

APPENDIX P: DETAILED IMPACTS RELATED TO HUMAN HEALTH

I. Thermal Stress

Annual average temperatures in Washington State are rising inexorably. Although data is not yet available for Washington State, it is estimated that 400-700 people die from documented thermal stress, or hyperthermia, each year in the United States. Bernard and McGeehin, 2004. Because the actual cause of death is usually some form of cardiovascular failure, and hyperthermia is often not noted on the death certificate as an underlying factor, the number of heat-related deaths is underestimated (Wolfe et al., 2001; CDC, 2006).

The most devastating loss of life from weather events during the last 30 years have been due to relatively short but intense heat waves which led to hundreds of deaths in the United States and thousands of deaths in Europe. (Jones et al., 1982; Naughton et al. 2002; Kaiser et al., 2007; Karl and Knight, 1997; Changon et al., 1996; Whitman et al., 1997). Climate projections suggest that these events will become more frequent, more intense and longer lasting in the second half of the 21st century (Meehl and Tebaldi, 2004). The greatest impacts will be in cities with milder summers, less air conditioning and higher population density, (Medina-Ramon and Schwartz, 2007), which describes the major cities of Washington State. An aging population will also put more people at risk. (Smoyer et al., 2000)

Retrospective epidemiological research allows us to identify the population groups most likely to be harmed by heat waves, and to potentially mitigate these harms through public interventions. The groups at greatest risk include:

- Children. Exercising children in particular are slower than adults to adapt to heat stresses. (American Academy of Pediatrics, 2000)
- The elderly. The physiological ability to maintain normal body temperature declines with advanced age. The elderly, especially if they have one of the other risk factors outlined in this list, account for the largest number of deaths during extreme weather events (Borrell et al., 2006; Basu et al., 2005; CDC 2005)
- Poor and isolated populations. As in the rest of our society, the most vulnerable groups are minority populations and the poor. (Greenberg et al., 1983; Browning et al., 2006; McGeehin and Mirabelli, 2001; Naughton et al., 2002)
- Urban dwellers and those living in heat islands within cities. Not only do urban areas constitute heat islands within the larger landscapes, but poorer neighborhoods with fewer plants and more asphalt within cities are hotter than more affluent neighborhoods. (Grimmond and Oke, 1999; DeGaetano and

- Allen, 2002; Smoyer et al., 2000)
- Outdoor laborers. Adults engaged in heavy outside labor during heat waves are at greater risk. (Greenberg et al., 1983)
 - People with chronic illnesses. Illnesses such as diabetes and heart disease – and the medications used to treat these diseases – increase vulnerability to sustained heat. (Medina-Ramon et al., 2006)
 - The mentally ill. People with severe mental illness are at higher risk, both because of behavioral factors and the effect of psychoactive medications (Kaiser et al., 2001)

Quantifying the potential public health impacts of rising temperatures in Washington State is part of the future work plan of the Climate Health Impact Team (CHIT) at the University of Washington. The CHIT is currently working with the Climate Impacts Group to determine the extent, frequency and duration of heat waves in Washington State over the last decade, and using the climate models to predict changes over the next century.

II. Degradation of Air Quality

Climate change is likely to contribute to poorer air quality. As a result, air pollution issues are a major priority in the assessment of human health impacts of climate change (US Climate Change Science Program 2007).

Based on preliminary Pacific Northwest modeling of meteorological parameters and ambient air pollutants, the CIG scenario for Washington State translates into expected increases in ambient concentrations of ozone and fine particulate matter (Brian Lamb, Washington State University Dept. of Atmospheric Sciences, personal communication). In addition, increases in temperature may also produce a longer pollen season and increase the allergenicity of some aeroallergens (Beggs, 2004).

Ozone and fine particulate matter already have a deleterious impact on human health in Washington State. Ozone is produced through atmospheric reactions among precursors that include nitrogen oxides (NO_x) from industrial sources and fossil fuel burning along with volatile organic compounds (VOCs) from manmade and natural sources. Levels of ozone are highest in the summer, when temperatures rise and accelerate these ozone-forming reactions.

Particulate matter (PM) is regulated as two size fractions, with the smaller or fine fraction (PM_{2.5}) of greatest concern because of its impact on human well-being. Sources of PM_{2.5} include wood burning (woodstoves, field burning, and forest fires), , as well as vehicle exhaust including cars, diesel trucks, and buses. Temperature inversions contribute to trapping of PM and cause localized peaks in concentrations. Higher temperatures in the PNW would almost certainly increase the frequency of wild fires

(McKenzie et al. 2004, Littell 2006). Over the last two decades, a nearly fourfold increase in the incidence of large Western wildfires (i.e., fires that burned at least 400 hectares) has been ascribed to increases in springtime temperatures (Running, 2006; Westerling et al., 2006).

Epidemiological studies have identified a number of acute and chronic respiratory and cardiovascular (heart disease and stroke) health risks from exposure to these airborne contaminants. Increased exposure to ozone and PM air pollution have been implicated in premature death in adults, increased rates of infant mortality, worsened asthma or chronic obstructive pulmonary disease (COPD) in children and the elderly, low birth weight or prematurity in newborns, and serious respiratory infections, lung cancer, heart attack and stroke. Asthma and other allergic diseases such as seasonal allergic rhinitis (“hay fever”) have increased in the population in the last decades and pollen is an important trigger for asthma and allergic symptoms. Ozone and PM are also asthma “triggers” and have been implicated in the development of asthma in children. It has been argued that the climate change that has already occurred may explain some of the rise in asthma incidence (Beggs and Bambrick, 2005). In addition, studies suggest co-exposure to allergens and air pollutants increase the potential for allergic symptoms to develop and may also increase the severity of response (Wyer et al., 2000).

These air pollution related morbidities are important public health priorities in Washington State. Heart disease is the leading cause of death in Washington State citizens over 65 years of age (WA Dept of Health Data Book, 2005). Prematurity and low birthweight are the second leading causes of infant mortality in Washington State (WA Dept of Health Data Book, 2005). Washington’s asthma rate is among the highest in the United States and 1 in 10 households (with children) have a child with asthma (WA Dept of Health Asthma Program, 2007). Asthma costs in medical expenditures and lost productivity are already more than \$400 million every year.

Qualitative assessment of CIG models suggests that climate change will increase ozone, PM, and pollen/fungal spore concentrations, and will thus adversely affect the cardiopulmonary health of Washington State residents. Specifically:

Ozone

- There will be an increase in the average summertime ozone concentration, and the number of days where ozone concentrations exceed regulatory standards.
- The increased concentrations in ozone may result in ozone exposures that produce human health compromise, particularly for individuals with asthma, COPD, and those who work or play outside for extended periods of time.
- Climate change may undermine current and planned policy and regulatory efforts to improve air quality via reduced emissions and ozone precursors.

Pollen/Fungal spores

- There will be an increase in concentrations of some aeroallergens (pollens, fungal spores), and the duration of the pollen season will increase.
- The allergenicity of some aeroallergens (due to biological factors and combined exposure with increased particulate matter) will increase.
- These may increase the number of individuals who develop allergic symptoms and worsen symptoms in those already affected.

Particulate Matter

- There will be an increase in wildfire generated PM.
- PM_{2.5} associated with wildfires may yield a subsequent increase in the burden of both acute respiratory and cardiovascular effects in those exposed. This includes increased physician, emergency department visits and hospitalizations for asthma, heart attacks and other cardiopulmonary conditions. Long term increased exposure to PM_{2.5} may contribute to decreases in life expectancy and development of diseases such as asthma and lung cancer. It might also contribute to increased numbers of infants who die in their first year or who are born prematurely or of low birth weights.

In general, worsening air quality will have a disparate impact on elderly, young, urban & rural poor (due to lack of access to chronic condition care and urban hotspots for ozone/particulate matter, rural hotspots for wildfire impacts). Also, there will be relatively higher exposure for individuals who spend more time outside such as the homeless, children active in sports, and outdoor laborers.

III. Increase in Vector-borne and other Infectious Disease

Infectious diseases are potentially a major source of illness and death, and increased temperatures could influence infectious disease in several ways. First, global warming may increase the rate of reproduction of the pathogen, and may also have an effect on the immune response of the host-both animal reservoirs and humans. Also, temperature may affect exposure to infectious agents through changes in vector ranges and reservoir habitat, and via human behavior that may increase or decrease exposure to vectorborne, foodborne and waterborne diseases, e.g., recreational water use, outdoor food preparation and consumption, and increased or decreased clothing coverage.

Extreme precipitation and flooding may increase exposure especially to waterborne pathogens that may contaminate surface and ground water supplies, and that may also alter the habitats of reservoir populations (e.g., shellfish). The large number of climate sensitive variables in vector-borne disease transmission makes the modeling of the effects of climate change very complex (National Research Council, 2001). Moreover, there are

a limited number of studies of the effects of climate change on ranges of vectors like ticks and mosquitoes, and at this point we do not know if we will experience an increased disease incidence with increased vector range (Wegbreit and Reisen 2000; Subak 2003; McCabe and Bunnell 2004; DeGaetano 2005; Purse *et al.* 2005; Kunkel *et al.* 2006; Ostfeld *et al.* 2006; Shone *et al.* 2006). The following are diseases most likely to be affected by climate change in Washington.

Mosquito-Borne Diseases

Mosquito-borne viral illness such as malaria, dengue and West Nile (referred to collectively as arboviral diseases) are a concern in Washington State. All 24 malaria cases in 2005 were contracted outside the United States, but the disease vectors for malaria exist in Washington. Between 1830 and 1833 a major outbreak of malaria in the lower Columbia and Willamette River valleys decimated the Native American population with a reported mortality over 90% (Boyd, 1999). Malaria has been subsequently reported in Washington since at least 1921, with significant spikes in reports occurring in the mid-1940s and early 1950s (Department of Social and Health Services, 1983). West Nile virus (WNV) has been detected in birds, horses and mosquitoes in the state, and 3 human cases acquired in-state were identified in 2006

(<http://www.doh.wa.gov/notify/nc/wnv.htm> [accessed 11/12/2007]). Dengue is not endemic, but could become established if the vector were transported into the state.

Other arboviral diseases that have occurred in Washington State and that may be sensitive to climate change are Western Equine Encephalitis and St. Louis Encephalitis, though no cases have been reported since 1988 (Washington State Department of Health, 2005).

Food- and Water-Borne Illnesses

Foodborne and waterborne illnesses are a significant source of morbidity throughout the United States and continue to be greatly underreported (Mead *et al.*, 1999). Most food- and waterborne pathogens are enteric pathogens transmitted via the fecal-oral route. Climate change may influence the pathogen directly (e.g., growth, virulence, persistence) or indirectly through a combination of land use and climate events, for example, floods that contaminate food crops with animal waste.

The most commonly reported enteric disease in Washington is campylobacteriosis, a bacterial food- and waterborne illness with 1,045 reported cases in 2005 and nearly 1,000 in 2006. This disease appears to have peak occurrence in warmer seasons but disease incidence cannot be reliably correlated with temperature. Gastroenteritis is also caused by a range of viruses (e.g., norovirus, rotavirus, enterovirus) and may be transmitted via food, drinking water or recreational water. Though seasonal in peak occurrence, no studies have clearly linked temperature to disease incidence. Gastroenteritis is not a reportable condition in Washington.

Vibriosis, caused by the pathogen *Vibrio parahaemolyticus* and other species, is primarily contracted through consumption of raw or undercooked shellfish. Twenty cases were reported in the state in 2005 (Washington State Department of Health, 2005) and 113 cases were found in 2006 (DeLoach and Lillie, 2007); none were fatal. *Vibrio* species are generally restricted to warmer waters, and in Washington most cases occur in summer months. Unusually warm weather and increased sun exposure in 2006 contributed to the outbreak. Washington oysters also infected at least 56 residents in nearby states between May and August (DeLoach and Lillie, 2007). Vibriosis is very likely to be an increasing threat to human populations with warmer summer temperatures.

Salmonellosis also appears to be directly influenced by climate change; of foodborne illnesses of known cause, 55% were traced to salmonella bacteria (Lynch et al., 2006). More than 600 cases were reported in Washington State in 2005 and again in 2006. Salmonella cases peak in summer months, though it is unclear if this occurs due to some intrinsic property of the bacterium or to seasonal eating habits and other human behaviors.

Waterborne illnesses may also increase with increased frequency of flooding events. Outbreaks of waterborne diseases frequently follow heavy precipitation (Curriero et al., 2001; Thomas et al., 2006), hurricanes (Setzer and Domino, 2004) and flooding (Wade et al., 2004). Both surface water and ground water used for drinking may be affected (Rose et al., 2000), though generally surface water contamination is the greater risk. *Campylobacter* and *E. coli* have been found to contaminate drinking water supplies (Auld et al., 2004). Cases of enterohemorrhagic *E. coli* (149 cases reported in 2005 and 162 in 2006) and campylobacteriosis in Washington State have been primarily food-related (Washington State Department of Health, 2005), however, flood events can result in contaminated crops that may transmit *E. coli*, Salmonella, or other enteric pathogens.

Cryptosporidiosis (*Cryptosporidium parvum*) and giardiasis (*Giardia lamblia*), both caused by parasites, are seasonal and are most frequently associated with recreational water use. As temperatures rise, increased use of water for recreation may lead to increased disease incidence. Nearly 100 cases of cryptosporidiosis were reported in 2005 and 2006, and over 400 cases of giardiasis were reported in each year.

Hantavirus Pulmonary Syndrome

Hantavirus, a zoonosis endemic to Washington, is carried by deer mice and other species, and humans are infected by inhalation of dust containing contaminated excreta. Incidence of the disease seems to be related to distribution and density of the rodent population (<http://www.doh.wa.gov/Notify/guidelines/hantavirus.htm> [accessed 11/2/2007]), which in turn is linked to the geospatial distribution of vegetation. Between its appearance in-state in 1994 and 2005, 29 cases were reported, 9 of which were fatal (Washington State Department of Health, 2005). Three more cases, 2 fatal, were

reported in 2006 (<http://www.doh.wa.gov/Notify/nc/incidence/hanta.pdf> [accessed 10/3/2007]).

Past experiences with these diseases allow us to pinpoint populations that are at elevated risk of illness and to develop interventions that prevent or mitigate exposure to disease-causing pathogens.

The groups at greatest risk include:

- Children under 5 years of age and infants are at greatest risk of contracting foodborne and waterborne illnesses, especially E. coli and Salmonella, and they may suffer serious complications from severe infections; children are also at elevated risk for dengue and malaria
- The elderly also have increased risk with respect to foodborne and waterborne illnesses and Dengue
- Pregnant women have increased risk with respect to foodborne illnesses and malaria
- Those with compromised immune systems are at greater risk for foodborne and waterborne illnesses, especially cryptosporidiosis and giardiasis, and also malaria
- The rural poor and outdoor laborers have a higher risk of contracting hantavirus and other vector-borne diseases
- Socio-economically disadvantaged groups are at elevated risk of contracting infectious disease in general; the increased psychological stress of living in poverty can impair proper function of the immune system (Cohen et al., 2007)

IV. Impact of Extreme Weather Events: Storms, Coastal Erosion, and Flooding

Climate change research suggests that weather events will become more severe in the Pacific Northwest and Alaska, as increased terrestrial and oceanic heating increase the power of storms. (Greenough et al., 2001; Ashley et al., 2005) Coupled with rising sea levels from melting of ice world-wide, coastal erosion is expected to become severe. (Moser and Tribbia, 2006) Rain-on-snow events increase the likelihood of destructive river flooding. Coastal inundation, flooding, and landslides create direct hazards to humans who are living or traveling in harm's way. (Nicholls et al., 1999) In addition, flooding can spread toxins and infectious agents and contaminate water sources, and disrupt sewage systems, all of which threaten human health in the short and long term.

Washington State is in many ways defined by its proximity to water: a large coastal terrain adjacent to the Pacific Ocean; the estuaries and bays that connect to the ocean; and the rivers that are fed by the snow and the ice in the mountains that characterize Washington's topography. As climate change progresses, the interaction of water and the human population will change. Rising temperatures globally will result in higher sea-levels, and potentially increase the intensity of storm events such as storm surges.

(Nicholls, 2004) Higher temperatures will lead to more rain-on-snow events, a major trigger of the periodic river flooding that is already a frequent occurrence in the state. (Hoo and Sumitani, 2005) Increasing population- much of which will settle near the coast or rivers – will increase the number of people affected by these forces. (Huppert and Sparks 2006) And climate change may lead to increased precipitation, although this is less certain.

The potential impacts climate change impacts on the weather patterns in Washington State include:

- Slowly progressive coastal and estuarine inundation as sea-levels rise. (National Wildlife Foundation, Sea-level Rise and Coastal Habitats in the Pacific Northwest, 2007).
- Acute flooding of coastlines as storms generate higher and more energetic storm surges on top of sea-level rise.
- Flooding of low-level inland areas as river flows increase during times of heavy precipitation and melting.

These geophysical changes in local weather patterns have the potential to cause direct human harm through the following mechanisms:

- Flooding – both coastal and inland – can hurt and kill people by destroying buildings, roads, and other portions of the built environment where humans reside during and after storm events.
- Landslides and avalanches can hurt and kill people through similar destruction of structures and roads.
- Flooding and coastal inundation can disrupt water supplies and sewage treatment facilities, and potentially lead to the spread of toxins, vectors of disease, and human pathogens.

As discussed above, the CIG predicts increases in mean temperature in Washington State of 3.2 to 7 degrees F over the next century, and projects that the sea level in this region will rise from 7 to 23 inches. These predictions will be refined during the next year, and will be used to refine the estimates in the final report of the Climate Health Impact Team (CHIT). Storm frequency and intensity, and the impacts of coastal inundation, landslides and riverine flooding will also be projects as the project continues over the next year. (Climate Impacts Group, 2007)

Despite the current lack of specificity, it is clear that the physical impact of sea level rise and more intense storm events will place a greater proportion of the Washington state population in harm's way. The specific threats have been enumerated above, and our work over the next year will add allow us to refine our estimates of the location and number of people threatened by these events. The extent of future damage is very

sensitive to the extent to which the state prepares for and adapts to the inevitable changes in weather and its physical consequences.

V. Social and Psychological Impacts, and Increases in Social Disparities

The previous sections have focused on the effects of climate change on human health through mediating factors of the physical environment, e.g., the heat island effect of urban settlements, worsening air quality, the increased range of disease vectors or persistence of zoonosis, and the immediate safety hazards of landslides and floods. In this section, we explore the links between climate change and a broader range of human welfare components as these are mediated through social institutions. An exhaustive assessment of the disruptive effects of climate change at this level might encompass such phenomena as human migration patterns and population displacement; increased demand for social services; increased demand for energy; decreased employment, production and tax base; and disrupted delivery of essential services in the event of disasters (e.g., floods) that impact infrastructure (transportation, communication).

Migration

Estimates place the number of global environmental refugees at 50 million by 2010 (UNU Institute for Environment and Human Security) and 150 million by 2050 (Myers, 1994). Hurricane Katrina forced 1 million people from their homes, and one year later 250,000 people still had not returned (Brown, 2006). Climate refugees may not return to their homes for years after an environmental disaster (Morris et al., 2002). Incremental changes in climate may also lead to migration. Decreased agricultural and industrial production may contribute to job loss in some areas, leading residents to look for work elsewhere (DFID, 2004). Sea level rise will displace others as low-lying settlements are abandoned. A flow of wealthy climate refugees from Europe is also to be expected (Schwartz and Randal, 2003). Two streams of migration must be considered: inflows from outside Washington State, as immigrants from harder hit areas escape disasters or seek employment or less extreme weather conditions; and internal displacement within Washington State for the same reasons.

Social Services and Public Health

Displaced persons within Washington State and migrants from outside the state will further encumber social services, requiring assistance with shelter, food, clothing, healthcare and job placement. Those in poverty will lean more heavily on social services. Mitigation of the growing risks to health from climate change already discussed will likely require more resources for a growing public health infrastructure than are currently available. For example, the demands of increased maintenance and improvements to critical infrastructure due to climate change in Seattle alone (Hoo and Sumitani, 2005) increase competition for public funding. Also, the increase in wildfires predicted for Washington State is expected to double the costs for preparedness and response by the

2040s (Bauman, et al., 2006). The primary long-term factor cited in the inadequate response to hurricane Katrina was chronic understaffing of state and local agencies that plan for emergency response (U.S. Senate Committee on Homeland Security and Governmental Affairs, 2006).

Economic Impacts

The potential economic impacts of climate change are numerous. Higher temperatures, precipitation variability and runoff, and damage to infrastructure may result in reduced agricultural and industrial output, lower labor productivity, and reduced tax revenues (DFID, 2006; Bauman, et al., 2006). In Washington State a good example is the impact warming has already had on the shellfish industry. Warmer temperatures likely contributed to outbreaks in disease-causing microorganisms, and costs to the industry are substantial when growing time and market share are lost because of these outbreaks (DeLoach and Lillie, 2007). Washington industries that are likely to be affected by climate change are forest products, fisheries, recreation and agriculture, especially dairy and winemaking (Bauman, et al., 2006). Also, the health impacts of climate change will exact an economic toll in public health costs as well as lost earnings and impaired productivity related to illness and death. Finally, in the case of disasters, insurance rates can rise dramatically in the aftermath as premiums are adjusted to match increased risk; those choosing to rebuild face much higher premiums and may have difficulty getting insurance at all (Larsen, 2006). On the individual level these factors add up to reduced employment, lower wages and lost earnings, and an increased cost of living; at the community level there are fewer resources for adaptation and recovery.

Energy Demand

While there is expected to be less demand for energy for heating during the winter as average temperatures in Washington State climb, during the summer there may be increased demand for energy for cooling (Bauman, et al., 2006). Moreover, because of Washington's reliance on hydropower for generating electricity, and the predicted effects of climate change on snowpack and the timing of the snowpack melt, peak production of electricity will likely occur earlier in the spring and winter (Bauman, et al., 2006), potentially leading to supply shortfalls in the summer months. Heat waves in other states have resulted in temporary failure of electrical utilities, notably, the 1995 Chicago heat wave, when unusually high demand for electrical power caused brownouts. Heat was directly implicated in 521 deaths in Chicago alone, many of which could have been avoided had cooling been available. In addition, the city's water supply was threatened as hundreds of fire hydrants were illegally opened by residents seeking relief from heat (Klinenberg, 2002). Energy constraints may have other effects on health; shortfalls in petroleum could jeopardize the ability of hospitals to use emergency generators if public utilities fail (Frumkin et al., 2007).

Stress, Alienation and Health

Ultimately, the effects of migration, unemployment, cost of living, and reduced services is experienced by individuals in terms of their ability to cope in their daily lives; psychological stress has been defined as occurring when “an individual perceives that environmental demands tax or exceed his or her adaptive capacity” (Cohen et al., 1995). The effects of stress on illness are well established; stress effects immune and inflammatory responses and is implicated in cardiovascular disease, depression, infectious disease, and others (Cohen et al., 2007). Public safety is another important component of wellbeing. Unemployment and perceptions of blocked opportunities are related to crime and social conflict (Vowell and May, 2000; Baron and Hartnagel, 1997). Reduced public safety in turn becomes another source of stress. Weakening of the social and physical environment can undermine trust in government and policies; this lack of trust impairs civic engagement (Urslaner and Brown, 2005), further alienating those most burdened by climate change. Finally, the same processes that increase business costs and reduce productivity and employment pose additional threats to health care access for the poor and underserved. The effect of these processes is to aggravate inequality, growing an underclass that is even sicker and more impoverished than before.

A community-level study of vulnerability to climate change shows that counties of western Washington are among those most at risk (Zahran et al., forthcoming). Vulnerability was operationalized as physical vulnerability in combination with adaptive capacity, or the socioeconomic ability of communities to make the necessary policy changes to mitigate expected impacts. Key vulnerabilities:

- Employment and productivity in natural resource-dependent industries, including agriculture, fishing, hydroelectric power, and industries requiring reliable access to clean water may be threatened by warming temperatures and changes in precipitation patterns and runoff.
- State and local revenues from economic activities vulnerable to climate change; declining revenues will be paired with increased demand for resources in many areas, including critical infrastructure, emergency preparedness, security and public health.
- Energy production and consumption, including projected peak consumption; the swings in the cost of energy will produce incremental changes, and the security of energy supplies will be critical to relief efforts during climate events like heat waves and floods.
- Increased costs of production (e.g., agriculture, energy, transportation) will lead to increased cost of living for everyone.
- Migration, especially climate refugees from outside Washington State, leading to increased demand for social services, employment, affordable housing and health care.
- Socio-economically disadvantaged populations have fewer resources for adapting to a demanding environment; the poor are most vulnerable not only to the direct health impacts of warming but to indirect health impacts as well, namely

increased economic pressures leading to worsened health care access and public safety, and increased stress and illness.