Cascadia Lifelines Program (CLiP)
O-HELP 2.0

Integrated Decision Support System for Infrastructure Resilience
Vision White Paper

***Figure 1** – Conceptual illustration of the envisioned components for the next phase of CLiP*

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Background

The Cascadia Lifelines Program (CLiP) was established to “conduct research that will allow Oregon’s lifeline providers to implement value- and cost-informed decisions to mitigate damage to Pacific Northwest infrastructure from Cascadia Subduction Zone earthquakes.” Several important lifeline providers in Oregon are part of this program. During the first phase of CLiP a variety of impactful research projects were completed towards characterizing potential damages and analyzing their impact on infrastructure and the public. One of the many impactful projects produced a web-GIS platform, the Oregon Hazards Explorer for Lifelines Program (O-Help, http://ohelp.oregonstate.edu). This platform was initially built to disseminate the geohazard data from the Oregon Resilience Plan (ORP); however, as a result of the funding provided through CLiP, additional scenario events have been created and added to O-Help. Prior to O-Help, much of this information was difficult to access by engineer, planners, and the general public. Without reliable and realistic hazard maps, it is difficult for communities and public entities to identify risk and vulnerabilities as well as develop robust solutions and strategies. Supporting analysis tools (http://geotech.forestry.oregonstate.edu/OHELP/o-help_tools.html) have also been created and made available to enable these data to be utilized in infrastructure specific analyses.

Vision for next Phase

Building on the many successes of the first phase of CLiP, we propose to advance the current visualization tools in O-Help to develop more robust analysis and decision support tools in a new and improved platform, O-Help 2.0, that can integrate the research results from the other CLiP projects as well as elements from other relevant research activities (e.g., NIST) currently underway at OSU. To achieve this synergistic vision, in this second phase, CLiP funds will be primarily used towards an integrated project with several subtasks centered around this goal rather than smaller, discrete projects that were completed in the first phase. Figure 1 presents a schematic of the overarching concept and integration of supporting research.

In this next phase, O-Help is envisioned to be a central hub to integrate the wide range of research directions related to the mission of CliP as well as relevant aspects of the Oregon Resilience Plan. This hub will both rely on and support research and outreach activities in the following areas: Hazard Modeling and Mapping (HaMM), Infrastructure Vulnerability Analysis Tools (IVAT), Public Impacts (PI), and Workforce Development (WorD). Contributions to each of these focus areas will be made in the next phase of CLiP that will contribute towards and be integrated with the overarching goal of producing a decision support system available to CLiP members.

To maximize impact, we will focus on increasing collaboration with the Oregon Resilience Plan and related work occurring at the national level through NIST, FEMA, USGS, etc. We also will identify opportunities to integrate results from other research activities at OSU that are relevant and find ways to tailor those to CLiP members as useful research products.

Hazard Modeling and Mapping

Digital GIS maps are a critical element in conveying hazard information as well as evaluating the vulnerability of system networks. The following tasks are envisioned over the next several years of CLiP:

- With CLiP members, identify priorities for mapping efforts including locations and types of maps.
- In the O-Help platform, we seek to have updated, living maps taking advantage of recent advances in modeling/analysis tools, new geospatial and other data. Part of these updates come from new knowledge created in CLiP projects such as evaluating the liquefaction susceptibility of the Willamette silts. The ORP map development process was based on FEMA's HAZUS methodology. While widely utilized, the HAZUS methodology utilizes very outdated techniques (e.g., 1980's science) that have been significantly advanced. New mapping techniques also need to be validated based on recent events elsewhere (e.g., Japan, Chile, New Zealand).
- As part of developing new, up to date maps, we seek to apply more of the rigor of site-specific techniques to statewide mapping as much as possible. Currently, the engineering community tends to have very detailed analysis techniques for a localized site but then very coarse methods for analyzing a large region. Sometimes the local site techniques can be simplified to consider a few basic parameters that can be obtained or estimated at the regional scale to provide better estimates than current techniques.
- Develop maps considering different scenario events. Currently in O-Help, the ground motion maps are based on Cascadia Subduction Zone events; however, other faults in Oregon such as the Portland Hills Fault have the potential to be damaging as well. Addition of these maps to O-Help would be helpful to understand the context of those hazards and their possible impacts on infrastructure.
- Additional simulation, data analytics, and design algorithms will be developed to allow users to generate their own custom scenario maps and analyses within the decision support system to help evaluate infrastructure vulnerability (See *Infrastructure Damage/Loss Analysis Tools)*
- Ability to have additional hazard curves available for a site to support design in addition to the seismic hazard curves provided by the USGS. (See Figure 3).
- When appropriate, use of 3D mapping (see Figure 2, http://web.engr.oregonstate.edu/~olsen/3DGIStest/3DMaptest2.html) can help communicate hazards better as well as be used to create visualizations when communicating with stakeholders and the general public. 3D is also important to provide context that can be lost in a flattened, 2D representation. To this end, we are currently working towards updating the O-Help interface to support the 3D data.

To improve the reliability of these mapping efforts as well as current design procedures, much effort remains to characterize and quantify the hazards in Oregon better. One ongoing question that has been supported through CLiP is related to the liquefaction susceptibility of the Willamette Silt including laboratory and field testing. Improved characterization of this soil (including its spatial variability) that covers an extensive area of the Willamette Valley will facilitate prioritization of seismic retrofits, development of recovery and response protocols, and resilience planning to locations and infrastructure that is most at-risk. Additional predictive models of cascading hazards such as landslides, rockfalls, and tsunamis are needed to delineate at-risk regions in the state. Landslide susceptibility that leverages existing landslide inventories will enable more geology-specific assessment of future failures under a seismic influence. These new maps will be created for both existing landslides and unfailed terrain with a focus on how these failures might affect infrastructure. With this data, a series of interactive tools will be developed that highlights potential closure impacts, such as time, to enable a more tangible assessment of landslide risk. This data can be used to inform damage or loss of buried infrastructure based on fragility curves for pipelines or other utilities.

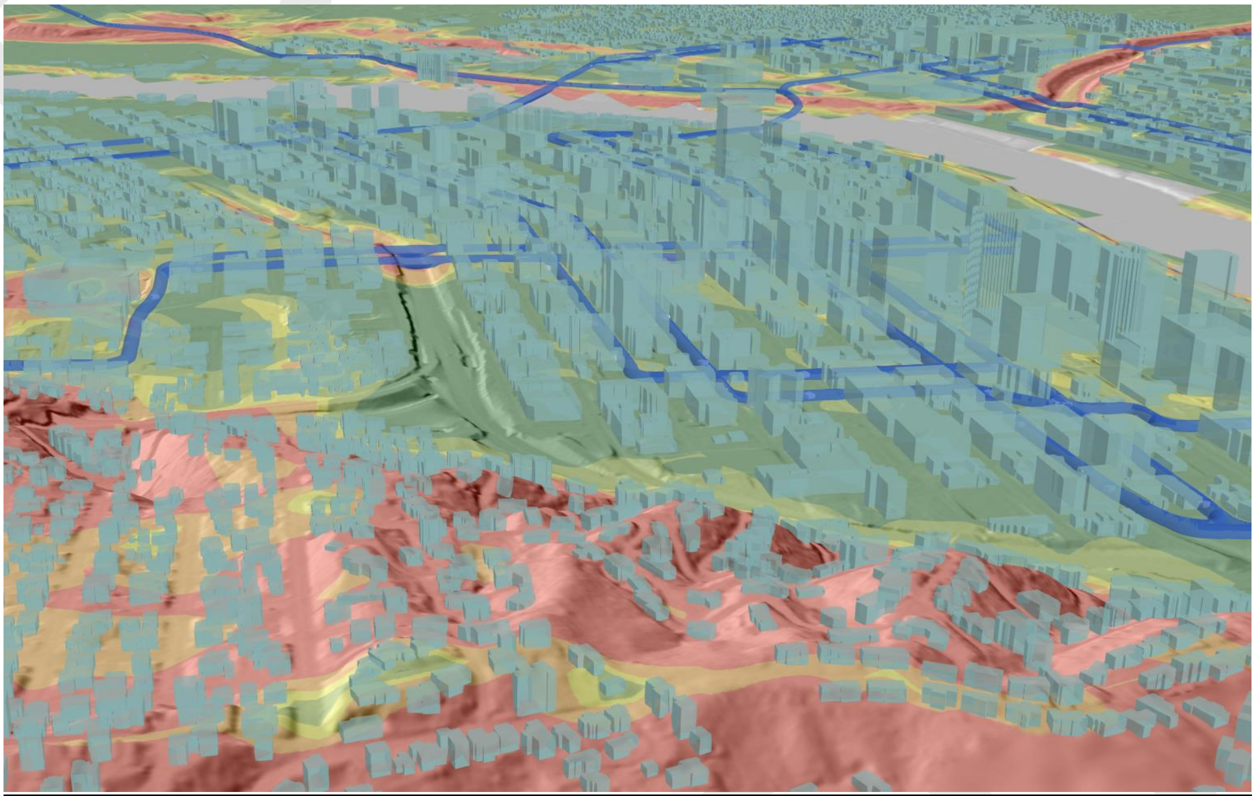

Figure 2 - *Example 3D visualization of landslide probability hazard map, lidar elevation data, buildings, and Trimet lines in the Portland Metro.*

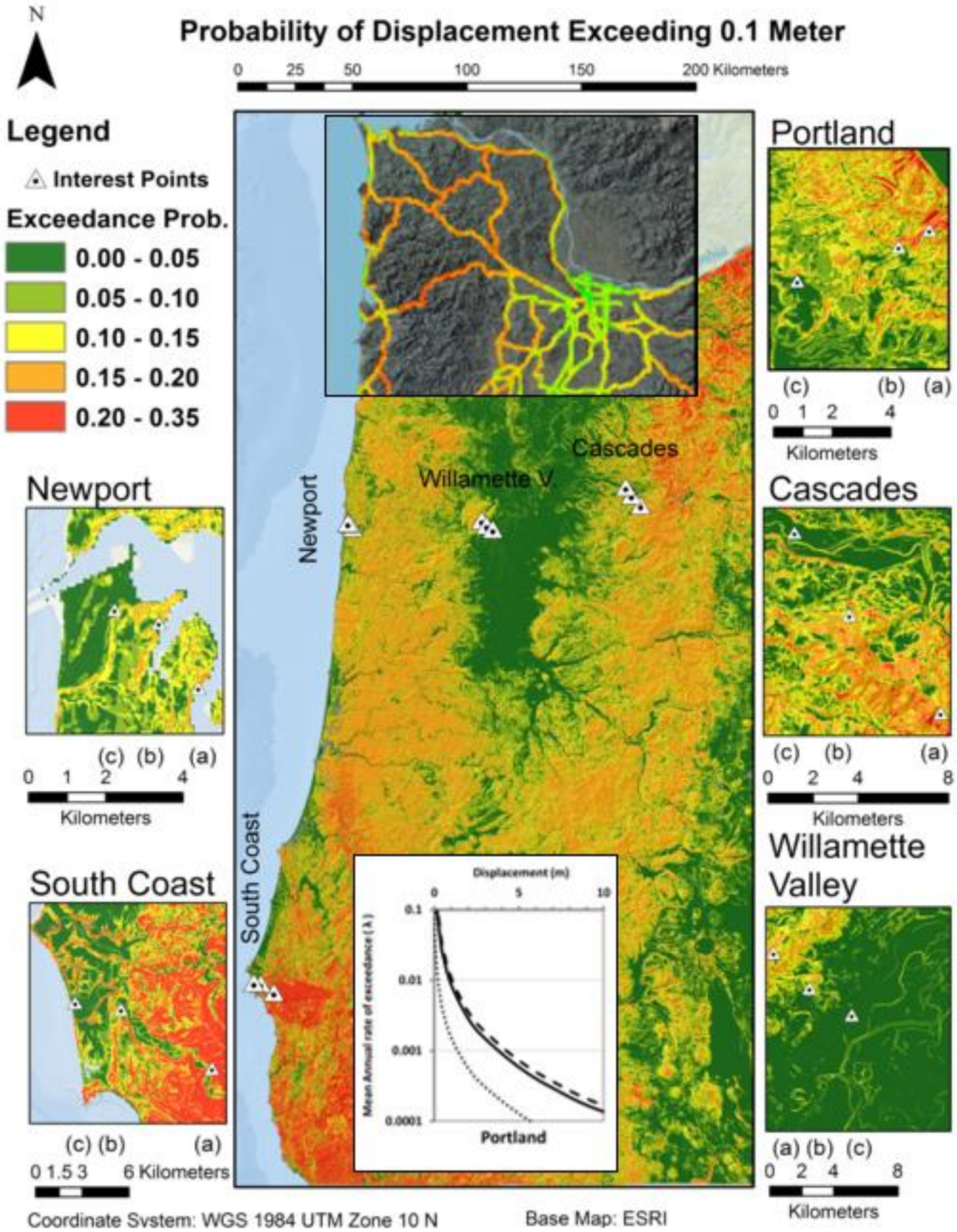

Figure 3 *- Example probabilistic landslide hazard map with an extracted highway vulnerability map developed for Oregon DOT. The curves shown in the figure represent mean annual rates of exceeding displacements due to landslides for 3 sites. With a set of maps, a curve is available for each pixel to support performance based design.*

Infrastructure Damage/Loss Analysis Tools

Additional tools and techniques are needed to appropriately relate those hazards characterized and mapped to the estimated infrastructure damage and loss. Figure 4 shows an example analysis completed to determine damage states of bridges in Oregon. Information related to the hazard levels were extracted from the O-Help scenario maps and then related to damages through fragility curves. Several fragility curves were tested and showed significantly different results, indicating the need for additional research to better relate infrastructure damage to hazard levels. The methodology developed herein can be expanded and applied to other infrastructure such as pipelines and transmission lines to assess the vulnerability of those systems. Once those damage states are obtained, network level analyses and interdependencies can be evaluated.

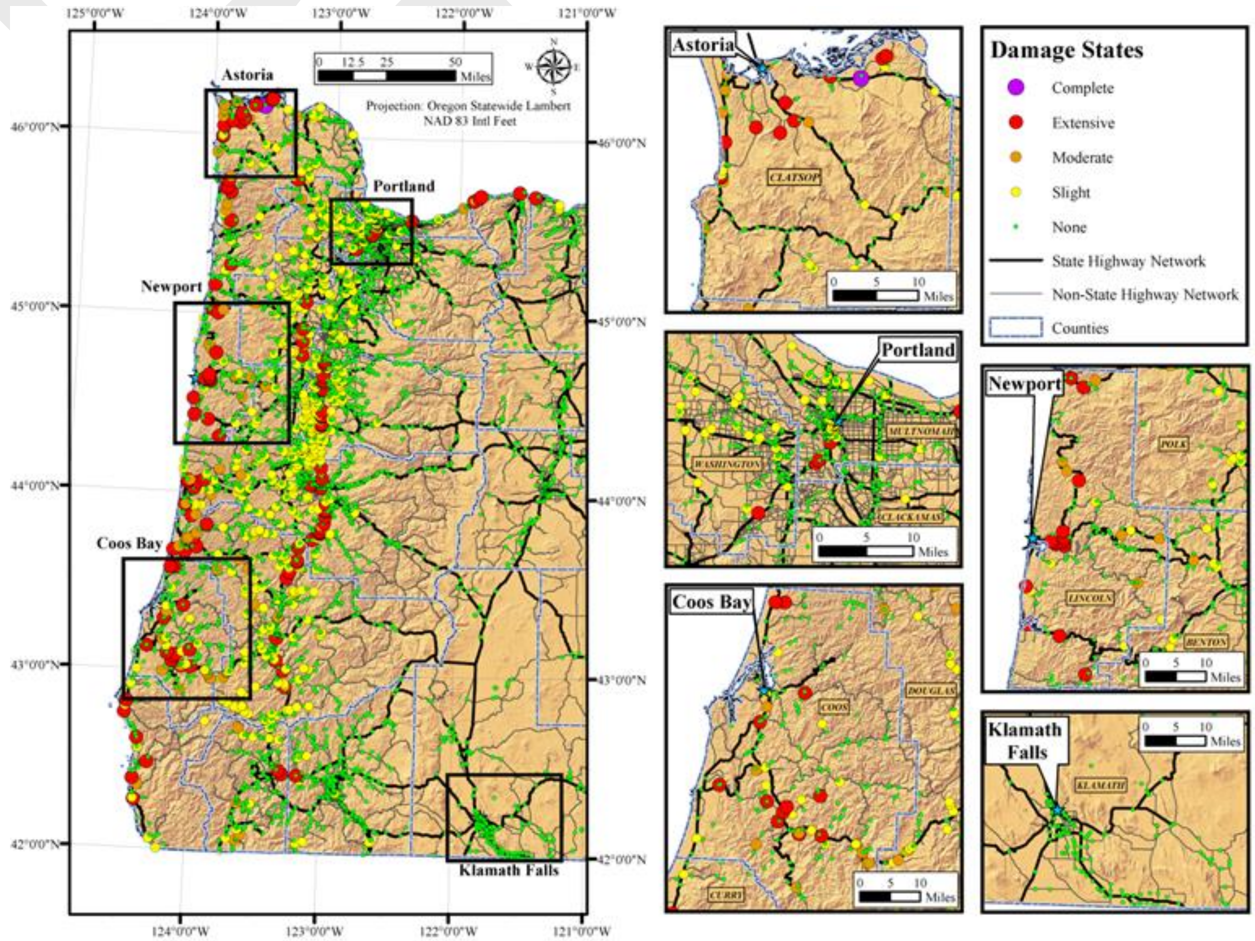

Figure 4- *Example damage state evaluation in bridges in Oregon for a M9.0 earthquake event.*

Some steps toward building such as system include:

- Build a separate experimental/secure version of OHELP where these types of evaluations can be tested and shared with CLiP board members through web mapping services but not be made available to public.

- Conduct a systematic study to identify gaps in fragility curves for Oregon (i.e., evaluate which important hazards and structure types we have fragility curves and which we do not). The study would also evaluate if the existing fragility curves are appropriate to be applied in Oregon given our geology and seismic characteristics). Develop fragility curves based on recent events that can translate ground motions, landsliding, liquefaction to estimated damage on structures.
- Perform network level analysis of different infrastructure systems such as water (both water in pipes as well as water stock), sewer, electric, gas, highways, buildings, and critical facilities to determine their vulnerability. As an example, a study could focus on how co-seismic landsliding in the coast range and Cascades would affect our water supply, treatment, and distribution infrastructure, and determine what losses/damages are expected in terms of damage or potential sediment deposition. Displacement data from slope failures could be used to characterize potential damage or loss of buried infrastructure. Another example would be expanding on the highway network modeling from the first phase of CLiP to evaluate increases in travel time stemming from cascading hazards.
- Develop of "on-the-fly" analysis tools where users can upload their data via a web interface and perform these assessments.

Public Impacts

The analysis of infrastructure losses and damages can then be integrated with socio-economic data (e.g., population density) to determine overall impacts (e.g., costs, time delays, etc.) to the public. These impacts can be evaluated for the response phase immediately after the event, and the long-term operation of the community. The information and data that is produced from this research will inform utility companies, municipalities, and emergency management agencies to strategically plan based on expected performance of infrastructure and based on the needs of a community to operate. Key questions to consider are:

- ***Risk*** - Integration of socio-economic data can be used to identify human impacts and risk to the public related to the loss of functionality of the infrastructure. The impacts can be evaluated with respect to ability to evacuate, ability to operate immediately after an extreme event, and long-term operation of a community.
- ***Resilience*** - The decision analysis tools can be utilized to identify vulnerable links in the network to prioritize for pre-disaster mitigation and post-disaster repair that will provide the maximum benefits to the public both socially and economically. The decision analysis tools could also be used for simulation purposes to evaluate network robustness and redundancy and evaluating the overall network performance. These tools will provide a community with scientific and engineering data to inform discussions with the public and decision making within a community.
- ***Recovery*** - Similar to fragility curves, recovery or restoration curves can be developed and integrated into the decision support system to make predictions of time associated with repairs, and therefore downtime of services in different locales based on the likely damage to occur.
- ***Response*** - Performing these simulations provides information on areas most likely affected such that response plans can be ready to go based on likely events, improving

the efficiency of the response. In the aftermath of the event, event specific maps could be quickly generated and integrated in the platform quickly after the event occurs and used in more refined analyses in the immediate aftermath of the event enabling improved loss estimation and response efforts.

By taking a holistic approach to a community's impacts we are able to help communities plan for pre-disaster mitigation in a strategic manner and engages all of the members of the community and aims to lessen the impacts of an extreme event on a community.

Workforce Development

CLiP, in its first phase, has supported a variety of workforce development opportunities. This section will highlight some of those activities as well as some new ideas moving forward in the next phase to promote workforce development both with practicing professionals and students at OSU.

1. **Webinars –** We have held training webinars for O-Help for CLiP members to promote its use. A recording of the webinar is available on the O-Help website. In the next phase, we propose hosting a regular (maybe quarterly) webinar series as a mechanism to inform CLiP members of current research occurring both within CLiP and other research activities at OSU. For example, faculty and students actively present at conferences and could share that same presentation as a webinar to CLiP members to stay up to date.
2. **Short Courses**- Over the last several years, OSU has hosted a variety of resilience-focused seminars . In this next phase we propose to host periodic short courses (e.g., once a year) that CLiP members would be invited to attend. We will capitalize on other efforts and short courses being held by faculty.
3. **Working Groups** – In the most recent cycle of CLiP projects, a new CSZ surveyor's group was formed after identifying a major gap in the ORP as to the role of surveyors in recovery efforts. It was clear that the surveying community needed additional planning and training to provide the various data products needed to support recovery efforts. This working group holds regular meetings. In this next phase, we will identify gaps or other communities that need to be engaged or better integrated and work with local practitioners to formulate working groups, if appropriate.
4. **Research Experience for Undergraduates (REU) -** Over the last several years, CLiP has been involved in the Summer Undergraduate Research Fellowship (SURF) program which provides research experiences by pairing SURF students up with graduate students to be trained in hazards and resilience. The products developed by those SURF students are then integrated into the larger CLiP project. The SURF students also share their results and experiences at a poster session. A new REU site on "Engineering for Bouncing Back" has now been established at OSU, one that is funded by National Science Foundation (NSF) and supports research on the theme of community resilience. CLiP will partner with this new REU site and support additional REU projects on this theme, moving forward.
5. **Graduate Student support –** Another ancillary benefit to CliP is the support and training provided to graduate students focused on hazards and resilience. Most of the

students previously supported on CLiP have continued making impacts by sharing and expanding their knowledge of hazards and resilience in their current employment.

6. **Improved classroom experience in resilience** - Several faculty members involved in CLiP have shared and integrated CLiP research results in their coursework to reach a broader audience of students who develop skills in hazard analysis and resilience.

<u>Next steps</u>

Our milestone for the end of the next 5 year phase of CliP (Spring 2024) would be to have a completed, functional decision support system in place where CliP members can import geospatial databases of their infrastructure into the system and perform these analyses and simulations to relate the hazards to infrastructure damage to ultimately loss and restoration. To this end, we will work with CLiP board members in our February teleconference to determine the priorities for functionality of this system to focus our efforts in the next year to establish specific goals based on those priorities. We will then identify the appropriate personnel at OSU to tackle these priorities and outline specific steps. In Spring 2019, we will have a formal CLiP meeting to outline the specific tasks to be completed in this first year towards that objective as well as the formal timeline.

The vision above is certainly ambitious, includes a lot of potential directions, and full realization likely would require more resources beyond what CLiP is able to support with its current membership. However, to achieve the broader vision described in this white paper, in many ways CliP projects can serve as an incubator for other related research at OSU where faculty and students can test out new ideas to then seek additional funding support to tackle many of these challenges and then bring those research products back into CLiP from the broader effort and develop tools that will enable CLiP members to take advantage of the results of those research efforts to improve resilience in the State of Oregon.