Oregon Climate Change Effects, Likelihood, and Consequences Workshop

Fall 2019

Workshop Summary Report prepared by
The Oregon Climate Change Research Institute

OCCRI

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A Workshop Summary Report

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Introduction

To support the State of Oregon's Climate Adaptation Framework and Natural Hazard Mitigation Planning processes, the Oregon Climate Change Research Institute (OCCRI) convened a full day workshop on August 20, 2019 in Corvallis, Oregon at Oregon State University. The workshop brought together subject matter experts from the State's regional public universities along with Oregon state agency staff to discuss the likelihood, confidence, and consequences of a range of climate change effects in Oregon. Meeting objectives included:

1. Assist the State of Oregon's Climate Adaptation Framework and Natural Hazard Mitigation Planning processes by characterizing the present state of the science around the likelihood, confidence, and consequences associated with a suite of climate change effects.
2. Describe the geographic variability of each of the climate change effects likelihood of occurring in Oregon.
3. Catalogue existing and recommend future vulnerability assessments for each of the climate change effects in Oregon.

Climate Adaptation Framework Context – Comments from Chris Shirley (DLCD)

Oregon has experienced many of the climate change effects anticipated in the State's original 2010 Climate Adaptation Framework such as extreme heat events, changes to the ocean environment, wildfire, and drought. A better understanding of climate change and its effects is helping to drive an initiative, begun in 2018, to update the State's Framework. Presently, the Climate Adaptation Framework process consists of 23 state agencies, where potential actions and adaptations may ultimately be implemented, working together to update the Framework by 2020. From this workshop, the Climate Adaptation Framework process is looking to gain a better understanding of current science to help with prioritizing adaptation objectives.

Natural Hazard Mitigation Planning Context – Comments from Marian Lahav (DLCD)

To be eligible for federal disaster assistance, states are required to discuss the probability of future hazard events for each natural hazard addressed in their Natural Hazard Mitigation Plans. Probability includes projected changes in natural hazard occurrences in terms of location, extent, intensity, frequency, and duration as well as the effects of long-term changes in weather patterns and climate on the identified hazards. OCCRI, via this workshop and other activities, is presently supporting Oregon natural hazard mitigation planning at the state, regional, and county level. The draft update to the State's Natural Hazard Mitigation Plan is due in spring 2020.

Additional Oregon Context – Comments from Director Jim Rue (DLCD)

Oregon's cap and trade bill HB 2020 did not survive the 2019 legislative session. However, if the bill passes during the 2020 short session, the Climate Adaptation Framework could serve as a roadmap for potential future investments.

Meeting Format

To achieve the meeting's objectives, with the above contextual information in mind, the format of the meeting was as follows:

We spent approximately half an hour per climate risk (covering 12 in all), with 10-minute presentations and 20 minutes of discussion (See Appendix 1 for meeting participants and Appendix 2 for meeting agenda). In general, we used the IPCC AR5 risk framework throughout the meeting to guide our discussions. Prior to the workshop we sent out a Questionnaire (Appendix 3) to help frame our conversations about each climate risk around the following topics:

1. Likelihood
2. Confidence
3. Geographic variability (see Figure 1)
4. Consequences (if time allows)
5. Vulnerability assessment (if time allows)

This summary report synthesizes the outcomes from workshop presentations, questionnaires, and discussions for each climate-related risk considered.

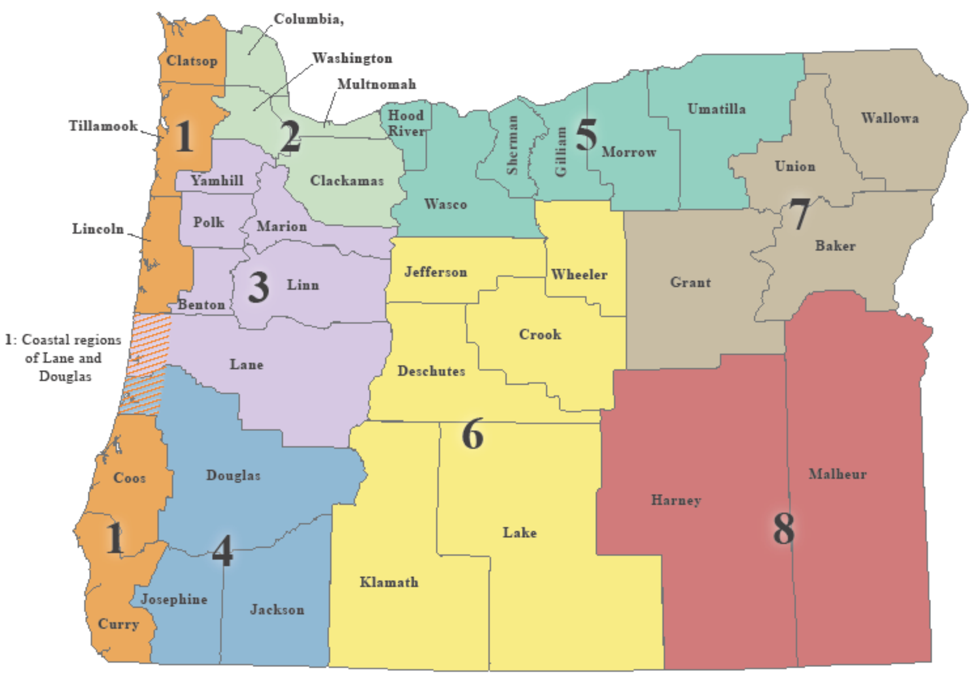

Figure 1: Natural Hazard Mitigation Planning Regions and Counties

Summary of Climate Risks

Likelihood & Confidence

Table 1 summarizes in a matrix the final likelihood and confidence rankings for the twelve climate related risks considered in the 2019 Climate Change Effects, Likelihood, and Consequences Workshop. Toward the end of the meeting, the group discussed and refined the likelihood and confidence rankings of all risks together (Table 2), noting changes from the 2010 Oregon Climate Adaptation Framework (Table 3). Changes included:

1. Upgraded increased temperature and extreme heat to Extremely Likely from Very Likely since it is the most likely of all risks and other risks stem from this finding.
2. Risks related to ocean and coastal changes (ocean temperature and chemistry, coastal hazards, wetland ecosystems), changes to water quality, and increases in human diseases upgraded to Very Likely from Likely
3. A new risk added to Likely (>66%): changes to air quality.
4. Upgraded increased frequency of extreme precipitation and floods to Very Likely (>90%) from More Likely Than Not.
5. Two risks were not considered in the workshop: changes in plant species habitats (Likely) and landslides (More Likely Than Not).

Table 1 Matrix of likelihood and confidence ranking for risks considered in the 2019 Oregon Climate Risk Workshop

Confidence ➔ Likelihood 🡻	**Low**	**Medium**	**High**	**Very High**
Extremely Likely (<95%)				Risk 4. Increases in temperature and extreme heat
Very Likely (>90%)		Risk 9. Increases in human diseases	Risk 1. Changes in hydrology Risk 3. Increases in extreme precipitation and floods Risk 7. Changes to water quality Risk 10. Changes in ocean temperature & chemistry Risk 11. Increases in coastal erosion/floods Risk 12. Loss of wetland ecosystems	
Likely (>66%)	Risk 6. Changes to air quality	Risk 2. Increases in drought Risk 8. Increases in invasive species and pests	Risk 5. Increases in wildfire	
More Likely Than Not (>50%)				

Table 2 Summary of likelihood and confidence rankings and geographic variability notes for risks considered at 2019 Oregon Climate Risk Workshop. Likelihood rankings from the 2010 Oregon Climate Adaptation Framework are in parentheses. EL=Extremely Likely; VL=Very Likely; L=Likely; LTN=More Likely Than Not; Confidence rankings are VH=Very High; H=High; M=Medium; L=Low.

Risk	Likelihood	Confidence	Geographic Variability
1. Changes in hydrology	VL (VL)	H	Greatest changes in basins with snow component
2. Increases in drought	L (L)	M	Snow: mid-to-low elevations Summer moisture/runoff: western
3. Increases in extreme precipitation and floods	VL (LTN)	H	Extreme precipitation: more likely in eastern OR Extreme river flow: more likely upstream
4. Increases in temperature and extreme heat	EL (VL)	VH	Least on coast, more inland
5. Increases in wildfire	L (L)	H	Western OR vegetation type change
6. Changes to air quality	L	L	
7. Changes to water quality	VL	H	
8. Increases in invasive species and pests	L (L)	M	
9. Increases in human diseases	VL (L)	M	Yes, based on social vulnerability
10. Changes in ocean temperature and chemistry	VL (L)	H	Region 1-coastal issues

11. Increases in coastal erosion/floods	VL (L)	H	Region 1-coastal issues
12. Loss of wetland ecosystems	VL (L)	H	SLR-region 1/other factors all of OR

Table 3 Comparison of likelihood rankings from the 2010 Oregon Climate Adaptation Framework and the 2019 Oregon Climate Risk Workshop. Please note that risks were renumbered in 2019, but shading shows same risks.

New (2019) Risks: Changes to air quality; Changes to water quality; Increases in human diseases

Risks (2010) Not Considered: Landslides, vegetation shifts

Likelihood Level	2010 Oregon Climate Change Adaptation Framework Climate Risks	Proposed Changes from 2019 Oregon Climate Risk Workshop
Extremely Likely (>95%)		Risk 4. Increase in average annual air temperatures and likelihood of extreme heat events.
Very likely to occur (>90%)	Risk 1. Increase in average annual air temperatures and likelihood of extreme heat events. Risk 2. Changes in hydrology and water supply; reduced snowpack and water availability in some basins; changes in water quality and timing of water availability.	Risk 1. Changes in hydrology and water supply; reduced snowpack and water availability in some basins; changes in water quality and timing of water availability. Risk 2. Increased incidence of drought driven by temperature changes. Risk 3. Increased frequency of extreme precipitation events and incidence and magnitude of damaging floods. Risk 7. Changes to water quality. Risk 10. Increase in ocean temperatures, with potential for changes in ocean chemistry and increased ocean acidification. Risk 11. Increased coastal erosion and risk of inundation from

		increasing sea levels and increasing wave heights and storm surges. Risk 12. Loss of wetland ecosystems and services. Risk 9. Increases in human diseases.
Likely to occur (>66%)	Risk 3. Increase in wildfire frequency and intensity. Risk 4. Increase in ocean temperatures, with potential for changes in ocean chemistry and increased ocean acidification. Risk 5. Increased incidence of drought. Risk 6. Increased coastal erosion and risk of inundation from increasing sea levels and increasing wave heights and storm surges. Risk 7. Changes in abundance and geographical distributions of plant species and habitats for aquatic and terrestrial wildlife. Risk 8. Increases in diseases, invasive species and insect, animal and plant pests. Risk 9. Loss of wetland ecosystems and services.	Risk 5. Increase in wildfire frequency and intensity. Risk 6. Changes to air quality. Risk 8. Increases in invasive species and insect, animal and plant pests.
More likely to occur than not (>50%)	Risk 10. Increased frequency of extreme precipitation events and incidence and magnitude of damaging floods. Risk 11. Increased incidence of landslides.	Risk 2. Increased incidence of drought driven by precipitation changes.

Risk 1: Changes in Hydrology and Water Supply; Reduced Snowpack and Water Availability in Some Basins; Changes in Timing of Water Availability

Speaker: Heejung Chang (PSU)
Returned Questionnaires: Heejung Chang, Oregon Health Authority

Summary:

Overall, it is very likely (>90%) that Oregon will experience changes in hydrology (*high confidence*) with the greatest changes in basins with a snow component.

Likelihood:

Annual flow: no substantial change
Winter flow: *likely* to increase
Summer flow: *very likely* to decrease
Reduced snowpack: *very likely*
Center timing of flow: *likely* to move to earlier date (depending on snow contribution)
Stream temperature: summer stream temperature is *very likely* to increase
Turbidity: winter turbidity is *likely* to increase

Confidence:

Annual flow: *high confidence*
Winter flow: *high confidence*
Summer flow: *high confidence*
Reduced snowpack: *very high confidence*
Center timing of flow: *high confidence*
Stream temperature: *very high confidence*
Turbidity: *high confidence*

Geographic Variability:

Basins with a snow component will experience the greatest changes in hydrology and water supply and availability.

Characterization:

Annual streamflow is not expected to change substantially, however, the timing and magnitude of seasonal runoff is expected to change. Across most of the state, fall (SON) and winter (DJF) runoff is projected to increase, particularly from the Cascades eastward. Mountainous regions (Coast Range, Cascade Range, Blue Mountains) are projected to experience decreases in spring and summer runoff. The Oregon portion of the Columbia Plateau and southeastern Oregon may experience increases in spring and summer runoff.

In terms of water supply vulnerability in the mid-21st century, defined as the county total annual water use divided by total annual runoff, western and northeastern Oregon, particularly Klamath, Union, and Baker counties, are expected to become more vulnerable whereas southeastern Oregon is projected to become less vulnerable. This is due to decreases in total annual runoff in most of the state and increases in annual runoff in southeastern Oregon. Historically, southeastern Oregon was more vulnerable than coastal areas because the water use to runoff ratio was higher. Note that changes in water demand and use were not taken into account in these assessments.

Snow levels are projected to rise in elevation by the end of the 21st century under both lower (i.e., "mitigating") and higher ("business-as-usual") greenhouse gas emissions scenarios. Snow levels indicate the altitude below which only rain is falling. This leads to declines in snowfall frequency (i.e., days receiving snow versus rain). Declines are nonlinear: business-as-usual emissions lead to an increased rate of decline through the second half of the 21st century, whereas mitigating emissions results in decreased rates. For example, at Clackamas Lake, Oregon, snow was falling during 42.5% of wet days historically, whereas by the end of the 21st century under the higher emissions scenario, only 14.4% of wet days were projected to be snowing.

When evaluating future changes in streamflow, we can look at four standard metrics: mean annual daily flow (representing mean conditions), 90% flow (representing high flow), 7-day average of low flow (representing low flow), and center timing of volume (representing timing of flow). Future trends in these flow metrics are generally quite variable geographically. Heejun Chang's presentation at the workshop focused on four locations: Clackamas (High Cascades with aquifer system), South Santiam (Western Cascades), Deschutes (aquifer system), and Lower Willamette.

Future trends in mean annual daily flow are small with Willamette and Clackamas decreasing and Deschutes and South Santiam increasing slightly. Future trends in the 90% flow are geographically quite variable. On the Willamette River, high flows are not expected to change. On the Clackamas River, high flows are projected to decrease slightly whereas the Deschutes and South Santiam Rivers are projected to see greater high flows. Future trends in low flows are also geographically variable with the Willamette and Clackamas projected to experience slight increases in minimum flows whereas the Deschutes and South Santiam are projected to experience further decreases in minimum flows. Future trends in the center timing of flow indicate little to no change for many areas, but earlier center of timing for the Deschutes River and Clackamas where snow contribution to summer flow is currently higher than the other low basins.

Stream temperature is projected to increase with increasing air temperatures and changing daily flows. This is particularly important for critical thresholds for fish life stage events. For example, stream temperatures greater than 21°C are very detrimental to habitat suitability, yet projections show stream temperatures rising over this threshold in a Western Cascade stream by the end of the 21st century. The probability of 7-day average daily maximum stream temperature greater than 17.8°C stream temperatures, a threshold important for fish habitat, is expected to increase for many streams, particularly under the high emission scenario.

In recent years, the conversation has shifted toward climate change increasing the frequency of snow droughts. Snow drought is defined as a period of abnormally low snowpack for the time of year and there are two types: dry snow drought (below-normal, cold-season precipitation) and warm snow drought (a lack of snow accumulation despite near-normal precipitation caused by warm temperatures and precipitation falling as rain rather than snow, or unusually early snowmelt). Snow drought is addressed under Risk 2: Increased Incident of Drought.

In summary, fall and winter runoff are projected to increase statewide, while spring and summer runoff are likely to decrease only in western and northeastern parts of the state. Water resource vulnerability is likely to increase in western and northeastern counties. Snow levels are likely to increase and snowfall frequency is projected to decrease, particularly under the higher emissions scenario. There are substantial uncertainties and spatial variations of various flow metrics. Summer stream temperature is projected to increase, particularly under the higher emissions scenario in the western Cascade basins where summer flow reduction is high.

Select Literature:

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- Jaeger, K.W. Amos, A., Bigelow, D.P., Chang, H., Conklin, D.R., Haggerty, R., Langpap, C., Moore, K., Mote, P., Nolin, A., Plantinga, A. J., Schwartz, C., Tullos, D., Turner, D.T., Finding water scarcity amid abundance using human-natural system models, Proceedings of the National Academy of Sciences 111(45): 11884-11889.

Discussion Topics

Groundwater

The High Cascades region is relatively resilient compared to the Western Cascades due to ground water. However, with more rain than snow projected the actual water that recharges groundwater may decrease. Further, surface warming will eventually warm groundwater, but it is unclear how long that will take.

Tree Thresholds for Drought

There is a risk to trees with higher temperature, even if there is available water the growing environment may not be suitable. The impact to trees growing environment is very species dependent. More knowledge in this area can help with adaptation actions.

Food Security

Impacts on salmon are already impacting tribal food sources. Salmon survival is limited for stream temperature increases (with significant geographic variability). Changes in seasonality can significantly affect growers (e.g., onion growers). In the Willamette Water 2100 project, there was not a significant impact on food security since farmers adapted by planting earlier in the year to avoid later summer drought.

Future Water Demand

Future water demand estimates are presently difficult to translate into actual changes in water use. Therefore, future water demand should be a future research area.

Atmospheric Rivers

Atmospheric river days are projected to increase. Atmospheric rivers will carry more water vapor but won't necessarily increase precipitation.

Consequences:

Public Health Consequences

- Reduced water availability can reduce the quality and quantity of available water for drinking, cooking, sanitation and hygiene, thereby leading to water insecurity.
- Avoidable health outcomes associated with water insecurity include illness from water contamination, sanitation and hygiene-related illness, dehydration, emotional distress (fear, worry, anger, bother) and mental health issues (depression and anxiety). Reduced water availability can also contribute to vector- and food-borne diseases and threaten food production, thereby contributing to food insecurity and malnutrition, especially for low-income populations.
- Native American Tribal Nations that rely on fish as an important part of their diet will be affected by reduced fish populations.

Other Consequences

- Increasing water demand and competition over allocation, particularly during the summer
- Increasing cost of treating drinking, stormwater, and wastewater
- Negative effects on water-dependent industries
- Projected changes may require different dam operation rules

Vulnerability Assessments:

- No comprehensive statewide water resource vulnerability assessment has been completed, although small-scale assessments have been done in some specific watersheds.
- Oregon Health Authority Public Health Division (OHA-PHD) and the Department of Environmental Quality (DEQ) assessed land use-related vulnerabilities to drinking

water sources throughout the state and provided these assessments to system operators.
- Water system master plans are required for systems serving 300 or more connections. The plan must include an evaluation of the water supply's ability to meet anticipated demand over the next 20 years and identify and plan for solutions as necessary
- Funding for the development of a resiliency plan is available to public water systems serving more than 25 people.

Comments and Recommendations:

- Assess combined vulnerability of compounding hazards (e.g., heat wave, flood risk, fire).
- Understand the feedback between increasing temperature and precipitation variability, fire occurrence, droughts and floods, and water quality.
- Assess the effectiveness of some adaptive strategies to reduce water resource vulnerability.
- Oregon lacks a financing tool to assist the 900+ public water systems not eligible for federal capital assistance.
- Oregon's public health system has very limited capacity to track adverse health effects of water insecurity on communities and susceptible populations.

Risk 2: Increased Incidence of Drought

Speaker: David Rupp (OSU)
Returned Questionnaires: Meghan Dalton, Oregon Health Authority

Summary:

It is likely (>66%) to very likely (>90%) that Oregon will experience an increase in the frequency of one or more types of drought. An increase in drought frequency caused by increasing temperature is more likely than an increase in drought frequency caused by an increase in periods of low precipitation, and the confidence of this assessment is higher for temperature driven drought (*high confidence*) than for precipitation driven drought (*medium confidence*).

Likelihood:

Drought can be classified according to the cause of a low water/moisture supply. Here we classify droughts by their 1) low spring snowpack (snow drought), 2) high spring/summer evaporative demand, 3) low summer precipitation, 4) low summer soil moisture, 5) low summer runoff, and 6) low annual to multi-annual precipitation. A drought may have multiple causes (e.g., low spring snowpack and high spring evaporative demand).

1) It is very likely (>90%) that drought frequency due to low spring snowpack will increase.
2) It is very likely (>90%) that drought frequency due to high spring/summer evaporative demand will increase.
3) It is more likely than not (>50%) that drought frequency due to low summer precipitation will increase.
4) It is more likely than not (>50%) that drought frequency due to low summer soil moisture in *the upper soil layer* will increase.
5) It is likely (>66%) that drought frequency due to low summer runoff will increase.
6) It is less likely than not (<50%) that drought frequency due to annual and multi-annual drought periods of low precipitation will increase.

Confidence:

Confidence is high for temperature-driven drought because of very high confidence in temperature increases combined with other strong evidence (historical observations, established theory, multiple sources, consistent results, well documented and accepted methods, etc.).
Confidence is medium for precipitation-driven drought due to uncertainty in changes in the atmospheric circulation in response to global heating (the majority, but not all, climate model simulations indicate decreases in summer precipitation, and results vary spatially over Oregon).

Geographic Variability:

Snow drought is very likely to increase in mid-to-low elevation mountainous regions of the Cascades and eastern Oregon.

Droughts due to lower summer precipitation, soil moisture, and runoff are more likely to increase in western Oregon than in eastern Oregon (particularly Regions 6 and 8) due to projected spatial patterns in precipitation changes.

Characterization:

“Snow droughts” are the most likely type of drought to increase in frequency because of the direct link between temperature and snow accumulation and melt. The 2015 snow drought provides a glimpse into the future. From the NCA4: “Snowpacks in Oregon and Washington in 2015 were the lowest on record at 89% and 70% below average, respectively. These levels are more extreme than projected under the higher scenario (RCP8.5) by end of century (65% below average). However, with continued warming, this type of low snowpack drought is expected more often. For example, the 2015 extreme low snowpack conditions in the McKenzie River Basin (which sits largely in the middle elevation of the Oregon Cascades) could occur on average about once every 12 years under 3.6°F (2.0°C) of warming. For each 1.8°F (1°C) of warming, peak snow-water equivalent in the Cascades is expected to decline 22%–30%.” Marshall et al. (2019) calculated that the “average frequency of consecutive snow drought years (SWEmax < historical 25th percentile) is projected to increase from 6.6% to 42.2% of years.”

Select Literature:

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- OCAR3, “Drought Risk” (p. 22).
- NCA4 Northwest chapter: https://nca2018.globalchange.gov/chapter/24/

Discussion Topics

See discussion topics in Risk 1 section as Risk 1 and Risk 2 were discussed together during the workshop.

Consequences:

Public Health Consequences

- Droughts will reduce the quality and quantity of available drinking water for drinking, cooking, sanitation, and hygiene, thereby leading to water insecurity.
- Avoidable health outcomes associated with water insecurity include illness from water contamination, sanitation and hygiene-related illness, dehydration, emotional distress (fear, worry, anger, bother) and mental health issues (depression and anxiety).
- Droughts may also reduce food production and the viability of subsistence fisheries, and thus contribute to food insecurity and malnutrition.

Environmental Consequences

- Longer dry seasons and more pronounced droughts are projected to reduce wetland habitat extent and duration, causing changes in waterfowl movement. (NCA4 NW chapter)
- Hotter temperatures are projected to increase risk of tree mortality during drought which may lead to reduced carbon storage, increased fuel loads, reduced habitat, and vegetation transformations. (OCAR4)

Vulnerability Assessments:

- Water system master plans are required for systems serving 300 or more connections. The plans must include an evaluation of the water supply's ability to meet anticipated demand over the next 20 years and identify and plan for solutions as necessary.
- Funding for the development of a resiliency plan is available to public water systems serving more than 25 people.

Comments and Recommendations:

- Oregon lacks a comprehensive water plan for extreme drought conditions and how ground water resources will be affected.
- Oregon's public health system has very limited capacity to track adverse health effects of drought on communities and susceptible populations.

Risk 3: Increased Frequency of Extreme Precipitation Events and Incidence and Magnitude of Damaging Floods

Speaker: David Rupp (OSU)
Returned Questionnaires: David Rupp (OSU), Bart Nijssen(UW), Oregon Health Authority, Oregon Department of Transportation

Summary:

It is very likely (>90%) that Oregon will experience an increase in the frequency of extreme precipitation events (*high confidence*). It is very likely that Oregon will experience an increase in the frequency of extreme river flows (*high confidence*). The answer to the question of whether these extreme river flows will lead to an increased incidence and magnitude of damaging floods depends on local conditions (site-dependent river channel and floodplain hydraulics) so is beyond the scope of the workshop and this summary report. Still, given that the pattern is toward increased river flows, it is likely (>50%) that there would be an increase in the incidence and magnitude of damaging floods (*low confidence*).

Likelihood:

It is very likely (>90%) that increases in extreme precipitation events will be experienced in Oregon over the next several decades.
It is very likely (>90%) that increases in extreme river flows will be experienced in Oregon over the next several decades. Such extreme river flows may lead to damaging floods, depending on local conditions.

Confidence:

Confidence is very high in the assessment of an increase in extreme precipitation events due to strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.).
Confidence is high in the assessment of an increase in extreme river discharge (established theory, multiple sources, consistent results, well documented and accepted methods, etc.).
Confidence is low in the assessment of an increase in the incidence and magnitude of damaging floods. Ongoing work by the United States Army Corps of Engineers (USACE) should help address this question for selected locations.

Geographic Variability:

Limited regional high-resolution climate modeling indicated the likelihood of increase in extreme precipitation events is greater east of Cascades (Regions 5, 6, 7, 8 – see Appendix 3) than west (Regions 1, 2, 3, 4). The lower likelihood west of the Cascades may be due to changes in orographic effects due to changes in winds (Regions 1, 2, 3, 4).
Along the Willamette River and its tributaries (Regions 2, 3, and 4), the largest increases in extreme river flows are more likely to be upstream (towards Cascades headwaters), and less likely as one travels downstream. Along the lower Columbia (northern border of Region 1), large increases in extreme flows are least likely. The coast range (Region 1) and eastern OR have not been well studied (region 5, 6, 7, 8).

Increases in extreme river flows leading to damaging floods will be less likely where storm water management (urban) and/or reservoir operations (river) have capacity to offset increases in flood peak.

Characterization:

There is a substantial body of literature showing that, in general, extreme precipitation intensity will increase as a result of increasing water vapor in the atmosphere with increasing air temperature. However, predictions of the magnitude of this change for particular locations remain highly uncertain due to other atmospheric factors effecting precipitation intensities (stability, winds).

Increased precipitation intensity from land-falling atmospheric rivers has been summarized in the Oregon Climate Assessment Reports (http://www.occri.net/publications-and-reports/publications/), but these results come from global climate models (GCMs) that do not resolve the Oregon Coast Range, therefore do not provide highly reliable predictions of local changes.

Extreme river flow, while affected by extreme precipitation, is also driven by antecedent conditions (soil moisture, water table height), snowmelt, river network morphology, and spatial variability in precipitation and snowmelt. Most projections of extreme river flows show increases in flow magnitude at most locations across OR, however, there are some contradictory results as to how the changes in rain-on-snow events will affect flood magnitudes.

Results from the RMJOC-II project show widespread increases in extreme river discharge, e.g. the 100-year return period flow (Queen, et al, 2019). To our knowledge, scientific literature providing quantitative projections of change in likelihood of flood inundation in Oregon is not available.

Select Literature:

- Queen, L. E., Mote, P. W., Rupp, D. E., Chegwidden, O., and Nijssen, B.: Ubiquitous increases in flood magnitude in the Columbia River Basin under climate change, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2019-474, in review, 2019.
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- Tohver, I. M., Hamlet, A. F., & Lee, S. Y. (2014). Impacts of 21st ‐ century climate change on hydrologic extremes in the Pacific Northwest region of North America. JAWRA Journal of the American Water Resources Association, 50(6), 1461-1476. https://doi.org/10.1111/jawr.12199

Consequences:

Public Health Consequences

- Increased flooding will place large numbers of people and structures at risk. Some areas may experience repeat events, and areas once thought to be outside the floodplain may now experience flooding.
- Increased flooding will increase risk of injuries, illnesses, death, and displacement. The health effects of flooding include not only direct impacts, such as drowning, but also secondary impacts such as mold-exacerbated respiratory illness, carbon monoxide poisoning, and gastrointestinal illness due to contamination of the drinking water supply.
- Floods may disrupt transportation and create barriers to accessing critical resources, including medical care.
- People are also at risk of both short- and long-term negative effects on their mental and emotional health.

Others:

- Loss of life (human and animal)
- Damage to property (domestic, commercial, agricultural)
- Disruption (short-term due to inundation, long-term due to damaged infrastructure) of transportation corridors
- Reduced water quality (e.g., turbidity)
- Fish mortality (excessive dissolved oxygen below spillway)

Vulnerability Assessments:

- RMJOC-I (2011). Does not include inundation. Focus on federal dams. https://www.bpa.gov/p/Generation/Hydro/Pages/Climate-Change-FCRPS-Hydro.aspx
- RMJOC-II (ongoing). Is assessing changes in stage height at/near federal dams. https://www.bpa.gov/p/Generation/Hydro/Pages/Climate-Change-FCRPS-Hydro.aspx
- Corvallis Water Master Plan (ongoing). Does not include inundation.
- Wu, H., & Johnson, B. R. (2019). Climate change will both exacerbate and attenuate urbanization impacts on streamflow regimes in southern Willamette Valley, Oregon. River Research and Applications. https://doi.org/10.1002/rra.3454. Does not include inundation.
- OHA has contributed to the updated Flood Annex to the state Emergency Operations Plan (2018).
- OHA has developed a toolkit to help local public health authorities to access and use data to identify populations with medical needs who may require assistance to evacuate.

Comments and Recommendations:

- Create hydrodynamic modeling of flood-prone regions under future river discharge scenarios and/or future extreme precipitation events. Deliverables could include FEMA flood maps considering future climate and built-environment scenarios.
- Oregon lacks a comprehensive, integrated inventory and assessment of both historic and likely future extreme precipitation events and their impacts on the built and natural environments.
- Oregon lacks reliable assessments of likely future flood conditions and relative flood risk in areas where development and infrastructure improvements are likely to occur.

Risk 4: Increase in Average Annual Air Temperatures and Likelihood of Extreme Heat Events

Speaker: Paul Loikith (PSU)
Returned Questionnaires: Paul Loikith, Oregon Health Authority

Summary:

It is extremely likely (>95%) that Oregon will experience an increase in average annual air temperatures and likelihood of extreme heat events (*very high confidence*). The greatest warming and increase in extreme heat events is expected to occur in inland Oregon, with the least warming along the Oregon coast.

Likelihood:

It is extremely likely (>95%) that increases in average annual temperature will be experienced in Oregon over the next several decades. It is extremely likely that the frequency and severity of extreme heat events will increase over the next several decades across Oregon.

Confidence:

Confidence is very high due to strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), and high consensus.

Geographic Variability:

Annual average temperatures are projected to continue to warm across all Oregon regions over the coming decades. However, climate model projections show more summer warming east of the Cascade Mountains with warming of the greatest magnitude projected over regions 6, 7, and 8. Coastal regions (region 1) will see the lowest degree of warming due to proximity to the moderating effect of the ocean and ocean breezes.

All regions are projected to experience an increase in the frequency and severity of very warm temperatures, relative to the local climate. Inland areas at lower elevations, which climatologically see the greatest number of very hot temperature days, will see an even greater number of very hot days in the coming decades. Very hot days, measured in an absolute sense, will continue to be rare in coastal and high elevation regions.

Characterization:

Oregon has warmed by about 2.5°F since 1900, similar to the observed magnitude of warming in other parts of the western and northeastern United States. Cool years are not as cool and warm years are warmer than they used to be. Despite large year-to-year variability, all regions of the state have experienced warming and are projected to continue to warm. Projections of mean temperature warming have been fairly consistent over time in the scientific literature. Seasonally, warming has occurred in both winter and summer and summer warming in Oregon is projected to be of greater magnitude than in winter. Warming is projected to be greatest in the summer, particularly in inland Oregon. The coast is expected to experience the least warming. Winter warming is projected to be greater at higher elevations than at lower elevations.

Extreme heat has increased in frequency and severity and is projected to continue to increase. Recent extremely hot summers (2015, 2017, 2018) in highly populated parts of western Oregon have been unprecedented and have brought increased interest in the effect of global warming on local summer temperatures. In Oregon's biggest city, Portland, summer extreme heat in terms of annual total days over 90°F has steadily increased in frequency and severity despite large year-to-year variability. The record number of days over 90°F in Portland was set in 2018. Today, Portland sees about nine more days above 90°F than in 1940. This trend will continue, though the rate of change may increase, along with continued year-to-year variability. The hot summers of 2015, 2017, and 2018 serve as wake-up calls for what is to come. These summers were extreme even in the context of the current level of global warming, however, they are good examples of what is projected to be relatively common by the mid-21st century. Future change will likely be greater, more rapid, and may lead to increasingly severe impacts in coming decades.

Global warming will make hot days hotter and cool days less cool. Warm and cold extremes are projected to warm across Oregon, much like in the rest of the Continental United States. The magnitude of this effect will be greatest in the summer. While extreme heat will continue to be felt primarily through individual heat wave episodes, the overall warming of the temperature probability distribution will make it so that days that were considered unusually warm in the past become relatively common. In this sense, over time, persistent summer heat will become more common in addition to more severe heat episodes. Each year will not necessarily be warmer than the previous year or years due to natural climate variability; however, over the scale of decades this warming will be continuous. Over time, even relatively "cool" summers will be hot relative to the historical climate.

Discussion

Nighttime Low Temperatures & Urban Heat Island Effects

Nighttime low temperatures have been warming quite rapidly. This year, Portland almost broke the record for number of consecutive days that didn't get below 60°F. Urban heat island effects are more related to variations in ground surface properties (e.g., green spaces, reflective surfaces, etc.) than population density. The surface properties of urban development would help identify areas most susceptible to islands of urban heat.

Projected Change in Humidity during Heat Events

There aren't many studies looking at humidity during heat events in Oregon. As the ocean warms there will be more moisture in the atmosphere. Compared to other regions, Oregon is not humid so any changes would not likely be a first order impact. However, nighttime lows have been warmer this summer due to higher humidity.

Temperature Thresholds for Public Health Impacts

Thresholds vary depending on location and what health impact is being assessed. In Oregon, 90°F is a threshold to begin seeing more pronounced heat-related health impacts, but this threshold will vary across the country. Big health impacts can occur when temperatures don't recover overnight during consecutive hot days, however Oregon typically can recover overnight. Another indicator is when local governments begin to open cooling centers.

Consequences:

Public Health Consequences

- Extreme heat in urban areas poses risk to human health and safety (especially those disproportionately exposed to the elements, the elderly, and those with underlying health conditions) (see Risk 9), increased energy and water demand, and disruption to civic and economic activity.
- Higher average air temperatures will lead to poor health outcomes directly related to heat, illnesses caused by poor air quality (see Risk 6), and environmental conditions exacerbated by heat. Extreme heat will increase negative outcomes in both physical and mental health. Physical illness such as heat stroke will become more prevalent, and more days of extreme heat could lead to increases in aggression and violence. Even small increases in average summer temperatures can lead to increases in heat-related deaths, especially among those with underlying medical conditions.
- Higher temperatures will increase air pollution and pollen counts, both of which adversely affect respiratory health of some populations and people. Increased pollen production from extended blooming seasons and invasive plants will likely make allergies more severe.
- Higher average temperatures could also have negative environmental impacts such as to reduce the quantity and quality of drinking water and increased episodes of cyanobacterial blooms (aka harmful algal blooms). Oregon began monitoring these blooms in 2005 and steady increases in the number and duration of these episodes have been seen throughout the state (see Risk 7).
- Increased temperatures may increase the threat of food insecurity, particularly among low income populations.
- Higher temperatures increase the threat of human illness from both waterborne diseases and vector borne illnesses.
- Heat waves will result in increased deaths and illness among vulnerable populations. The worst health effects of higher temperatures will be felt by the elderly, infants, children, pregnant women, chronically ill, low income communities, outdoor workers, and those with underlying health conditions.
- The population of Oregon is projected to grow in the future, expanding the number of people at higher risk of illness and death from extreme.

Environmental Consequences

- Prolonged warm temperatures and severe heat are associated with forest conditions favorable to wildfire and wildfire spread, making it more difficult to fight ongoing wildfires (see Risk 5).
- Warming in the winter will decrease snowpack both in spatial and temporal extent. More mountain precipitation will fall as rain instead of snow as a result (see Risk 1).
- Prolonged warm temperatures and heat waves can lead to tree mortality.
- Warmer atmospheric temperatures increase stream temperatures which impacts fish habitat.

Vulnerability Assessments:

None known.

Comments and Recommendations:

- Extreme heat is associated with more fatalities than any other severe weather event in the United States. The Oregon Health Authority identified a need for assessing the vulnerability of populations most at risk of extreme heat events.
- The use of ESSENCE, a syndromic surveillance tool developed at John's Hopkins, to gather and analyze data on heat-related illnesses could be more supported and coordinated across the state in the future.
- Crisis and Emergency Risk Communications toolkit for extreme heat has been developed by OHA, translated into multiple languages, and promoted for use by local public health authorities. This toolkit provides critical information about the signs of heat illness and protective actions.
- Public Health Duty Officer is routinely notified by National Weather Service (NWS) staff of impending extreme weather, including heat waves, and participates in NWS weather briefings.

Risk 5: Increase in Wildfire Frequency and Intensity

Speaker: Tim Sheehan (OSU)
Returned Questionnaires: Tim Sheehan, Oregon Health Authority, Oregon Department of Transportation

Summary:

It is likely (>66%) that Oregon will experience an increase in wildfire frequency and intensity (*high confidence*). The greatest increased risk will be in the western and southern portions of the region, and more so at lower elevation wildlands than higher elevation wildlands.

Likelihood:

Overall, it is likely (>66%) that increases in wildfire frequency and intensity will be experienced in Oregon over the next several decades, with some geographic variability.

Confidence:

Confidence is high across the majority of the state due to moderate evidence (several sources, some consistency, varying methods, etc.), and medium consensus. Confidence is very high in region 4 (southwest Oregon) due to high consensus and multiple sources with consistent results.

Geographic Variability:

Increasing wildfire frequency and intensity is greatest (*very likely*) in the lower elevations of the Coast and Cascade Ranges (Region 2-3) and southern portion of Region 4. Increasing wildfire frequency is *likely* in the rest of the state as well. The Oregon Department of Transportation is most concerned with wildfires affecting infrastructure across the state, but particularly in Regions 4, 6, and 7. Western Oregon (Regions 1-4) is most likely to experience vegetation changes.

Characterization:

Increases in fire frequency and intensity have been observed in the state. The Fourth Oregon Climate Assessment Report (2019), http://www.occri.net/ocar4/, provides a good summary. Future climate projections indicate that Oregon will experience warmer, wetter winters and hotter, drier summers. Modeled projections of future fire frequency indicate more frequent fires for the Pacific Northwest, particularly west of the Cascade Mountains where fires have been infrequent historically. In coastal areas, fire frequency is projected to change from approximately every 100 years to every 60 years. In central and eastern Oregon and grasslands, conditions are conducive to fires virtually every year assuming ignition sources. Fire suppression has an effect on fire frequency: without fire suppression future projections indicate even greater increases in fire frequency with climate change. Wildfire frequency and intensity changes due to climate differ depending on the type of vegetated system (e.g., ignition-limited systems, moisture-limited systems, fuel-limited systems, and managed areas).

Ignition-limited systems are found on the east side and southern portions of the state. These might also be characterized as suppression limited due to the history of a fire suppression management regime. Fire suppression has resulted in high fuel loads, these forests have closer canopies, and experience greater water competition. These forests experience long, dry fire seasons and are frequently at high fire danger and have a very high potential to burn if exposed to an ignition source. This can be thought of in terms of debt, suppression keeps borrowing more time, but eventually we'll have to pay. In ignition/suppression-limited systems, winter warming will lead to more fine fuels due to greater growth during the cold season; hotter and drier conditions combined with a suppression management regime will lead to large quantity of fuel and closer canopies. Large and severe fires ("unsuppressable megafires") are a result of this large fire debt and climate change combined.

Moisture-limited systems are found in the Cascade and Coast ranges. Historically, fires are less frequent and less severe, though there have been large wildfire events in the past related to synoptic weather patterns. In moisture-limited systems, warming winters will lead to more fine fuels from greater cold season growth. Hotter and drier conditions lead to large fuel quantities, which leads to large and severe fires. Permanent changes in climate may lead to structural changes in the forest system and an ignition-limited fire regime resulting in fire frequency increases (e.g., from once every 500 years to once every 5 years).

Fuel-limited systems in eastern and southeastern Oregon have non-contiguous fuels including sagebrush and bunchgrasses. As invasive annual grasses increase (e.g., Cheatgrass), fuels become contiguous as invasive grasses regrow quickly outcompeting other vegetation. In fuel-limited systems, warming winters will lead to more fine fuels from greater cold season growth. Also, conditions conducive to conversion to invasive grasses can lead to frequent fires and conversion to invasive-dominated systems as climate changes, including reduction in habitat for sage grouse.

Managed areas, including un-thinned, replanted stands (i.e., "dog hair"), plantations, and grazing areas, experience different effects from different actions. In managed forests, large stands of monoculture trees that are on a 60-year rotation interval, for example, could see a lot of warming and likely become maladapted to new climate conditions. This may lead to stress and mortality, possibly creating more fuel available to fires. Furthermore, the density of the stands may amplify water limitations during drought. Monoculture also reduces resilience and refugia. There is also potential for rapid fire spread due to unbroken canopies. Thinning in these stands may not reduce mortality or fire risk as thinning has the potential to increase evaporation below the canopy. Also, with higher summer temperatures and lower summer precipitation, increased evapotranspiration may exceed the existing vegetation's ability to transfer water to its canopy, regardless of available soil moisture.

Increasing wildfire frequency would have consequences for lives, infrastructure, crops, firefighting costs, lost natural resources, carbon, and habitat, or even an unforeseen chain of catastrophes. Also, increasing population could increase ignitions. In addition, vegetation type is expected to change with climate, particularly on the west side of Oregon and Washington, from predominantly conifer forests to warm mixed forests by the end of the

21st century according to climate and vegetation modeling (*medium confidence*). However, climate velocity may outpace the time it takes for forests to mature.

Discussion:

Vegetation Shifts & Assisted Migration

In terms of projected vegetation shifts for western Oregon 80 years from now, what is the level of confidence? Medium or higher confidence that climatic conditions will shift to support projected vegetation types, but low confidence that vegetation will actually shift to match the shifting climate conditions at the same rate. People are talking about assisted migration for forests. There are tools that guide the selection of seed stock from areas where the current climate more closely matches the projected climate of the area to be planted (e.g., Conservation Biology Institute Seedlot Selection Tool).

Pine Needles & Fire

The Paradise Fire had a heavy mat of pine needles that caught fire. Does climate change influence pine needle drop as fuel for fire? There may be climate-related events that affect needle fall over short periods of time. For example, Swiss needle cast causes trees to drop needles. Beetle kill can increase the fuel load, but only in the "red stage" shortly after the kill. Warmer winters could increase beetle outbreaks.

Modeling Ignitions

How does the vegetation modeling simulations handle ignitions, is lightning included? Yes, the model includes lightning and assumes ignition happens if fuel conditions meet a threshold. If threshold is lower, then fire can be put out. Presenter Tim Sheehan has done some exploratory modeling with stochastic ignitions and it changes the timing and frequency of events.

Cheatgrass & Invasive Grasses

Statements about invasive grasses and impact on fire return interval are based on observations since the vegetation model does not handle invasive species. There is high confidence in increasing fire frequency because we're already observing it. Monsanto has an escaped bioengineered turf grass.

Fire Aftermath

What should we be thinking about in the aftermath of fire? We should be thinking about changes in hydrology, erosion, flooding. Recovery depends on resources and management priorities (e.g., replanting). The best way to recover is to avoid disaster. We cannot treat our way out of the wildfire conundrum entirely, but will have to look at what can be prevented. Prevention costs less than recovery.

Fire Modeling & Suppression

Fire suppression is not modeled until 1950. It makes a big difference in some areas like Montana. There is a potential for this model to be used in blended/management studies using a stochastic/arbitrary function for chance of ignition and catching, but this would take significant resources.

Consequences:

Environmental Consequences:

- Lost natural resources, carbon, and habitat.
- West of the Cascade Crest: Loss of legacy vegetation combined with climate change outpacing the time to maturity for new forest types. This has the potential to leave the region relatively unforested. This would result in loss of carbon sequestration and other ecosystem services.

Economic Consequences:

- Increasing direct firefighting costs.
- Damage to crops and livelihoods.

Infrastructure Consequences:

- Damages roads and can result in closures due to extreme heat and wildfires.
- Greater frequency of fires at the wildland-urban interface in which houses and structures become the fuel load instead of trees.

Public Health Consequences

- Increased wildfire frequency and intensity will result in greater potential for injury and loss of life at the urban-wildland interface. Wildfire may affect areas where it has not been experienced in the recent past, thus potentially placing unprepared communities at risk.
- Fire-caused road closures reduce access, mobility, and the movement of essential services. Populations surrounding wildfires will be at risk for fire-related illness, injuries, and displacement.
- Fire control crews are at risk from fire-related injuries and illness.
- Wildfire smoke exposure increases respiratory and cardiovascular hospitalizations, emergency department visits, medications needed for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease, and respiratory infections. Longer repeated fire seasons might even increase the risk of some cancers due to polycyclic aromatic hydrocarbons exposure.

Vulnerability Assessments:

- Recently completed study for Oregon and Washington west of the Cascade crest looking at the risk of biomass loss: Sheehan T, Bachelet D. A fuzzy logic decision support model for climate-driven biomass loss risk in western Oregon and Washington. PLoS 1. In press.
- Various state agencies collaborated on the development of the Oregon Wildfire Response Protocol for Severe Smoke Episodes. This guidance document was developed in 2013, is updated annually and is used consistently.
- A "Wildfire Adaptation Case Study" assesses public health system response and adaptation opportunities and is under final review within OHA-PHD.
- DEQ, OHA-PHD, and others have partnered to provide health risk information regarding wildfires.

- ODOT Climate Change Adaptation Strategy Report – preliminary risk assessment and review of agency programs
- ODOT Climate Change Vulnerability Assessment and Adaptation Options Study – a regional assessment of state highways conducted in Clatsop and Tillamook counties
- ODOT Green Infrastructure

Comments and Recommendations:

- An integrated, state-wide assessment tying together fuels, ignitions, climate, infrastructure, ecosystem services, potential health impacts, and ecological vulnerability.
- Multi-agency assessments that take into account shared risk factors and shared opportunities for adaptation strategies between state agencies, such as geographies for where highest risk areas are located and co-benefit strategies to address those risks.
- Oregon lacks a comprehensive and quantitative assessment of future wildfire risk.
- The State and most local public health agencies have very limited capacity to track adverse health effects of wildfires.

Risk 6: Changes to Air Quality

Speaker: Group Discussion
Returned Questionnaires: Oregon Health Authority

Summary:

It is likely (>66%) that Oregon will experience changes to air quality due to changes in fire, heat, and vegetation (*low confidence*). Changes in air quality could be experienced across the state.

Likelihood:

It is likely (>66%) that changes to air quality will occur in Oregon. Likelihood depends in part on the likelihood of increases in wildfires in Oregon.

Confidence:

Confidence is low due to limited published sources of evidence.

Geographic Variability:

Changes in air quality could be experienced across the state. Air quality issues related to wildfire smoke cross the urban-rural divide as fires in one place can produce smoke drifting to other regions. Air quality issues related to ground-level ozone are more likely to be experienced in urban areas.

Characterization:

The risk of changes to air quality was not a separate risk considered in the 2010 Oregon Climate Adaptation Framework, but because it frequently comes up it was decided to include it in this workshop. A single expert did not speak on the topic, but there was an open discussion around any concerns and knowledge workshop participants had. The discussion included air quality issues related to fire, heat, air stagnation, dust, and pollen.

Fire

Changes in wildfires will have a direct impact on air quality and health impacts through influencing particulate matter. Poor air quality from wildfires crosses the urban-rural divide as smoke from wildfires in one location can drift to other regions. Changes in the jet stream can advect smoke bringing to Oregon smoke from other areas (Canada, CA, etc.). There is some indication of a southward shift in the jet stream during winter in the eastern Pacific. Smoke can impact all of Oregon economically much more broadly than just local forest owners.

The discussion focused on questions and tradeoffs on the role of forest and wildfire management in mediating smoke exposure, types of particulate matter, and health impacts.

- Do prescribed/managed fires produce different type of smoke or particulate matter than spontaneous fires, producing different health impacts?
- Should we prescribe burns in winter to prevent larger fires in summer?
  - This could influence wintertime air quality.
  - Would this change the health risk to fire fighters and managers?

- The Boardman coal plant is closing. This may presents an opportunity to burn forest fuels with air quality controls as opposed to prescribed burning, however, hauling wood out of the forest is expensive.
- When field burning was banned in the Willamette Valley due to air quality concerns, producers had to shift to increased use of pesticides. The tradeoff being reduced smoke, but increased chemicals.

Ground-Level Ozone

As temperatures increase and heat waves become more frequent, ground level ozone will increase. This was noted as an area that should be considered in climate adaptation planning.

Air Stagnation

Fall and winter air stagnation events can affect air quality in Oregon. These events are unlikely to change due to climate change, although confidence is low due to limited studies on this topic. Summertime inversions can hold smoke near the ground, but there is not much evidence for a change in these occurrences due to climate change (unlikely to change with low confidence). There may also be fewer precipitation events to clear out the air.

Aeroallergens & Pollens

Vegetation changes could change pollen loads in terms of which plants are producing pollen and when, but this impact will be species dependent. Some people may experience associated changes in allergies. Changes in the jet stream could also impact pollen loads, however, there is high uncertainty in expected changes. In the winter, there is some indication of a southward shift of the Jetstream in the eastern Pacific.

Dust

Dust was mentioned at the workshop as a source of poor air quality. Limited information exists on how climate change would influence air borne dust concentrations in Oregon.

Consequences:

Public Health Consequences

- Air pollution from increased ground-level ozone ("smog") and wildfire smoke will worsen respiratory and cardiovascular illnesses (see Risk 4 and Risk 5).
- Increased CO_2 concentrations and higher temperatures will affect pollen counts and prolong allergy seasons, complicating respiratory conditions.

Vulnerability Assessments:

For wildfire-specific particulate matter, Liu et al. (2016) produced a fire smoke risk index by county in the western US for present day and mid-century. The Third Oregon Climate Assessment Report (OCAR3) (http://www.occri.net/publications-and-reports/third-oregon-climate-assessment-report-2017/) highlighted this index for Oregon counties (see Figure 7.2 in OCAR3).

- Liu JC, Mickley LJ, Sulprizio MP, Dominici F, Yue X, Ebisu K, Anderson GB, Khan RFA, Bravo MA, Bell ML. 2016. Particulate air pollution from wildfires in the Western US

under climate change. *Climatic Change*, 138(3–4): 655–666. https://doi.org/10.1007/s10584-016-1762-6.

Comments and Recommendations:

- Air Quality was identified as a priority concern in the Oregon Climate and Health Resilience Plan and disproportionately affects low-income people and people of color. Outdoor workers have a higher risk of exposure.
- Climate mitigation actions can improve overall air quality by decreasing greenhouse gas emissions that carry co-pollutants. Projected climate-driven air quality risks could be partly mediated by decreasing non-climate-driven air pollution (such as transportation-related emissions).

Risk 7: Changes to Water Quality

Speaker: Theo Dreher (OSU)
Returned Questionnaires: Theo Dreher, Oregon Health Authority

Summary:

It is very likely (>90%) that Oregon will experience changes to water quality due to increases in temperature, changes in precipitation, and other factors (*high confidence*). All regions in Oregon will be affected.

Likelihood:

It is very likely (>90%) that changes to water quality will occur in Oregon, and in particular that cyanobacterial harmful algal blooms (CHABs) will be a problem as climate changes.

Confidence:

Confidence is high due to high consensus that cyanobacterial harmful algal blooms (CHABs) will be a problem in lakes.

Geographic Variability:

All regions will be affected by climate-related changes in water quality. If projections for increased summer precipitation in southeast Oregon materialize (and result in higher rates of flushing in lakes and reservoirs), there may be less changes in risk of CHABs compared with the rest of the state in which decreases in summer precipitation are projected.

Characterization:

CHABs can be thought of as an indicator of several changes in water quality since they respond to increased nutrient levels, higher temperatures, and low flow. Direct climate change projections are for higher temperature and lower flow rates in summer when these blooms occur. The lower flow rates mean less flushing and higher nutrient levels if inputs are the same; projections for higher intensity of weather events (such as thunderstorms) would cause inflow events that carry new nutrients and can trigger blooms.

Several variables influence CHABs tipping the prevalence of cyanobacteria over diatoms and dinoflagellates. Increases in temperatures and resulting stratification favor cyanobacteria (very high likelihood, high confidence). Increasing pH and CO_2 may favor other types of phytoplankton more than cyanobacteria. Increased rainfall intermittency and decreased summer precipitation can favor cyanobacteria (less confidence). Increased nutrient inputs can favor cyanobacteria, but humans can control this factor to control blooms.

CHABs could be considered sentinels of poor water quality. Their presence further degrades water quality through shading/turbidity, high pH and excessive dissolved oxygen [DO] when concentrated, low DO associated with bloom crash, release of toxins, and release of organic matter that exacerbates low DO in the hypolimnion in lakes. The conditions that support blooms also can be directly detrimental to other aquatic organisms.

CHABs are characteristic of lakes, but the ecological consequences of bioactive toxins can be transferred hundreds of kilometers down rivers. The ecological consequences need to be studied more as CHABs can deliver cells to new places where a new bloom might develop or where toxin bioaccumulation can occur. A 2011 Department of Environmental Quality study estimates that 25% of Oregon's lakes greater the 50 acres are at risk of CHABs. We are already seeing changes in CHABs in most regions in Oregon. For example, Upper Klamath Lake had a toxic *Microcystis* bloom with peak concentrations comparable to the massive annual *Aphanizomenon* bloom, for perhaps the first time, in October 2014.

CHABs are indicative of disrupted ecosystems. They shade other phytoplankton, they are poor nutrition as primary producers at the bottom of the food chain, they intensify organic matter deposition and hypoxic zones near sediment, and they produce bioactive compounds (including toxins) with unknown effects on ecosystems. CHABs won't be the only populations affected. Blooms of other phytoplankton (e.g., diatoms) in shoulder seasons outside the season of highest temperatures and stratification could increase biological productivity. CHABs are typically preceded by diatom blooms in the spring.

Select Literature:

- HW Paerl and J Huisman, 2008, Science, 320:57-58.
- JM O'Neil et al., 2012, Harmful Algae 14:313-334.
- Eldridge, S Driscoll, C and Dreher, T, 2017. USGS Scientific Investigations Report 2017–5026.

Discussion

Management

Management techniques to limit CHABs (e.g., banning agricultural nutrient runoff, detergents, etc.) can be fairly effective, particularly at a limited level, but it is challenging at the state-level.

Detroit Lake

What was the source of bloom nutrients in Detroit Lake and Salem's drinking water supply? Detroit Lake is not heavily influenced by anthropogenic nutrients but does have elevated phosphorous derived from Cascade Range volcanics. CHABs are common in Cascade foothill reservoirs, though not all are toxic.

Geographic Variability

What about satellites to observed geographic variability? EPA and other agencies process near-daily data from the European Sentinel satellite, allowing remote monitoring of larger lakes (weather permitting). For some locations, these data are being added to earlier collections from the Meris satellite to provide baseline and ongoing data to look for CHAB changes across Oregon geography.

Other Water Quality Indicators

Other than harmful algal blooms, particularly cyanobacterial harmful algal blooms, water temperature is an important indicator for water quality concerns from a forestry perspective as well as from a fish health perspective.

Consequences:

Environmental Consequences

- Stress on health of aquatic (river, lake, estuary) ecosystems, including threatened or endangered species and on human populations.
- Increased infection risk (e.g., to fish) due to decreased flows and increased stressors.

Public Health Consequences

- Water quality is compromised by changes in hydrology, drought and increased water temperatures, leading to conditions that give rise to harmful algal blooms and waterborne diseases.
- Drinking water sources can also become contaminated from flooding or saltwater intrusion.
- Drought conditions affect agricultural production which could lead to an increased use of chemicals, threatening Oregon waterways.

Vulnerability Assessments:

- A Schaedel, Oregon DEQ Harmful Algal Bloom (HAB) Strategy, 2011, https://www.oregon.gov/deq/FilterDocs/HABstrategy.pdf
- OHA-PHD and DEQ assessed land use-related vulnerabilities to drinking water sources throughout the state and provided these assessments to system operators following the appearance of cyanotoxins in City of Salem drinking water (2018).
- Water system master plans are required for systems serving 300 or more connections. The plan must include an evaluation of the water supply's ability to meet anticipated demand over the next 20 years and identify and plan for solutions as necessary
- Funding for the development of a resiliency plan is available to public water systems serving more than 25 people.
- OHA has contributed to the updated Flood Annex to the state Emergency Operations Plan (2018).
- OHA has developed a toolkit to help local public health authorities to access and use data to identify populations with medical needs who may require assistance to evacuate.
- DEQ and OHA-PHD partner to sample near-shore waters for bacterial contamination and communicate risks of water contact. Regular posting of recreational advisories: https://www.oregon.gov/oha/ph/newsadvisories/Pages/RecreationalAdvisories.aspx
    - Cyanobacterial (algal) bloom advisories
    - Beach advisories
    - Fish and shellfish advisories and guidelines
    - Stay Safe in the Outdoors
        - Water-related illness
        - Willamette River Recreation Index – river sampling data from the City of Portland

Comments and Recommendations:

- Ensure that ongoing water quality measurements are comprehensive and publicly available for research, planning and management purposes.
- Assess in particular the intersection of water diversions (e.g., for irrigation) and effects on stream/lake volumes and water quality as summer stream flows decrease; will diversions need to be managed or restricted?
- Oregon lacks a financing tool to assist the 900+ public water systems not eligible for federal capital assistance.
- Oregon's public health system has very limited capacity to track adverse health effects of water insecurity on communities and susceptible populations.
- Oregon lacks a comprehensive water plan for extreme drought conditions and how ground water resources will be affected.
- Oregon lacks a comprehensive, integrated inventory and assessment of both historic and likely future extreme precipitation events and their impacts on the built and natural environments.
- Oregon lacks reliable assessments of likely future flood conditions and relative flood risk in areas where development and infrastructure improvements are likely to occur.
- OHA-PHD has small occupational health and pesticide reporting programs, but they are not equipped to proactively address climate-related factors that could increase occupational hazards among farmworkers and others.
- Harmful cyanobacterial (algal) bloom monitoring program is limited.

Risk 8: Increases in Invasive Species, and Insect, Animal, and Plant Pests

Speaker: David Shaw (OSU)
Returned Questionnaires: Oregon Health Authority

Summary:

It is likely (>66%) that Oregon will experience climate change induced increases in invasive species, pests, and associated diseases (*medium confidence*). High elevation forests are becoming more vulnerable and coastal areas are currently experiencing high disturbance activity.

Likelihood:

It is likely (>66%) that increases in invasive species, pests, and diseases will occur in Oregon.

Confidence:

Confidence is medium due to suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging etc.) and competing schools of thought.

Geographic Variability:

The coast (Region 1) is experiencing a lot of disturbance activity even though temperature increases are less than in other places. This has more to do with warmer winter temperatures and mild summer temperatures in this area. Invasive species are well established on the coast including sudden oak death, Port Orford cedar root disease, and spruce aphid. New introductions at ports are highly likely. Native pests and pathogens are interacting in with forest management landscapes, and the pattern and degree of climate change could influence what emerges.

Regions 2 and 3: Invasive species emerging from ports in the North Willamette Valley as well as interstate highways is likely for Oregon. Particularly threated is the horticulture industry. Drought and heat are increasing for low elevation forests and conifer in the oak zone which has increased native insect pests of Douglas-fir.

Region 4. The threat of invasive species is large, especially as California has a growing list of species, such as the gold spotted oak borer, which could enter Oregon from the south. Drought and heat are interacting with native bark beetles and wood boring insects to cause mortality in forest trees, especially at lower elevations and upper snow zone where snowpack has been low.

Regions 5, 6, and 7: Invasive species are currently causing problems in high elevation and mixed conifer forests of five-needle pines, true fir and western larch. New introductions are likely and could impact forestry. Invasive weeds are degrading range and forage. Native pests and pathogens are expected to increase associated with drought and heat, but are tightly linked to seasonality of weather and predictions are difficult.

Region 8. Invasive weeds are currently causing great loses in this region and impacting forage quality. Future climate change is likely to interact with new weeds to potentially reduce productivity of rangelands.

In general, high elevation areas are becoming more vulnerable due to increasing temperatures.

Characterization:

Climate change is expected to increase the prevalence of invasive species and forest insects and diseases. Climate change will allow invasive species limited by certain climate variables to spread into new areas. The number one factor controlling invasive species however is human assisted movement (e.g., trade, especially wood packaging and live plants for planting). Once introduced, climate change can influence boundaries. Solving this problem requires dealing both with climate change adaptation and regulation of trade. For example, assisted migration facilitated white pine blister rust when the US sent seedlings to France where they became infected. The infected trees were then planted back in North America.

It should be noted that the threat from invasive species is distinct from the threat by native pest and disease-causing species. International trade in plants for planting and plant products is increasing and therefore the likelihood and confidence that invasive species will be introduced to Oregon and cause impacts is high. Climate change can increase impacts and invasive-ness of pest and pathogen species by allowing for more warmer weather pests to establish.

Assisted migration, the movement of tree species to more climatically suitable areas in anticipation of changing climate, could be a major pathway for invasive species to enter new regions. For example, sudden oak death is spread on rhododendrons from infected nurseries. The problem for native forests would be the introduction of non-native pathogens and pests in soil and in/on plants, introduction of trees that are maladapted to local insect pests and pathogens, introduction of weedy plant material (e.g., the tree), and the potential for negative biodiversity impacts. For example, *Phytophthora cambivora* is killing golden chinquapin along the California/Oregon border area, where drought tolerant Douglas-fir grows.

Near-term climate changes projected for the Pacific Northwest that influence invasive species, forest insects and pathogens, and tree mortality include hotter droughts; hotter, drier, longer growing season; warmer, wetter winters; shift in late-spring and summer precipitation, and more extreme events.

Hotter droughts are associated with increased vapor pressure deficit (VPD), which is a major driver of tree mortality (e.g., 120 million trees, *Pinus ponderosa*, dying in California). The primary biotic response to hotter drought in California conifer forests appears to be bark beetles, which are associated with tree death. California has elevated levels of beetles. Once drought abates, beetles can still have a lagged effect. Drought in Oregon is exemplified by recent mortality of Douglas-fir (*Pseudotsuga menziesii*) in southern Oregon. It has occurred along forest edges and associated with flat-headed fir borers in trees near Ashland and Medford. Warmer temperatures and late spring and summer VPD in this region was higher than normal during 2013-2018 and is the leading hypothesis to explain the mortality observed. Western red cedar, big leaf maple, grand fir, and Douglas-fir are all sensitive to VPD due to catastrophic failure of water transport system.

A hotter, drier, and longer growing season may allow some diseases to intensify impacts. Examples include black stain root disease (*Leptographium douglasii*) and hemlock dwarf mistletoe (*Arceuthobium tsugense*). In the temperate forest biome generally, high disturbance activity is consistently linked to warmer and drier than average conditions across the globe during the period 2001-2014 (Sommerfeld et al., 2018).

Swiss needle cast in Douglas-fir on the Oregon Coast, caused by fungi (i.e., *Nothophaeocrpytopus gaeumannii*, *Mycosphaerellaceae*, *Ascomycota*), has increased in area affected between aerial surveys from 1996 to 2016 caused by warmer winter temperatures and a period of cooler/wetter conditions in the late spring early summer related to leaf wetness from 2003-2012.

In conclusion, invasive species impacts will most likely increase. Short-term (decadal) climate patterns control the general forest conditions. Long-term patterns drive resilience to rebound to previous conditions. Even though there may be long-term climate trends, diseases depend on short-term climate variability. Warmer and drier patterns appear to be impacting disturbance globally. Insects and diseases of younger forests are now predominant on the landscape. 41% of the landscape is less than 50 years old and only 7% is old growth (greater than 250 years old).

Select Literature:

- Agne, M.C., P.A. Beedlow, D.C. Shaw, D.R. Woodruff, E.H. Lee, S.P. Cline, and R.L. Comeleo. 2018. Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington. Forest Ecology and Management 409: 371-332.
- Bradley, B.A., et al. 2012. Global change, global trade, and the next wave of plant invasions. Front Ecol Environ 2012; 10(1): 20–28, doi:10.1890/110145
- Ritokova, G., D.C. Shaw, G. Filip, A. Kanaskie, J. Browning, and D. Norlander. 2016. Swiss needle cast in Western Oregon Douglas-fir plantations: 20-year monitoring results. Forests 7, 155; doi:10.3390/f7080155.
- Sommerfeld A, Senf C, Buma B, D'Amato AW, Després T, Díaz-Hormazábal I, Fraver S, Frelich LE, Gutiérrez ÁG, Hart SJ, Harvey BJ, He HS, Hlásny T, Holz A, Kitzberger T, Kulakowski D, Lindenmayer D, Mori AS, Müller J, Paritsis J, Perry GLW, Stephens SL, Svoboda M, Turner MG, Veblen TT, Seidl R. 2018. Patterns and drivers of recent disturbances across the temperate forest biome. *Nature Communications*, 9(1): 1–9. https://doi.org/10.1038/s41467-018-06788-9.

Discussion

Oregon Ash

Invasive species are coming, it is just a question of when, what, and where from. If emerald ash borer comes to Oregon we could lose 90% of ash trees. It's extremely hard (expensive) to remove all the dead ash trees from a city, and the loss will impact streamflows and cost millions in Portland.

Consequences:

Public Health Consequences

- Changes in habitats and species have the potential to affect human health through pollen production (allergies/respiratory illness); poisonous plants (adverse reactions); habitat for new disease vectors (emerging infections); and encounters with wildlife near residences (injuries).
- More pests interfering with agriculture could result in an increase in pesticide use and risk of exposures among farmworkers. Increased pesticide use could lead to increased risk of run-off into nearby streams and waterways.
- In addition to disease-related impacts, these changes may alter the ability of Oregonians to raise food, both for themselves and for others. Even if these changes enhance the growing conditions, it will take time for growers and the systems that support them to adapt to these changes.

Vulnerability Assessments:

- None known.

Comments and Recommendations:

- OHA-PHD has small occupational health and pesticide reporting programs, but they are not equipped to proactively address climate-related factors that could increase occupational hazards among farmworkers and others.
- Work with Oregon Invasive Species Council to prevent invasions.
- Oregon Department of Agriculture and Oregon Department of Forestry both have capacity to assist with these concerns.
- Forest management predictive tools can help where tree mortality/vulnerability (stand age, composition, environment) is anticipated (lower elevations, higher elevations)

Risk 9: Increases in Human Diseases

Speaker: Jeff Bethel (OSU)
Returned Questionnaires: Jeff Bethel, Oregon Health Authority

Summary:

It is very likely (>90%) that climate-sensitive health outcomes will increase in Oregon (*medium confidence*). All of Oregon will experience increases in climate-sensitive health outcomes, but geographic variability across the state depends on the climate exposure and health outcome considered as well as social vulnerability.

Likelihood:

It is very likely (>90%) that heat-related illness, respiratory illness, vector-borne disease, water-borne disease, food insecurity, and reduced mental health and well-being will increase in Oregon with climate change. It is unlikely that cold-related illnesses will increase. Given the variety of health impacts due to climate change, the likelihood of impacts varies as well. The likelihood of many climate-sensitive health outcomes increasing ranges from Likely to More Likely Than Not.

Confidence:

The level of confidence is medium due to suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging etc.) and competing schools of thought.

Geographic Variability:

All of Oregon would experience increases in climate-sensitive health outcomes. The geographic variability of the likelihood of occurrence of various climate-sensitive health outcomes varies by the climate-sensitive health outcome under examination. For example, we anticipate incidence of heat-related illness/death to be greater in regions 2-8 compared to region 1 (coastal area). Another example is respiratory complications from wildland fire. The Fire Smoke Risk Index in the future (2046-2051) will be in the 'high risk' category in regions 2-4 (west of the Cascades). Areas east of the Cascades will see levels in the 1-4 categories (see Third Oregon Climate Assessment Report, Figure 7.2, http://www.occri.net/publications-and-reports/third-oregon-climate-assessment-report-2017/). Geographic variability of experiencing climate-sensitive health outcomes would also depend on the geographic variability of social vulnerability across the state.

Characterization:

Climate change impacts a wide range of health outcomes. Climate change drivers such as rising temperatures, more extreme weather, rising sea levels, and increasing CO_2 levels increases the human exposure to extreme heat, severe weather, air pollution, changes in vector ecology, increasing allergens, water quality impacts, water and food supply impacts, and environmental degradation. Changes in these climate exposures lead to multiple health outcomes. This risk includes all climate-sensitive health outcomes, including infectious and communicable diseases and respiratory and cardiovascular diseases, among others.

Health effects of climate change are diverse and vary geographically. Results showing the health impacts of climate change in the Pacific Northwest, including Oregon, are limited and the 2017 Third Oregon Climate Assessment Report (Chapter 7; http://www.occri.net/publications-and-reports/third-oregon-climate-assessment-report-2017/) describes the most recent information. Heat-related illness, respiratory illness, vector-borne disease, water-borne disease, food insecurity, and reduced mental health and well-being are likely to increase with climate change. Cold-related illness is unlikely to increase.

In terms of extreme heat, the Third Oregon Climate Assessment Report (Chapter 7; http://www.occri.net/publications-and-reports/third-oregon-climate-assessment-report-2017/) cites one study projecting future increases in heat-attributable premature deaths for four cities in Oregon under a medium emissions pathway. In Portland, for example, there are projected to be 153–234 additional heat-attributable premature deaths by 2100 compared to 1990.

There is a burgeoning literature regarding mental health and well-being based on natural disasters and uncertainty surrounding climate change.

In terms of climate change adaptation, the analogous public health term is "prevention". Zero order prevention consists of mitigation of greenhouse gas emissions. First order prevention consists of reducing exposures projected to occur with climate change (e.g., redesigning cities to reduce urban heat islands). Second order prevention consists of preventing the onset of adverse health outcomes (e.g., surveillance of emerging or re-emerging vector-borne diseases). Third order prevention consists of measures to reduce long-term impairment and disability (e.g., treatment).

Some groups of people are more vulnerable to climate-sensitive health outcomes than others. Vulnerable groups can be identified and we can look for areas within the state that meet these conditions and target our adaptation (prevention) efforts. Groups particularly vulnerable to heat stress include the elderly, those with chronic medical conditions, infants and children, pregnant women, urban and rural poor, and outdoor workers. Groups particularly vulnerable to respiratory illness include children, those with pre-existing heart or lung disease, athletes, and outdoor workers. Groups particularly vulnerable to extreme weather events include the poor, pregnant women, those with chronic medical conditions, and those with mobility and cognitive constraints. Groups particularly vulnerable to water- and food-borne illness include those with compromised immune systems, the elderly, and infants, with specific risks for specific consequences (e.g., E. coli). Groups particularly vulnerable to vector-borne illness include children, outdoor workers, rural poor, infants, elderly, and those with compromised immune systems.

Climate change is a health equity issue. When considering the full range of threats from climate change as well as other environmental exposures, communities of color, children, older adults, and low income communities are among the most exposed, most sensitive, and have the least individual and community resources to prepare for and respond to health threats. Vulnerable populations face high risk of exposure to adverse climate-related health threats. However, there are adaptation measures that can help address the disproportionate impacts. For example, children have higher risk of heat stroke and illness than adults, yet adults can lessen the risk by monitoring exertion and hydration. Another example is that low-income families are at risk of physical and mental illnesses during flooding and in crowded shelter conditions, yet comprehensive disaster management can improve resiliency for people with limited resources. Oregon has many plans around this issue thinking about different vulnerable populations.

The Center for Disease Control and Prevention developed a framework called BRACE (Building Resilience Against Climate Effects) to facilitate climate readiness among public health agencies. It is an iterative approach to adaptively manage the health effects of climate change. The framework includes: 1) forecasting climate impacts and assessing vulnerabilities, 2) projecting the disease burden, 3) assessing public health interventions, 4) developing and implementing a climate and health adaptation plan, and 5) evaluating impact and improving quality of activities. Oregon has received funding to implement this framework in several counties.

Discussion

Ecological Trauma

A question was posed asking whether ecological trauma could be generational. We don't know at this point, however, these types of events are occurring every year.

County-Level Adaptation Strategies

What types of adaptation strategies are counties trying to implement? It changes county to county and depends on the health outcomes prioritized. For example, in terms of heat-related illnesses, counties could set up cooling centers. For something like smoke, interventions are not well identified and the literature has not been conclusive on how well interventions have done. For example, air conditions generally don't have filters that are sufficient for smoke. There are individual measures (e.g., home infiltration, face masks), but it remains an open question how to implement measures on a population level.

Climate Migration

Will there be climate migrants coming to Oregon and causing a strain on our health systems? There is no research specifically on this question, though it is theoretically possible. David Wrathall at OSU does research on climate migration on a global scale. There was a suggestion to look into migration of homeless populations in response to climate changes.

Vector-Borne Diseases

The geographic ranges of vectors (e.g., mosquitoes and ticks) are expected to change under a changing climate, which would expand the associated vector-borne disease range. Vector-borne disease epidemics can also be driven by episodic, stochastic climate events. For example, the Zika epidemic was driven by temperature and rainfall that facilitated huge amounts of mosquitoes. In terms of *Cryptococcus gattii* spreading into the Northwest, there have been six or seven deaths, but it is yet unclear whether it is a yeast or a fungus.

Consequences:

This risk focuses on climate-sensitive health outcomes (i.e., the consequences) and not the climate drivers. The Oregon Health Authority identified public health consequences and considerations for each climate risk considered in the 2019 Oregon Climate Risk Workshop. They are included below and in each Risk section of this workshop report.

Risk 1: Changes in Hydrology and Water Supply

Consequences

- Reduced water availability can reduce the quality and quantity of available water for drinking, cooking, sanitation and hygiene, thereby leading to water insecurity.
- Avoidable health outcomes associated with water insecurity include illness from water contamination, sanitation and hygiene-related illness, dehydration, emotional distress (fear, worry, anger, bother) and mental health issues (depression and anxiety).
- Reduced water availability can also contribute to vector- and food-borne diseases and threaten food production, thereby contributing to food insecurity and malnutrition, especially for low income populations.
- Native American Tribal Nations that rely on fish as an important part of their diet will be affected by reduced fish populations.

Considerations

- OHA-PHD and DEQ assessed land use-related vulnerabilities to drinking water sources throughout the state and provided these assessments to system operators.
- Water system master plans are required for systems serving 300 or more connections. The plan must include an evaluation of the water supply's ability to meet anticipated demand over the next 20 years and identify and plan for solutions as necessary
- Funding for the development of a resiliency plan is available to public water systems serving more than 25 people.
- Oregon lacks a financing tool to assist the 900+ public water systems not eligible for federal capital assistance.
- Oregon's public health system has very limited capacity to track adverse health effects of water insecurity on communities and susceptible populations.

Risk 2: Increased Incidence of Drought

Consequences

- Droughts will reduce the quality and quantity of available drinking water for drinking, cooking, sanitation and hygiene, thereby leading to water insecurity.
- Avoidable health outcomes associated with water insecurity include illness from water contamination, sanitation & hygiene-related illness, dehydration, emotional distress (fear, worry, anger, bother) and mental health issues (depression and anxiety).
- Droughts may also reduce food production and the viability of subsistence fisheries, and thus contribute to food insecurity and malnutrition.

Considerations

- Oregon lacks a comprehensive water plan for extreme drought conditions and how ground water resources will be affected.
- Oregon's public health system has very limited capacity to track adverse health effects of drought on communities and susceptible populations.
- Water system master plans are required for systems serving 300 or more connections. The plans must include an evaluation of the water supply's ability to meet anticipated demand over the next 20 years and identify and plan for solutions as necessary.
- Funding for the development of a resiliency plan is available to public water systems serving more than 25 people.

Risk 3: Increased Frequency of Extreme Precipitation Events and Damaging Floods

Consequences

- Increased flooding will place large numbers of people and structures at risk. Some areas may experience repeat events, and areas once thought to be outside the floodplain may now experience flooding.
- Increased flooding will increase risk of injuries, illnesses, death, and displacement. The health effects of flooding include not only direct impacts, such as drowning, but also secondary impacts such as mold-exacerbated respiratory illness, carbon monoxide poisoning, and gastrointestinal illness due to contamination of the drinking water supply.
- Floods may disrupt transportation and create barriers to accessing critical resources, including medical care.
- People are also at risk of both short- and long-term negative effects on their mental and emotional health.

Considerations

- OHA has contributed to the updated Flood Annex to the state Emergency Operations Plan (2018).
- OHA has developed a toolkit to help local public health authorities to access and use data to identify populations with medical needs who may require assistance to evacuate.
- Oregon lacks a comprehensive, integrated inventory and assessment of both historic and likely future extreme precipitation events and their impacts on the built and natural environments.
- Oregon lacks reliable assessments of likely future flood conditions and relative flood risk in areas where development and infrastructure improvements are likely to occur.

Risk 4: Increased in Average Annual Air Temperatures and Likelihood of Extreme Heat Events

Consequences

- Higher average air temperatures will lead to poor health outcomes directly related to heat, illnesses caused by poor air quality, and environmental conditions exacerbated by heat. Extreme heat will increase negative outcomes in both physical and mental health. Physical illness such as heat stroke will become more prevalent, and more days of extreme heat will lead to increases in aggression and violence. Even small increases in average summer temperatures can lead to increases in heat-related deaths, especially among those with underlying medical conditions.
- Higher temperatures will increase air pollution and pollen counts, both of which adversely affect respiratory health of some populations and people. Increased temperatures.
- Increased pollen production from extended blooming seasons and invasive plants will likely make allergies more severe.
- Higher average temperatures could also have negative environmental impacts such as reduce the quantity and quality of drinking water and increased episodes of cyanobacterial blooms (aka harmful algal blooms). Oregon began monitoring these blooms in 2005 and steady increases in the number and duration of these episodes have been seen throughout the state.
- Increased temperatures may increase the threat of food insecurity, particularly among low income populations.
- Higher temperatures increase the threat of human illness from both waterborne diseases and vector borne illnesses.
- Heat waves will result in increased deaths and illness among vulnerable populations. The worst health effects of higher temperatures will be felt by the elderly, infants, children, pregnant women, chronically ill, low income communities, and outdoor workers, and those with underlying health conditions.
- Oregon's population is projected to grow in the future, expanding the number of people at higher risk of illness and death from extreme heat are the main groups threatened by heat waves.

Considerations

- Use of ESSENCE to gather and analyze data on heat-related illnesses. In the future, could be more supported and coordinated across the state.
- Crisis and Emergency Risk Communications toolkit for extreme heat has been developed by OHA, translated into multiple languages, and promoted for use by local public health authorities. This toolkit provides critical information about the signs of heat illness and protective actions.
- Public Health Duty Officer is routinely notified by National Weather Service (NWS) staff of impending extreme weather, including heat waves, and participates in NWS weather briefings.

Risk 5: Increase in Wildfire Frequency and Intensity

Consequences

- Increased wildfire frequency and intensity will result in greater potential for injury and loss of life at the urban-wildland interface. Wildfire may affect areas where it has not been experienced in the recent past, thus potentially placing unprepared communities at risk.
- Fire-caused road closures reduce access, mobility, and the movement of essential services. Populations surrounding wildfires will be at risk for fire-related illness, injuries, and displacement.
- Fire control crews are at risk from fire-related injuries and illness.
- Wildfire smoke exposure increases respiratory and cardiovascular hospitalizations, emergency department visits, medications needed for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease, and respiratory infections. Longer repeated fire seasons might even increase the risk of some cancers due to polycyclic aromatic hydrocarbons exposure.

Considerations

- Various state agencies collaborated on the development of the Oregon Wildfire Response Protocol for Severe Smoke Episodes. This guidance document was developed in 2013, is updated annually and is used consistently.
- A "Wildfire Adaptation Case Study" assesses public health system response and adaptation opportunities and is under final review within OHA-PHD.
- DEQ, OHA-PHD, and others have partnered to provide health risk information regarding wildfires.
- Oregon lacks a comprehensive and quantitative assessment of future wildfire risk.
- The State and most local public health agencies have very limited capacity to track adverse health effects of wildfires.

Risk 6: Changes to Air Quality

Consequences

- Air pollution from increased ground-level ozone ("smog") and wildfire smoke will worsen respiratory and cardiovascular illnesses (SEE RISK #4 and RISK #5).
- Increased CO_2 concentrations and higher temperatures will affect pollen counts and prolong allergy seasons, complicating respiratory conditions.

Considerations

- Air Quality was identified as a priority concern in the Oregon Climate and Health Resilience Plan and disproportionately affects low-income people and people of color.
- Climate mitigation actions can improve overall air quality by decreasing greenhouse gas emissions that carry co-pollutants. Projected climate-driven air quality risks could be partly mediated by decreasing non-climate-driven air pollution (such as transportation-related emissions).

Risk 7: Changes to Water Quality

Consequences

- Water quality is compromised by changes in hydrology, drought and increased water temperatures, leading to conditions that give rise to harmful algal blooms and waterborne diseases.
- Drinking water sources can also become contaminated from flooding or saltwater intrusion.
- Drought conditions affect agricultural production which could lead to an increased use of chemicals, threatening Oregon waterways.

Considerations

- See Considerations in Risks 1, 2, 3, 8, 10, 11.

Risk 8: Increases in Invasive Species, and Insect, Animal, and Plant Pests

Consequences

- Changes in habitats and species have the potential to affect human health through pollen production (allergies/respiratory illness); poisonous plants (adverse reactions); habitat for new disease vectors (emerging infections); and encounters with wildlife near residences (injuries).
- More pests interfering with agriculture could result in an increase in pesticide use and risk of exposures among farmworkers. Increased pesticide use could lead to increased risk of run-off into nearby streams and waterways.
- In addition to disease-related impacts, these changes may alter the ability of Oregonians to raise food, both for themselves and for others. Even if these changes enhance the growing conditions, it will take time for growers and the systems that support them to adapt to these changes.

Considerations

- OHA-PHD has small occupational health and pesticide reporting programs, but they are not equipped to proactively address climate-related factors that could increase occupational hazards among farmworkers and others.

Risk 9: Increases in Human Diseases

Consequences

- Climate change is increasing the burden of disease in Oregon in myriad ways. By fracturing and reducing animal and plant habitats, it has driven more interaction between people and wildlife, which increases the risk of transmission of zoonotic diseases such as rabies, tularemia, and hantavirus pulmonary syndrome.
- It has expanded and changed disease host and vector ranges, bringing diseases like Lyme disease, Rocky Mountain Spotted Fever, Colorado Tick Fever, and West Nile virus infection to new parts of Oregon.
- It has also extended typical transmission seasons for some diseases and has been shown to increase likelihood of transmission of other pathogens, including *Vibrio parahaemolyticus* and *Cryptococcus gattii*.

- Noncommunicable and non-infectious disease exacerbations (e.g., asthma) have already been observed to increase with wildfire smoke exposure. Respiratory, cardiovascular, stress-related, and other diseases are also anticipated to increase with various climate change related exposures and conditions.

Considerations

- The OHA Public Health Division (PHD) tracks reports of noncommunicable, vector-, food- and waterborne diseases through medical provider reports and laboratory-confirmed case reports. All multi-case outbreaks are investigated. As the PHD becomes aware of new diseases, it works with clinicians and laboratorians to ensure reporting and expand tracking.
- PHD tracks fresh water cyanobacterial (algal) blooms, based on local, state or federal monitoring data, and issues public advisories. PHD tracks and investigates reports of human and animal illnesses associated with cyanobacterial (algal) blooms in addition to bloom and shellfish advisories issued by the Oregon Department of Agriculture.
- PHD has implemented some ad hoc surveillance of ticks around the state, tracking both species and disease carriage.
- An ESSENCE hazard report is published seasonally.
    - It has previously reported insect bite activity, but those data proved difficult to interpret, so the query has not been refined and it has not been reported recently.
- Per Oregon Administrative Rules (OAR) Chapter 333, Divisions 18 (Health services) and 19 (Investigation and control of diseases), and Chapter 433 (433.001-035), many diseases are reportable to PHD. Contact OHA-PHD for a list of reportable diseases affected by climate change.

Risk 10: Increase in Ocean Temperatures and Increased Ocean Acidification

Consequences

- An increase in harmful cyanobacterial (algal) blooms in the marine environment would increase risks to public health and safety. Increased toxic events would increase risk of poisoning from ingestion of shellfish.
- More events and different species of toxin-producing cyanobacteria (algae) could increase the number of seafood species subject to food safety concerns. Some species of cyanobacteria (algae) can produce toxins dangerous for direct water ingestion or skin contact by humans (currently no record of these in Oregon ocean waters). If these species were to become established in Oregon, there would be an increase risk to swimmers, waders, anglers, etc.

Considerations

- Harmful cyanobacterial (algal) bloom monitoring program is limited.
- DEQ and OHA-PHD partner to sample near-shore waters for bacterial contamination and communicate risks of water contact.

Risk 11: Increased Coastal Erosion and Risk of Inundation

Consequences

- By the end of the 21st century, sea levels are projected to place thousands of people and homes and over 100 miles of roads in Oregon at risk of inundation from annual flood events that reach four feet above high tide.
- Higher sea levels could result in saltwater intrusion into coastal aquifers used to supply drinking water and agriculture uses.
- Higher waves and storm surges can increase risk of injury and death to residents of shoreland properties.
- Damaged or closed roads and bridges could isolate communities, increasing risks of food and water insecurity, and disrupting access to medicines and medical services.

Considerations

- OHA-PHD completed a joint case study with the Oregon Dept. of Transportation, “How Tillamook Weathered the Storm”, to understand the challenges and adaptations in response to more frequent and severe coastal flooding.
- Oregon does not have a policy framework for managing retreat from areas subject to increased threat of climate-related hazards.

Risk 12: Loss of Wetland Ecosystems and Services

Consequences

- Loss of wetlands that mitigate flooding and protect coastal infrastructure from storm/wave impacts may increase risk of flood injury and death.
- Large floods can overwhelm water treatment facilities causing outbreaks of waterborne illnesses.
- Loss of wetlands that purify water may degrade drinking water sources and recreational water use.
- Loss of wetlands that provide recreational opportunities may result in reduced physical and mental health.

Considerations

- Regular posting of recreational advisories: https://www.oregon.gov/oha/ph/newsadvisories/Pages/RecreationalAdvisories.aspx
    - Cyanobacterial (algal) bloom advisories
    - Beach advisories
    - Fish and shellfish advisories and guidelines
    - Stay Safe in the Outdoors
        - Bats and rabies
        - Food safety in warm weather
        - Heat-related illness
        - Water-related illness
        - West Nile virus and mosquito bite prevention
        - Wildfires and smoke

    - Willamette River Recreation Index – river sampling data from the City of Portland

Vulnerability Assessments:

Oregon Health Authority Public Health Division has various relevant publications including a Climate and Health Vulnerability Assessment (2015) and the 2018 Climate Change and Public Health Policy Paper offering a recent analysis of climate and health research and vulnerability assessment: https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/CLIMATECHANGE/Documents/2018/2018-OHA-Climate-and-Health-Policy-Paper.pdf.

See also the bullet points under "Considerations" in each risk subsection above.

Comments and Recommendations:

- An updated Climate and Health Vulnerability Assessment is greatly needed in Oregon given the last was in 2015. However, Oregon Health Authority received funding for its Climate and Health Program from the Centers for Disease Control and Prevention, which has greatly cut the budget for its own Climate and Health Program. The previous report focuses on social vulnerability (i.e., demographics, chronic disease, unemployment, etc.). Future assessments also need these data, but need to also include estimates of the increase in the number of cases of climate-sensitive health outcomes across the states (easier said than done!).
- If prioritizing risks, OHA suggests considering other factors beyond likelihood of occurrence, including the potential magnitude of consequences, exposure, sensitivity to exposures, and adaptive capacity. Sensitivity to climate threats and adaptive capacity are not evenly distributed across any given geographic region within Oregon. The cumulative consequences of climate risks disproportionately affect certain populations due to social and historical determinants, and this may not be apparent if risks are evaluated and ranked separately. Even when including analysis of vulnerable populations by risk, it's important to consider the interconnectedness of vulnerabilities across climate risks.
- The conditions where people live, work, learn and play affect a wide range of vulnerabilities. These conditions are known as social determinants of health and are the biggest predictors of our length and quality of life. There is growing consensus across scientific communities and jurisdictions that climate vulnerability is largely driven by social determinants. The 2015 US Climate and Health Assessment concluded that over time, the "accumulation" of multiple, complex stressors among populations of concern is expected to become more evident as climate impacts interact with stressors associated with existing mental and physical health conditions and with other socioeconomic and demographic factors.
- Data-driven tools for identifying these populations can provide valuable inputs into decision-making but are considered only part of a complete vulnerability analysis. Using community-based participatory methods and engaging meaningfully with identified populations to ground truth findings with additional qualitative data are a necessary step in ensuring that any limitations and assumptions are modified based on local lived experiences.

- With these considerations in mind, an OHA-PHD workgroup analyzed the 2010 Climate Adaptation Framework Risks and identified the need for assessments of populations most at risk of:
    - extreme heat events
    - wildfires and smoke intrusion
    - drinking water insecurity
    - flooding events
- Based on recent program activities and the 2018 Climate Change and Public Health Policy Paper, OHA also identified the need for the following:
    - An assessment of institutional vulnerabilities within State agencies
    - An assessment of adaptive capacity among state agencies, and their partners, to adapt to future climate challenges.
    - An expanded and more detailed vulnerability assessment of the Oregon population

Risk 10: Increase in Ocean Temperatures, with Potential for Changes in Ocean Chemistry and Increased Ocean Acidification

Speaker: Francis Chan (OSU)
Returned Questionnaires: Oregon Health Authority, Oregon Department of Fish and Wildlife

Summary:

It is very likely (>90%) that Oregon will experience an increase in ocean temperatures with potential for changes in ocean chemistry and increased ocean acidification (*high confidence*). The direct impact of these changes will be felt along the Oregon coast (Region 1) with indirect impacts felt throughout the state.

Likelihood:

Warming and increasing stratification – very likely (offshore)
Decreased dissolved oxygen – very likely
Increased CO_2 – Certain
Increased nutrients in source water – likely
Increased upwelling – likely
Increased export production (and increased dissolved oxygen loss and CO_2 release at depth) - likely

Confidence:

Confidence is high due to moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus.

Geographic Variability:

The impacts of projected changes will be felt along the Oregon coast but with significant spatial variability.

Characterization:

Ocean temperatures, hypoxia, and acidification are increasing due to fossil fuel combustion and related accumulation of carbon dioxide (CO_2) and other greenhouse gases. The earth's oceans have absorbed 30% of the excess CO_2 produced from fossil fuel combustion since the Industrial Revolution (mid 1800s). This has led to major ecosystem and economic impacts, which are already reverberating through our tourism and seafood industries.

While ocean warming exhibits a clear pattern globally, there isn't a specific pattern for Oregon coastal ocean due to climate variability (e.g., Pacific Decadal Oscillation). Presently, temperature anomalies in the surface ocean are currently (as of August 2019) 2 degrees warmer than average and marine heat waves such as these may increase in the future. However, geography matters with significant variability along the Oregon coast. There is a tight connection between ocean surface temperature and productivity and an increase in ocean temperature is anticipated to create shifts in the ranges and types of marine species found in coastal waters of Oregon. High temperature anomalies may lead to malnourished salmon and whales and maybe fisheries losses, as a result of shifting food web structures. There is also recent work on the effects of temperature on phytoplankton community assembles and fatty acid content. Changes to the base of the food web will have subsequent effects on other animals.

Hypoxia (low oxygen) conditions are also on the rise as a result of climate change, due to changing wind and weather patterns. This is leading to extended periods of hypoxia in some of Oregon's coastal waters, impacting a wide range of marine animals from nonmoving organisms to crabs to fish (e.g., halibut). Repeated occurrences of low-oxygen (hypoxic) and high CO_2 conditions in Oregon waters have caused acute effects and mortality among demersal fish and invertebrates and have resulted in large-scale larval mortalities in shellfish hatcheries.

When absorbed by seawater, CO_2 undergoes chemical reactions that lower seawater pH (making it more acidic), and thus hampers shell formation in marine life. Oregon's exposure to ocean acidification is outpacing much of the rest of the world as upwelling brings to the surface deep waters that are naturally enriched in carbon dioxide, and lower in dissolved oxygen.

In summary, Oregon's oceans are suffering from a multi- stressor problem: decreased dissolved oxygen, increased CO_2, warming and increased stratification; increased upwelling; increased export production, and increased dissolved oxygen loss and CO_2 release at depth. It is very likely that continued increases in Ocean Acidification and Hypoxia (OAH) will affect the condition, productivity, and economic vitality of Oregon's ocean ecosystems significantly.

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North Pacific pelagic marine ecosystems." *Global change biology* 23, no. 3 (2017): 1000-1008.

Discussion:

Other potential impacts
Higher ocean temperatures may contribute to higher incidences of harmful algal blooms that have been linked to paralytic shellfish poisoning.

Marine heat waves
The Pacific Northwest warm 'blob' is larger than the Gulf of Mexico. During the 2014-2016 marine heatwave, as warm near-surface waters were advected to and impacted coastal waters, the enhanced vertical stratification reduced the efficacy of coastal upwelling to supply nutrients to the euphotic zone which negatively impacted coastal productivity.

Possible points of action
Continued monitoring is important, however moving into adaptation may be more important. As an example, research groups are working with industry to put out sensors to measure hypoxia. This has the co-benefits of collecting new data while also allowing crabbers to have a better idea of where to put their traps.

Consequences:

Economic Consequences
- Declines in hatchery oyster seed supplies (e.g., lowered larval growth and survival)
- Potential for reduced growth in juvenile and adult stock (e.g., for pacific oysters, blue mussels)
- Olfactory effects on Salmon (and other finish species) affecting their homing to rivers and streams for spawning - potential for declines in overall stock
- Declines in egg quality and larval supply for Dungeness crabs (and possibly other crab species)- potential for declines in overall stock
- Any decline in fisheries quotas or an increase in fisheries efforts, would indirectly affect supporting industries (shipyards, processing plants, refrigeration/ice transport).

Ecosystem Consequences
- Unknown impacts on submerged aquatic vegetation (SAV; e.g., eel grass, kelp, salt marsh)
- Olympic oyster biomass may decline due to reduced growth and survival of juveniles.
- Declines in pteropods – primary prey for many forage fish including salmon and pacific cod
- Overall change in food web structure due to changes in primary productions and primary consumers.
- Possible links to increased occurrences of harmful algal blooms (HAB)

Cultural Consequences

- Declines or loss of access to traditional foods for tribal groups – such as oysters, salmon, crab, blue mussels.
- Declines or loss of recreational fishing and harvesting opportunities – such as oysters, salmon, crab, blue mussels.

Public Health Consequences

- An increase in harmful cyanobacterial (and other algal) blooms in the marine environment would increase risks to public health and safety. Increased toxic events would increase risk of poisoning from ingestion of shellfish.
- More events and different species of toxin-producing cyanobacteria (and other algae) could increase the number of seafood species subject to food safety concerns. Some species of cyanobacteria can produce toxins dangerous for direct water ingestion or skin contact by humans (currently no record of these in Oregon ocean waters). If these species were to become established in Oregon, there would be an increase risk to swimmers, waders, anglers, etc.

Vulnerability Assessments:

- DEQ and OHA-PHD partner to sample near-shore waters for bacterial contamination and communicate risks of water contact.

- Regional Vulnerability Assessment: Ocean Acidification in the Pacific Northwest
  http://pacshell.org/pdf/rva-oa_1pager.pdf

- Geospatial Patterns and Species Impacts of Changing Ocean Chemistry on the West Coast https://www.lenfestocean.org/en/news-and-publications/fact-sheet/new-research-to-analyze-geospatial-patterns-and-species-impacts-of-changing-ocean-on-the-west-coast

Comments and Recommendations:

- Implement the State of Oregon Ocean Acidification and Hypoxia Action Plan.
- Harmful cyanobacterial (algal) bloom monitoring program is presently limited.

Risk 11: Increased Coastal Erosion and Risk of Coastal Flooding from Increasing Sea Levels and Changing Patterns of Storminess

Speaker: Peter Ruggiero (OSU)
Returned Questionnaires: Oregon Health Authority, Oregon Department of Transportation

Summary:

It is very likely (>90%) that the Oregon coast will experience an increase in coastal erosion and flooding hazards due to climate change induced sea level rise (*high confidence*) and possible changes to storminess patterns (*medium confidence*). Direct impacts will be felt along the coast (Region 1) with possible indirect impacts felt throughout the state (e.g., loss of recreation, economic losses).

Likelihood:

It is very likely (>90%) that coastal erosion and flood hazards will increase due to sea level rise.

Confidence:

Confidence is very high that sea level will continue to rise and increase coastal erosion and flood hazards due to strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.) and high consensus. Confidence is only medium that changing patterns of storminess (e.g., changes to ENSO, trends in wave heights) will change coastal erosion and flood hazards due to only suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging etc.) and competing schools of thought.

Geographic Variability:

Since vertical land motions (VLM) vary along the coast, the rates of relative sea level rise and associate impacts will vary along the coast. In general, the south coast and the north coast are experiencing higher VLM than the central coast.

Characterization:

The risk of coastal erosion and flooding hazards is expected to increase with climate change due to sea level rise and possibly other factors including changing wave dynamics.

Changes in global sea levels occur due to ocean thermal expansion, glacier and ice sheet mass loss, and land water storage. Regional and local sea levels on the Pacific Northwest's coast are governed by the global mean sea level, but also by natural variability (El Niño–Southern Oscillation affects ocean currents, wind fields, and temperatures), by vertical land motions from subducting ocean plates, and by post-glacial isostatic adjustment. Global average sea level has risen by about 7–8 inches (about 16–21 cm) since 1900, with almost half this rise occurring since 1993 as oceans have warmed and land-based ice has melted. Relative to the year 2000, sea level is very likely to rise 1 to 4 feet (0.3 to 1.3 m) by the end of the 21st century. Emerging science regarding Antarctic ice sheet stability suggests that, for higher scenarios, a rise exceeding 8 feet (2.4 m) by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed.

A crucial point about both Greenland and Antarctica is that even after global temperatures are stabilized, melting will continue until a new equilibrium is reached. In the case of Greenland, there is growing concern that any warming beyond 1.5-2°C could lead to the irreversible melting of the entire ice sheet. In the case of Antarctica, recent research by Oregon scientists shows that the equilibration to a new climate would take thousands of years. Their analysis suggests that stabilizing global climate at 2°C above preindustrial would limit sea level rise to less than 3.3 ft (1m) by 2300, but even so, it could reach 9m by the year 9000. Higher emissions scenarios could lead to increases in global mean sea level of almost 10m by the year 2500 and over 50m by the year 9000. The authors note that the policy consequences of limiting emissions now will last for millennia.

Local sea level along the central Oregon coast has risen about four inches during 1967–2013 and is projected to rise by 1.7 to 5.7 feet by 2100 based on the Intermediate-Low and Intermediate-High global sea level scenarios used in the 2018 U.S. National Climate Assessment. This range of sea level rise scenarios is similar to the *very likely* range projected for the higher emissions scenario, RCP8.5, by 2100. These local sea level projections include vertical land movement trend estimates derived from GPS measurements and tide gauge platforms.

Wave heights increased in the northeast Pacific between the early 1980s and the early 2000s, as did extreme wave events. Such waves were partially responsible for concurrent increases in coastal flooding and erosion. However, attributing increasing wave heights to climate change may not be possible until the second half of the 21st century because natural variability is quite large. Future projections of average and extreme wave heights along the West Coast are presently mixed as they rely on predictions that are difficult to make about extratropical storms and extreme winds. Coastal water levels and wave heights are also affected by major El Niño-Southern Oscillation (ENSO) events. During El Niño events the Pacific Northwest's coast can experience elevated sea levels; but both the top six El Niño and top five La Niña events during 1979–2016 amplified coastal erosion and wave energy in the Pacific Northwest.

Large waves, intense storms, and ENSO events can combine with sea level rise to produce coastal erosion and inundation hazards. For example, most of the Lincoln and Tillamook County coastline have generally been in an erosional regime on average since the 1960s. This may be a reflection of positive relative sea level trends in this region unlike other coastal segments of Oregon in which vertical uplift rates are higher than relative sea level change. The projected increase in local sea levels along the Oregon coast raises the starting point for storm surges and high tides making coastal hazards more severe and more frequent in the future.

Discussion:

Envisioning Coastal Futures Projects

These projects are attempting to link policy and climate drivers to assess coastal community resilience. They are exploring a range of different adaptation options, quantifying different metrics Oregon coastal residents care about (e.g., beach accessibility). The primary audience for the Oregon Coastal Futures Project includes citizens, county planners, county commissioners, DLCD, DOGAMI, and other agencies. At this point, it is not clear whether or not tsunami hazard awareness along the coast gives Oregon higher adaptive capacity to climate driven coastal hazards.

Consequences:

Infrastructure Consequences

- Damages roads and can result in closures from increased wave heights, flooding, storm surge, and coastal erosion.
- Infrastructure damage and loss
- Land loss and habitat loss
- Salinization of drinking water sources

Public Health Consequences

- By the end of the 21st century, sea levels are projected to place thousands of people and homes and over 100 miles of roads in Oregon at risk of inundation from annual flood events that reach four feet above high tide.
- Higher sea levels could result in saltwater intrusion into coastal aquifers used to supply drinking water and agriculture uses.
- Higher waves and storm surges can increase risk of injury and death to residents of shoreland properties.
- Damaged or closed roads and bridges could isolate communities, increasing risks of food and water insecurity, and disrupting access to medicines and medical services.

Vulnerability Assessments:

- OHA-PHD completed a joint case study with the Oregon Dept. of Transportation, "How Tillamook Weathered the Storm", to understand the challenges and adaptations in response to more frequent and severe coastal flooding.
- ODOT Climate Change Adaptation Strategy Report – preliminary risk assessment and review of agency programs
- ODOT Climate Change Vulnerability Assessment and Adaptation Options Study – a regional assessment of state highways conducted in Clatsop and Tillamook counties
- Sea Level Exposure Inventory for State Highways-
- ODOT Green Infrastructure
- Envisioning Tillamook County Coastal Futures (http://envision.bioe.orst.edu/StudyAreas/Tillamook/)
- Envisioning Oregon's Coastal Futures (http://explorer.bee.oregonstate.edu/Topic/CoastalResilience/)

Comments and Recommendations:

- Oregon does not have a policy framework for managing retreat from areas subject to increased threat of climate-related hazards.
- Multi-agency assessments that take into account shared risk factors and shared opportunities for adaptation strategies between state agencies, such as geographies for where highest risk areas are located and co-benefit strategies to address those risks.
- More assessment work can be done specific to sea level rise, esp. as it relates to areas (gaps) not addressed in the 2017 DLCD inventory, specifically Columbia River and most vulnerable areas along the open coast.
- Complete coastwide extreme total water level projections including sea level rise and variability in ENSO magnitude and frequency.

Risk 12: Loss of Wetland Ecosystems and Services

Speaker: Laura Brophy (OSU)
Returned Questionnaires: Laura Brophy, Oregon Health Authority

Summary:

It is very likely (>90%) that Oregon will experience a loss of wetland ecosystems and services (*high confidence*). Loss is expected to occur in all regions with the coast responding to different drivers (sea level rise) than non-coastal regions (temperature and precipitation changes).

Likelihood:

It is very likely (>95%) that Oregon will experience a loss of wetland ecosystems and services (*high confidence*).

Confidence:

Confidence is high due to moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.) and medium consensus.

Geographic Variability:

For all regions, the risk of loss of wetland ecosystems and services is very high. However, the climate drivers of this risk vary geographically. On the coast (region 1), the primary threat to tidal wetlands will be sea level rise, with rising temperatures, changing precipitation patterns, and storms likely to be less important threats (though still present). For wetlands in noncoastal regions (regions 2-8), the primary threats will be temperature increases, changes in precipitation patterns of precipitation, reduced snowpack, and the resulting changes to wetland hydroperiod and heat/drought stress. Within each region, these risks will vary among locations depending on elevation, local topography, surrounding habitat types, presence or absence of system engineers (especially beaver), and other factors. Nontidal wetlands on the coast will also be subject to impacts from changing precipitation, snowpack, and storms, but these impacts will be reduced by the moderating effects of the nearby ocean (such as cooler temperatures, and moisture contributed by coastal fog).

Characterization:

Oregon tidal wetlands form where fresh water from rivers and streams meets the saltwater of the ocean. They take the form of salt marshes, tidal forested wetland, beaches and steep river mouths. Tidal wetlands are among the most productive and diverse ecosystems on Earth. Wetland ecosystems provide a wide range of ecosystem services including:

- Fish and wildlife habitat
- Primary production and food web support
- Native plant support
- Water storage and delay / flood reduction
- Sediment stabilization

- Nutrient retention and processing
- Carbon sequestration
- Water temperature moderation
- Others, depending on specific wetland type

Recent mapping has shown that less than 15% of historic tidal wetlands remain along the Washington, Oregon and California coastlines. Other research indicates rising seas caused by climate change could soon drown much of what habitat remains. Climate factors that are driving this risk include:

- Rising sea level
- Rising air and water temperatures
- Changing rainfall patterns
- Decreased snowpack
- Increased storm severity

Rising sea levels result in increased frequency, depth, and duration of inundation with consequences including inundation stress, drowning of vegetated wetlands and conversion to mudflats, and reduction/loss of most wetland functions such as wildlife habitat, salmonid prey production, nutrient processing, organic matter production, carbon sequestration, and temperature moderation.

Discussion:

Stakeholder Discussions

Recent mapping products showing landward migration of tidal wetlands have been shared with stakeholders. Reaction from management groups was positive, as they have used similar maps for past conservation and restoration planning. However, in general, planning for landward migration of tidal wetlands is challenging and controversial. Discussions on climate change impacts on tide gates have been sparse. Farmers at some past stakeholder meetings have said they would open their tide gates in winters to allow more sediment in, helping to maintain land surface elevations as sea levels rise. However, the efficacy of gravity operated tide gate systems will be rapidly reduced with SLR, particularly for subsided lands (typical of diked agricultural lands on the Oregon coast). Thus, some agricultural lands may eventually be abandoned from agricultural use. Active drainage (via pumping) could potentially maintain drainage of ag lands, but at much higher cost. With further SLR, even pumping could become ineffective, as groundwater seepage raises water tables and/or salinities behind dike/tide gate systems. Abandoned agricultural lands within tidal range may return to tidal wetland status via planned or unplanned dike breaches or dike removals, but remaining dike segments could act as partial barriers to sediment flows, increasing the vulnerability of these areas to SLR-induced drowning and conversion to unvegetated wetlands.

Adaptation Recommendations

A land use policy that prevents development on potential future tidal wetland areas ("landward migration zones") would help avoid future tidal wetland losses, and such a policy might also align well with tsunami planning. However, the process of incorporating current data into local land use planning processes and ordinances can be slow and challenging.

Consequences:

Public Health Consequences

- Loss of wetlands that mitigate flooding and protect coastal infrastructure from storm/wave impacts may increase risk of flood injury and death.
- Large floods can overwhelm water treatment facilities causing outbreaks of waterborne illnesses.
- Loss of wetlands that purify water may degrade drinking water sources and recreational water use.
- Loss of wetlands that provide recreational opportunities may result in reduced physical and mental health.

Loss to Ecosystem Services

- Wetlands provide a broad range of ecosystem services such as those listed below. Levels of these services vary depending on wetland type and location. If wetland ecosystems are lost or degraded, these functions will be reduced:
  - Fish and wildlife habitat
  - Primary production and foodweb support
  - Water storage and delay / flood reduction
  - Sediment stabilization
  - Nutrient retention and processing
  - Carbon sequestration
  - Water temperature moderation
  - Native plant support
  - Others, depending on specific wetland type

Vulnerability Assessments:

- Action-oriented spatial analysis of sea level rise vulnerability is available for the entire coast for sea level rise, but needed for other climate threats: Brophy, L.S., and M.J. Ewald. 2017. Modeling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future. Report to the MidCoast Watersheds Council, Newport, Oregon. Corvallis, Oregon: Institute for Applied Ecology. Available from: http://ir.library.oregonstate.edu/concern/technical_reports/tt44ps38k. 2017
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Comments and Recommendations:

- Recommended analysis would combine climate change with other prioritization factors and human dimensions.

Discussion of Gaps & Next Steps

Gaps

Vulnerability

While some existing vulnerability assessments have been identified in this workshop report, significant gaps remain. Ultimately, our ability to prioritize climate risks will require considering other factors beyond likelihood of occurrence, including the potential magnitude of consequences, exposure, sensitivity to exposures, and adaptive capacity. Presently, adaptive capacity is not evenly distributed across any given geographic region within Oregon. The cumulative consequences of climate risks disproportionately affect certain populations due to social and historical determinants, and this may not be apparent if risks are evaluated and ranked separately. Even when including analysis of vulnerable populations by risk, it's important to consider the interconnectedness of vulnerabilities across climate risks.

Wind

A brief discussion was held regarding whether there are any projected changes in wind and what the drivers are. There are a lot of competing factors and that likelihood of changes in wind due to climate change is low with low confidence.

Landslides

The risk of landslides was not addressed at this workshop, primarily due to the fact that the risk of this hazard is a blend of several climate drivers.

Risks versus Drivers

Some of the wording of the 'climate risks' in this workshop was changed from the 2010 Framework in an attempt to clarify inconsistencies between climate drivers and consequences. Future efforts might consider splitting up some of the climate risks. For example, separating invasive species from non-native and native pests might help focus Risk 8.

Fish & Wildlife

It was pointed out by several workshop attendees that there is no clear category of climate risks focused on fish and wildlife. However, impacts to fish and wildlife do show up in several of the discussion sections above.

Other

Future climate risk assessments should pay more attention to the cascading effects of multiple hazards.

Next Steps

- DLCD hosted an in-person meeting to work on the Climate Adaptation Framework on Friday August 23rd. Weekly zoom meetings will continue for the foreseeable future.
- A draft of this workshop summary report developed by OCCRI will be available to review in Fall 2019.

Appendix 1. Workshop Participants

Chris Shirley	Oregon Department of Land Conservation and Development
Marian Lahav	Oregon Dept. of Land Conservation and Development
Rose Anderson	Oregon Public Utility Commission
Ali Hamade	Oregon Health Authority
Jessica Gabriel	Oregon Parks and Recreation Department
Geoff Crook	Oregon Department of Transportation
Jerri Bohard	Oregon Department of Transportation
Kevin Jeffries	Oregon Department of Consumer and Business Services
Kara Anlaauf-Dunn	Oregon Department of Fish and Wildlife
Lesley Jantarasami	Oregon Department of Energy
Shaun Clements	Oregon Department of Fish and Wildlife
Jim Rue	Oregon Dept. of Land Conservation and Development
Paul Loikith	Portland State University
Arielle Catalano	Portland State University
Heejun Chang	Portland State University
David Rupp	Oregon State University
Meghan Dalton	Oregon State University
Peter Ruggiero	Oregon State University
Francis Chan	Oregon State University
Jeff Bethel	Oregon State University
Laura Brophy	Institute for Applied Ecology/Oregon State University
Nick Siler	Oregon State University
Tim Sheehan	Oregon State University
David Shaw	Oregon State University
Desiree Tullos	Oregon State University
Linnia Hawkins	Oregon State University
Laura Queen	Oregon State University
Susan Osredker	Oregon State University
Susan Wherry	US Geological Survey
Theo Dreher	Oregon State University
Oriana Chegwidden	University of Washington
Meredith C. Leung	Oregon State University
Charlotte Regula Whitefield	Oregon Department of Fish and Wildlife
Peter Canepa	Oregon Department of Environmental Quality
Danny Norlander	Oregon Department of Forestry
Jordan Beamer	Oregon Water Resources Department
Larry O'Neill	Oregon State University

Appendix 2. Workshop Agenda

Oregon Climate Change Effects, Likelihood, and Consequences Workshop

August 20, 2019; 9:00am-4:00 pm (coffee and snacks at 8:30!)
Strand Ag Room 363
Oregon State University

Meeting Objectives:

1. Assist the State of Oregon's Climate Adaptation Framework and Natural Hazard Mitigation Planning processes by characterizing the present state of the science around the likelihood, confidence, and consequences associated with a suite of climate change effects.
2. Describe the geographic variability of each of the climate change effects likelihood of occurring in Oregon
3. Catalogue existing and recommend future vulnerability assessments for each of the climate change effects in Oregon

TIME	Title and Speaker
9:00	Welcome, Introductions – *Peter Ruggiero, (OSU, Interim Director of OCCRI)*
9:05	Climate Adaption Framework Process – *Chris Shirley (DLCD)* Natural Hazards Mitigation Plan Process – *Marian Lahav (DLCD)*
9:15	Risks 1 and 2: Changes in hydrology and water supply; reduced snowpack and water availability in some basins; changes in timing of water availability – *Heejung Chang (PSU);* Increased incidence of drought – *David Rupp (OSU)*
10:00	Risk 3: Increased frequency of extreme precipitation events and incidence and magnitude of damaging floods – *David Rupp (OSU)*
10:30	**Break**
10:45	Risk 4: Increase in average annual air temperatures and likelihood of extreme heat events – *Paul Loikith (PSU)*
11:15	Risk 5: Increase in wildfire frequency and intensity –*Tim Sheehan (OSU)*
11:45	Risk 6: Changes to Air Quality – *group discussion*

12:00	**Lunch**
12:30	Risk 7: Changes to Water Quality – *Theo Dreher (OSU)*
1:00	Risks 8 and 9: Increases in invasive species, and insect, animal and plant pests – *David Shaw (OSU)*; Increases in human diseases - *Jeff Bethel (OSU)*
1:45	Risk 10: Increase in ocean temperatures, with potential for changes in ocean chemistry and increased ocean acidification – *Francis Chan (OSU)*
2:15	**Break**
2:30	Risk 11: Increased coastal erosion and risk of coastal flooding from increasing sea levels and changing patterns of storminess – *Peter Ruggiero (OSU)*
3:00	Risk 12: Loss of wetland ecosystems and services – *Laura Brophy (OSU)*
3:30	Climate Risk cross-walk – compare likelihood assessments across risks - *group discussion*
3:45	Gaps, Next Steps, Wrap up - *group discussion*

Appendix 3. Workshop Questionnaire

Climate Risk Likelihood/Consequences Workshop Questionnaire in support of Oregon's Climate Adaptation Framework and Natural Hazards Mitigation Plan Processes

Please fill out the below questionnaire and return to Susan Osredker at Susan.Osredker@oregonstate.edu by 16 August 2019

1. Please indicate which climate risk/climate change effect you are describing

Risk #	Climate Risk/Climate Change Effect
1	Changes in hydrology and water supply; reduced snowpack and water availability in some basins; changes in water quality and timing of water availability
2	Increased incidence of drought
3	Increased frequency of extreme precipitation events and incidence and magnitude of damaging floods
4	Increase in average annual air temperatures and likelihood of extreme heat events
5	Increase in wildfire frequency and intensity
6	Changes to air quality
7	Changes to water quality
8	Increases in invasive species, and insect, animal and plant pests
9	Increases in human diseases
10	Increase in ocean temperatures, with potential for changes in ocean chemistry and increased ocean acidification
11	Increased coastal erosion and risk of inundation from increasing sea levels and changing patterns of storminess
12	Loss of wetland ecosystems and services

2. Based on your research and/or the state of the science, what is the **likelihood** (very likely, >90%; Likely, >66%, more likely than not, >50%) of this particular climate risk occurring in Oregon in the next several decades (by the ~2050s-2060s)

3. If possible, please comment on geographic variability of this risk's likelihood of occurring in Oregon (using the 8 regions delineated by the State's Natural Hazards Mitigation Plan – see below).

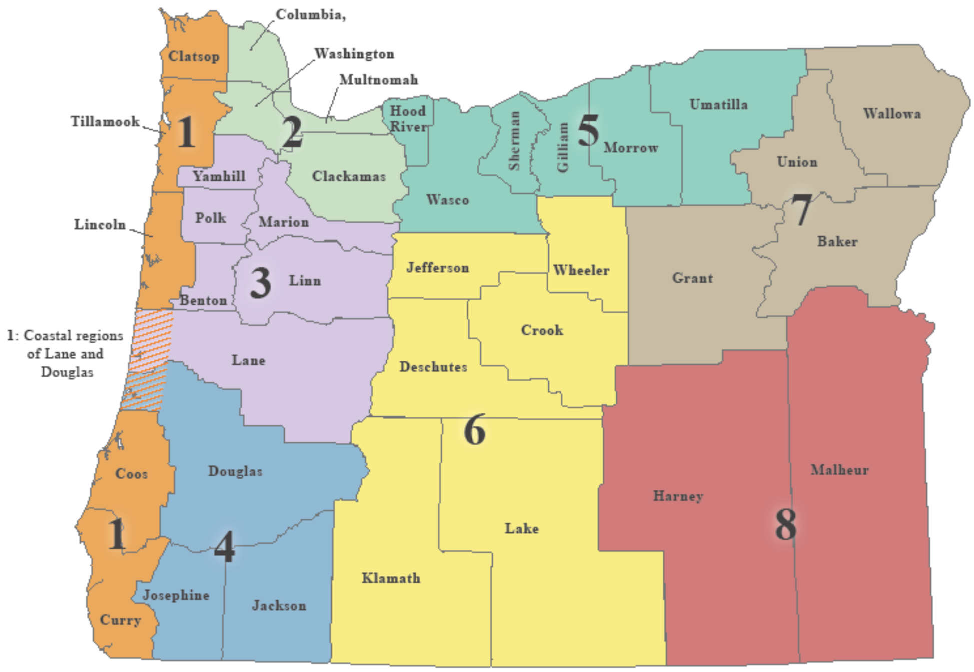

Figure 1: Natural Hazard Mitigation Planning Regions and Counties

4. What is the **level of confidence** in the above likelihood estimation (Very High; High; Medium; Low – using the rubric below)

Table 1. Confidence Level Rubric	
Very High	Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging etc.), competing schools of thought
Low	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

5. Characterization of risk – Please provide a brief summary of the scientific research pertinent to the PNW and specific to Oregon that the risk will occur; please include any knowledge available about the temporal emergence of the signal; will the risk be expressed episodically or chronically?

We are really looking for information/knowledge that is new beyond the previous Oregon/Pacific Northwest Climate Assessments that have already been completed: http://www.occri.net/publications-and-reports/
If time is short for synthesizing new science, please simply provide us with the best sources of (published) information.

6. Please list the consequences associated with this climate risk (a few bullets is fine); please specify geographic variability of consequences if possible.

7. What, if any, vulnerability assessments have been completed for this climate risk in Oregon?

8. Please make recommendations for ongoing/future vulnerability assessments.