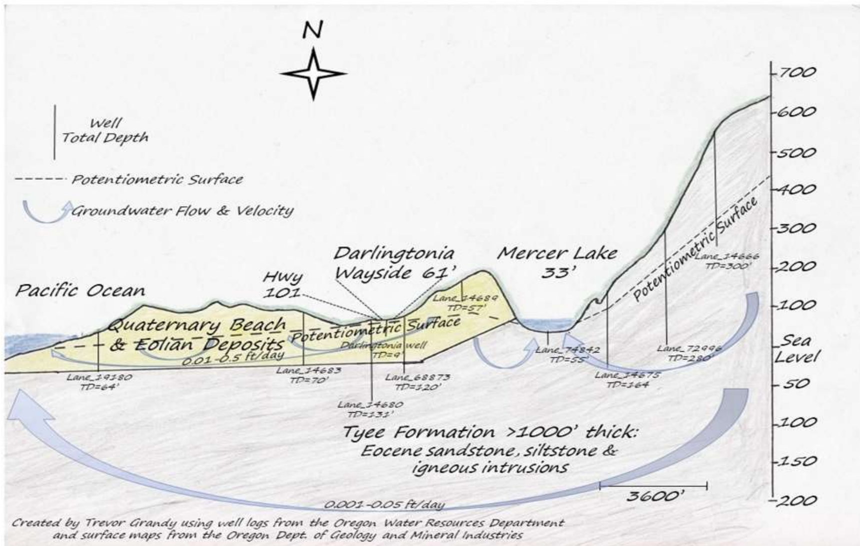


Figure 1: Cross-section of North Florence Dunal Aquifer

Welcome to Darlingtonia Botanical Wayside, a groundwater-dependent wetland and home to a thriving community of the carnivorous *Darlingtonia californica*, Oregon's only native pitcher plant. As you walk around the boardwalk, you'll notice standing water nearly year-round. That is because this site sits in the middle of a fen, or an area where groundwater is close enough to the surface to interact with plant life producing anaerobic and peaty soils. These unique conditions create a productive environment for rare plant species producing abundant biodiversity compared to other ecosystems of equal size. The mineral-rich groundwater of the North Florence Dunal Aquifer (Figure 1) provides nutrients to the fen creating a unique ecosystem for rare and shallow-rooted plants, like the Cobra Lily, to thrive. Vegetation within fens have distinct life-cycles and are critical for ecosystem maintenance.

Groundwater dependent ecosystems provide valuable ecosystem services including flood control, resistance to soil erosion, and pollution remediation. Recreation and tourism are another benefit of healthy groundwater ecosystems drawing naturalists, hikers, and water lovers of all sorts. Other groundwater-dependent ecosystems include:

- Springs
- Lakes
- Streams
- Wetlands & peatlands (fens, marshes, swamps, bogs)
- Coastal lagoons
- Wet forests (vegetation with deep, groundwater penetrating root systems)
- Subterranean ecosystems (caves, aquifers)

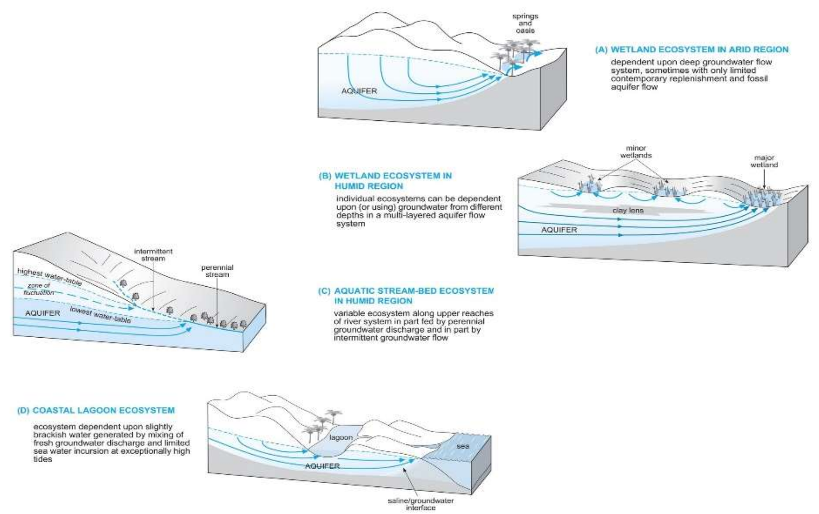


Figure 2: Groundwater dependent ecosystem models (Source: World Bank, 2006)

Monitoring the Threats of the Aquifer & Darlingtonia

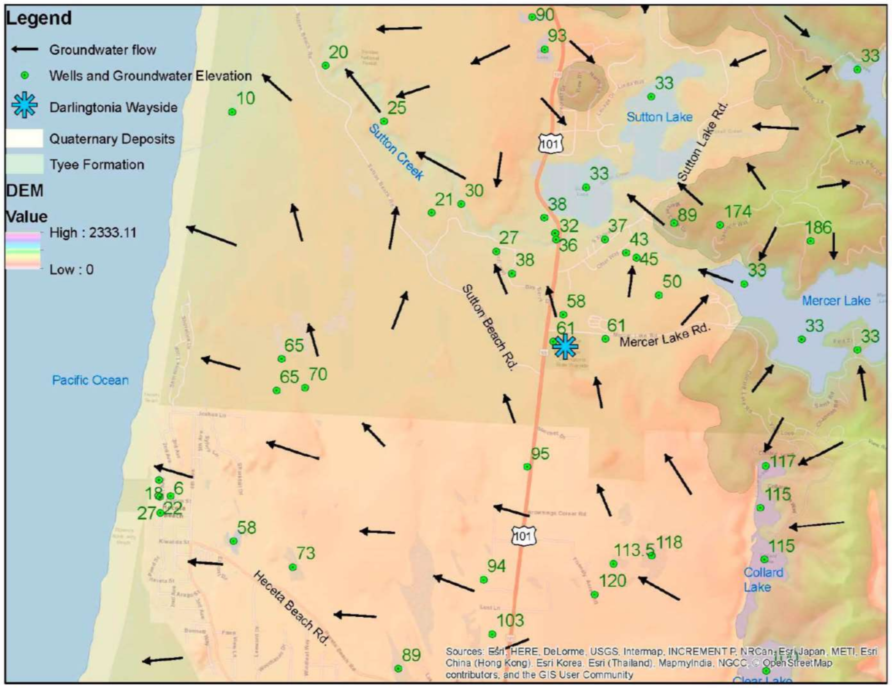


Figure 3: North Florence Dunal Aquifer flow patterns and water table elevations

What are we doing?

While the Cobra Lily is a carnivorous insect-eating plant, the ecosystem requires special conditions for healthy growth and vigor. Current research conducted by Oregon State Parks in collaboration with Oregon State University has established a program to monitor the Cobra Lily population at Darlingtonia Wayside. Cobra Lilies thrive in these coastal fens, but, like the Cobra Lily, hydrology is temperamental. Land use changes on one part of the aquifer, can affect the groundwater health and activity in other parts of the aquifer, much like actions up-stream have consequences down-stream. OSU scientists have installed a geotechnical boring on site to observe the health and supply of water at Darlingtonia Wayside. Hydrologists are also mapping and developing models to observe groundwater patterns of the North Florence Dunal Aquifer to determine sources and potential sources of contamination.

Coastal aquifers, like the one beneath your feet, face a variety of risks including salt-water intrusion, water table drawdown, and contamination from natural and human activities. Groundwater is constantly flowing, much like a river or lake, but at a much slower rate. All groundwater stakeholders are linked by their subsurface water sources, a call for responsible water use and pollutant management. For every action affects all aquifer users, including the Darlingtonia. Figure 4, to the right, displays common pressures on the North Florence Dunal Aquifer.