SECTION 13

How Will Climate Change Affect Human Health?

Climate change could affect human health in the Puget Sound region via the direct effects of more intense heat waves and higher flood risk, and via the indirect effects of increasing wildfire severity, declining summer water supply, shifting infectious disease dynamics, and declining air quality. Projected changes in climate are likely to have widespread implications for Puget Sound's population, and a disproportionate effect on its most vulnerable residents (i.e., over age 65, children, homeless). Projected increases in the frequency and intensity of extreme heat events are expected to increase hospitalizations due to heat stress, and have the potential to reduce air quality. Increasing fire risk could affect human health via smoke exposure and increased occupational hazards for emergency responders. Washington's state and local governments are in the early stages of identifying how climate change may affect human health and public health infrastructure.

Climate Drivers of Change

Climate change is expected to exacerbate existing public health challenges by altering the frequency, duration, or intensity of climate-related hazards to which Puget Sound[A] communities are exposed.[1,2] In some cases (e.g., disease vectors), climate change may also lead to the introduction of new risks, and subsequently, new diseases.

- *Observations show a clear warming trend, and all scenarios project continued warming during this century*. Most scenarios project that this warming will be outside of the range of historical variations by mid-century (see Section 2).[3,4] Warming is expected to affect health via more intense and more frequent heat waves,[1] increased winter flood risk, decreased summer water supply, increased wildfire risk, lower air quality, and shifts in the types and distribution of vectors that transmit infectious and fungal diseases (Figure 13-1).

- *Heavy rain events are projected to become more intense.* Current research is consistent in projecting an increase in the frequency and intensity of heavy rain events.[5] This would increase the risk of flooding and associated health risks.

- *Most models are consistent in projecting a substantial decline in summer precipitation.*

[A] Throughout this report, the term "Puget Sound" is used to describe the marine waters of Puget Sound and the Strait of Juan de Fuca, extending to its outlet near Neah Bay. The term "Puget Sound region" is used to describe the entire watershed, including all land areas that ultimately drain into the waters of Puget Sound (see "How to Read this Report").

Projected changes in other seasons and for annual precipitation are not consistent among models, and trends are generally much smaller than natural year-to-year variability.[4] Declining summer water availability may result in reduced water quality for some locations.[6]

- *The climate-related effects on human health will disproportionally affect vulnerable populations.* Vulnerable populations include those over age 65, children, poor and socially isolated individuals, homeless, the mentally ill, outdoor laborers, and those with underlying health problems.

- *Very few studies have evaluated the climate-related effects on human health within the Puget Sound region.[7]* A small number of heat-related health outcome studies have provided a glimpse of the region-specific human health effects likely to be experienced in the Puget Sound region as a result of climate change. The remaining examples in this section reflect a general understanding of climate-related health effects, and do not exclusively address projected responses for the Puget Sound region.

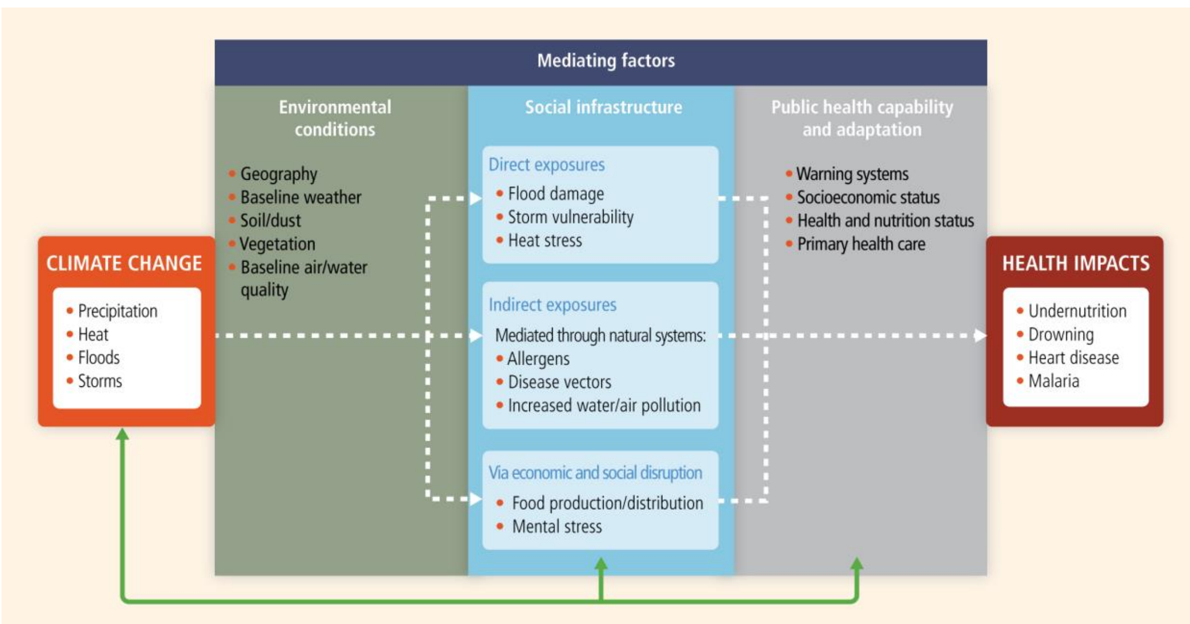

Figure 13-1. Conceptually, there are three primary ways that climate change affects health: directly through climate and weather; indirectly through natural systems that are influenced by climate; and indirectly via effects on economic and social well-being. Health effects occur when climate change influences a region's baseline environmental conditions (green box) creating new or differing exposure pathways (blue box). These effects can be further modified by factors such as the public health system's existing infrastructure and adaptive capacity (gray box). Green arrows show how some of these factors may be affected by one another. *Figure Source: IPCC (2013).[8]*

Direct Pathways

DIRECT ***Changes in the frequency, intensity, or duration of extreme weather events directly affect health outcomes.***

- *The frequency, duration and intensity of extreme heat is expected to increase in Washington State*. Heat-health exposure studies focused on Puget Sound counties have identified the warmest 1% of historical days (approximately 97°F, or 36°C, Humidex),[B,C,D] as the threshold at which significant adverse health outcomes occur.[9,10,11,12] Figure 13-2 illustrates the relationship between mortality rates and increasing humidex for 1980-2010. Climate models project that extreme heat events will become more frequent and more intense, while extreme cold events will become less frequent (see Section 2).

- *Mortality, hospitalizations, and emergency medical service call rates significantly increase on an extreme heat day compared to a non-heat day.* A King County study found that, for all ages, extreme heat (Humidex > 97°F) elevated the risk of: all-cause (+10%), circulatory (+9%), cerebro-vascular (+40%) and accident-related (+19%) mortality;[11] chronic kidney failure (+57%), acute kidney failure (+68%) and natural heat-related exposure (+244%) causes of hospital admissions;[10] and emer-gency medical service call volume by +16% on an extreme heat day compared to a non-heat day.[E,13]

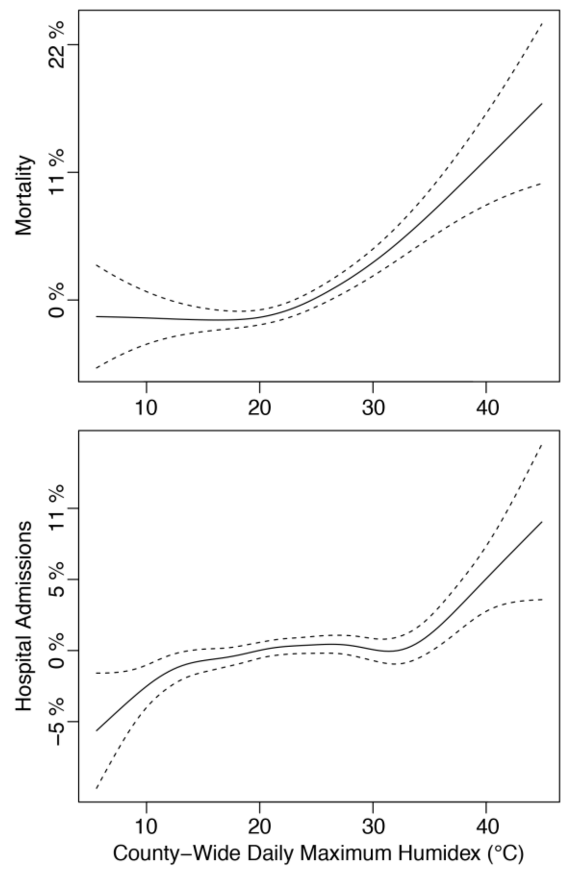

Figure 13-2. Strong link between heat stress and health outcomes in King County, Washington. The figures show the change in mortality (top) and hospital admissions (bottom) as a function of humidex. In both plots, the black line shows the fitted relationship (cubic spline) based on the observed data (analyzed for 1980-2010), and the dashed lines show the 95% confidence limits. On the graph, any value over zero represents an increase. *Figure Source: Isaksen et al. 2014.*[12]

[B] Humidex is an index that measures the combined effects of air temperature and humidity on the human body. For example, the threshold humidex of 97°F (36°C) could correspond to an air temperature of 90°F and a humidity of 35%, or to an air temperature of about 80°F at 80% humidity.

[C] Each study used a different time period for the analysis, all within the range of 1970-2010.

[D] The air temperature thresholds used to define extreme heat vary by location. Studies focused on Puget Sound counties define the threshold around 97°F (36.0°C) humidex.

[E] The analyses were based on the following time frames: 1980-2006 & 1980-2010 for the mortality studies; 1990-2010 for the hospitalization analysis; and 2007-2012 for the emergency medical services analysis.

Table 13-1. Heat-vulnerable population health estimates observed and predicted for Puget Sound communities.

Variable	Location	Observed Change
Age		
0-4 & 5-14	King County	Historical +14% and +7% increase, respectively, for all-causes of emergency medical service calls on extreme heat days.[F]
65+	King, Pierce Snohomish County	Historical +10% increase in mortality on extreme heat days[F,9]; Projected annual excess heat-related mortality[G] ranged from +64 to +200 for 2025, depending on the greenhouse gas scenario.[H,I,9]
65-84	King County	Historical +6% increase in mortality on extreme heat days.[F,11]
85+	King County	Historical +18% increase in mortality and 8% in hospital admissions on extreme heat days.[F,10,11]
85+	King, Pierce Snohomish County	Projected 2.3–8.0 (2025) and 4.0–22.3 times higher (2045) mortality for low compared to high warming scenarios.[I,J,12]
Underlying Health Conditions		
Diabetes	King County	Historical 78% increase in diabetic-related mortality on an extreme heat day,[F] 45-64 year old age group; 8% increase in diabetic-related emergency medical service calls, all-ages [11,E]
Acute Kidney Failure	King County	Historical 76% increase in acute kidney failure hospitalizations on an extreme heat day,[F] 45-64 year old age group[10]
Chronic Kidney Failure	King County	Historical 99% increase in chronic kidney failure hospitalizations on an extreme heat day,[F] 45-64 year old age group[10]
Outdoor Occupation		
	Washington State	78.5% of all heat-related injury workers' compensation claims in the State of Washington occur as a result of working outdoors. The construction sector experienced the highest rate of HRI at 12.1 per 100,000 FTE. [14]

[F] Heat events were defined as one or more consecutive days where the humidex was above the 99th percentile humidex threshold calculated for a historical period (1970-2006). [9]

[G] Excess deaths are the number of expected deaths above the baseline number of deaths. The baseline number of deaths was calculated between 1980-2006.[9]

[H] This study included King, Pierce, and Snohomish Counties. Projected change in mortality for those over age 65, relative to a base period of 1980-2006.

[I] Projections are based on the average of two global climate models and two greenhouse gas scenarios: the PCM1 model run with a low (B1) greenhouse gas scenario and the HADCM1 model run with a moderate (A1B) greenhouse gas scenario. Population was held constant at the level projected for year 2025.

[J] This study included the greater Seattle area. Projected change in mortality was estimated relative to a base period of 2002-2006.

- *Certain populations are more vulnerable to extreme heat*, resulting in increased risk of mortality, hospitalization, and emergency medical service utilization (Table 13-1).

- *Projected reductions in the frequency and severity of winter cold snaps may not be closely tied to health benefits.* Most studies are consistent in projecting a smaller decrease in cold-related mortality than the increase projected for heat-related deaths. One reason for this is that wintertime mortality is primarily associated with the seasonal effects of cold weather (e.g., influenza), and is not strongly affected by the frequency or severity of daily extremes. Recent studies have found evidence that the number of cold deaths is unlikely to change with warming.[15,16]

- *Flooding is a health concern for Puget Sound residents.* Flood waters present direct, short-term physical threats to health. In addition, floods can indirectly affect health by conveying biological and chemical agents to drinking, storm, and recreational waters; and by establishing favorable conditions for mold growth.[1,17] Risk of illness increases as individuals and communities are exposed to pathogens through contact with contaminated waters and/or mold-filled dwellings.

    - *Future increases in the severity of heavy rainfall and flooding, and sea-level rise, may exacerbate these health risks.* Heavy rainfall events are projected to become more intense (see Section 2). On average in the Northwest,[K] the intensity of the heaviest 24-hour rain events is projected to increase by +22% by the 2080s (2070-2099 relative to 1970-1999, see Section 2).[L,M,18] Rising air temperatures are also projected to result in a shift from snow-dominant to rain-dominant watersheds, thereby increasing peak river flows during flood events (see Section 3). These changes are projected to result in more severe flooding in middle and low-elevation basins (see Section 3). Additionally, sea-level rise (see Section 4) could affect Puget Sound in a variety of important ways including increasing the potential for higher tidal/storm surge and associated coastal flooding.

    - *Flooding is rarely related to mortality in Washington State.* Since 1995, nationwide, there have been 1,455 deaths attributed directly to floodwaters, but only 14 have occurred in Washington State.[19]

[K] Many characteristics of Puget Sound's climate and climate vulnerabilities are similar to those of the broader Pacific Northwest region. Results for Puget Sound are expected to generally align with those for western Oregon and Washington, and in some instances the greater Pacific Northwest, with potential for some variation at any specific location.

[L] The study evaluated the top 1% (99th percentile) in daily water vapor transport, the principal driver of heavy rain events in the Pacific Northwest. Projections are based on an analysis of 5 global climate model projections and a high greenhouse gas scenario (RCP 8.5). Projected changes in intensity were evaluated for latitudes ranging from 40 to 49N.

[M] Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "moderate" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 1 for details.

- *Other health effects of flooding: learning from Katrina.* Research is lacking regarding the long-term, indirect effects from flooding in the Puget Sound region and Washington State. Although there are many important differences relative to what can be expected in the Puget Sound region, a lot has been learned about health effects from Hurricane Katrina.

  - Following the storm, illnesses accounted for 67% of all reports of post-hurricane injuries and illnesses, while injuries accounted for 32%, and chemical exposure accounted for less than 1% of the total.[20] After floodwaters receded, 46% of the homes had visible mold growth[N,21], and the average outdoor spore concentration in flooded areas was twice the concentration in non-flooded areas.[20] Upper respiratory and lower respiratory symptoms increased by +54% and +27% in children and adolescent patients, respectively, compared to before the flooding occurred.[22]

Indirect Pathways

Climate change is likely to have indirect effects on health outcomes through the modification of natural systems and social dynamics.

INDIRECT ***Projected increases in wildfire activity could affect respiratory health, income, and entail heightened occupational hazards for emergency responders.*** Wildfire emissions can have acute or long-term health effects for those exposed. Health can be affected through exposure to air pollutants, stress from loss of property or belongings, or as an occupationally-related injury/exposure while wildfire fighting. As with other effects, there is a lack of analyzed Puget Sound region and Washington State-specific wildfire-associated health impact data.

- *Wildfire risk is projected to increase.* Two different studies estimate that the annual area burned for Northwest forests west of the Cascade crest could more than double, on average, by 2070-2099 compared to 1971-2000.[O,23,P,24]

- *Wildfire smoke has been linked to increased hospitalizations.* Smoke from the 2012 wildfires in Chelan and Kittitas counties contributed to an additional 350 hospitalizations in those counties for respiratory conditions and 3,400 student absences from school.[Q]

[N] Because of its cooler and drier climate, Puget Sound would likely to have less mold growth under the same conditions.

[O] Based on a statistical model linking wildfire area burned with climate conditions. Projections are based on ten global climate model projections for a low (B1) and a moderate (A1B) greenhouse gas scenario.

[P] Changes from historical (1971-200) to future (2070-2099) modeled using MC1 vegetation model projections based on three global climate models (CSIRO-Mk3, Hadley CM3, and MIROC 2.3 medres) under a high (A2) greenhouse gas scenario.

[Q] Glen Patrick, Manager of the Environmental Epidemiology, Washington State Dept. of Health, personal communication.

- *The economic cost of smoke exposure can be high.* A California-based study looked at quantifying all health-related costs of wildfire smoke exposure from the California Station Fire of 2009. They estimated the costs from wood smoke-related illness at $9.50 per exposed person per day, however, total costs, which included defensive actions taken to avoid exposure to smoke, were considerable higher at $84.42 per exposed person per day.[25] Although wildfire risk is expected to rise, no study has quantified the implications for smoke exposure.

- *Occupational health risks* associated with wildland firefighting include reduced lung function, increased upper and lower respiratory symptoms, injuries, and related mortality.[26]

INDIRECT ***Reductions in summer water supply can negatively affect health.*** Increasing air temperatures, less rainfall in summer, reductions in snowpack, and more frequent episodes of low streamflow (see Section 2 & 3) – these are all projected to further limit summer water supply, which may negatively affect water quality in some locations.[6] Health can be affected through exposure to compromised drinking and recreational water sources.[1] Mental health effects also increase as droughts persist.[27] As with wintertime flooding, few studies have analyzed regionally-specific drought-health impact data.

- *With less water available, contaminants in both surface and well waters become more concentrated.* Municipal water quality is unlikely to be affected, since water from these systems is purified. In contrast, private water systems that rely on shallow wells (less than 50-100 feet deep), those that are already at risk for seawater intrusion, or those with low productivity (less than 10 gallons/minute) are more vulnerable during drought conditions.[28,29] Consumers are at an increased risk for bacterial and/or chemical (e.g., nitrates) exposures associated with drinking and bathing in these waters.

INDIRECT ***Climate change could alter patterns of infectious disease.*** Few studies have analyzed region-specific relationships between climate and infectious diseases. However, there is evidence linking various pathogens and exposure pathways to anticipated changes in climate. The following are examples of the pathways by which climate change could affect diseases, exposure, and the resulting health outcomes.

- *Vector-borne example: West Nile Virus.* There are approximately 65 mosquito species capable of carrying West Nile Virus (WNV), 27 have been detected in Washington State.[30] Increasing air temperatures and changes in precipitation patterns may affect vector (e.g., mosquito, tick, flea, etc.) distribution, habitat, and population growth. Changes in vector prevalence may increase the incidence of existing or emerging diseases.[31] It is not known to what extent climate played a role in the emergence of WNV in 1999 along the east coast of the United States and the ensuing westward spread throughout North America.

- *Food-borne example: Vibrio parahaemolyticus and Vibrio vulnificus. Vibrio parahaemolyticus* (Vp) and *Vibrio vulnificus* (Vv) are strains of bacteria that can cause illness in humans consuming raw or undercooked shellfish (specifically oysters). [32] *Vv* was first detected in sediment from Willapa Bay, Washington in 1984.[33] Since August 2013, *Vibrio vulnificus* (*Vv*) has been detected in routine Washington State PH Laboratory monitoring oyster tissue samples, and represents a potential shellfish-borne illness risk. Increasing sea-surface temperatures increase the spread of these bacteria strains.[34]

- *Water-borne example: Cryptosporidiosis. Cryptosporidium parvum* and *Cryptosporidium hominis* are the parasites that cause Cryptosporidiosis, a diarrheal disease affecting humans and animals. Transmission of occurs when environmentally resilient cysts (oocysts) are ingested. These environmentally resilient cysts, or oocysts, are found in most surface waters, and the concentration of these cysts is positively associated with increased rainfall and peak river flow (see Sections 2 & 3).[35] Because these cysts are extremely chlorine resistant, recreational waters are a particular risk for transmission. [36]

- *Emerging pathogens example: Cryptococcosis.* Cryptococcosis is a rare infection caused by inhalation of spores from *Cryptococcus gattii*, a tropical and subtropical fungus found on eucalyptus trees. The infection can affect the lungs, brain, and/or spinal cord, as well as other parts of the body. Warmer, drier summers may have contributed to the establishment of *C. gattii* in British Columbia[37,38] and the subsequent emergence in the Puget Sound region.[39]

INDIRECT ***Warming increases the risk of Harmful Algal Blooms (HABs) and as a result, shellfish poisoning.*** During HAB events, the algae *Alexandrium catenella* produces neurotoxins. Consuming shellfish contaminated with these toxins can result in paralytic shellfish poisoning. This poisoning is distinct from the illness associated with consuming naturally-occurring pathogenic bacteria such as *Vibrio parahaemolyticus* and *Vibrio vulnificus* (discussed above). Climate change is projected to increase the risk of HAB events and lengthen the season over which the can take place (see Section 7).

INDIRECT ***Increasing air temperatures, longer heat waves, and decreasing summer precipitation (see Section 2) all have the potential to alter ambient ground-level ozone and fine particle levels (<2.5 micrometers), affecting respiratory and cardiovascular health outcomes.*** Dry conditions and wildfire activity can also lead to short-term increases in particulate air pollution.

- *Increased ground-level ozone, possible increases in particulates.* Higher summer air temperatures are expected to lead to the production of more ground-level ozone, particularly in urban areas. This could slow air quality improvements made in recent decades in urban areas.[9] Heat waves are often associated with air stagnation, which can cause fine particulate matter ($PM_{2.5}$) to accumulate.[40]

- *Increased deaths due to ozone.* Projections of future ground-level ozone concentrations combined with population growth in the Greater Seattle area are estimated to increase the attributable number of excess deaths[G] during the summer months from 69 per year (95% range: 35–102 per year) in 1997-2006 to +132 per year (95% range: 68–195 per year) by mid-century.[R,9]

- *Increased deaths due to particulates.* Projections of future $PM_{2.5}$ concentrations, combined with population growth in Washington State, are projected to cause +139 more deaths per year (95% CI 52–226) by mid-century compared to 2001.[R,41]

INDIRECT ***Changing air temperature and pollution affect aeroallergen levels.*** The relationship between climate change, aeroallergen levels and adverse health outcomes has not been studied in the Puget Sound region.

- *Increasing production of allergens.* Earlier start dates and longer pollen seasons have been detected for some ragweed species[42], while total pollen production and biomass, per plant, has increased significantly with rising CO_2 levels.[43] Similarly, studies have found that birch trees are more allergenic during episodes of higher air temperatures. [44]

- *Ozone exacerbates allergy symptoms.* Ground-level ozone, which is projected to increase (see above) enhances allergic responses in susceptible individuals.[45]

Mental Health

MENTAL HEALTH ***Climate change could affect mental health outcomes both directly and indirectly.*** Direct psychological effects would result from the emotional and psychological stress related to a particular extreme weather event, while indirect effects would be associated with perceived threats to emotional well-being and concern regarding the uncertainty of future risks.[46]

- *Research on the effect of climate-related events on mental health in Washington State is lacking.* Possible mental health effects of climate change include: post-traumatic stress disorder and unhealthy coping mechanisms (e.g., increased alcohol or tobacco use, poor dietary habits); non-trauma related anxiety and depression related to feelings of losing control over a situation, or uncertainty about the future; and grief the loss, or potential loss, of culturally important resources, traditions, or places.[1,46,47] These effects would disproportionally affect vulnerable populations and individuals with pre-existing mental conditions.[46]

- *Hot conditions have been linked to mental health deaths.* In King County, mental health disorder-related mortality increased +43% on extreme heat days relative to non-heat days for the 65-84 year-old age group (1980-2010).[11]

[R] The study domain was the Greater Seattle area. Projected changes in mortality are relative to a base period of 1990-1999. Projections based on MM5/CMAQ model run with the high (A2) greenhouse gas scenario. Population levels were held constant at year 2025.

Climate Risk Reduction Efforts

CLIMATE RISK REDUCTION ***Washington's state and local governments are in the early stages of identifying how climate change may affect human health and public health infrastructure.***

- *Washington State Department of Health:* In October 2014 the Washington State Department of Health began developing a set of climate and health indicators. Currently, there are 15 indicators in five categories: health, environment, human vulnerability, mitigation, and adaptation. The set will be used as an adaptation tool to help the agency raise public awareness about the linkages between climate and health, track changes in trends over time, and develop materials that local health jurisdictions can use for communicating to the public and writing adaptation plans. The project has already helped identify areas where surveillance needs to be improved and where the agency may be able to collaborate with new partners to collect data. It is anticipated that the indicators will be finalized by December 2015 and hosted on Washington's Environmental Public Health Tracking data portal (the Washington Tracking Network) by March 2016. http://www.doh.wa.gov/DataandStatisticalReports/EnvironmentalHealth/WashingtonTrackingNetworkWTN

- *Public Health Seattle/King County:* King County is partnering with the University of Washington's Department of Environmental and Occupational Health Sciences to identify and plan for the effects of climate change on human health, including synthesizing data on the effects of changing air temperatures on illness and death in King County. They have also recently updated their King County Strategic Climate Action Plan. The plan is a five-year blueprint for County action to confront climate change, integrating climate change into all areas of County operations and its work in the community. By 2020 the King County public health sector aims to implement a data surveillance system to monitor and report the human effects of climate change, conduct community and stakeholder engagement, and establish systems to detect and respond to current and emerging health threats. http://your.kingcounty.gov/dnrp/climate/documents/2015_King_County_SCAP-Full_Plan.pdf

- *Clark County Public Health:* As part of Clark County's Comprehensive Growth Management Plan revision process, Clark County Public Health produced and included a health element - *Growing Healthier* that addressed climate change effects in their county. Though not a Puget Sound County, the background reports are good examples of incorporating climate change and public health science to support policy recommendations. http://www.clark.wa.gov/public-health/community/growing_healthy/documents/ClimateLitReviewandCCFINAL_32912.pdf

- *Thurston County Public Health and Social Services:* Thurston County Public Health and Social Services received a one-year demonstration grant from the National Association of County and City Health Officials to assess local capacity to address public health effects from climate change and to increase awareness. Educational materials were created to inform the conversation. These materials can be found online and include a white paper and several PowerPoint presentations. http://www.co.thurston.wa.us/health/admin/initiatives/climatechange.html

- *EpiTRENDS: A monthly online illness trend publication produced by the Washington State Department of Health.* The Washington State Department of Health has developed this website as a means of disseminating information and monitoring emerging health issues over time. http://www.doh.wa.gov/DataandStatisticalReports/DiseasesandChronicCondition/CommunicableDiseaseSurveillanceData/EpiTRENDS

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