Oregon Department of Transportation

Stage 1 Research Problem Statement

Number*: 25-33*

Proposed Title: Quantifying Impacts to Estuarine Soils due to Climate Change-Driven Sea Level Rise and Saltwater Intrusion

1. Concisely describe the **transportation issue** (including problems, improvements, or untested solutions) that Oregon needs to research.

Numerous coastal communities are served by state highways that act as vital links within Oregon's transportation network; maintaining these links is critical for achieving equitable connection of people and goods to places, evacuation routes, and lifelines for emergency responders – particularly the underserved rural low-income and tribal communities. Importantly, several highways (e.g., 6, 18, 30, 34, 53, and 101) cross and are adjacent to many intertidal estuaries which form the interface between fresh and saltwater environments and are the home to deeply impactful, enriched ecosystems and habitats such as the Salmon River estuary, served by Highway 18. ODOT studies (e.g., SPR 719) have identified this estuary as one of many threatened by climate change and have collected critical data on the fluctuations in dissolved oxygen and conductivity (a measure of salinity). Estimates of sea level rise (SLR) cited by the Oregon Department of Land Conservation and Development and the Oregon Coastal Management Program range from one to six feet over the next 80 years for Newport and Astoria, with 22.2 and 9.1 miles of roadway in Yaquina and Alsea Bays expected to be inundated under a 50% annual chance coastal flooding and SLR in long-term projections (i.e., in the year 2100), along with numerous impacts to railways. However, these estimates do not account for the land subsidence expected following the rupture of the Cascadia Subduction zone, which will produce an additional six to ten feet of estimated relative SLR. Unfortunately, relative SLR is accompanied by ocean acidification, which may further exacerbate impacts on our coastal environment and underserved communities.

Regardless of the exact amount of relative SLR, any increase will serve to accelerate acidic saltwater intrusion into the estuarine soils which provide foundation support to highway slopes, embankments, and bridge foundations, and buffers against the erosion of ODOT right-of-way (ROW). ODOT ROW situated within estuaries and adjacent to wells used to pump groundwater will serve to accelerate saltwater intrusion. The effects of saltwater intrusion are being increasingly recognized, including that: (1) the ionic strength of the porewater increases, increasing the rates of cation exchange of sodium, calcium, and magnesium, and (2) the alkalinity of the porewater increases, increasing sodium, and calcium and magnesium carbonates, which can lead to geochemical changes in the soil structure or fabric (e.g., clay mineral dispersion). Depending on the type and amount of clay minerals present in an estuarine deposit, saltwater intrusion may lead to unknown changes (either beneficial or detrimental) to mechanical soil properties including compressibility, stiffness, and static and seismic strength. This phenomenon will be most acute in low-plasticity estuarine silts which contain a relatively small amount of clay minerals (~5 to 10%) owing to the higher hydraulic conductivity relative to soils with higher clay contents, which serves to exacerbate saltwater intrusion.

2. Document how this **transportation issue** is important to Oregon and will meet the [Oregon Research Advisory Committee Priorities]

The 2023 Oregon Transportation Plan (OTP) sets clear goals for achieving resilience in the face of climate change and natural hazards, whi`le balancing economic and community vitality and social equity, among other important goals. Specifically, this research addresses OTP Objectives EC.2, EC.4, SP.3.3, SP.6, and SC.2. Economic investment into the expansion and repair of highway infrastructure must achieve resilience in the face of climate change-driven and natural hazards, and must serve critical lifelines and evacuation routes for underserved rural low-income and tribal communities. These hazards manifest in the form of short-term, acute storm, flooding, and seismic events, and long-term SLR-driven changes to our shared environment. ODOT has already identified those estuaries which are expected to be most impacted by SLR. Although saltwater intrusion is recognized as an inevitable product of SLR, the impact of SLR-driven saltwater intrusion on the mechanical properties of coastal estuarine deposits is presently unknown.

In contrast, it is well known that changes in porewater salinity can significantly impact the behavior of marine clays. For example, reductions in porewater salinity are responsible for significant "quick clay" slides in the marine clays commonly found in the St. Lawrence Seaway and the fjords of Norway and Sweden and have caused significant loss of life and damage to the built environment. The effect of increased salinity and alkalinity on the erodibility, strength, and stability of fine-grained estuarine deposits (mixtures of fine sands, silts, and clay minerals) is unknown, though their mechanical properties may improve due to increased ionic strength and strengthened chemical bonding between clay particles. Establishing the current aqueous chemistry of the porewater in estuarine deposits and determining how increasing levels of salinity in the porewater can impact the mechanical properties of these soils would serve to inform current and long-term environmental and geotechnical design and management of highway infrastructure along coastal highway alignments, including assessments of water quality, erosion, slope stability (i.e., landslides), and the vertical and lateral load-bearing capacity of bridge substructures. This interdisciplinary research could have significant, wide-ranging impacts on ODOT's policies and priorities, helping to achieve its resilience goals in the face of climate change.

3. What **final product or information** needs to be produced to enable this research to be implemented?

At present, it is unknown if changes to porewater salinity and alkalinity due to climate change and SLR-driven saltwater intrusion will result in beneficial or detrimental changes in the environmental quality and mechanical properties of the estuarine soils which support ODOT highway infrastructure. Specifically, no previous study documenting such effects on mechanical properties is readily available in the literature. To implement the findings of this work, guidelines relating to the determination of salinity and alkalinity in groundwater and estuarine soils (Tasks 3 – 5), and expected changes in specific soil properties based on a given change in salinity and alkalinity as a result of SLR, are necessary (Task 6 product). Recommendations for the development of specific screening criteria for determining which of ODOTs assets within estuaries are most likely to be impacted by SLR and changing soil properties (Task 6 product), compatible with and extending the guidelines in NCHRP 15-61, must be generated. Finally, policy documents relating to stewardship of the estuaries within ODOT's right-of-way that address SLR and water and groundwater quality monitoring are necessary to implement the findings of this research.

4. (Optional) Are there any individuals in Oregon who will be instrumental to the success of implementing any solution that is identified by this research? If so, please list them below.

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5. Other comments:

The effects of saltwater intrusion on estuarine soils supporting highway infrastructure are unknown and require interdisciplinary teams to successfully advance our understanding of mechanistic behavioral changes in response to long-term SLR. The envisioned scope of work, summarized below, is proposed to be conducted as a joint geotechnical-environmental investigation, led by the submitter and Dr. Tala Nevab-Daneshmand (OSU) to assure that meaningful and actionable results are obtained:

Task 1 – Literature Review: Perform a detailed survey of the literature on SLR-driven saltwater intrusion into coastal deposits, focusing on estuarine deposits, and the effects of changing aqueous chemistry (i.e., pH, alkalinity, ionic strength, conductivity) on mechanical soil behavior. Salient findings from SPR 719 will be summarized. Anticipated rates of increased salinity and alkalinity with SLR reported in the literature will be identified to inform Task 5.

Task 2 – Field Investigation: One or more estuaries which contain existing highway infrastructure and low-plasticity estuarine deposits (e.g., Salmon River estuary, Millport Slough, Young's Bay Bridge) will be identified in consideration of Oregon's underserved communities and in coordination with ODOT staff. A limited series of monitoring wells at various setbacks from the shore will be installed, enabling seasonal, long-term groundwater sampling and conductivity testing at specific depths of interest. Drilling and intact sampling of estuarine soils will be performed. Seasonal sampling and conductivity testing of the free water column will be conducted at multiple depths in the estuary in proximity to the monitoring wells to quantify the free water salinity driving saltwater intrusion. Sampling protocols will take advantage of the findings in SPR 719.

Task 3 – Assessment of Aqueous Chemistry: Samples of free water and groundwater (Task 2), and porewater (Task 4) will be subject to chemical analysis including salinity, ionic strength, pH, alkalinity, conductivity, and chemical composition to determine types and quantities of chemical constituents and seasonal variations.

Task 4 – Assessment of Baseline Geotechnical Properties: Intact samples retrieved in Task 2 will be used to establish baseline geotechnical properties, including index tests, plasticity, compressibility, monotonic and cyclic strength. Porewater extracted from intact samples will be subjected to chemical analyses (Task 3). Scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy dispersive spectroscopy (EDS) will be performed to establish the elemental composition and clay mineralogy.

Task 5 – Assessment of Changing Salinity on Geotechnical Properties: Laboratory-prepared reconstituted soil specimens will be prepared at the baseline salinity and pH, and alternative levels of increased salinity and pH (Task 1) and subjected to the same laboratory analyses in Task 4 to examine the role of saltwater intrusion on changes to aqueous chemistry, elemental composition, index characteristics, and engineering properties (compressibility, monotonic and cyclic strength).

Task 6 – Synthesis, Recommendations, and Reporting: The work conducted in Tasks 1 – 5 will be summarized and synthesized to form coherent guidance on the role of saltwater intrusion on the chemical and mechanical characteristics of soils within ODOT right-of-way. Tasks, analytical methods and results, and the resulting guidance will be documented in a Final Report and presented during an interactive, statewide seminar to ODOT's policy scientists and engineers, and their consultants. The recommendations stemming from this work will provide the basis for changes to ODOT policy and guidance documents with the coordination and assistance of ODOT personnel. Specifically, guidelines relating to the determination of salinity and alkalinity in groundwater and estuarine soils and the expected changes in specific soil properties based on a given change in salinity and alkalinity stemming from SLR will be provided (e.g., if the effects are beneficial, the rate of increase in strength and stiffness can be incorporated into assessments of repair/replacement; if detrimental, assets which are most at risk can be identified and prioritized). The report will include recommendations to develop screening criteria for the evaluation of ODOTs assets within estuaries most likely to be impacted by SLR and changing soil properties.

The scope of work and outcomes described in this Stage I Problem Statement are highly aligned with the vision and mission of the CREATE University Transportation Center (UTC). The CREATE UTC is led by Dr. Stacey Kulesza, P.E. of Texas State University, with Oregon State University serving as one of several member institutions. If selected, this study could leverage the funds, methodologies, and findings developed under a proposed, parallel CREATE study focusing on the erosion resistance and electromagnetic signatures of coastal soils subject to SLR-driven saltwater intrusion. The parallel proposal is a collaborative study between the submitters and Dr. Kulesza.

6. Corresponding Submitter's Contact Information:

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