Urban Heat Island (UHI) Effect in the Puget Sound Region: Adaptation and Biomimetic Strategies to Mitigate the Effects of Climate Change

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Abstract

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Urban heat island (UHI) is a reverse oasis: where cities’ air and surface temperatures are hotter than their rural surroundings. The reverse oasis can be seen in urban areas across the world. It can create health consequences like heat stroke, respiratory problems, and damage to natural ecosystems.

This paper explores the effect of climate change on urban heat island effect within the Puget Sound region of Washington State. My research focuses on three cities: Seattle, Everett, and Snoqualmie. These cities exemplify large, medium, and small urban landscapes. I focus my research around the following questions: (1) How has and will climate change impact urban heat island (UHI) effect? and (2) What are some adaptability tools and strategies to mitigate these effects? I compare the UHI effects between the three city scales and begin to explore current, new, and biomimetic strategies to mitigate UHI effect in the face of climate change.

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Chapter 1: Introduction

Urban heat island (UHI) is a reverse oasis: where cities’ air and surface temperatures are hotter than their rural surroundings.[1] In 1818, Luke Howard first discovered an excess of heat in London’s city center compared to the countryside. Since Howard’s discovery, research has progressed on the reasons why heat islands prevail in the world.[2]

Urban heat islands are complex phenomena that occur throughout the world, forming in both urban and suburban landscapes. The United States Census Bureau classifies urban as

> “all territory, population, and housing units located within an urbanized area (UA) or an urban cluster (UC). UA and UC boundaries encompass densely settled territory, which consists of: [1] core census block groups or blocks that have a population density of at least 1,000 people per square mile and [2] surrounding census blocks that have an overall density of at least 500 people per square mile.”[3]

The definition stated includes suburban landscapes within urban clusters or urbanized areas. Rural landscapes are outside of these areas.[4]

In 2010, approximately 82% of people in the United States live in

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[1] Gartland, Lisa. Heat Islands: Understanding and Mitigating Heat in Urban Areas. London: Earthscan, 2008: 1.
[2] Ibid.
[3] “Census 2000 Urban and Rural Classification,” U.S. Department of Commerce, United States Census 2000, accessed May 29, 2012, http://www.census.gov/geo/www/ua/ua_2k.html.
[4] Ibid.

urban areas.[5] With urban growth rates increasing, cities in the U.S. will see an increase in development through urban sprawl. This means over time natural landscapes, or rural areas, surrounding urban areas will be developed into either residential or commercial developments.[6]

With the increasing populations and the exacerbated amount of construction, urban areas will expand. Thus, there will be an increase in urban heat islands throughout the United States. This can cause many problems like increased pollution, increased heat, decrease in human health, and increased energy expenditure.[7]

Although urban heat islands (UHI) are not an unknown phenomena, I decided to concentrate my thesis on the Puget Sound region because of the common misperception that UHI does not affect cities in mild or moderate climates. UHI tends to be studied in hot, arid climates like Phoenix, Arizona. By concentrating my studies on the Puget Sound, I can see the dynamic interplay of UHI and water, due to the large amounts of precipitation and water bodies within this region.

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[5] "North America::United States World Factbook," Central Intelligence Agency – United States of America, accessed May 29, 2012, https://www.cia.gov/library/publications/the-world-factbook/geos/us.html.

[6] "Analyzing Land Use Change in Urban Environments," United States Geological Survey, accessed May 29, 2012, http://landcover.usgs.gov/urban/info/factsht.pdf.

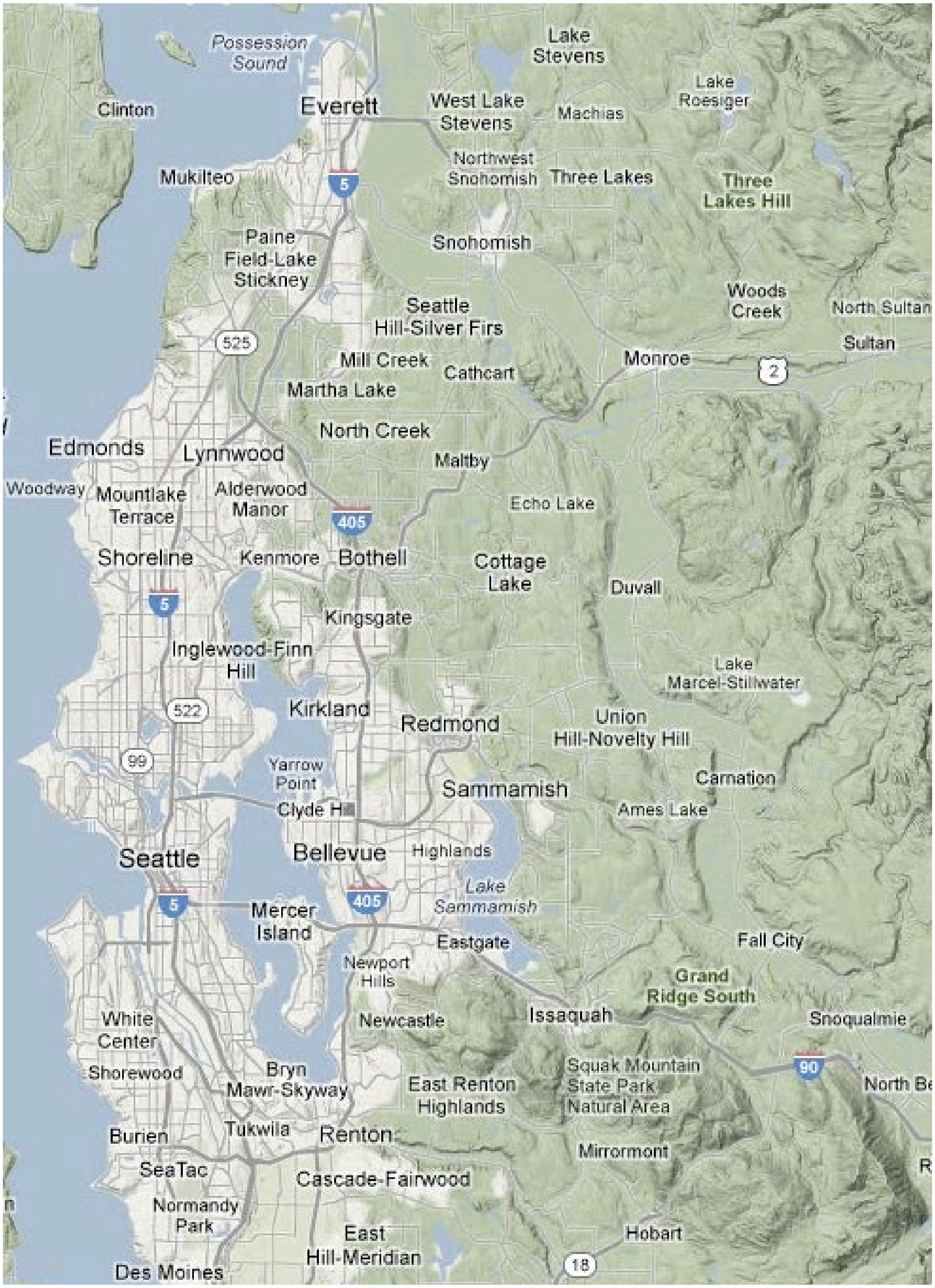
[7] Gartland, Lisa. Heat Islands: Understanding and Mitigating Heat in Urban Areas. London: Earthscan, 2008.

This paper examines the (1) current dynamics of urban heat islands; (2) climate change impacts to the urban heat islands; and, (3) strategies to mitigate and adapt the urban heat island effect within the Puget Sound region of Washington State. These three investigations allow further study on the interplay of water bodies within the urban heat island phenomena.

I focus my research on three cities: Seattle, Everett, and Snoqualmie. These cities exemplify large, medium, and small urban landscapes next to sources of water, shown in Figure 1 on the next page.

After analyzing urban heat island’s condition within these three urban landscapes, I explore tools with which urban planners and architects can mitigate the effects of urban heat island. With climate change increasing, the effects of urban heat island will heighten. This creates larger design and environmental challenges for urban planners and architects. Current strategies and tools will not be able to handle the heightened increase in heat seen in the urban landscape. By using a variety of new, current, adaptive biomimetic strategies, designers and planners may be able to allow adaptation to the urban heat island phenomena present within the Puget Sound region.

Figure 1: Map of Puget Sound Region, Google Maps



SUMMARY

This paper explores the effect of climate change on urban heat island effect within the Puget Sound region of Washington State. I focus my research around the following questions: (1) How has and will climate change impact urban heat island (UHI) effect? and (2) What are some adaptability tools and strategies to mitigate these effects? I compare the UHI effects between three city scales and begin to explore current, new, and biomimetic strategies to mitigate UHI effect in the face of climate change. I investigate the interplay of water within the urban condition and how it can be used as a resource to create adaptive solutions to the urban heat islands.

Chapter 2: Literature Review

Chapter 2 explores urban heat island effect, its characteristics, how to analyze the phenomenon, and the state of the science. Furthermore, I explore current thoughts and research on climate change; and, define and explain how mitigation, adaptation, and biomimetic strategies can be vehicles to positively affect urban heat islands in the Puget Sound region.

URBAN HEAT ISLANDS

Urban environments are complex. Multiple parts of the urban environment impact urban heat islands. The main characteristics planners have to consider when looking at urban heat island are displayed in Table 1 on the next page.

Each characteristic, or variable, is dependent on all the others. All of these characteristics make up the diverse urban landscape most Americans live in. Moreover, each of these factors contributes to the intensity of urban heat island.[8]

In urban and suburban landscapes, a positive feedback loop is created. Building materials are impermeable and water resistant. The sun’s heat is trapped and stored within the materiality, creating

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[8] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

greater heat gains.

Table 1: List of Characteristics for Urban Heat Islands (UHI) and their applicable definitions.[9]

Characteristic	**Definition**
Population	All people who live in the same geographical area.
Density	Number of people per square mile.
Geography	The science that studies the lands features, inhabitants, and Earth's phenomena.
Topography	The study of surface shape and features of the Earth.
Air Temperature	A measure of how hot or cold the air is. It is the most commonly measured weather parameter.
Cloud Cover	Refers to the fraction of the sky obscured by clouds when observed from a particular location.
Solar Radiation	Radiant energy emitted by the sun, particularly electromagnetic energy.
Wind Speed	The velocity of wind. It affects weather forecasting, growth and metabolism rate of many plant species, and countless other implications.
Pollution	The introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem.
Land Use	The human use of land. It involves the management and modification of the natural environment or wilderness into the built environment.
Vegetation	All plants or plant life of a place, taken as a whole.
Water	A liquid that descends from clouds as rain, forms streams, lakes, and seas, and is a major constituent of all living matter.[10]
Buildings	Any human made structure used or intended for supporting or sheltering any use or continuous occupancy. Buildings are made up of multiple components, which all cannot be listed within this table. Materiality, Height, Energy Consumption, and Reflectivity are the four main categories in which building components fall into.

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[9] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

[10] "Water," Merriam-Webster, accessed May 29, 2012, http://www.merriam-webster.com/dictionary/water.

Materiality	The materials or substances in the medium of a building.
Height	Vertical distance.
Energy Consumption	Energy used in the operations of the building. This can include energy consumed for heating, air conditioning, personal computer use, etc.
Reflectivity	The ratio of the energy of a wave reflected from a surface to the energy possessed by the wave striking the surface.
Pavements	A hard smooth surface, especially of a public area or thoroughfare that will bear travel.[11]
Impervious	Not permitting penetration or passage, especially of water or air.
Permeable	Pavings that allows for the movement of water and air around the paving material.

Due to greater heat gain, more energy is used to cool the buildings through air conditioning systems, etc. Heat is trapped due to common construction materials which absorb and retain the sun's energy within the built environment. Natural materials, e.g. plant life, trap less energy from the sun. Thus rural areas and natural landscapes trap energy, through plant life's photosynthesis process, creating cooler temperatures.[12]

But how do planners determine the degree of urban heat island effect within a city's borders? One of the main ways to calculate urban heat islands is by examining the energy balance of the urban environment versus the rural environment. The energy balance is the

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[11] "Pavement," Merriam-Webster, accessed May 29, 2012, http://www.merriam-webster.com/dictionary/pavements.

[12] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

amount of energy transferred to and from the Earth’s surface.[13] The equation is:

Convection + Evaporation + Heat Storage = Anthropogenic Heat + Net Radiation.[14]

Each variable of the above equation has a distinct definition and key dimensions which characterize the energy balance. Table 2 defines each factor of the equation and describes the key dimensions that contribute its calculation.

Table 2: Energy Balance Variables[15]

Variable	**Definition and Key Dimensions**
Convection	Energy transferred from the Earth’s surface to the air above it. Key factors include: Topography, Wind Speed and Location, and Air and Surface Temperature. The greater the wind speed, the greater increase in convection rates. If the air is more turbulent, the greater the temperature differential is.
Evaporation	Energy transferred away from the Earth’s surface by water vapor. An increase in evaporation occurs when (1) More moisture is available (e.g. water bodies, land cover, and topography); (2) Wind speeds are greater; and, (3) Air is drier and warmer (e.g. high air and surface temperature and an increase in dew point).
Heat Storage	It is the thermal conductivity and heat capacity of the study area. Key factors are land cover and materiality. Increase in both surface and air temperatures are caused by (1) High thermal conductivity leading to more heat

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[13] Ibid.

[14] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

[15] Ibid.

	within their depths; and, (2) Increase heat capacity leading to storing more heat within the bulk of the item.
Anthropogenic Heat	It is man-made heat caused by buildings, machinery, people, land cover, and population density.
Net Radiation	It is the total radiation within the energy balance. Net radiation is calculated through the following equation: Net Radiation = Incoming Solar – Reflected Solar + Atmospheric Radiation – Surface Radiation

As can be seen on the previous page, urban heat island is a complicated phenomenon that happens in urban landscapes. Especially when analyzing cities surrounding the Puget Sound, figuring out how topography and water bodies play into the intricacies of the urban heat islands can become a complicated situation.

Net radiation further complicates the UHI phenomenon. All the factors that go into the net radiation equation are described in Table 3.

Table 3: Net Radiation Variables[16]

Variable	**Definition and Key Dimensions**
Incoming Solar	Amount of energy from the sun. Key dimensions include Day and Night Conditions; Seasonality; Cloud Cover; and, Pollution.
Reflected Solar	Amount of solar energy that bounces off a surface. Key dimensions include land cover and materiality (e.g. darker colors absorb, lighter colors reflect).
Atmospheric Radiation	Heat emitted by particles in the atmosphere. Key dimensions include Water Vapor (e.g. dew point, land cover, topography); Cloud Cover; Pollution; and, Dust. An increase in variable equals an increase in energy emittance.

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[16] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

Surface Radiation	Heat emitted by the surface conditions of the Earth. Surface Materiality is the key dimension of this variable.

By calculating all the variables within Tables 2 and 3, planners and researchers are able to calculate a city’s urban heat island. If the energy balance equation does not balance, it means that urban heat island is affecting the given study region. In other words, the amount of energy being transferred from the sun and climate to the Earth’s surface is less than the amount of energy being transferred back into the atmosphere. This creates larger amounts of pollution and higher energy loads for buildings.[17]

Figure 2 on the next page exemplifies the difference between energy balances in the urban and rural environments. One can see in the rural landscape how the amount of energy being transferred from the sun and atmosphere approximately balances the amount of energy transferred back up to the atmosphere. This is mainly due to the larger amounts of vegetation and water features seen in rural landscapes. On the opposite end of the spectrum, the urban environment has a significant amount of extra energy being transferred into the atmosphere than is being received from the sun.[18]

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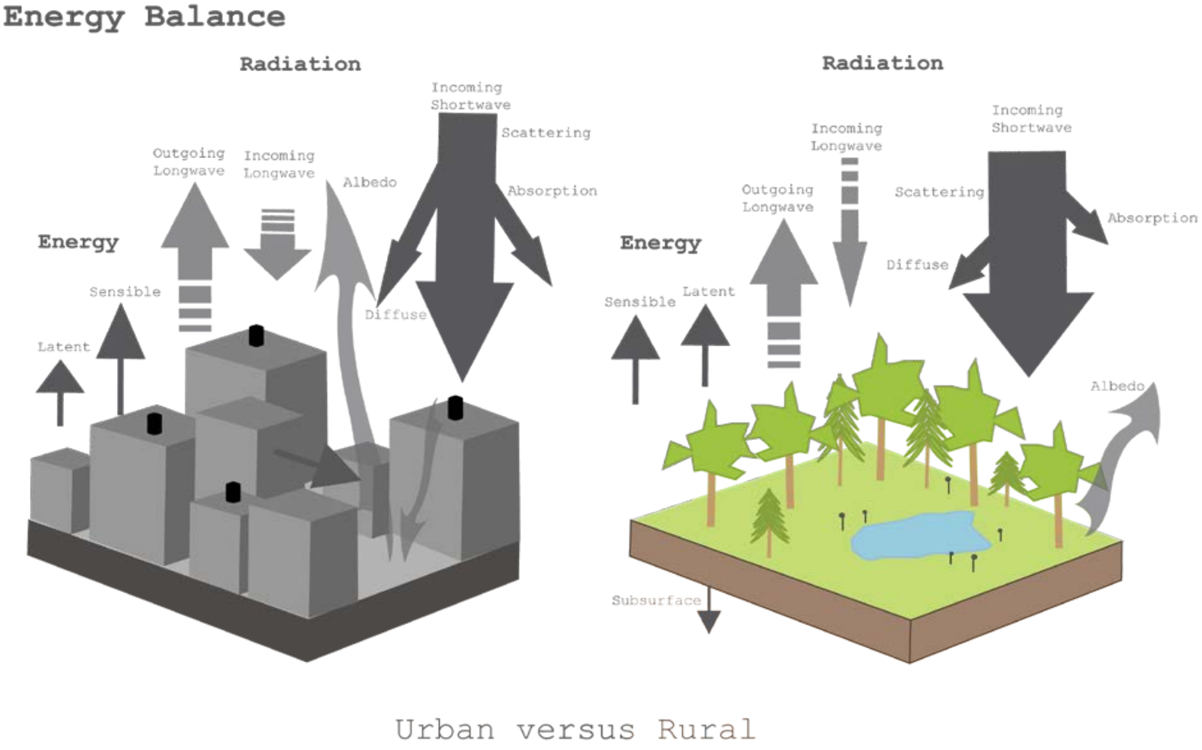
[17] Gartland, Lisa. *Heat Islands: Understanding and Mitigating Heat in Urban Areas.* London: Earthscan, 2008.

[18] Oke, T. 1988, The Urban Energy Balance, Progress in Physical Geography, 12:471-508.

The diagram gives planners a general idea of how energy is transferred in the two most prominent types of environments: urban and rural. But these dynamics do not consider wind. As tables 2 and 3 describe, wind plays a large part within the urban heat island effect. Figure 3 brings in the influences of wind and pollution within urban and rural scales. It also depicts how urban and rural environments interact with each other.

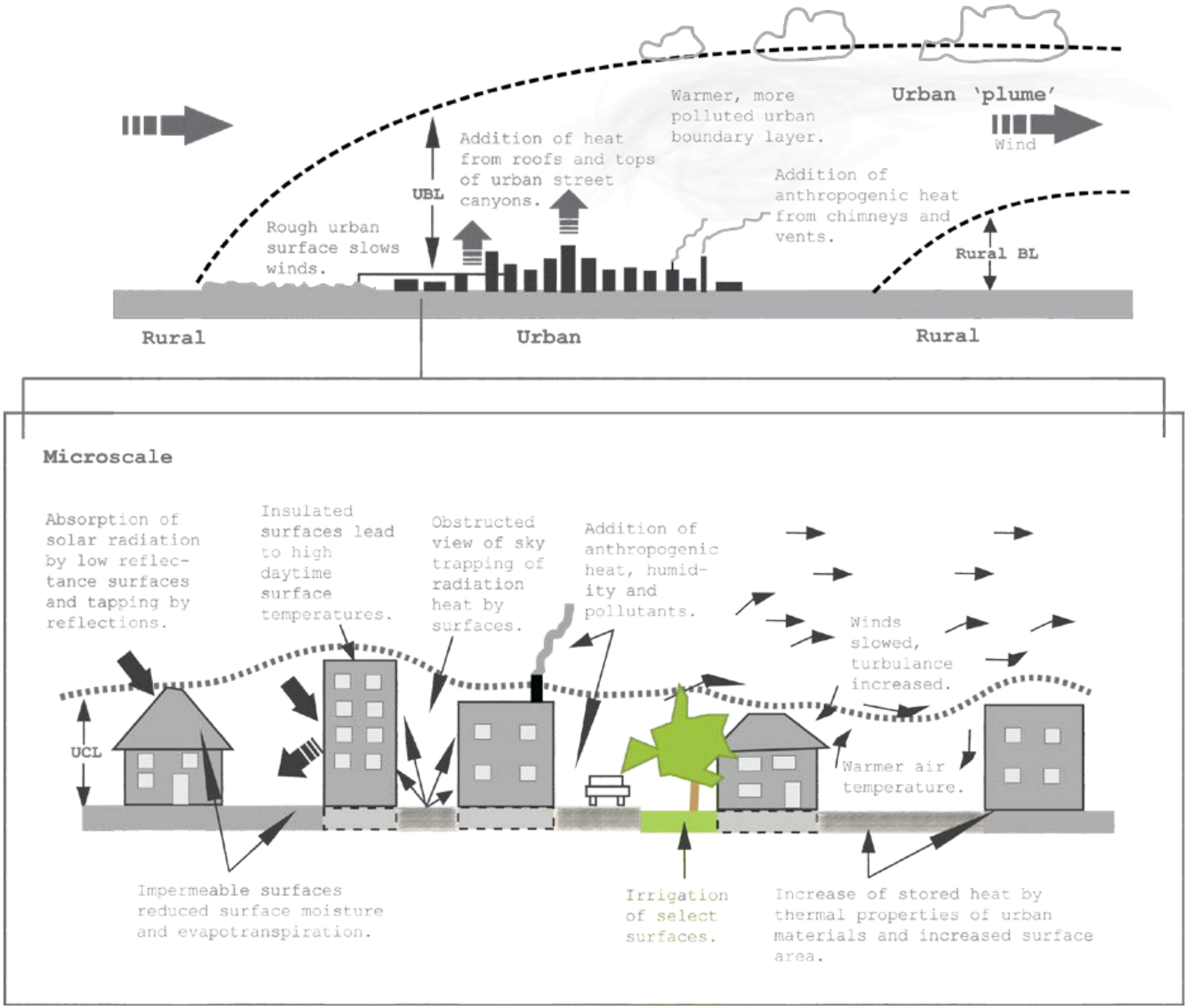
Figure 2: Urban Versus Rural Energy Balance



Redrawn from: Oke, T. 1988, The Urban Energy Balance, *Progress in Physical Geography*, 12:471-508.

The micro-scale diagram on the next page depicts the energy generated by buildings and captured by the materiality of surfaces. Every facet of the built environment plays an integral role in how wind is moved throughout the urban system. The wind captures the pollution in the urban sphere around the downtown areas. In this diagram, we can also see how vegetation and irrigation can improve the air and temperature conditions within the urban landscape.[19]

Figure 3: Wind dynamics of Urban Heat Islands in Rural and Urban Landscapes



Redrawn from: Surat City Climate Change, “Urban Heat Islands,” last accessed on March 4, 2012. http://www.suratclimatechange.org/page/8/urban-heat-islands.html.

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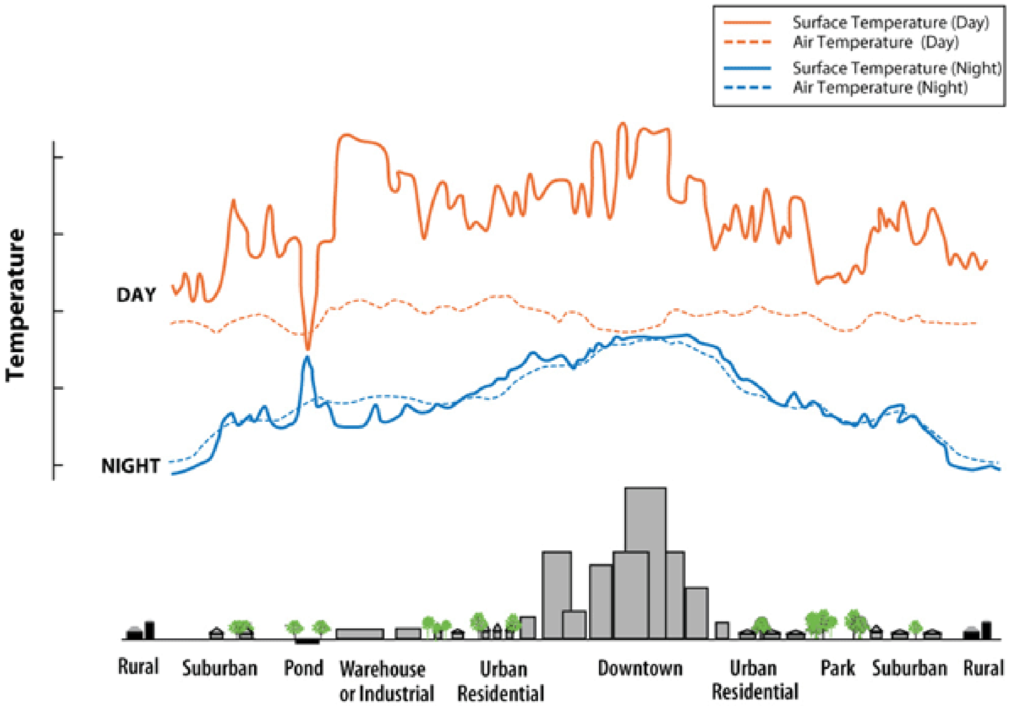
[19] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

Water and Urban Heat Islands

The prevalence of urban heat islands is due to the great amount of impervious material constructed throughout urban landscapes. These materials absorb the heat from the sun.

Water has been seen to mitigate this effect. Planners and designers currently use plant life and water bodies throughout urban landscapes to alleviate the negative effects of UHI. Figure 4 below shows how vegetation and water bodies reduce temperatures throughout the landscape.[20]

Figure 4. Water and Vegetation within the Urban Heat Island Condition



Source: "Heat Island Effect," United States Environmental Protection Agency, accessed May 29, 2012, http://www.epa.gov/heatisld/images/UHI_profile-rev-big.gif.

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[20] "What is an Urban Heat Island?," United States Environmental Protection Agency, accessed May 29, 2012, http://www.epa.gov/heatisld/about/index.htm.

The graphic above, produced by the Environmental Protection Agency (EPA), gives a general idea how day and night air temperatures change throughout the three types of land cover: urban, suburban, and rural. Heat is highest both in day and night conditions over the downtown urban center. Suburban land cover also experiences extensive heat conditions during the day, but cools off at night. Rural landscapes show the closest to natural conditions of how temperature acts. Rural landscapes have low impervious surface cover and suggest the result of vegetative mitigation strategies for the urban heat island.[21]

CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) is the world's leading scientific body for the assessment of Climate Change. First established by the United Nations Environment Programme and the World Meteorological Organization, the IPCC provides reports, assesses, and creates knowledge of the potential environmental and socio-economic impacts of climate change.[22] The IPCC defines climate change as:

> "A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or variability of its properties and that persists for an

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[21] "What is an Urban Heat Island?," United States Environmental Protection Agency, accessed May 29, 2012, http://www.epa.gov/heatisld/about/index.htm.

[22] "Organization," Intergovernmental Panel on Climate Change, accessed May 29, 2012, http://www.ipcc.ch/organization/organization.shtml#.T5CT1rau8bs.

> extended period, typically decades or long. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."[23]

In sum, climate change is a change in the climate condition (weather, precipitation, cloud cover, etc.) that will persist over an extended period of time, in excess of a decade.

Climate change contention has been seen recently within the science community. This is mainly due to the standard variability of climate and the relatively short time climate change has been studied throughout the world. The Royal Society, a fellowship of scientists within the fields of engineering, science, and medicine, produced an overview of the current state of climate change science. They have compiled the 8 most misleading arguments against climate change in order to explain how and why these statements are not true. The most common reasons are displayed in table 4.

Table 4: Arguments against Climate Change and What the Science Says.

	Argument Against Climate Change	**What Science Says**
1	"The Earth's climate is always changing and this is nothing to do with humans."	There has been varying global climate change see throughout the world for centuries. This is due to the natural greenhouse gas effect that keeps the Earth 30° Celsius warmer than it otherwise would be. But with the increase in greenhouse gases in the atmosphere due to humans, more heat is trapped and will cause an increase in temperature throughout the world.

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[23] "IPCC Introduces New 'Climate Change' Definition," The Global Warming Policy Foundation, accessed May 29, 2012, http://thegwpf.org/science-news/4374-ipcc-introduces-new-climate-change-definition.html.

		This is further exhibited when looking at polar ice cores. It was found that there is 35% greater amount of carbon dioxide emissions in our atmosphere than there has been for at least the last 650,000 years.
2	“Carbon dioxide only makes up a small part of the atmosphere and so cannot be responsible for global warming.”	Although carbon dioxide is only a small percentage of gas that makes up the atmosphere, carbon dioxide is the only gas that retains heat. With an increase in carbon dioxide in the atmosphere, there will be a greater retention of heat.
3	“Rises in the levels of carbon dioxide in the atmosphere are the result of increased temperatures, not the other way round.”	Although it is true that there can be increase carbon dioxide in the atmosphere due to increase levels in temperature, tests have shown that the 30% increase in carbon dioxide within the atmosphere is not from natural causes but rather man-made emissions such as the burning of fossil fuels.
4	“Observations of temperatures taken by weather balloons and satellites do not support the theory of global warming.”	In the early 1990s initial estimations did show that temperature in the lowest part of the Earth’s atmosphere was not increasing. This way mainly due to problems with data gathering and analysis, in which since has been resolved since then.
5	“Computer models with predict the future climate are unreliable and based on a series of assumptions.”	Computer models are based on standard scientific principles and observations of climate and its functions. With more knowledge on climate and improvements in technology, computer models are continually increasing in accuracy. Current models are now able to produce past and present changes accurately, and are used as a guide in discovering how climate change outcomes may occur.
6	“It’s all to do with the Sun – for example, there is a strong link between increased temperatures on Earth and the number of sunspots on the Sun.”	The sun does account for a lot of our changes in climate, but it does not account for the overall increase in average temperature seen around the globe in the past century.
7	“The climate is actually caused by cosmic rays.”	Although comic rays could have an effect on climate, it is most likely to be rather small. Unfortunately, there is not a lot known about cosmic rays and how it affects our atmosphere.

8	"The scale of the negative effects of climate change is often overstated and there is no need for urgent action."	In short term, the negative effects of climate change can be seen as positives, (for instance, increase in crop production, etc). But once climate change progresses, negative effects will be dominant throughout most of the world.

From: The Royal Society, "Climate Change Controversies: A Simple Guide." December 2008. London. http://royalsociety.org/policy/publications/2007/climate-change-controversies/.

Climate change is believed by most of the world's scientific community and is a genuine concern for scientists, governments, and planners throughout the world. With the impending increase heat, the global community is going to start having to mitigate conditions such as melting polar icecaps, sea-level rise, desertification, increases in flooding, increases in hazardous weather conditions, melting snow packs, and many other conditions depending on one's specific area on the globe.[24]

For the purposes of my research, I look at urban heat islands and the extent of which climate change increases its effects. I took climate change projections from the Climate Impacts Group (CIG), a focused research group within the University of Washington. The CIG gets their projections from the IPCC and focuses their predictions on the Pacific Northwest. Their forecasts are internationally recognized and the CIG is one of most recognized climate change

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[24] Davoudi, Simin, Jenny Crawford, and Abid Mehmood. 2009. *Planning for climate change strategies for mitigation and adaptation for spatial planners*. London: Earthscan. http://public.eblib.com/EBLPublic/PublicView.do?ptiID=471072: 28.

organizations in the Pacific Northwest.[25]

The Climate Impacts Group projects the Pacific Northwest will have an average annual increase in temperature and in precipitation within the next 30 years. This means that all seasons will be warmer, especially the summer months, and precipitation rates will increase, especially in the winter months. With the increase in temperature and precipitation, the resulting side effects will include:

- Increase in summer droughts due to warmer temperatures;
- Increase in winter flooding;
- Reduced snowpack for late summer stream flows; and,
- Greater uncertainty regarding intensity of precipitation.[26]

Table 5 shows three climate change projections for the years 2020, 2040, and 2080. They include changes in annual mean temperature and precipitation, showing the low, average, and high climate change predictions for these years.

Table 5. CIG: Pacific Northwest, Changes in Annual Means

Changes in Annual Mean		
	Temperature	**Precipitation**
2020s		
Low	+1.1°F *(0.6°C)*	-9%
Average*	+2.0°F *(1.1°C)*	+1.3%

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[25] "Home," The Climate Impacts Groups: Climate Science in the Public Interest, accessed May 29, 2012, http://cses.washington.edu/cig/.

[26] "Climate Change Scenarios," Climate Impacts Groups: Climate Science in the Public Interest, accessed May 29, 2012, http://cses.washington.edu/cig/fpt/ccscenarios.shtml.

High	+3.3°F *(1.8℃)*	+12%
2040s		
Low	+1.5°F *(0.8℃)*	-11%
Average*	+3.2°F *(1.8℃)*	+2.3%
High	+5.2°F *(2.9℃)*	+12%
2080s		
Low	+2.8°F *(1.6℃)*	-10%
Average*	+5.3°F *(3.0℃)*	+3.8%
High	+9.7°F *(5.4℃)*	+20%

Redrawn from: “Climate Change Scenarios,” Climate Impacts Group, accessed April 22, 2012, http://cses.washington.edu/cig/fpt/ccscenarios.shtml.

The CIG base their projections off of the IPCC climate change scenarios B1 and A1B. The details of these projection scenarios are described in Appendix A.

URBAN HEAT ISLANDS AND CLIMATE CHANGE

It seems simple to see that with increased temperatures, urban heat island effect will become more exaggerated as climate change progresses. Urban heat islands and climate change create a positive feedback loop. With ambient air temperatures rising, buildings and people will continue to use more energy, thus releasing more heat into the air. This process will exacerbate urban heat islands throughout the world. The extra heat and energy outputs create higher levels of pollution, increasing carbon dioxide within the atmosphere causing air temperatures to go even higher. This cycle is hard to stop and will continue to worsen as climate change progresses.[27, 28]

MITIGATION, ADAPTATION, BIOMIMICRY

Within my research I explore current mitigation strategies to lower the effects of urban heat island, climate change, and adaptation solutions to minimize the effects. With climate change increasing the effects of urban heat island, new strategies and adaptation solutions need to be implemented to mitigate the negative effects. To mitigate and adapt, there will not just be one tool to fix the multiple issues that cause urban heat island, but rather multiple strategies working together to cool our built environments.[29]

Mitigation

Mitigation, as defined by the IPCC, is the “[T]echnological change and changes in activities that reduce resource inputs and emissions per unit of output... mitigation means implementing policies to

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[27] William D. Solecki et al., “Urban Heat Island and Climate Change: An Assessment of Interaction and Possible Adaptations in the Camden New Jersey Region,” *Environmental Assessment and Risk Analysis Element – Research Project Summary*, April 2004, http://www.state.nj.us/dep/dsr/research/urbanheat.pdf.

[28] Shimoda, Yoshiyuki. 2003. "Adaptation measures for climate change and the urban heat island in Japan's built environment." Building Research & Information 31, no. 3/4: 222. Business Source Complete, EBSCOhost (accessed April 23, 2012).

[29] Shimoda, Yoshiyuki. 2003. "Adaptation measures for climate change and the urban heat island in Japan's built environment." Building Research & Information 31, no. 3/4: 222. Business Source Complete, EBSCOhost (accessed April 23, 2012).

reduce greenhouse gas emissions and enhance sinks.”[30] Mitigation is a term used widely through the planning and science communities. It is a key strategy to reduce the impacts of climate change further into the future. Unfortunately, many scientists believe that due to the high amount of carbon dioxide emissions already in the atmosphere, mitigation will not solve all the progress of climate change over time. Yet, a variety of mitigation strategies will need to be implemented to reduce humans’ outputs of carbon dioxide.[31]

Adaptation

Adaptation, as defined by the IPCC, is the

> “[A]djustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous, and planned adaptation.”[32]

Adaptation strategies are widely studied throughout the planning field to best plan, design, and build for climate change conditions. Planners are trying to develop strategies and solutions in which

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[30] IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, http://srren.ipcc-wg3.de/report/IPCC_SRREN_Annex_I.pdf: 962.

[31] Davoudi, Simin, Jenny Crawford, and Abid Mehmood. 2009. *Planning for climate change strategies for mitigation and adaptation for spatial planners*. London: Earthscan. http://public.eblib.com/EBLPublic/PublicView.do?ptiID=471072: 10.

[32] IPCC, “Climate Change 2007: Working Group II: Impacts, Adpatation and Vulnerability,” The Nobel Foundation, (accessed April 23, 2012). biomhttp://www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessglossary-a-d.html.

society will best use climate change to their advantage. An example of an adaptation strategy for drought is implementing local rainwater harvesting and floodwater storage. This will allow cities to cope with water shortages.[33] Continued innovative rainwater solutions will further expand access to a precious natural resource that will be in greater demand.

Adaptation is meant to keep natural resources in supply during change and physical stress to a community.

Biomimicry

Biomimicry, or biomimetics, is a form of adaptation. Pioneered by Janine Benyus, biomimicry is defined as "an innovating [design] method that seeks sustainable solutions by emulating nature's time-tested patterns and strategies."[34] Benyus is a natural science writer, author, and founder of both the Biomimicry Guild and Biomimicry Institute whose main goal is to "help designers, engineers, architects, and business leaders solve design and engineering challenges sustainably."[35] Benyus is the leader of the

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[33] Davoudi, Simin, Jenny Crawford, and Abid Mehmood. 2009. *Planning for climate change strategies for mitigation and adaptation for spatial planners*. London: Earthscan. http://public.eblib.com/EBLPublic/PublicView.do?ptiID=471072: 28.

[34] "What is Biomimicry?," The Biomimicry Guild, accessed May 29, 2012, http://www.biomimicryguild.com/guild_biomimicry.html.

[35] "Janine Benyus," Biomimicry Guild – Biomimicry Institute, accessed May 29, 2012, http://janinebenyus.com/.

field of biomimetics. Taking Benyus’s lead, planners should use the knowledge, presented by nature through evolution, to help solve some of society’s design and planning problems.[36]

Currently, biomimetics is mainly applied within product design. Many architecture firms are beginning to use biomimicry as a strategy to design sustainably, especially for dynamic or strenuous environments.[37]

Ecologists study ecological resilience, which is closely related to biomimetics. Ecological resilience is “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks.”[38] Through ecological resiliency, ecologists and scientists see how the natural environment deals with change. Due to the natural environment evolving since the birth of the planet, adapting and changing in extreme conditions, natural systems have a greater capacity for resiliency than man-made objects.

By using strategies perfected by nature, planners and society will be better equipped to adapt to the ever-changing dynamic of cities

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[36] Benyus, Janine M. 2002. *Biomimicry: Innovation Inspired by Nature*. New York: Perennial.

[37] Benyus, Janine M. 2002. *Biomimicry: Innovation Inspired by Nature*. New York: Perennial.

[38] Walker, B., Holling C.S., Carpentter, S.R, Kinzig, A. (2004). “Resilience adaptability and tranformabilitiy in social-ecological systems” *Ecology and Society* 9 (2): 5.

and climate.

My research examines the different adaptation strategies that can be applied to urban heat island within the Puget Sound region. These strategies are discussed after my analysis of urban heat island condition. Biomimetics is the key focus of adaptation strategies examined within Chapter 5.

SUMMARY

Climate change is exacerbating urban heat island’s negative effects on the built environment. It creates a feedback loop that ends up generating more heat, temperature, and pollution within urban landscapes and the global atmosphere.

Chapter 3: Methodology

This chapter explains the methods I used to determine the effects of climate change on urban heat island effect within the Puget Sound Region of Washington State. Again, I am focusing my research on the following two questions: (1) How has and will climate change impact urban heat island (UHI) effect? and (2) What are some adaptability tools and strategies to mitigate these effects? To do this, I compare the UHI effects between three city scales, urban to rural, and explore current, new, and biomimetic strategies to mitigate and adapt to UHI effect in the face of climate change.

CASE STUDIES

My analysis is structured by case studies. Specifically I examine three cities: Seattle, Everett, and Snoqualmie. By examining these three cities, I determine if urban heat is produced through the examination of weather, land cover, and city scale. Furthermore, I see how climate change affects current urban heat island conditions. Each city studied is in close proximity to large water bodies; has significant topographical relief; and varies in size (population and acreage). These characteristics give me a good baseline reading of current dynamics for UHI in the Puget Sound Region within Washington State. Additionally, these three cities have plentiful natural resources, in close proximity, affording opportunities for mitigation, adaptation, and biomimetic strategies to cope with urban heat islands and climate change.

I chose to constrain my research to the city limits of the three cities, focusing on the three scales of urban development. For comparison purposes, I observed weather stations that were in undeveloped, vegetated areas close to the studied city limits. This helped me determine whether urban heat island is prevalent in the studied cities.

Within each case study, I explore how each characteristic of the environment plays a role in determining urban heat island. The following sections describe:

- Data collection
- Analysis
- Discussion.

Data Collection

The process of collecting data began by listing the main characteristics from the built environment that would be used to calculate the Energy Balance equation. I listed all these characteristics in Table 1 (seen in chapter 2). By synthesizing all the unique attributes for each city, I began to collect the appropriate data and sources for my study, including:

- GIS data: Spatial data and metadata that allows the analysis of land cover and natural attributes of each city; and,
- Weather Stations: Locations, descriptions, and data of climate throughout each study region.

GIS Layers

WADGA, the Washington State Geospatial Data Archive,[39] and Snohomish County[40] are the two primary resources for GIS data appropriate for my analysis of urban heat island for Seattle, Everett, and Snoqualmie. The layers I focus on contain the characteristics that most affect urban heat islands. Referring back to Table 1, I discovered which built characteristics are most important to urban heat island effect.

Below is the listing of spatial features and their importance:

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[39] "Washington State Geospatial Data Archive," University of Washington, accessed May 29, 2012, http://wagda.lib.washington.edu/.

[40] "Information Services: What is GIS?," Snohomish County Washington, accessed May 29, 2012, http://www1.co.snohomish.wa.us/Departments/Information_Services/Divisions/About_GIS.htm.

- Building Outlines:

  Although they are not depicted within the maps, due to readability, the building outlines inform the amount of impervious surface located within urban developments.

- City Limits:

  The borders of the city delineate the ends of the study region. NOTE: All weather stations fully examined are constrained within the city limits.

- LANDSAT Data:

  LANDSAT images are satellite photographs, provided by NASA, taken with three light spectra. This allows analysts and researchers to conduct remote sensing.[41] Remote sensing is an ArcGIS tool allowing researchers to categorize whether land cover is either vegetative or built through the reflective quality of light hitting the object.

- Parcels:

  The parcel outlines inform the amount of impervious surface located within urban developments.

- Roads:

  Roads are a good indicator to where urban developments are located and are a guide map to the city layout.

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[41] “The Numbers Behind Landsat,” National Aeronautics and Space Administration, accessed May 29, 2012, http://landsat.gsfc.nasa.gov/data/.

- Trees/Parks

  Even though remote sensing gives a more accurate view of land cover within the city landscape, trees and parks check whether remote sensing calculations are accurate and they provide important data to help determine adaptation techniques that can be applied.
- Topography (100′ Contours):

  The topographic layers show the proximity of weather stations to bodies of water; help determine wind patterns; and are key to understanding how temperature is different throughout the city’s environment.
- Water Bodies:

  Water bodies depict where there will be natural cooling within the city. Water also gives opportunities to design and develop innovative adaptation strategies to have cities more resilient to urban heat islands and climate change.

Using these layers, in combination with weather data, I was able to synthesize the general characteristics of the city, like impervious surface cover and amount of vegetation.

Weather Data

There are a number of weather stations located throughout each studied city. They were found using Weather Underground, a source for historical data and weather station information for cities throughout the world.[42, 43] I researched each weather station making sure the data available was complete: full yearly data for precipitation and temperature. Many weather stations also give data for wind, humidity, and dew point. These other data fields are used as guides to see what the impacts of climate change are for the overall thermal comfort of the urban environment.

Table 6 describes the data provided by weather stations.

Table 6. Weather Station Data Terms

Term	**Definition**
Temperature	A measure of how hot or cold the air is. It is the most commonly used weather parameter.
Dew Point	The temperature at which air must be cooled at the constant pressure in order for it to become saturated with respect to a plane surface of water.[44]
Humidity	The amount of water vapor in the air.[45]
Wind Speed	The velocity of wind. It affects weather forecasting, growth and metabolism rate of many plant species, and countless other implications.
Wind Gust	A sudden, brief increase in speed of the wind.[46]
Wind Direction	The cardinal direction wind or wind gust is moving.

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[42] "Weather Underground," Weather Underground, accessed May 29, 2012, http://www.wunderground.com/.

[43] NOTE: This is a weather forecasting website. It has no association with the radical 'Weather Underground' organization from the 1970s.

[44] Wallace, John M., and Peter Victor Hobbs. 1977.*Atmospheric science: an introductory survey*. New York: Academic Press.

[45] "Relative Humidity," Georgia State University: Department of Physics and Astronomy, accessed May 29, 2012, http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/relhum.html.

[46] "Wind Gust," National Oceanic and Atmospheric Administration's: National Weather Service, accessed May 29, 2012, http://graphical.weather.gov/definitions/defineWindGust.html.

Pressure	The amount of force per unit area that is exerted onto a surface by the amount of air above that surface.[47]
Precipitation	In the form of hail, rain, freezing rain, sleet, or snow, precipitation is when cloud particles become too heavy to remain suspended in the air.[48]

On top of weather station location and data collection, 30-Year Climate Normals were collected for each city. This is data collected for 30-years straight from NOAA’s National Climatic Data Center (NCDC), spanning from 1981 to 2010.[49] Each city’s climate normals are taken from a weather station depicted on the Weather Station Map (seen in Chapter 4). The climate normals are used as a base of comparison for the past three years’ of data I am analyzing to synthesize if climate change has already had an impact within the Puget Sound region.

The GIS layers and the weather station data provide baseline data needed for my initial analysis of current urban heat island impacts on the Puget Sound Region. The analysis section describes how I get my current conditions within my three study regions and how I applied climate change variances to the data.

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[47] “Low and High Pressure: The Basics of Pressure and Their Impact on the World’s Weather,” About.com Geography, accessed May 29, 2012, http://geography.about.com/od/climate/a/highlowpressure.htm.

[48] “Precipitation: Online Metrology Guide,” University of Illinois: The Weather World 2010 Project, accessed May 29, 2012, http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/cld/prcp/home.rxml.

[49] “1981-2010 Climate Normals,” National Environmental Satellite, Data, and Information Service (NESDIS), U.S. Department of Commerce: National Climatic Data Center, accessed May 29, 2012, http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

Limitations

There were two limitations to the data collected: (1) GIS data sets were updated at different times, creating inconsistencies when comparing urban heat island conditions between cities; and, (2) Weather station data is inconsistent in respect to both the data available and the time-frame of measurements. These two factors limited the amount of comparison I could perform between cities and restrict the amount of weather stations that were available for analysis.

ANALYSIS

Analysis of urban heat islands in the Puget Sound region consists of extrapolating current data to find trends in increased temperatures due to urban development and impervious pavements. My analysis includes:

- Measurements of current urban heat island conditions within Seattle, Everett, and Snoqualmie;
- Application of climate change variances within each city;
- Mapping of percentage of impervious and vegetative land cover; and,
- Determination of urban heat island condition.

These four investigations are the basis for determining whether urban heat islands are prevalent within the Puget Sound and how climate change will affect this phenomenon. Below are descriptions of each investigation performed.

Current Conditions

Through the production of graphs and maps, the temperatures and precipitation can be tracked for each weather station per city. This information determines whether temperatures within urban developments are hotter than their rural counterparts. This will mainly be seen through the comparison of the three cities, each at a different development scale, and differences in temperature conditions related to pervious and impervious surfaces.

Climate Change Variance

The application of climate change variances, using the 2040 projections provided by the Climate Impacts Group of the University of Washington (seen in Table 5), are applied to the 30-Year Climate Normals. The 2040 projections are the most accurate to what the climate change predictions state. The farther in the future climate change is projected; the less reliable projections are due to larger variance in carbon dioxide emissions and wind patterns.[50]

Within each city’s case study, graphs depict the current weather station temperatures and precipitation rates. The climate change variances are overlaid depicting the wide range of fluctuations that can occur throughout the year and seasonally.

Mapping

Multiple maps were produced to give a visual representation of each city, its characteristics, weather station locations, and seasonal temperatures and precipitation rates.

Urban Heat Island Determination

Through each of the three investigations, I was able to determine whether urban heat islands are present affect climate change will have.

Data extrapolated through weather stations, demographics, land use (pervious versus impervious land cover), and climate change

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[50] “Climate Change Scenarios,” Climate Impacts Groups: Climate Science in the Public Interest, accessed May 29, 2012, http://cses.washington.edu/cig/fpt/ccscenarios.shtml.

projections, enables the determination if urban heat islands are present in each of the case studies.

Each variable relates to a component to the Energy Balance equation. Within the energy balance equation, the net radiation calculation has difficult variables to determine, like atmospheric radiation. Standards provided by ARM, the Atmospheric Radiation Measurement Climate Research Facility,[51,52] do not directly apply to the Puget Sound region, which can greatly affect the energy balance equation. To determine whether the urban heat island condition is present in the three studied cities, I compared temperature and precipitation rates of the dense urban center of the city to the more rural single family residential areas. If there is an increased amount of heat observed in the urban center, where more impervious surface cover resides, then urban heat island exists.

Additionally, weather stations in vegetative areas were peripherally explored to see whether temperatures were cooler in natural landscapes compared to the urban landscape.

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[51] "Atmospheric Radiation Measurement (ARM) Climate Research Facility," U.S. Department of Energy: Office of Science, accessed May 29, 2012, http://www.arm.gov/.

[52] A U.S. Department of Energy scientific user facility for the study of global climate change by the national and international research community.

Limitations

Within the analysis section, there are many limitations to the research that could be performed. Mapping, remote sensing, and determining the urban heat island condition all have constraints on what analysis can be performed.

Mapping and Remote Sensing

Mapping is an integral part to determining urban heat island, through the location of weather stations and showing the amount of impervious land cover associated within each weather station radius. Due to size limitations, the building layer can be shown within the maps displayed within this paper. Although the building layer is an important factor for determining the impervious surface cover within a city, the remote sensing map shows the impervious surface cover that would be seen within the building layer.

Remote sensing also has limitations. The delineation of vegetative and impervious surface cover can be difficult when looking at low to mid densely populated areas. This is due to the mix of vegetative cover with impervious surfaces.

Determination of Urban Heat Island

The comparison between weather stations is not the most desired way to determine urban heat island effect within cities. Due to limitations of data and access to proper equipment, the comparison of weather stations is the only way in which to determine urban heat islands. The comparison of each weather station looks at temperature, precipitation, and land cover to see whether or not urban heat island is present within the city limits of each case study.

MITIGATION AND ADAPTATION

Another key component of my exploratory research is my analysis of adaptation and biomimetic strategies to create more resilient cities in the face of urban heat islands and climate change in the Puget Sound region.

Mitigation

Each cities urban heat island condition will call for a set of mitigation strategies that have been used by planners and designers. These techniques show the current practices of urban heat island mitigation and how they become my platform for synthesizing adaptation strategies for the urban environments to become more resilient with the increase heat due to climate change.

Adaptation

To adapt the built environment for climate change, many strategies will have to be created. Specifically looking at biomimicry, I studied the natural environment. I began by analyzing ways in which the natural environment cools itself. Through field studies in the Puget Sound region (specifically in areas around water), I began analyzing each layer of nature as if it were a characteristic of a city. For instance, tree roots and soil are the foundation and roads of the natural environment. By focusing on each facet of the natural environment as if it were a function of the built landscape, I was able to begin to synthesize how to ‘mimic’ nature to cool our urban landscapes.

Biomimetics, as an adaptation tool, is dependent on the analysis of urban heat island. It involves creating unique solutions for the given study region and research problem. Within Chapter 5, I discuss the findings of my study of the natural environment and how to begin to strategically adapt our cities for climate change.

Limitations

Adaptation solutions through biomimicry and ecological resilience have a number of limitations restricting how in-depth one is able to research. The main limitation is the amount of knowledge applying ecological resilience and forest management techniques on the urban landscape. Many biomimetic solutions are at the exploratory stage and further research and testing needs to be done before planners and design should implement the ideas discussed within the analysis chapter.

DISCUSSION

The discussion section focuses on mitigation, adaptation, and biomimetic strategies to lessen the effects of urban heat islands and climate change. These strategies are tailored to the analysis of each city.

By seeing the interplay between the scale of city, land cover, and temperatures, I was able to suggest appropriate strategies planners and designers may implement in the built environment. Specifically, I only consider the larger city scale for design strategies to mitigate the effects of climate change and urban heat islands.

SUMMARY

In sum, each case study presented within chapter 4, has an analysis of current conditions of the urban landscape within the city’s limits. The case studies analyze

- Demographics;

- Percentage of impervious pavements;
- Percentage of vegetation;
- Location and description of weather stations;
- Analysis of Urban Heat Island:
    - 2011 conditions,
    - 2040 climate change projections; and,
- Condition of Urban Heat Island within the city.

These investigations lead me determining urban heat island within the three study regions. After determining the urban heat island and climate change condition, I suggest mitigation and adaptation strategies to create a more resilient city landscape within the Puget Sound region.

CHAPTER 4: ANALYSIS

Three case studies are presented within Chapter 4: Seattle, Everett, and Snoqualmie. Each case study includes: Demographics; Percentage of impervious pavements; Percentage of vegetation; Location and description of weather stations; Analysis of Urban Heat Island: 2011 conditions and 2040 climate change projections; and, Condition of Urban Heat Island within the city. All these factors inform the adaptation solutions investigated within Chapter 5.

With each city’s profile, I was able to synthesize the extremity of urban heat island effect condition. I ran into constraints throughout the analysis. They include:

- Minimal weather stations within city limits
- Data constraints per weather station
- Unknown placement of weather stations

  Placement of the weather station can have an effect on the readings. If the temperature gage is placed in consistent shade, readings will be lower than the average air temperature for the area.
- Inconsistent net radiation data from Atmospheric Radiation Measurement (ARM) Climate Research Facility.

Furthermore, I only examined weather stations that have complete data. Compared to the number of available weather stations, this subsequently reduced the number of weather stations that were analyzed.

SEATTLE

Figure 5. Map of Seattle, Google Maps

Seattle is a large city, with a population of 608,660 in 2010.[53] Located on the Puget Sound, Seattle has a large downtown, consisting of 12 distinct neighborhoods. The city core, or Downtown, between Stewart and Cherry streets from the waterfront to I5, has an area of approximately 71 city blocks, or 216 acres.[54] In a dynamic topography, seven hills and three large lakes are contained within the city limits: Lake Washington, Lake Union, and Greenlake. The majority of residents live in the peripheral neighborhoods in single-family housing with

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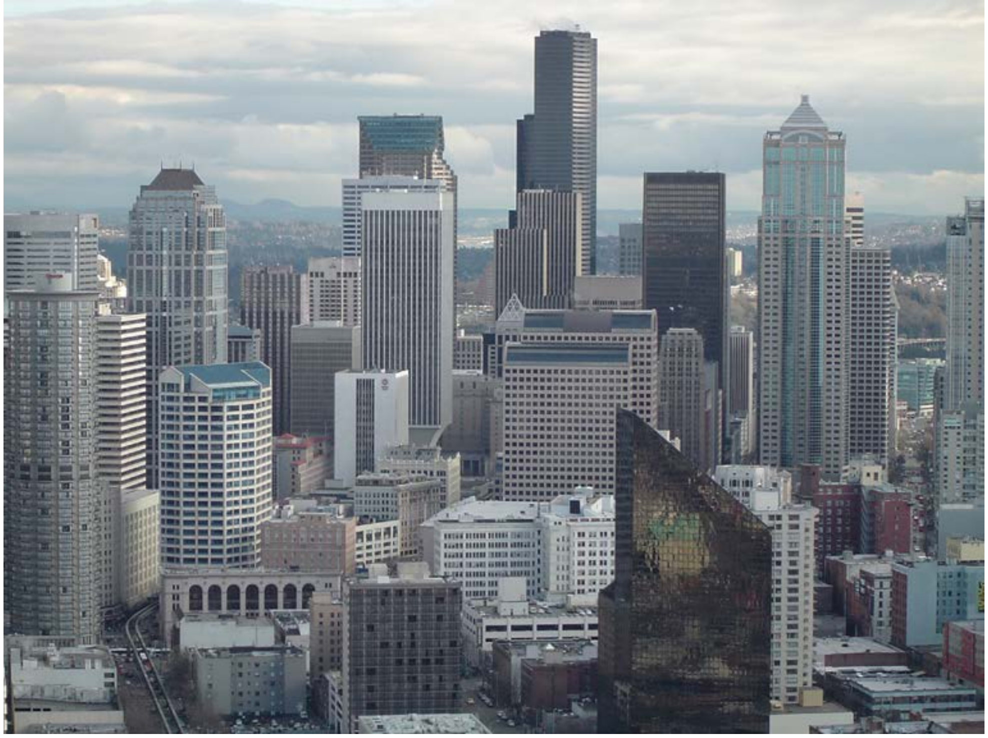
[53] "Seattle's Population and Demographics," City of Seattle: Department of Planning and Development, accessed May 29, 2012, http://www.seattle.gov/dpd/Research/Population_Demographics/Overview/default.asp.

[54] "KCGIS Center," King County GIS Data Portal, accessed May 29, 2012, http://www5.kingcounty.gov/gisdataportal/Default.aspx.

the downtown area containing mainly commercial and retail uses. Due to Seattle's proximity to the Sound, a consistent cloud cover covers the city for a significant part of the year. Considerable amounts of precipitation fall in the city throughout the year, which is accompanied by large gusts of wind carrying moisture from Puget Sound. Figure 5, on the previous page, is a map of Seattle showing the main locations of water bodies throughout the urban landscape. Shown below, Figure 6 is a photograph of the downtown urban core of Seattle. It shows large amount of impervious surface cover with large skyscrapers covering central downtown.

Figure 6. Photograph of Downtown Seattle



Source: "Seattle Downtown Skyline," Wikipedia, accessed May 29, 2012,http://upload.wikimedia.org/wikipedia/commons/2/23/Seattle_downtown_skyline.jpg

Seattle's Urban Heat Island

Weather Stations

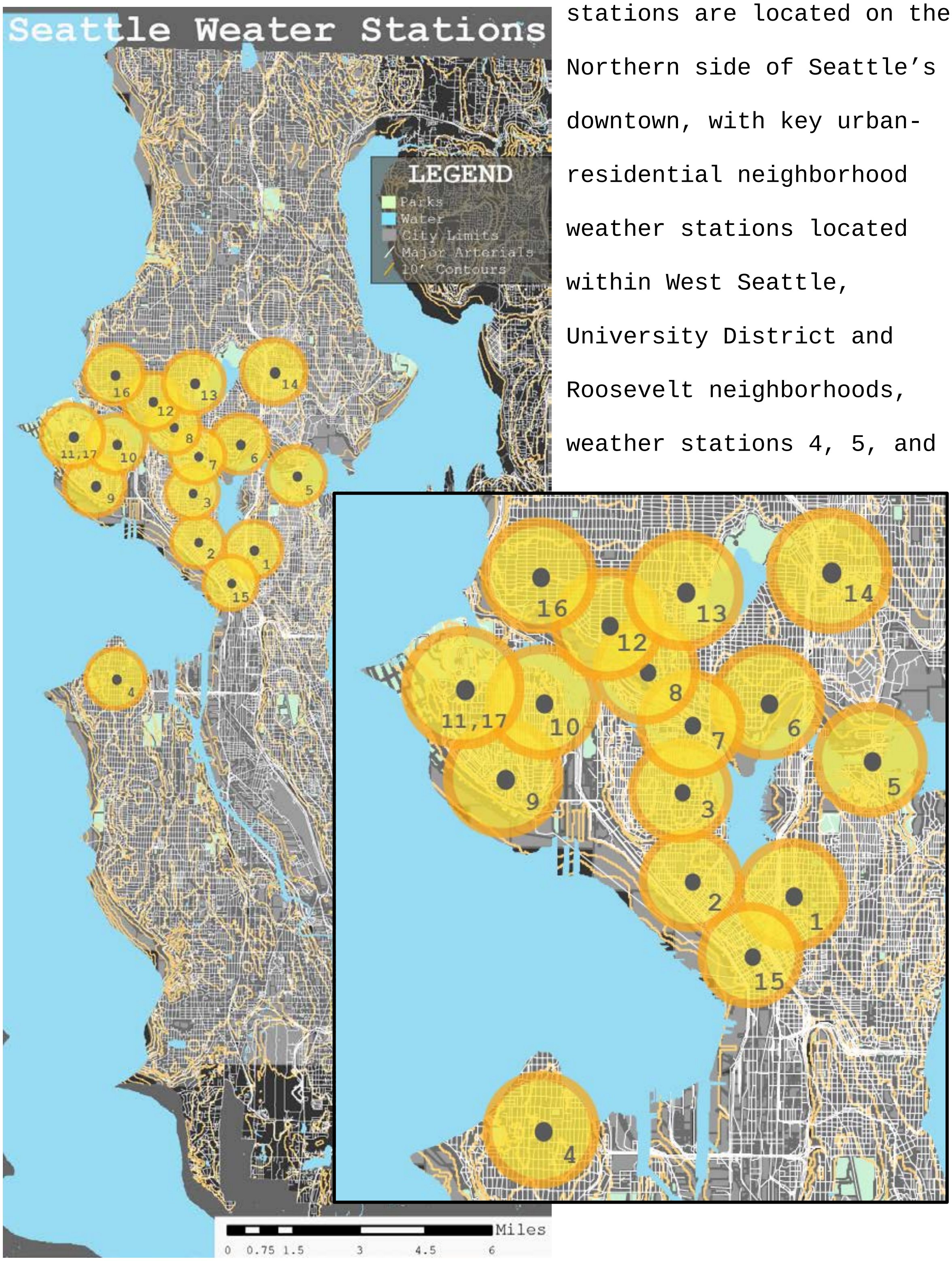
As part of my investigation, I first examined all the weather stations located within the city limits of Seattle. Weather station information required for my research was temperature and rainfall. Other information that is available from weather stations is described earlier in Table 6. Below, Table 7 lists all the weather stations within Seattle's city limits I used in my investigation of urban heat island effect.

Table 7. Seattle Weather Station Information

	Station Location	Start Year	Has All Info
1	Capitol Hill, Seattle, WA	2011	Y
2	Queen Anne - Southern Exposure, Seattle, WA	2009	Y
3	Queen Anne - Toddster weather, Seattle, WA	2008	Y
4	West Seattle (Two Dogs Observatory), Seattle, WA	2011	Y
5	University District, Seattle, WA	2008	Y
6	Wallingford, Seattle, WA	2011	Y
7	Fremont, Seattle, WA	2004	Y
8	Ballard, Seattle, WA	2009	Y
9	Magnolia - MaxHome, Seattle, WA	2009	Y
10	Magnolia, Seattle, WA	2007	Y
11	Magnolia, Seattle, Seattle, WA	2008	Y
12	Ballard - West Woodland, Seattle, WA	2012	Y
13	Phinney Ridge, Seattle, WA	2004	Y
14	Roosevelt - Tomster, Seattle, WA	2008	Y
15	APRSWXNET Seattle W, Seattle, WA	2011	Y
16	Ballard, Seattle, WA	2010	Y
17	Near Discovery Park, Seattle, WA	2010	Y

Source: "Seattle," Weather Underground, accessed May 29, 2012, http://www.wunderground.com/weather-forecast/98101.

Figure 7. Seattle Weather Stations



Most observered weather stations are located on the Northern side of Seattle’s downtown, with key urban-residential neighborhood weather stations located within West Seattle, University District and Roosevelt neighborhoods, weather stations 4, 5, and

14, respectively. Figure 7 is a map of all weather stations located within the Seattle’s city limits, each with a corresponding number associated with the weather station information in Table 7. All weather stations with complete data are shown in the map. Unfortunately, not many weather stations are located along the outskirts of the city. Even though there is not a variety of weather station locations, they are still located throughout a variety of urban densities and topographical features.

Figure 8. Seattle Urban versus Rural

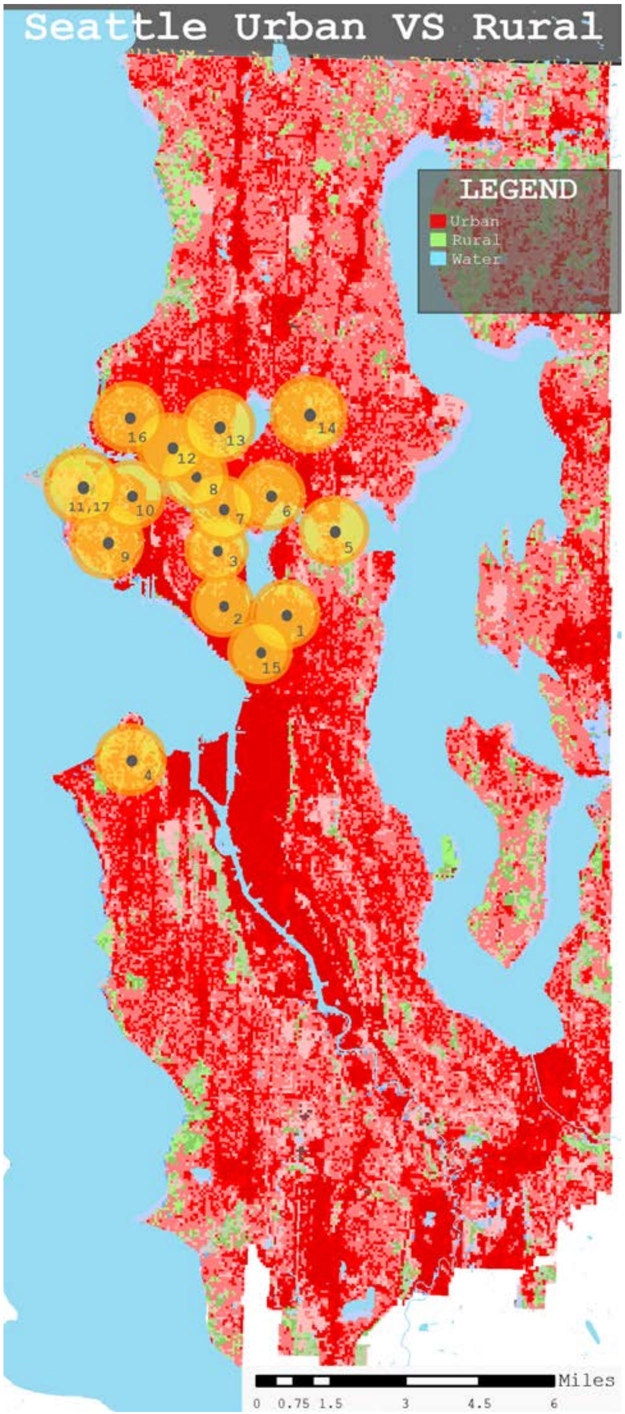


Figure 8 depicts the land cover for Seattle. Shown in red, most of Seattle is a dense urban environment with consistant concrete and impervious surface coverage spanning the city limits. Although there are parks and water bodies scattered throughout the landscape, urban, impervious landscape covers approximately 90% of the city compared to 10% of pervious, vegetative land cover.

Throughout the following section, I describe key components of weather stations through the examination of temperature, precipitation, geographic features, and land coverage. All weather station data, calculations, tables, and graphs for Seattle weather stations are presented in Appendix B.

Dense/Urban

Weather stations 1, 2, and 15, are within the urban core of Seattle. They are located within the Downtown, Capital Hill, and Lower Queen Anne neighborhoods.

Weather station 1, located atop Capital Hill, is in close proximity to the major highway that runs through the center of Seattle, Interstate-5. The weather station is within a mixed residential-retail use area, with mid-density population and 3-5 story building heights within the area. Due to the close proximity of the interstate and the distance from Puget Sound and other bodies of water, Weather Station 1 has some of the highest temperature readings and lowest precipitation rates within the Seattle city limits.

Located at the base of Queen Anne Hill, weather station 2 is within a residential-commercial area. The area is similar to Capital Hill with a mid-density population and consistent 3 to 5 story buildings. Where the weather station is located, there have been large-scale developments under construction (like the Bill and Melinda Gates Foundation building). This can cause an increase in temperatures, due to the extra activity in the area. Furthermore, the weather station is located in close proximity to the Seattle Center, which houses Key Arena, the Space Needle, and other venues creating tourism activity for the area. Temperature and precipitation rates are lower than weather station 1.

Weather station 15 is in the heart of downtown admist the skyscrappers and the main urban landscape of Seattle. Although weather station 15 is by the Elliot Bay, in Puget Sound, it is still located by the high outputs of building energy use. This causes large amounts of pollution through car and building emissions. Yet, the proximity of the water body still reduces the air temperature surrounding the weather station, especially compared to weather stations 1 and 2.

Residential

Weather stations 3 through 14 and 16, 17, are located within single-family residential areas with mid-sized commercial and retail stores located within neighborhood centers. For the most part, these stations have lower temperatures and higher precipitation rates than the urban core of Seattle. This is due to the increased amount of vegetation due to residential yards and the lower building heights seen throughout these areas (1 to 3 stories). Weather stations located near lakes and parks are observed to be even lower than those in the residential areas. Weather stations 5, 11, 14, and 17 are all located near lakes and parks. Table 8 summarizes 2011 Data, separated by month, from the weather stations examined.

Table 8. Seattle Weather Station Data, 2011

	Weather Station 1		**Weather Station 2**		**Weather Station 3**		**Weather Station 4**	
	Temp	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**
Jan	45.74	2.01	42.58	2.33	41.42	2.87	42.32	4.21
Feb	39.93	4.87	40.71	2.56	38.93	2.14	39.46	2.97
Mar	45.42	5.43	45.90	6.56	44.55	5.87	44.84	3.68
Apr	45.63	3.19	45.93	2.19	44.00	1.92	45.20	2.77
May	52.26	3.10	52.65	1.2	52.88	0.3	51.48	2.58
Jun	58.63	1.28	58.07	1.79	60.00	0.02	57.66	1.19
Jul	62.39	0.74	61.81	0.51	60.97	0.84	60.35	0.61
Aug	64.81	0.05	64.00	0.03	63.10	0.05	62.65	0.03
Sep	63.83	0.94	63.40	1.03	61.67	1.05	61.67	1.14
Oct	52.23	2.93	52.65	1.76	51.44	3.01	51.29	2.17
Nov	43.77	5.11	44.57	4.57	42.60	5.62	43.10	4.6
Dec	40.90	1.52	41.94	0.93	40.70	1.7	40.84	1.57
	Weather Station 5		**Weather Station 6**		**Weather Station 7**		**Weather Station 8**	
	Temp	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**
Jan	43.26	0.54	44.91	3.72	42.74	3.56	43.84	3.34
Feb	40.36	0.87	40.67	1.88	40.04	1.23	41.48	2.01
Mar	45.84	0.81	46.80	6.35	45.58	5.26	47.74	3.43
Apr	46.33	0.71	47.63	2.4	45.90	2.28	47.50	1.86
May	52.39	0.5	54.43	2.96	52.35	2.26	54.00	2.41
Jun	58.50	0.36	60.45	1.81	58.70	0.98	60.13	0.87
Jul	62.45	0.12	63.88	0.37	62.13	0.54	64.03	0.51
Aug	65.16	0.02	66.39	0.05	64.16	0.06	65.52	0.08
Sep	63.80	0.12	64.33	0.63	62.63	0.73	64.23	0.82
Oct	53.13	0.45	53.19	1.47	52.16	2.52	54.26	1.67
Nov	44.10	0.88	44.03	2.23	43.97	4.77	45.42	0.3
Dec	41.32	0.41	41.68	1.35	41.23	1.33	41.21	0.79

Table 9. Seattle Weather Station Data, 2011 - Continued

	Weather Station 9		Weather Station 10		Weather Station 11		Weather Station 12	
	Temp	Prec	Temp	Prec	Temp	Prec	Temp	Prec
Jan	41.42	1.77	42.42	1.85	41.45	4.23	42.65	4.14
Feb	39.73	3.18	38.70	1.44	38.29	3.13	40.00	3.36
Mar	45.04	6.97	44.94	0.65	43.94	6.73	46.00	6.79
Apr	45.97	4.81	46.26	3.31	44.50	2.5	46.47	3.05
May	52.32	3.03	54.26	1.33	51.10	2.13	52.71	3.09
Jun	58.30	1.07	58.08	0.44	57.34	0.98	59.10	1.07
Jul	61.58	0.76	63.31	0.53	60.45	0.64	62.65	0.66
Aug	63.65	0.06	65.08	0	62.74	0.07	64.42	0.1
Sep	62.23	1.08	64.64	0.39	61.33	0.95	62.57	1.1
Oct	52.14	2.39	53.08	1.65	48.29	1.12	52.23	3.39
Nov	43.63	6	39.53	3.01	43.03	5.6	43.47	6.19
Dec	38.00	0.47	42.00	1.18	38.84	1.66	41.19	1.69

	Weather Station 13		Weather Station 14		Weather Station 15		Weather Station 16	
	Temp	Prec	Temp	Prec	Temp	Prec	Temp	Prec
Jan	43.59	0	42.323	3.99	41.90	4.71	43.00	4.48
Feb	41.07	0	40.296	2.27	35.14	3.56	40.57	3.8
Mar	46.90	0	43.323	5.44	42.32	7.93	46.68	11.54
Apr	48.17	0	45.767	2.94	45.29	3.03	47.87	3.2
May	54.81	0	52.097	2.74	51.10	3.77	54.61	3.12
Jun	61.27	0	58.667	1.28	57.46	1.01	61.15	0.87
Jul	64.45	0	62.484	0.54	60.81	0.86	64.29	0.41
Aug	66.58	0	65.276	0.08	65.48	0.07	66.19	0.06
Sep	64.33	0	62.897	0.84	62.15	1.28	64.10	0.82
Oct	53.10	0	52.290	2.71	51.48	2.7	53.06	2.87
Nov	44.60	0	43.000	5.54	43.43	6.05	43.97	5.4
Dec	42.03	0	40.452	0.96	40.84	2.69	41.32	1.37

	Weather Station 17	
	Temp	Prec
Jan	42.77	4.08
Feb	40.32	3.53
Mar	45.58	7.6
Apr	46.03	2.82
May	52.06	2.91
Jun	57.73	1.07
Jul	60.90	1.04
Aug	63.32	0.06
Sep	62.30	0.98
Oct	52.29	2.65
Nov	44.43	6
Dec	41.84	1.63

Climate Change

Climate change brings added impacts to the built environment, especially in relation to urban heat island effect. With the increase in heat and the seasonal difference in precipitation, summer temperatures will become hotter while precipitation will increase in Fall and Winter months.

To see how climate change affects each weather station, I extrapolated University of Washington’s Climate Impacts Group 2040 climate change projections on the weather data for each station and the 30 year normals.

Climate Normals

As mentioned in Chapter 3, Climate Normals are 30 years of data that were gathered from NOAA’s National Climatic Data Center. Data spans from 1981 to 2010. The climate normals are used as a base comparison for all the data collected from each weather station within the Seattle region. Furthermore, they are the data that was used to base the climate change projections. In Table 10, the climate normals are presented with the climate change projections for Weather Stations A and B. They correspond to Weather Stations 5 and 11, respectively, in the Seattle maps and tables. Each month’s 2040 climate change projection from the Climate Impacts Group is the base data used for the temperature and precipitation graphs presented for each Weather Station in Appendix B.

Table 10. Seattle: 30 Year Normals and Climate Change Projections (Weather Stations A and B)[55]

	30 Year Normals (A)						Climate Change Projections			
	Temp - min	Temp - avg	Temp - High	Precip - 25%	Precip - Avg	Precip - 75%	Low CC Project - temp Min	High CC Project - temp Max	Low CC Project - Precip Min	High CC Project - Precip Max
January	37.3	43	48.6	3.97	5.46	6.85	38.80	53.80	3.53	7.67
February	37.1	44.3	51.4	1.98	3.53	4.19	38.60	56.60	1.76	4.69
March	39.7	47.6	55.4	2.93	3.87	4.37	41.20	60.60	2.61	4.89
April	42.9	51.4	59.9	2.05	2.5	3.29	44.40	65.10	1.82	3.68
May	48.8	57.3	65.8	1.24	2.09	2.69	50.30	71.00	1.10	3.01
June	53.3	62	70.7	1.07	1.54	2.09	54.80	75.90	0.95	2.34
July	56.6	66.3	75.8	0.45	0.69	1.33	58.10	81.00	0.40	1.49
August	57	66.6	76.2	0.31	0.62	1.08	58.50	81.40	0.28	1.21
September	53.1	61.9	70.8	0.23	1.24	2.04	54.60	76.00	0.20	2.28
October	46.8	53.7	60.7	2.04	3.04	5	48.30	65.90	1.82	5.60
November	40.6	46.5	52.4	4.47	5.44	6.92	42.10	57.60	3.98	7.75
December	36	41.4	46.9	4.51	5.55	7.78	37.50	52.10	4.01	8.71

	30 Year Normals (B)						Climate Change Projections			
	Temp - min	Temp - avg	Temp - High	Precip - 25%	Precip - Avg	Precip - 75%	Low CC Project - temp Min	High CC Project - temp Max	Low CC Project - Precip Min	High CC Project - Precip Max
January	37	42.1	47.2	3.29	4.99	6.07	38.50	52.40	2.93	6.80
February	36.9	43.4	50	2.09	3.08	4.44	38.40	55.20	1.86	4.97
March	39.3	46.6	53.8	2.6	3.46	3.93	40.80	59.00	2.31	4.40
April	42.5	50.5	58.5	2.1	2.68	2.94	44.00	63.70	1.87	3.29
May	47.8	56	64.3	1.34	1.95	2.91	49.30	69.50	1.19	3.26
June	52.3	61	69.7	1.04	1.54	2.25	53.80	74.90	0.93	2.52
July	56.1	65.9	75.7	0.3	0.72	1.1	57.60	80.90	0.27	1.23
August	56.8	66.5	76.3	0.33	0.6	1.24	58.30	81.50	0.29	1.39
September	52.5	61.6	70.7	0.64	1.67	2.06	54.00	75.90	0.57	2.31
October	46.5	53.3	60.1	2.03	3.41	4.41	48.00	65.30	1.81	4.94
November	41	46.2	51.4	4.53	5.42	7.17	42.50	56.60	4.03	8.03
December	36.3	41.1	45.9	3.94	5.06	6.97	37.80	51.10	3.51	7.81

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[55] "1981-2010 Climate Normals," National Environmental Satellite, Data, and Information Service (NESDIS), U.S. Department of Commerce: National Climatic Data Center, accessed May 29, 2012, http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

UHI Determination

Through synthesizing the climate normals and current temperatures and precipitation rates, air temperatures are consistent with the 30 year climate normals. Precipitation rates are inconsistent and depend on the weather station location whether the rate is either above or below the climate normals precipitation average.

Although current temperatures are consistent with climate normals, Seattle still experiences an increased in amount of impervious surface cover compared to the rural environments. This means more heat can radiate into the atmosphere than energy radiating from the sun into the urban and natural environment.

Precipitation does cool the urban environment. With the increased potential for cooling, Seattle could potentially get cooler if development stops and energy use decreases. Unfortunately, Seattle has a large growth forecast, thus increasing density and energy use within the urban environment.

Given the amount of impervious surface cover in Seattle, urban heat island is prevalent in the urban core of Seattle. This is seen when comparing weather station temperatures within the lower impervious surface cover areas within Seattle’s city limits. With the increase temperatures due to climate change and the projected growth for the region, urban heat island in Seattle will be exacerbated over time.

EVERETT

Figure 9. Map of Everett, Google Maps

Everett, located approximately 28 miles North of Seattle, is on Port Gardner Peninsula within the Puget Sound. With a population of 103,019,[56] Everett has a small- to mid-sized historic downtown center, from Grand Avenue to Broadway and from 26th Street to Pacific Ave, consisting of 40 city blocks or 100 acres. Due to the proximity of the Snohomish River, Everett is mainly within a floodplain, consisting of mainly flat terrain with small topographical features spread throughout the city. Many of the residents live in single-family housing and commute to their jobs. Figure 9 depicts a map of Everett. Figure 10, shown on the next page, is a photograph showing the main urban core of Everett.

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[56] “Everett (city), Washington,” U.S. Census Bureau, accessed May 29, 2012, http://quickfacts.census.gov/qfd/states/53/5322640.html.

Figure 10. Photograph of Downtown Everett

Source:AJM Studios, “Everett, Washington,” *Flickr,* accessed May 29, 2012, http://www.flickr.com/photos/ajmstudios/4975763580/lightbox/.

Everett’s Urban Heat Island

Weather Stations

This section explores the urban heat island effect in Everett, a smaller urban landscape, compared to Seattle. Table 8 shows all the weather stations located within the city limits of Everett that were examined in my research.

Table 11. Everett Weather Stations Information

	Station Location	Start Year	Has All Info
1	Howarth / Harborview Park Area, N. Mukilteo / Everett, WA	2011	Y
2	Lake Stevens, Everett, WA	2010	Y
3	Cascade View, Everett, WA	2009	Y
4	Silver Lake/Kingsridge, Everett, WA	2008	Y
5	Silver Lake, Everett, WA	2003	Y

6	Silver Lake, Everett, WA	2007	Y
7	Carriage Club Estates, Everett, WA	2008	Y

Source: “Everett,” Weather Underground, accessed May 29, 2012, http://www.wunderground.com/weather-forecast/98201.

Figure 11. Everett Weather Stations

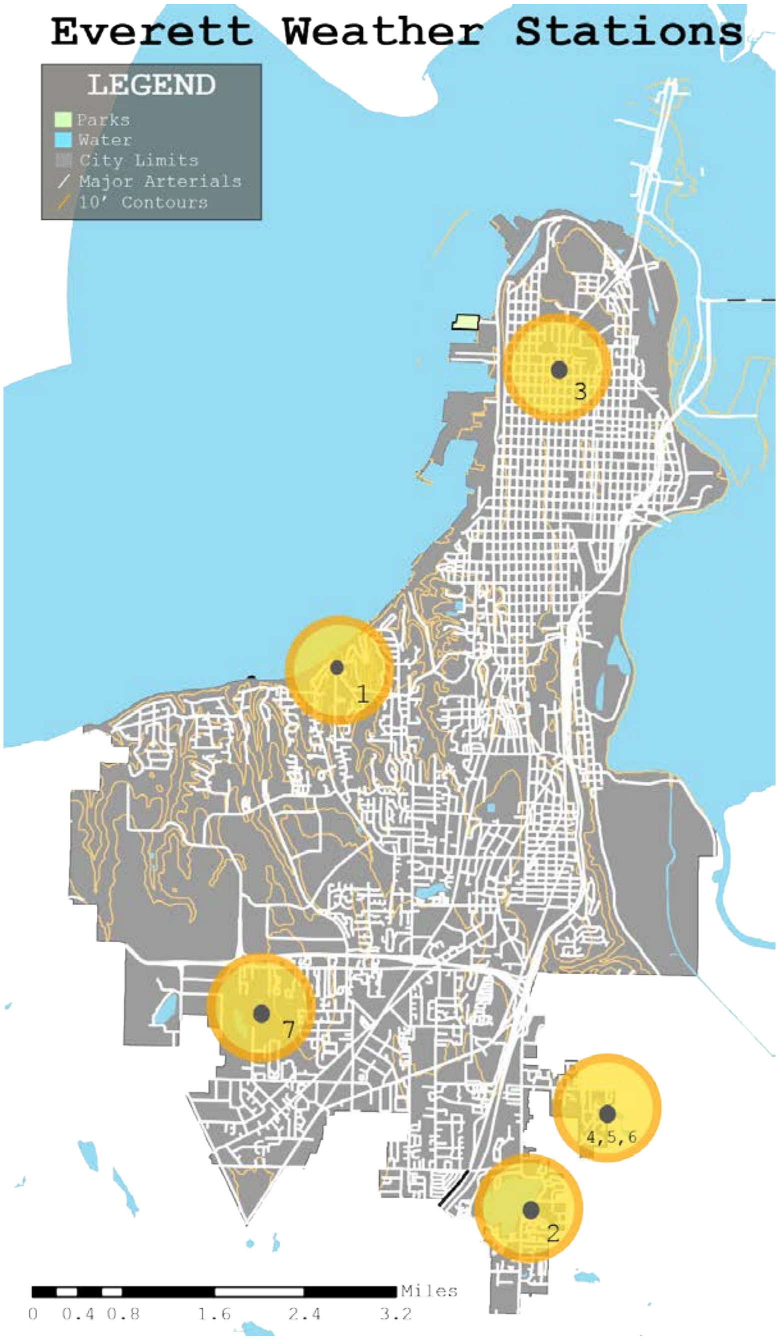
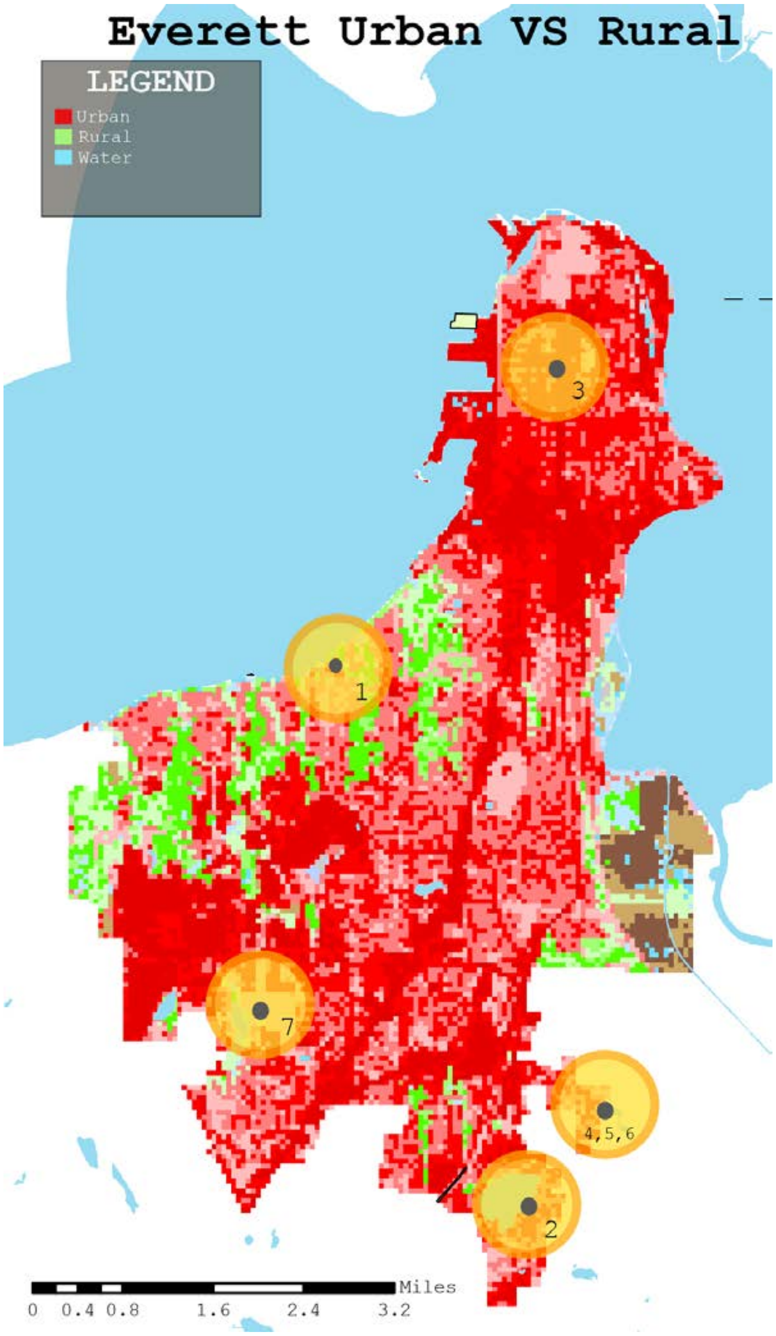


Figure 11 shows all 7 weather stations located within Everett’s city limits. The weather stations are located throughout all the different types of land use and topography seen within the ciy limits of Everett.

Figure 12, on the next page, shows the land cover exhibited in Everett. There is a large percentage of vegetative, rural land compared to Seattle. According to land coverage determined through remote sensing, Everett is approximately 73% urban land

Figure 12. Everett Urban versus Rural



cover with 27% vegetative. Urban land cover exhibits significant impervious surface cover. Building types span from mid-commercial buildings (5 to 7 stories) in the downtown and urban cores, to single-family residential throughout the city. Vegetation consists of mainly park lands and yard landscaping. Due to the moderate amount of population that lives in Everett, there is still a significant amount of buildable land for commercial and single-family housing.

Dense/Urban

Weather station 3 is located in the heart of downtown Everett, also known as the historical district of the area. Building height ranges from 3 to 10 stories, with most of the buildings being of older construction, mainly brick materiality. Temperatures within weather station 3 are consistent with those exhibited throughout Everett. Yet, precipitation rates are significantly lower.

Residential

Weather station 1 is located in the Harborview neighborhood, which is mainly residential with many parks in close proximity. The temperature data is highest at weather station 1, which may be explained by the exact location of the data meters. Even though the data ranges are higher, they are still within an appropriate range of the other weather stations data located throughout Everett. Precipitation is consistent with precipitation rates that are seen within the city limits.

Weather stations 2 and 7 are also located in strictly residential zones, with parks and water bodies in close proximity. This explains the cooler temperatures seen and the higher precipitation rates. With more vegetation and water bodies in close proximity to the weather stations, temperature readings are milder and produce a higher chance for precipitation.

Weather Stations 4, 5, and 6 are all by Lake Stevens, which is a mixed commercial, residential area with low-density population rates. The Lake Stevens area is a main urban core of Everett. All three weather stations exhibit consistent air temperature, with minimal differences. Yet, each weather station shows varied precipitation rates which can be explained through the specific micro-climate at each weather station location.

Table 12. Everett Weather Station Data, 2011

	Weather Station 1		**Weather Station 2**		**Weather Station 3**		**Weather Station 4**	
	Temp	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**
Jan	42.84	2.13	40.52	7.02	39.58	2.65	40.90	5.39
Feb	39.86	1.42	38.14	4.18	36.79	0.96	38.14	3.59
Mar	45.13	6.56	44.16	8.73	43.19	5.31	44.55	17.77
Apr	45.20	4.23	43.70	6.53	44.29	4.97	44.70	5.14
May	50.97	2.43	50.29	4.02	50.90	4.5	51.32	4.11
Jun	56.43	2.20	56.79	2.84	56.87	2.13	57.77	2.76
Jul	59.10	0.98	59.52	1.93	59.61	0.42	60.84	0.96
Aug	61.00	0.06	62.27	0.28	61.48	0.48	63.23	0.21
Sep	60.73	0.35	61.40	1.22	59.57	0	61.43	0.78
Oct	51.61	2.11	50.64	2.8	49.74	0.75	50.77	2.47
Nov	43.20	3.38	41.50	7.08	39.70	1.44	41.43	5.79
Dec	40.87	1.09	38.61	1.98	37.26	0.1	38.52	1.49

	Weather Station 5		**Weather Station 6**		**Weather Station 7**	
	Temp	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**
Jan	40.42	5.51	40.97	4.04	39.94	4.38
Feb	37.43	3.8	38.25	2.83	37.21	2.91
Mar	43.68	7.32	44.23	1.69	43.23	6.91
Apr	43.83	4.2	44.83	0.02	43.47	4.42
May	50.52	3.43	51.45	0	49.90	3.18
Jun	56.60	2.35	57.43	0	56.27	2.41
Jul	59.77	0.85	60.26	0	59.39	0.78
Aug	62.06	0.13	62.87	0.87	61.85	0
Sep	61.03	0.71	61.17	0.21	59.54	0.62
Oct	50.16	2.46	50.84	1.21	49.77	1.98
Nov	39.59	5.18	41.93	4.17	40.70	5.66
Dec	37.77	1.43	39.61	1.46	38.16	1.14

Table 12 shows a summary of Everett’s Weather Stations readings for 2011 showing the weather trends exhibited in each location. For full data tables and calculations for Everett’s Weather Stations, reference Appendix C.

Climate Change

Climate change brings added impacts to the built environment, especially in relation to urban heat island effect. With the increase in heat and the seasonal difference in precipitation, summer temperatures will become hotter while precipitation will increase in Fall and Winter months.

To see how climate change affects each weather station, I extrapolated University of Washington’s Climate Impacts Group 2040 climate change projections on the weather data for each station and the 30 year normals.

Climate Normals

As mentioned in Chapter 3, Climate Normals are 30 years of data that were gathered from NOAA’s National Climatic Data Center. Data spans from 1981 to 2010. The climate normals are used as a base comparison for all the data collected from each weather station within the Everett region. Furthermore, they have the data that was used as a basis for climate change projections. In Table 13, the climate normals are presented with the climate change projections. Each month’s 2040 climate change projection from the Climate Impacts

Group is the base data used for the temperature and precipitation graphs presented for each Weather Station in Appendix C.

UHI Determination

Due to the increased vegetation cover in Everett, the effects of urban heat island are not as significant as was seen in Seattle. This is seen through the lower temperature rates seen in the weather stations located throughout Everett compared to Seattle. Yet urban heat island effect is still prevalent within the Everett city limits. Although the water surrounding the urban landscape helps cool the environment, there is still a noted increase in air temperatures in the denser areas compared to the lower populated areas, making an urban heat island present in Everett. This is caused by the amount of impervious land cover that makes up a significant portion of Everett’s land cover, as shown earlier in Figure 12 on page 59.

When examining climate normals, current temperature, and precipitation trends within each weather station, air temperature trends are within the 30 year normals while precipitation varies per year and season. Here, it can be seen that there is a rise in precipitation rates as the annual amount of precipitation is higher.

As noted earlier, all graphs and tables for Everett are shown in Appendix C.

Table 13. Everett: 30 Year Normals and Climate Change Projections (Weather Stations A and B)[57]

	30 Year Normals (A)						Climate Change Projections			
	Temp - min	Temp - avg	Temp - High	Precip - 25%	Precip - Avg	Precip - 75%	Low CC Project - temp Min	High CC Project - temp Max	Low CC Project - Precip Min	High CC Project - Precip Max
January	34.4	41.2	48	3.44	4.69	6.65	35.90	53.20	3.06	7.45
February	34.1	42.4	50.7	1.98	3.05	4.04	35.60	55.90	1.76	4.52
March	37.2	46	54.9	2.65	3.89	4.63	38.70	60.10	2.36	5.19
April	41	50.3	59.7	2.58	2.89	3.63	42.50	64.90	2.30	4.07
May	46.1	55.7	65.2	2.18	2.6	3.4	47.60	70.40	1.94	3.81
June	51.1	60.5	69.9	1.3	1.76	3.19	52.60	75.10	1.16	3.57
July	54.4	64.5	74.6	0.52	0.9	1.71	55.90	79.80	0.46	1.92
August	54	64.7	75.5	0.38	0.98	1.82	55.50	80.70	0.34	2.04
September	48.6	59.3	70	1.04	2.01	2.63	50.10	75.20	0.93	2.95
October	42.4	51.6	60.7	2.38	3.38	5.3	43.90	65.90	2.12	5.94
November	37.6	44.8	52.1	4.19	6.06	7.29	39.10	57.30	3.73	8.16
December	33.2	39.6	46	4.01	5.62	6.79	34.70	51.20	3.57	7.60

	30 Year Normals (B)						Climate Change Projections			
	Temp - min	Temp - avg	Temp - High	Precip - 25%	Precip - Avg	Precip - 75%	Low CC Project - temp Min	High CC Project - temp Max	Low CC Project - Precip Min	High CC Project - Precip Max
January	37	41.4	45.8		4.08		38.50	51.00	3.63	4.57
February	37.2	42.8	48.4		3.33		38.70	53.60	2.96	3.73
March	39.6	45.8	52		3.37		41.10	57.20	3.00	3.77
April	42.5	49.2	55.9		2.58		44.00	61.10	2.30	2.89
May	47.2	54.4	61.7		2.28		48.70	66.90	2.03	2.55
June	51.4	58.8	66.2		2.05		52.90	71.40	1.82	2.30
July	54.6	62.7	70.8		0.95		56.10	76.00	0.85	1.06
August	55.1	63.8	72.4		1.05		56.60	77.60	0.93	1.18
September	52	59.5	67		1.7		53.50	72.20	1.51	1.90
October	45.2	51.5	57.8		3.27		46.70	63.00	2.91	3.66
November	40.4	44.8	49.3		6.14		41.90	54.50	5.46	6.88
December	35.5	39.6	43.7		5.25		37.00	48.90	4.67	5.88

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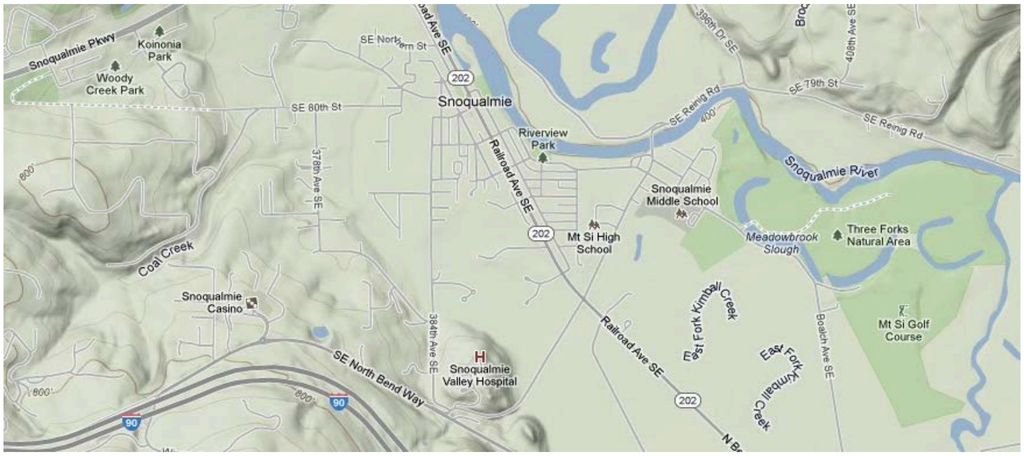
[57] “1981-2010 Climate Normals,” National Environmental Satellite, Data, and Information Service (NESDIS), U.S. Department of Commerce: National Climatic Data Center, accessed May 29, 2012, http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

SNOQUALMIE

Located in the lowland forests of King County, the city of Snoqualmie is best known for its close proximity to Snoqualmie Falls and Dam. Snoqualmie is a small city of 10,670[58] people located on the Snoqualmie River. Although small in population, it is the fastest growing city in Washington State.[59] The downtown core, 7 square city blocks, is located adjacent to the Snoqualmie River and greenway, soon to be developed into a park. Snoqualmie Ridge, separated from downtown, is also a unique urban center within the city limits, with many businesses having set-up there, like T-Mobile.[60] Figure 13 is a map of Snoqualmie showing the proximity of the city to the river. Figure 14 is a photograph of the downtown center of Snoqualmie.

Figure 13. Map of Snoqualmie, Google Maps



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[58] “Snoqualmie (city), Washington,” United States Census Bureau, accessed May 30, 2011, http://quickfacts.census.gov/qfd/states/53/5365205.html.

[59] “City of Snoqualmie: Community Profile,” City of Snoqualmie, accessed May 30, 2011, http://www.ci.snoqualmie.wa.us/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=11995&PortalId=0&TabId=273

[60] Ibid.

Figure 14. Photograph of Downtown Snoqualmie

Source: "Snoqualmie, Washington," ***Wikipedia,*** **accessed May 30, 2011, http://upload.wikimedia.org/wikipedia/commons/9/9b/Downtown_Snoqualmie_WA_01.jpg.**

Snoqualmie's Urban Heat Island

Weather Stations

Below is the table of the weather stations located within the city limits of Snoqualmie. There are only three weather stations located within Snoqualmie. Noted as Weather Station A and B in Figure 15, 2 weather stations are in close proximity of Snoqualmie's city limits that are strictly within vegetative areas. These two stations were peripherally observed to track vegetative land temperatures.

Table 14. Snoqualmie Weather Stations Information

	Station Location	Start Year	Has All Info
1	Snoqualmie, Snoqualmie, WA	2008	Y
2	Indian Hill, Snoqualmie, Snoqualmie, WA	2010	Y
3	Osprey Ct., Snoqualmie Ridge, Snoqualmie, WA	2008	Y

From: Weather Underground, Snoqualmie

Figure 15. Snoqualmie Weather Station Locations

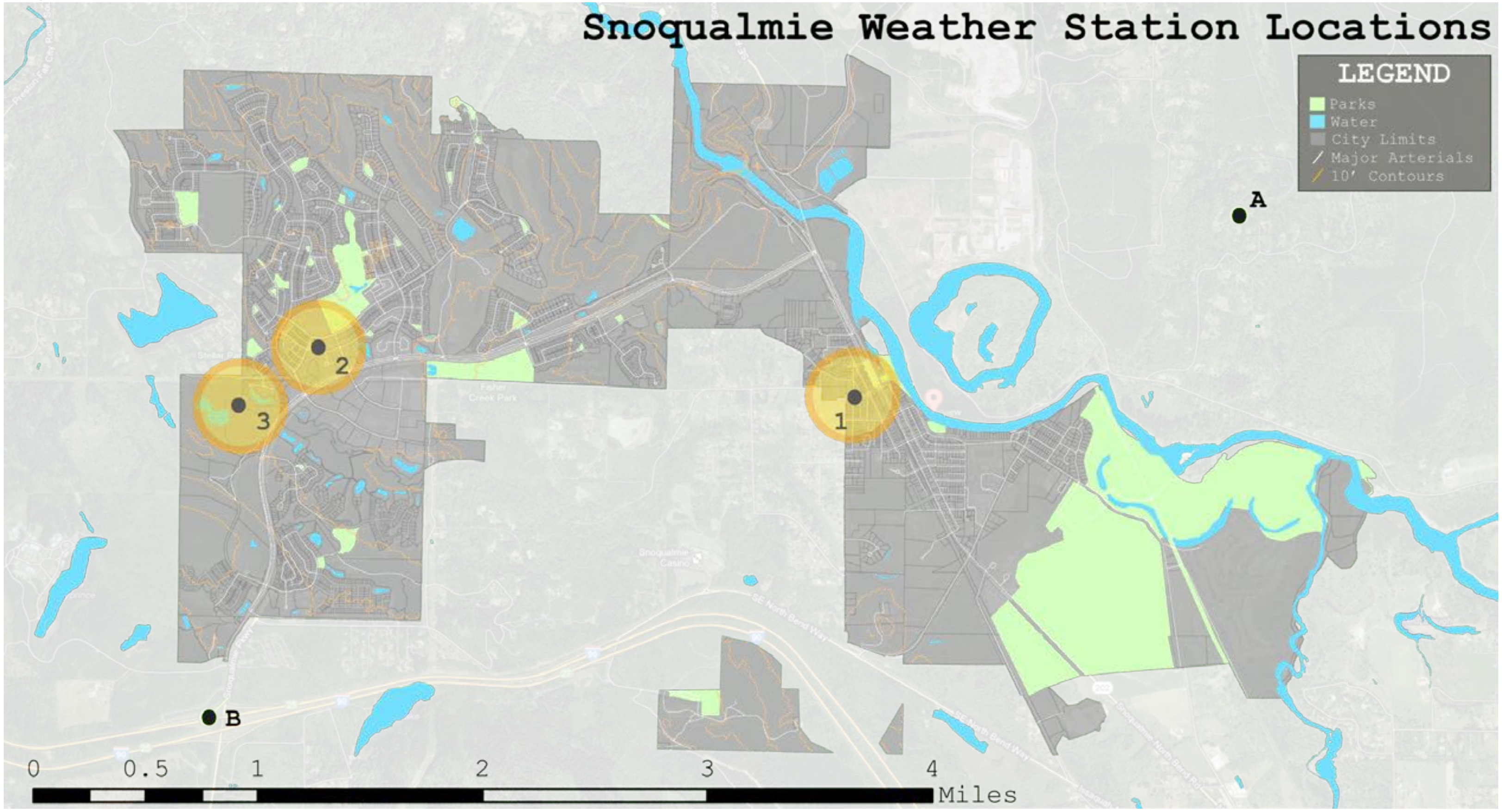

Figure 16. Snoqualmie Land Cover

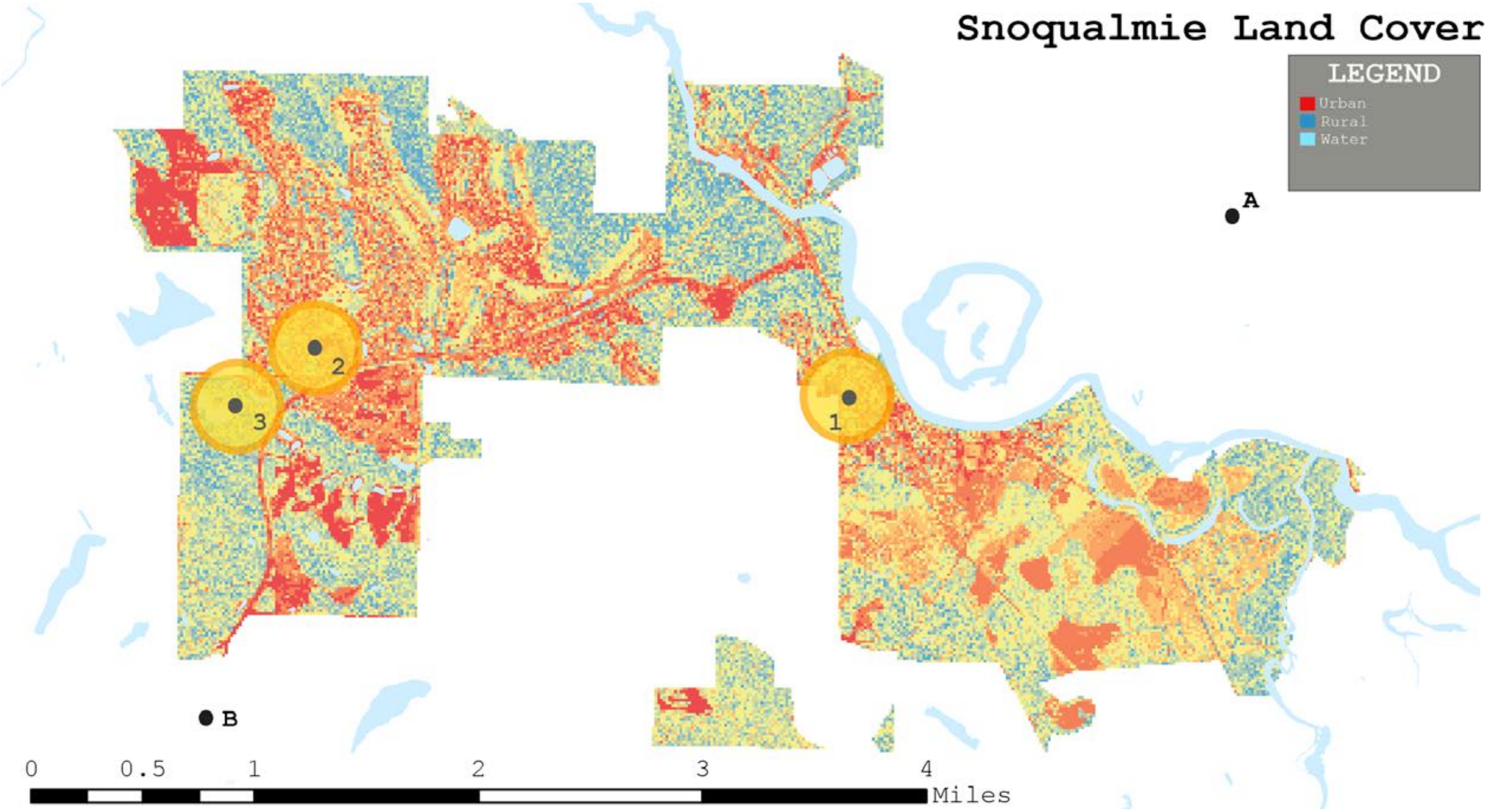

Figure 15 shows the three main weather stations located within Snoqualmie’s city limits. Through an analysis in ArcGIS (remote sensing), I have determined that 36% of the land cover is vegetative and 38% is urban. The rest cannot be determined either one way or another, and appears to be a suburban scape – with both vegetative and urban qualities. This is depicted in Figure 16.

Dense/Urban

Weather station 1 is located within the historic downtown core of Snoqualmie. Snoqualmie’s historic downtown has building heights from 1 to 3 stories. Alongside the downtown area, there is a promenade park that runs the length of the city center.

Although next to the Snoqualmie River, weather station 1 has higher temperature data than the other two weather stations within Snoqualmie’s city limits. Precipitation rates collected by weather station 1 are consistent with the other weather stations within the area.

Residential

Weather stations 2 and 3 are within the newly developed residential communities along Snoqualmie Ridge. They are apartment townhomes with retail and commercial uses mixed in. The area has significant vegetation next to three story developments. Where weather stations

2 and 3 are located, there is more development slated for single-family residential communities.

Due to the increase in vegetation land cover, temperature data is cooler than the downtown area of Snoqualmie. Dependent on the weather station, precipitation rates vary. Yet, they are consistent with climate normals.

Table 15 is a summary of the Snoqualmie weather stations data in 2011.

Table 15. Snoqualmie Weather Station Data, 2011

	Weather Station 1		**Weather Station 2**		**Weather Station 3**	
	Temp	**Prec**	**Temp**	**Prec**	**Temp**	**Prec**
Jan	40.03	10.24	40.58	10.37	39.68	12.56
Feb	36.96	5.57	37.14	5.84	36.11	7.09
Mar	43.29	9.03	43.35	11.06	42.65	12.27
Apr	43.53	6.79	42.63	8.28	42.27	9.95
May	50.55	5.18	49.39	4.7	49.10	5.48
Jun	57.47	2.60	56.13	2.71	55.87	3.23
Jul	61.19	1.03	60.52	1.15	60.13	1.41
Aug	62.55	0.14	62.77	0.32	61.97	0.42
Sep	60.50	1.94	61.83	1.89	60.50	2.26
Oct	49.97	4.98	49.97	5.06	49.26	7.55
Nov	40.53	7.76	41.37	10.28	40.37	11.85
Dec	37.45	5.36	38.32	3.91	37.03	4.66

Climate Change

Climate change brings added impacts to the built environment, especially in relation to urban heat island effect. With the increase in heat and the seasonal difference in precipitation, summer temperatures will become hotter while precipitation will increase in Fall and Winter months.

To see how climate change affects each weather station, I extrapolated University of Washington’s Climate Impacts Group 2040 climate change projections on the weather data for each station and the 30 year normals.

Climate Normals

As mentioned in Chapter 3, Climate Normals are 30 years of data that were gathered from NOAA’s National Climatic Data Center. Data spans from 1981 to 2010. The climate normals are used as a base comparison for all the data collected from each weather station within the Snoqualmie region. Furthermore, they have the data that was used to base the climate change projections off of. In Table 16, the climate normals are presented with the climate change projections. Each month’s 2040 climate change projection is the base data used for the temperature and precipitation graphs presented for each Weather Station in Appendix D.

Table 16. Snoqualmie 30 Year Normals and Climate Change Projections (Weather Station 1)[61]

	30 Year Normals						Climate Change Projections			
	Temp - min	Temp - avg	Temp - High	Precip - 25%	Precip - Avg	Precip - 75%	Low CC Project - temp Min	High CC Project -temp Max	Low CC Project -prcip Min	High CC Project - Precip Max
January	35.5	41.1	46.7	6.87	8.85	11.43	37.00	51.90	6.11	12.80
February	34.9	42.3	49.7	3.85	5.42	7.16	36.40	54.90	3.43	8.02
March	37.3	45.5	53.8	4.81	6.26	7.46	38.80	59.00	4.28	8.36
April	40.2	49.2	58.3	3.87	4.81	5.84	41.70	63.50	3.44	6.54
May	45.6	54.7	63.9	2.72	4.01	5.03	47.10	69.10	2.42	5.63
June	50.5	59.8	69	1.8	2.94	3.53	52.00	74.20	1.60	3.95
July	53.7	64.5	75.2	0.44	1.37	2.03	55.20	80.40	0.39	2.27
August	53.4	64.8	76.2	0.69	1.29	1.55	54.90	81.40	0.61	1.74
September	48.2	59.3	70.4	1.55	2.85	3.91	49.70	75.60	1.38	4.38
October	42.7	51.3	60	3.63	5.69	7.23	44.20	65.20	3.23	8.10
November	38.2	44.4	50.6	6.16	10.12	13.81	39.70	55.80	5.48	15.47
December	34.2	39.5	44.7	6.47	8.45	10.5	35.70	49.90	5.76	11.76

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[61] "1981-2010 Climate Normals," National Environmental Satellite, Data, and Information Service (NESDIS), U.S. Department of Commerce: National Climatic Data Center, accessed May 29, 2012, http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

UHI Determination

Snoqualmie is a small urban development on the outskirts of the Wenatchee forest. Due to the small amount of development, there is not a significant amount of urban heat island effect prevalent in the area. When looking at all the data presented in Appendix D, the historic downtown urban center has a slight temperature increase compared to the weather stations within the residential development areas. This is interesting due to the close proximity of the Snoqualmie River.

Annual precipitation measured in weather stations in Snoqualmie is higher than the climate norms observed by National Climate Data Center. Although weather station 1 has a lower annual precipitation rate than the other two stations, it is higher than the climate norms. This may be explained by the increase in climate change conditions.

When looking at Snoqualmie, there is an observed urban heat island when comparing the downtown area to the light residential areas of the city. Like we saw in Everett and Seattle, this is mainly due to the impervious surface cover seen within the city limits.

SUMMARY

All three case studies have urban heat island effect. This is caused by the increased impervious surface cover seen within the city limits of all three cities: Seattle, Everett, and Snoqualmie. There were limitations in calculating the energy balance for all three cities, due to the location of atmospheric reading provided by Atmospheric Radiation Measurement (ARM) Climate Research Facility. They have base numbers in which I was able to determine, dependent on land cover, whether urban heat island effect exists or not.
In Appendices B, C, and D, tables show actual temperature and precipitation readings and climate change projections for the year 2040. Due the urban heat island that occurs in all three cities, climate change will exacerbate these effects.

Additionally vegetative weather stations were peripherally explored and had observationally lower air temperatures than all three cities urban cores and impervious land cover areas.

The next chapter explores mitigation strategies planners and designers are already implementing in the built environment. I go beyond these strategies and explore the region’s natural environments to find biomimetic strategies to help jurisdictions adapt to urban heat island, especially in the face of climate change temperature increases.

CHAPTER 5: DISCUSSION

Chapter 5 explores the current mitigation strategies used to help urban heat island effect. Furthermore, I explore new innovative adaptation strategies cities can manage the increasing heat and seasonal precipitation changes that will be experienced during climate change.

CURRENT MITIGATION STRATEGIES

This section explores strategies planners and designers currently use to manage the effects of urban heat islands. They range from cooler roofing materials to increased vegetation and planting within the urban environment.

Cool Roofs

Roofs in urban and suburban environments cover approximately 20% of the built environment's land. They are typically the hottest surfaces due to closer proximity to exposure and typical materiality of roofs.[62] To create cooler roofs, two properties need to be exhibited: (1) High solar reflectance and (2) High thermal emittance – over 85%.[63]

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[62] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 46.
[63] Ibid: 48.

Higher Solar Reflectance

There are two variables that determine if a roof has higher solar reflectance: color and slope. To have a high solar reflectance means choosing materials lighter in color to easily reflect the sun’s energy. Another consideration for high solar reflectance is slope of roof. With a lower sloped roof, there is a higher solar reflectance compared to steeper roofs.[64]

Thermal Emittance

Thermal emittance is the ability for a material to radiate energy absorbed from the sun.[65] Thermal emittance depends on the roofing material. Thermal emittance of most materials are 85% or greater. The main roofing to stay away from is bare metallic material because its thermal emittance tends to be between 20% and 60%.[66]

Other Benefits

Besides reducing urban heat island effect, cool roof has other benefits. They are:

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[64] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 49.

[65] Turnbull, Peter. “What is a ‘Cool Roof?’,” Pacific Gas and Electric Company: Consortium for Energy Efficiency Workshop, created December 12, 2005, accessed May 30, 2012, http://www.cee1.org/cee/mtg/12-05_ppt/turnbull.pdf.

[66] Gartland: 49.

- Improved building comfort:

  Buildings stay cooler with cooler roofs, creating more thermal comfort within the building.[67]

- Reduced cooling energy use:

  With buildings staying thermally cooler, less energy is needed to be expended on air conditioning and other cooling devices.[68]

- Reduced building maintenance expenses:

  Maintenance coatings are applied to roofs to protect the roof structure. Hot roof coatings are applied every 10 years. Comparatively, cool roof coatings are applied ever 20 years.[69]

- Reduced peak electricity demand:

  During mid-day in summer, electricity demand is greatest. With cool roofs, less air conditioning is required. This reduces energy loads during the peak hours of energy demand.[70]

- Reduced air pollution:

  Directly and indirectly, air pollution is reduced through cool roofs. With less energy used, less direct greenhouse gas emissions will be generated. Furthermore, if there is a

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[67] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 72.
[68] Ibid.
[69] Ibid: 73.
[70] Ibid: 75.

significant amount of cool roof generated, there will be less urban heat island effect reducing the air pollution positive feedback loop created.[71]

- Reduced roofing waste to landfills:
  Cool roofing options have longer life than traditional roofs, thus reducing the amount of times roof replacements are needed in buildings.[72]

Cool Pavings

Pavements cover approximately 20% to 50% of cities land cover and tend to be the most dominant feature of the built environment. There are typically two types of pavings seen, asphalt and concrete. Both have low solar reflectance, approximately 10% and 30%, respectively. With time and high usage, both materials become dirtier and decrease in reflectivity.[73]

There are two ways in which pavements can be cooler: (1) increase in solar reflectance and (2) increase in permeability. As stated above, to increase solar reflectivity, pavements need to be lighter in

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[71] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 78.
[72] Ibid.
[73] Ibid: 50.

color. This means having lighter pigment aggregates incorporated into asphalt and concrete mixes.[74]

Permeability

Increasing permeability means to increase the amount of water allowed to drain through the pavement. Thus when it gets hotter, water will be able to evaporate over a long period of time, cooling the surrounding area. New technological advances have made it possible for asphalt and concrete to become more porous, especially through a new system called ‘open-graded.’ This means the smallest particles of sand and rock are not mixed into the concrete and asphalt mix, allowing room for more permeability. Unfortunately, it is more expensive to do this type of mix so ‘open-graded’ mixes tend to be valued engineered out of large scale projects.[75]

Yet, there are other options other than asphalt and concrete like block pavers and resin-based pavements.

- <u>Block Pavers</u>:
  They are blocks of concrete filled with soil, creating a space where vegetation can grow. They are only appropriate for

Figure 17. Block Pavers

Source: “Green Pavers,” *Pavers Plus,* accessed May 30, 2012, http://www.paverplusjax.com/turf-block.html

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[74] Ibid: 51.

[75] Gartland, Lisa. *Heat Islands: Understanding* *Areas.* London: Earthscan, 2008.

low-traffic areas because of weight restrictions.[76]

- Resin-Based Pavements:

  During the construction process for asphalt and concrete, tree resin replaces the binders that hold the pavement together. The resin is clear, so the pavements take on the coloring of the aggregate. Like block pavers, resin-based pavements cannot be used for high-traffic locations due to weight limitations. These types of pavements are typically used for trails and low-traffic sidewalks.[77]

Other Benefits

Other than reducing urban heat island effect, cooling pavement have a variety of other benefits:

- Cooler urban and suburban air temperatures:

  Hotter pavements create hotter ambient air temperature around their surfaces. Comparatively, if the pavements are cooler, the air temperature will thus decrease.[78]

- Better management of water run-off:

  If choosing porous pavements, water will then drain more natural than impervious pavements. When the urban environment is built out of impervious pavements, water has

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[76] Ibid: 52.

[77] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008.

[78] Ibid: 100.

to be re-routed into storm and sewer drains. This causes a loss of the natural cooling properties water provides.

- Increased pavement durability:
  Impervious pavements are damaged easier due to higher temperatures. High temperatures can cause rutting, shoving, aging, fatigue, and bleeding.[79] Cooler paving materials do not degrade as fast due to these factors.
- Better night-time illumination:
  Cooler paving has a higher solar reflectance. This solar reflectance also provides more efficient reflectivity of artificial light at night. This can also create greater lighting efficiencies especially in road lighting.[80]

Trees and Vegetation

Trees and vegetation are able to moderate urban heat island conditions through shading, evapotranspiration, and wind shielding.

Shading

“Leaves and branches on trees and vegetation shade the areas below them by reducing the amount of solar radiation that is transmitted through their canopy.” The amount of radiation transmitted is dependent on type of tree, but ranges from 6% to 30% in the summer

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[79] Definitions provided under the definition of asphalt.

[80] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 102.

and 10% to 80% in the winter.[81] Shading greatly reduces the temperatures of surface underneath tree and vegetation cover throughout the whole year.

Evapotranspiration

Trees and vegetation absorb water through their roots. Plants then emit water vapor through their leaves. Heat dissipates through the evaporation of the water vapor from leaves, cooling the surrounding environment.[82]

Wind Shielding

Plants, especially trees, reduce wind speeds by 20% to 80%, depending on the density of the tree canopy. Even though trees can obstruct cool summer winds, they also slow wind down. This causes less heat to be transported away from buildings and less air infiltration through windows and doors.[83]

Other Benefits

Vegetation and plants, through these three methods, create cooler urban environments. Shading, evapotranspiration, and wind shielding also provide other benefits to the urban environment other than reducing urban heat island effect:

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[81] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 110.
[82] Ibid.
[83] Ibid.

- Energy savings in buildings:

  Due to the cooling trees and vegetation provide for buildings, less air conditioning is needed. This reduces the energy load needed to operate buildings, especially in peak summer months.[84]

- Carbon dioxide reduction:

  Plants absorb carbon dioxide, a main variable within greenhouse gas (GHG) emissions, through the photosynthesis process. Carbon dioxide is sequestered within the plant for growth and emits oxygen back into the environment. This process restores the oxygen balance into the atmosphere, thus mitigating climate change.

  GHGs are also produced through the energy expenditure of buildings. Since trees and vegetation reduce the amount of energy used in buildings, they also reduce the amount of GHGs entering the atmosphere.[85]

- Reduced air pollution:

  Trees and vegetation remove pollution through the air through the absorption of gases through their leaves during the photosynthesis process. The greater the size of the trees' leaves and needles, the more air pollution is

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[84] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 111.

[85] Ibid: 112.

decreased in the urban environment. Note: dead trees do not conduct photosynthesis.[86]

- Decreased stormwater run-off:
  Soil is a permeable surface that allows water to seep in. With trees and vegetation, root systems are formed creating a network slowing water down. This gives water enough time to absorb into the ground instead of flowing into storm and sewer drains. By decreasing stormwater run-off, the potential for flooding decreases as with the number of pollutants entering into natural waterways and eventually into the ocean.[87]

Through the increased investment in cool roofs and pavements, infrastructure will radiate less heat into our urban environment. Trees and vegetative plantings will also decrease the amount of heat that reaches the atmosphere. I further explore natural systems in the next section expanding on the idea of natural tools to reduce urban heat island effect.

BIOMIMICRY

As described in chapter 2, biomimicry uses nature’s models, systems, processes, and elements to solve human problems. Through biomimicry,

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[86] Ibid.

[87] Gartland, Lisa. *Heat Islands: Understanding and Mitgating Heat in Urban Areas.* London: Earthscan, 2008: 116.

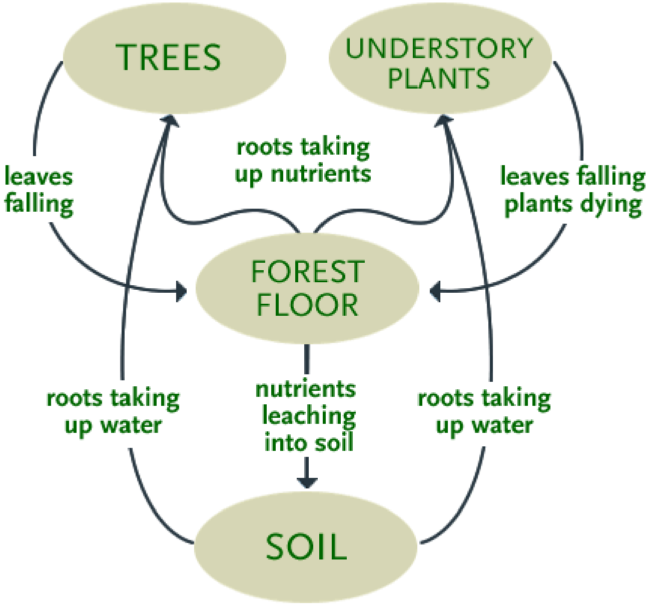
humans can learn from nature, which has been evolving for millions of years, and those lessons to solve human problems.[88] This section explores how nature would solve urban heat island effect in Seattle, Everett, and Snoqualmie at a city scale.

I focus on forest ecosystems because forest stands are seen throughout the Pacific Northwest. Each of the three cities in which the case studies were performed were once large forests filled with a variety of plant life.

Forest Ecosystems in the Pacific Northwest

Forest ecosystems are prevalent within the Pacific Northwest. Large forest stands contain a diverse amount of vegetation, life, and water. Figure 18 explains how forests are a self-perpetuating loop of four main components: trees,

Figure 18. Forest Ecosystem Diagram



Source: "Forest Ecology," ***Great Lakes Worm Watch,*** **accessed May 30 2012, http://www.nrri.umn.edu/worms/forest/ecosystems.html**

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[88] Benyus, Janine M. 2002. *Biomimicry: Innovation Inspired by Nature*. New York: Perennial.

understory plants, forest floor, and soil.

Although expressly stated in figure 18, hydrology is an important feature that both cools to the natural environment and supports life.

Below I investigate hydrologic cycles, vegetation (trees), and soil construction as key ways in which the urban environment would be able to mimic the natural environment.

Hydrology

Water is an essential part of the Earth’s natural cycle. Figure 19 shows how water is a key component keeping an ecosystem healthy. Water is an essential part of tree and plant growth. It also contributes to the precipitation and evaporation cycles that are essential to our world’s health. The cycle begins with clouds and water vapor that create precipitation. Precipitation feeds all life on Earth and cools the natural environment. As the water migrates throughout the system, water makes its way to the oceans. Throughout the hydrologic cycle, water is heated, and then evaporated by the sun’s heat, thus cooling the environment.[89]

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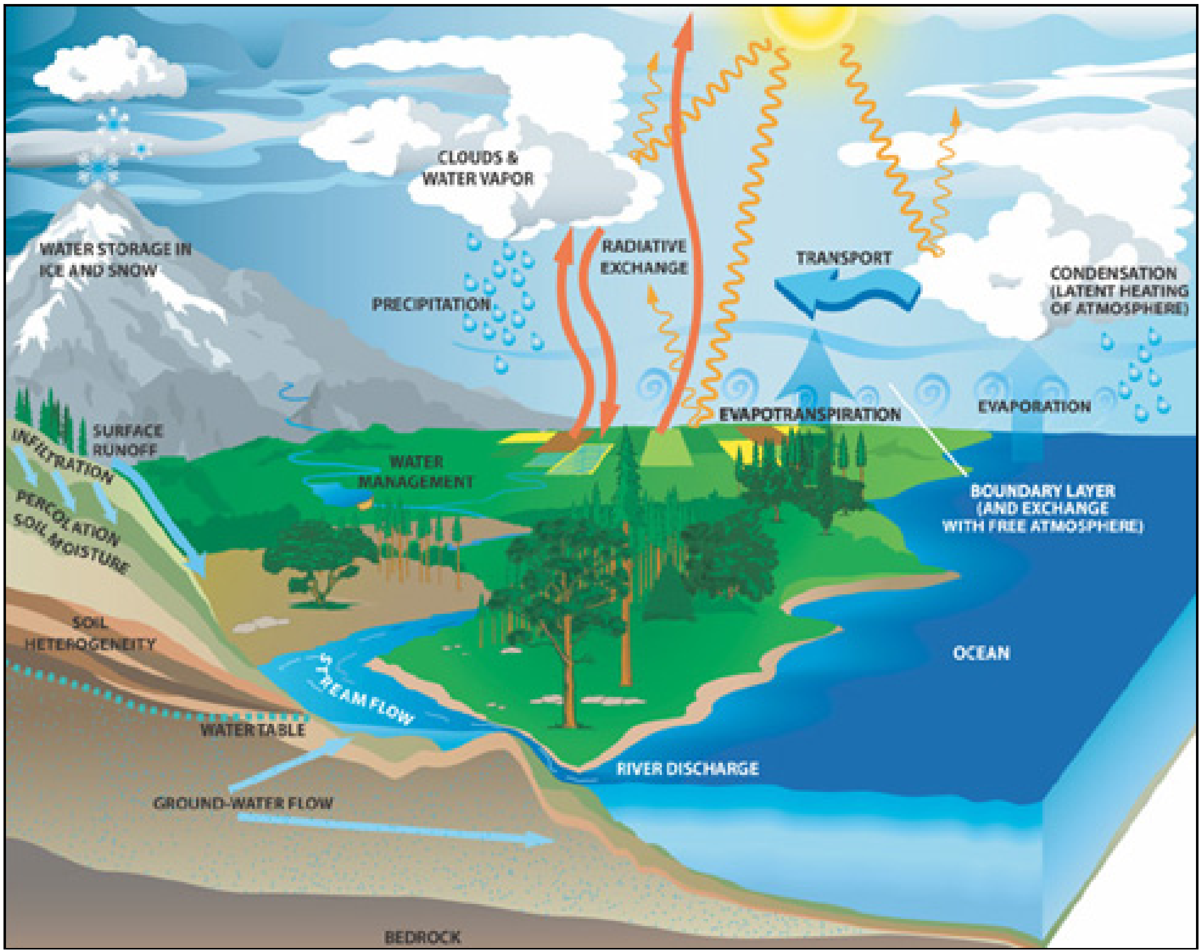
[89] “Water Cycle,” National Aeronautics and Space Administration, Earth, accessed May 30, 2012, http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle/.

Figure 19. Natural Hydrological Cycle

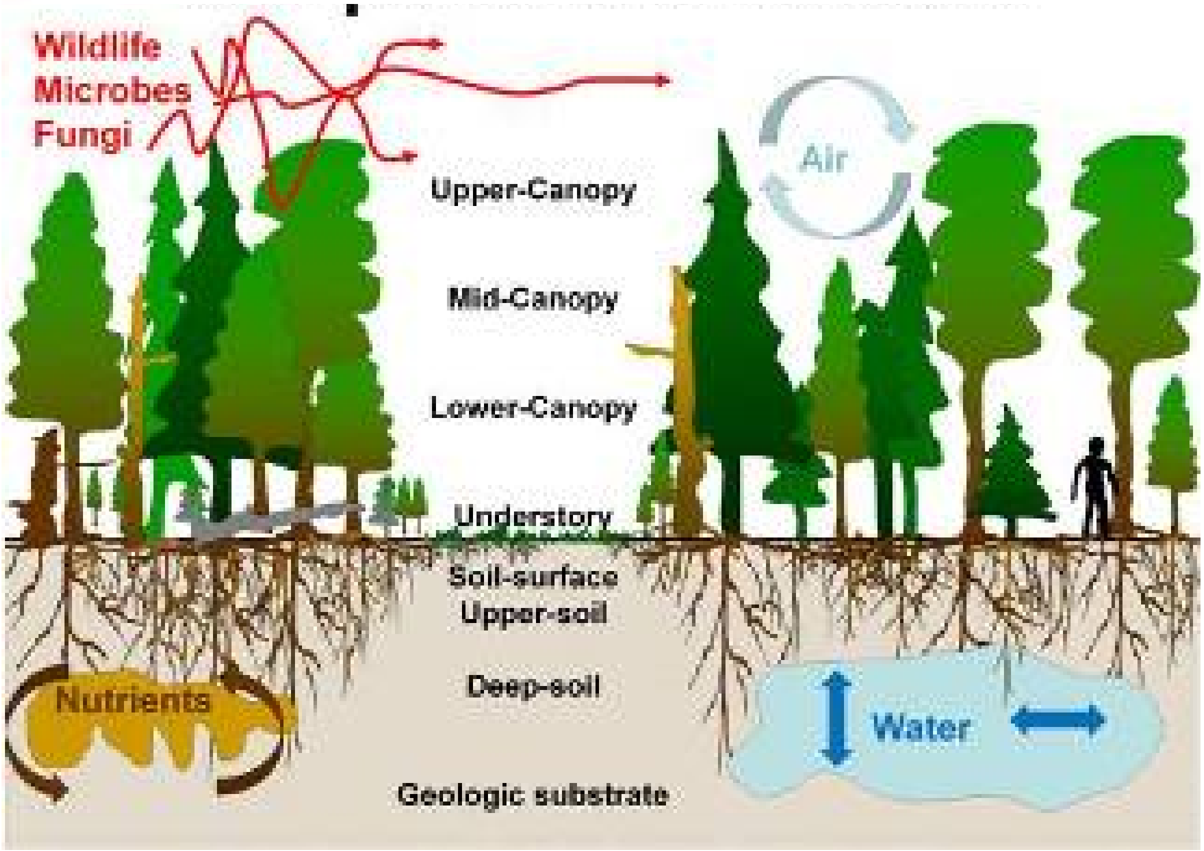


Source: “Hydrological Cycle,” National Aeronautics and Space Administration, accessed May 30, 2012, http://science.nasa.gov/media/medialibrary/2010/03/31/water_cycle.jpg.

Vegetation

In a forest, there are a variety of types of vegetation that are differentiated through location and size. Figure 20 shows the different components of a forest stand and how nutrients and water interact with the vegetative life. The upper- and mid-canopy shade the rest of the forest floor. These canopy layers absorb most of the sun's radiation, protecting the lower-canopy, understory, and soil-surface.[90]

Figure 20. Components of a Forest Stand



Source: Kolb, Peter. "Forest Ecosystems," WSU extension, accessed May 30, 2012, http://www.extension.org/pages/33599/forest-ecosystems.

Soil Permeability

A key element of ecosystem health is soil structure. Figure 21 shows how soil contains a mix of minerals, water, gases, organic matter, and micro-organisms. All these components add to the richness of

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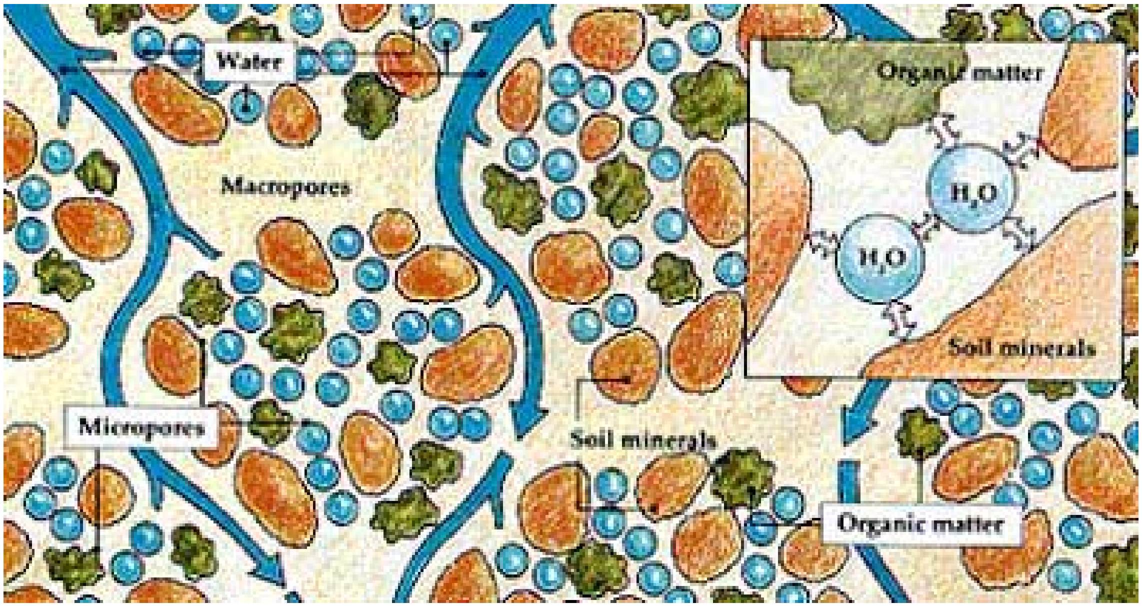
[90] Kolb, Peter. "Forest Ecosystems," WSU extension, accessed May 30, 2012, http://www.extension.org/pages/33599/forest-ecosystems.

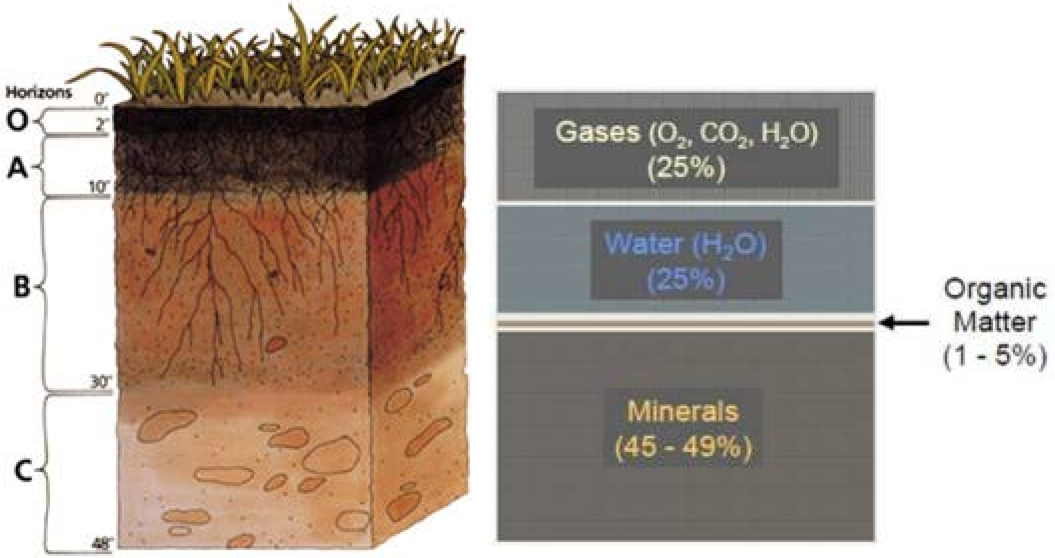
soil for vegetation health and the ability for water to permeate through to groundwater.

Figure 21. Soil Permeability



Source: DeGomez, Tom, "Basic Soil Components," Washington State University Extension, accessed May 30, 2012, http://www.extension.org/pages/54401/basic-soil-components.

Figure 22. Soil Profile



Source: Kolb, Peter, "Soils and Water Availability," WSU Extension, accessed May 30, 2012, http://www.extension.org/pages/33617/soils-and-water-availability.

Figure 22 shows the typical profile for soil make-up. Soil has a higher capacity for water depending on the amount of minerals that are present. Typical natural soil profiles have the capacity to contain 25% water, with 25% of gases (or air), the rest being a variety of minerals.[91]

Water, vegetation, and soil permeability are the three factors of Forest Ecology I examined. I believe these three components of forest ecosystems provide a useful framework to investigate biomimetic solutions on an urban scale.

Urban Adaptation

The key to biomimetic solutions is to make our urban environment act and behave as much like the natural environment as possible. This section looks at the main concepts of Forest Ecosystems within the Pacific Northwest and how the main features can be integrated into the urban landscape.

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[91] Kolb, Peter, “Soils and Water Availability,” WSU Extension, accessed May 30, 2012, http://www.extension.org/pages/33617/soils-and-water-availability.

My research performed on urban heat island effect, presented earlier, shows that water is an integral part of making cooler urban environments. There are three main lessons I can take from Forest Ecosystems that have been shown to increase water into the environment.

1. <u>Mixture of Vegetation</u>

   A mix of different species of plant life that covers the four main levels of a forest stand: Upper-canopy, Mid-canopy, Lower-canopy, and understory.

2. <u>Soil Permeability</u>

   Proper soil permeability allows approximately 25% water to infiltrate into the ground cover.

3. <u>Natural Hydrology</u>

   A natural hydrological cycle brings water to the surface through soil permeability, rivers, streams, and tissue of plant and forest materials.

All three factors listed above, create a healthy cool forest ecosystem which can easily be adapted into the urban environment.

To make the built environment more like the natural environment, planners and designers need to start to rethink how infrastructure is built and designed. Through the use of different systems, planners and designers need to bring water to the surface.
The next few sections describe different ways in which the built environment can be planned to be more like the natural environment. The main ways are through creating (1) a layer of urban forest, (2) a network of surface water, and (3) to development a more pervious surface system throughout the urban landscape.

Urban Forest

As mentioned earlier, forests have multiple layers of vegetation that help protect the understory from the sun's radiation. Plants and trees soak up the radiation, or atmospheric heat, from the air, transforming the energy into the photosynthesis process, creating cleaner air.

Increasing vegetation is already a current mitigation strategy for urban heat island effect. But urban planners need to start implementing vegetation on a larger scale throughout the urban landscape, creating forest conditions within the city. Instead of just having trees located around buildings and main street thoroughfares, planners need to develop a network of vegetation exploring all four layers of the forest canopy layers.

This strategy will not only create an understory of various plant types, but will also create a habitat that will promote animal life and nutrient system that will create a rich soil structure. Urban forests will help with shading buildings and pavements, reducing pollution, and absorbing heat from the atmosphere. Through the variety of plant life in an urban forest, vegetation will become more resilient.

To be able to adapt the urban environment to facilitate an urban forest, lands will need to be made available to house more vegetation. This may be done by reducing street size and increasing park lands especially in dense urban areas.

Urban Water Network

For an open water network to capture, hold, and use the water to cool the environment, a variety of surface layers need to be overlapped to create a more holistic use of urban water. This means urban surfaces need to be more permeable and have a vegetation understory around the water system for successful urban forest ecosystem.

Like urban forests, to create an urban water network there would need to be a lot of change in how we design and implement current infrastructure. To bring water to surface through streams and rivers, jurisdictions will need to give up valuable lands to create forested areas where water ways can move through the urban landscape.

Pervious Surface System

Already being developed by engineers, permeable surface covers are starting to become implemented, allowing water to permeate into the ground. Most research done is oriented toward replacing concrete and asphalt with more permeable materials.[92] Yet, these materials are not fully realized because they cannot handle high volume traffic or

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[92] Gartland, Lisa. *Heat Islands: Understanding and Mitigating Heat in Urban Areas.* London: Earthscan, 2008.

larger weights. With more time, these hard surfaces should be able to manage weight.

Urban environments not only have concrete and asphalt but also large amounts of sod. This is grass over hard non-nutrient saturated soil. This type of land cover is not the most efficient way to allow water into the ground and soil structure.

Planners are beginning to design with Low Impact Development, or LID. LID takes current lands, usually sod, and turns them into a more natural scape that will clean surface water and also allow water to naturally infiltrate into the ground. LID strategies are already being implemented throughout the Pacific Northwest, especially in Seattle and Snoqualmie.[93]

Most jurisdictions within the Pacific Northwest are already seeing the importance of using permeable surface cover within urban centers. These strategies not only create a more natural environment

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[93] “Transportation, Low Impact Development,” King County, accessed May 30, 2012, http://www.kingcounty.gov/transportation/kcdot/Roads/Environment/LowImpactDevelopment_MilitaryRd/AboutLID.aspx.

mitigating urban heat island and other known problems, but also save money on infrastructure maintenance and replacement.

SUMMARY

It is key to have all three biomimetic strategies implemented together. One will not be successful without the other. Forest ecosystems work as a network of multiple networks all working to create a holistic, healthy system. But this is also true for all the current mitigation strategies that are being used already.

There will not be just one answer that will mitigate urban heat islands in the Pacific Northwest. By using multiple mitigation and adaptation strategies, cities will be able to reduce urban heat island effect and adapt to the increase in heat as climate change becomes more prevalent throughout the world.

CHAPTER 6: CONCLUSION

Urban heat island is prevalent throughout the United States and also the Pacific Northwest. The three cities studied in my research, Seattle, Everett, and Snoqualmie, all have urban heat island conditions, slight to large. There were higher levels of heat outputted in the denser urban environments.

Water bodies have a significant influence on the ambient air temperature. If a water body is in close proximity to a dense urban environment, there is a greater chance for lower air temperatures than the urban spaces not apart from water bodies. This was seen through all the case studies.

Case Study Findings

Seattle

Seattle experienced some of the hottest temperatures among the two cities studied. The weather station located in the densest area experienced some of the lowest air temperatures, which can be explained through close proximity to the Puget Sound.

The other urban center weather stations experienced greater air temperatures than the rest of Seattle, showing urban heat island effect is currently experienced in the area.

Everett

Everett, although not as severe as Seattle, still exhibits urban heat island effect. There is more vegetative surface cover so the effects are not as extreme. Yet, in the downtown urban core there is still a significant increase in air temperature seen.

Snoqualmie

Snoqualmie is an interesting case because the only dense urban space was in close proximity to a water body. Interestingly, Snoqualmie historical downtown had the highest air temperatures within the city limits due to the amount of impermeable surface cover. The other two weather stations are located in residential developments on the edge of the Winatchee forest, causing a great decrease in air temperatures.

Mitigation and Adaptation

Current mitigation strategies have seen a lot of success in reducing urban heat island conditions. These strategies work best when implemented together. There will not be just one solution to stop the effects of urban heat islands. Mitigation is supposed to alleviate the reasons for urban heat islands.

Adaptation is meant to allow cities to live with the conditions of urban heat island. Because of climate change, cities will, no matter what, experience increased heat in urban environments throughout the world. To create a resilient city, adaptation strategies need to mimic nature’s solutions. One reason is because nature has been evolving for centuries and millennia, creating the most resilient system on earth. Furthermore, nature’s solutions are more efficient than man-made infrastructure.

Due to the location of Seattle, Everett, and Snoqualmie, I looked at Pacific Northwest Ecosystems; specifically forest stands to address urban heat island effects. Again the three main strategies I compiled would work best through collaboration with each other. There will not be just one large solution to urban heat island effect and climate change.

Through my biomimetic research, I found the three best strategies that cities need to start planning and designing for are:

1. Urban Forest
2. Urban Water Network
3. Pervious Surface System.

Future Research

There are multiple ways in which we could expand research on urban heat island adaptable solutions for the urban environment.

Urban Heat Islands

To expand research, I would further investigate the micro-climate dynamics urban heat islands in Seattle, Everett, and Snoqualmie. I would also investigate and examine weather stations located within expansive vegetative areas to show how the natural climate would be.

Furthermore, in the next year, all weather stations will have more data in which we would be able to analyze. This would give us a better idea what the urban heat island condition is throughout the exact of the city’s boundaries.

Biomimetics

The next step in looking at biomimetics, as an adaptation solution for climate change and urban heat island effects, is looking closely at the biological structure of forest ecosystems. This will give planners and designers a place to start to figure out the actual mechanics in which to implement these biomimetic strategies.

Furthermore, feasibility studies will need to be created to see if there would be a potential for cities to create urban forests, urban water networks, and permeable surfaces within the already built environment. Most likely a plan would need to be developed in phases creating a system in which cities will be able to slowly transform built features to resemble or mimic a resilient forest.

SUMMARY

Urban heat islands are an interesting phenomena that effect most cities within the United States. Urban heat island needs to be examined due to the health ramifications it can create if the conditions become too bad. Furthermore, climate change will further exacerbate urban heat island.

By implementing a variety of mitigation and adaptation strategies, urban heat island should be able to be controlled enough to lessen the negative effects.

Glossary

A

Air Temperature:

A measure of how hot or cold the air is. It is the most commonly used weather parameter.

Anthropogenic Heat:

‘Man-made’ heat generated by buildings, machinery, or people.

Asphalt Ageing:

Brittle and stiff asphalt caused through increasing age.

Asphalt Bleeding:

The asphalt binder material accumulates at the pavement surface.

Asphalt Fatigue:

Gradual pavement cracking.

Asphalt Rutting:

Channels caused by car tires from the pavement.

Asphalt Shoving:

Asphalt pushed in the direction of motion when heavy breaking occurs.

Atmospheric Radiation:

Heat emitted by particles in the atmosphere: water vapor, clouds, pollution, dust, etc.

B

Biophilia:

The suggestion that there is an instinctive bond between human beings and other living systems.

Biomimicry:

A design discipline that seeks sustainable solutions by emulating nature’s time-tested patterns and strategies.

Buildings:

Any human made structure use or intended for supporting or sheltering any use or continuous occupancy.

Building Height:

A buildings vertical distance.

Building Materiality:

The materials or substances in the medium of a building.

C

Cloud Cover:

Refers to the fraction of the sky obscured by clouds when observed from a particular location.

Convection:

Energy transferred from a solid surface to a fluid.

Cosmic Rays:

Fast moving particles which come from space, and release electric charge in the atmosphere.[94]

D

Density:

Number of people per square mile.

Dew Point:

The temperature at which water vapor in a volume of humid air at a constant barometric pressure will condense into liquid water.

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[94] Royal Academy “Considers of climate change.” Real footnote in chapter 2, table 4.

E

Ecosystem:

A system involving the interactions between a community of living organisms in a particular area and its nonliving environment.

Energy Balance:

Equation: Convection + Evaporation + Heat Storage = Anthropogenic Heat + Net Radiation

Energy Consumption:

Energy use in the operations of a building. This can include energy consumed for heating, air conditioning, personal computer use, etc.

Evaporation:

Energy transferred away from the Earth’s surface by water vapor.

Evapotranspiration:

Removes heat from the air through the evaporation of the water vapor.

G

Geography:

The science that studies the lands features, inhabitants, and Earth’s phenomena.

H

Heat Storage:

Dependent on properties of materials: (1) thermal conductivity and (2) heat capacity.

Humidity:

The amount of water vapor in the air.

I

Impervious Pavement:

Pavings that do not permitting penetration or passage, especially of water or air.

Incoming Solar:

Amount of energy radiating from the sun.

L

Land Use:

The human use of land. It involves the management and modification of the natural environment or wilderness into the built environment.

N

Net Radiation:

Equation: Net radiation = Incoming Solar – Reflected Solar + Atmospheric Radiation – Surface Radiation

P

Permeable Pavement:

Pavings that allows for the movement or passage, especially of water or air.

Pollution:

The introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem.

Population:

All people who live in the same geographical area.

Precipitation:

Any product of condensation of atmospheric water vapor that falls under gravity.

R

Reflected Solar:

Amount of solar energy that bounces off a surface, based on the solar reflectance.

Reflectivity:

The ratio of the energy of a wave reflected from a surface to the energy possessed by the wave striking the surface.

S

Solar Radiation:

Radiant energy emitted by the sun, particularly electromagnetic energy.

Surface Radiation:

Heat radiated from a surface itself.

T

Thermal Comfort:

State of mind in humans that expresses satisfaction with the surrounding environment.

Thermal Emittance:

The radiant emittance of heat.

Topography:

The study of surface shape and features of the Earth.

U

Urban Heat Island:

A reverse oasis, where cities air and surface temperatures are hotter than their rural surroundings.

V

Vegetation:

All plants or plant life of a place, taken as a whole.

W

Wind Speed:

The velocity of wind. It affects weather forecasting, growth and metabolism rate of many plant species, and countless other implications.

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Appendix A: Climate Change Scenarios

Greenhouse Gas Emission Scenarios

As part of the global effort to quantify future changes in climate, the Intergovernmental Panel on Climate Change (IPCC) has developed different scenarios of change in greenhouse gas and sulfate aerosol emissions for use in global climate modeling efforts. These scenarios are grouped in four categories, or storylines, based on different assumptions about demographic, social, economic, technological, and environmental change.

The CIG chose two scenario families for its most recent update of the Pacific Northwest climate change scenarios:

- **A1 Scenario Family.** The A1 scenario family assumes very high economic growth, global population peaking mid-century and then declining, and energy needs being met by a balance of fossil fuels and alternative technologies. A1B (a subset of the A1 family) lies near the high end of the spectrum for future greenhouse gas emissions, particularly through mid-century. A1B projects a future where technology is shared between developed and developing nations in order to reduce regional economic disparities.

- **B1 Scenario Family.** The B1 scenario family lies near the lower limit of projected changes in greenhouse gas emissions. The B1

> scenario assumes global population growth peaks by mid-century and then declines, a rapid economic shift towards service and information economies, and the introduction of clean and resource-efficient technologies.

Copied From: “Climate Scenarios and Models Used for Developing the 2008 Pacific Northwest Climate Change Scenarios,” The Climate Impacts Group, accessed May 30, 2012, http://cses.washington.edu/cig/fpt/climatemodels08.shtml#ghgscenarios.

Appendix B: Seattle UHI Tables and Graphs

WEATHER STATION 1:

Figure 23. Seattle Temperature and 2040 Projections - Weather Station 1, 2011

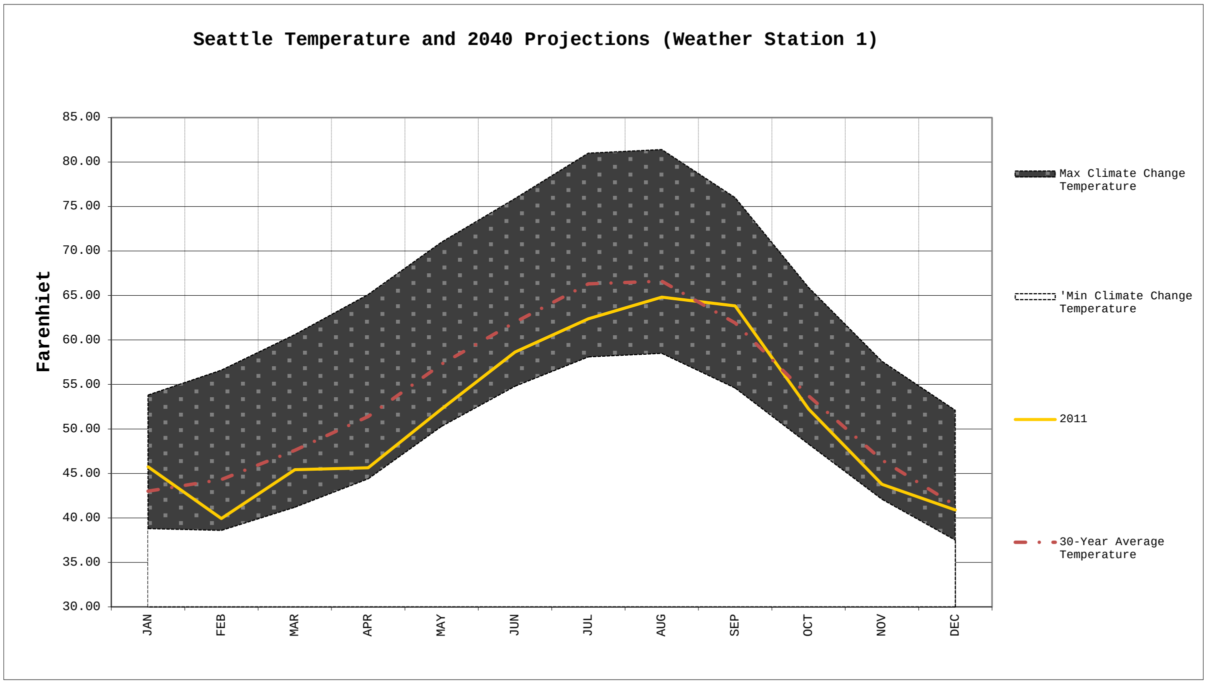


Figure 24. Seattle Precipitation and 2040 Projections - Weather Station 1, 2011

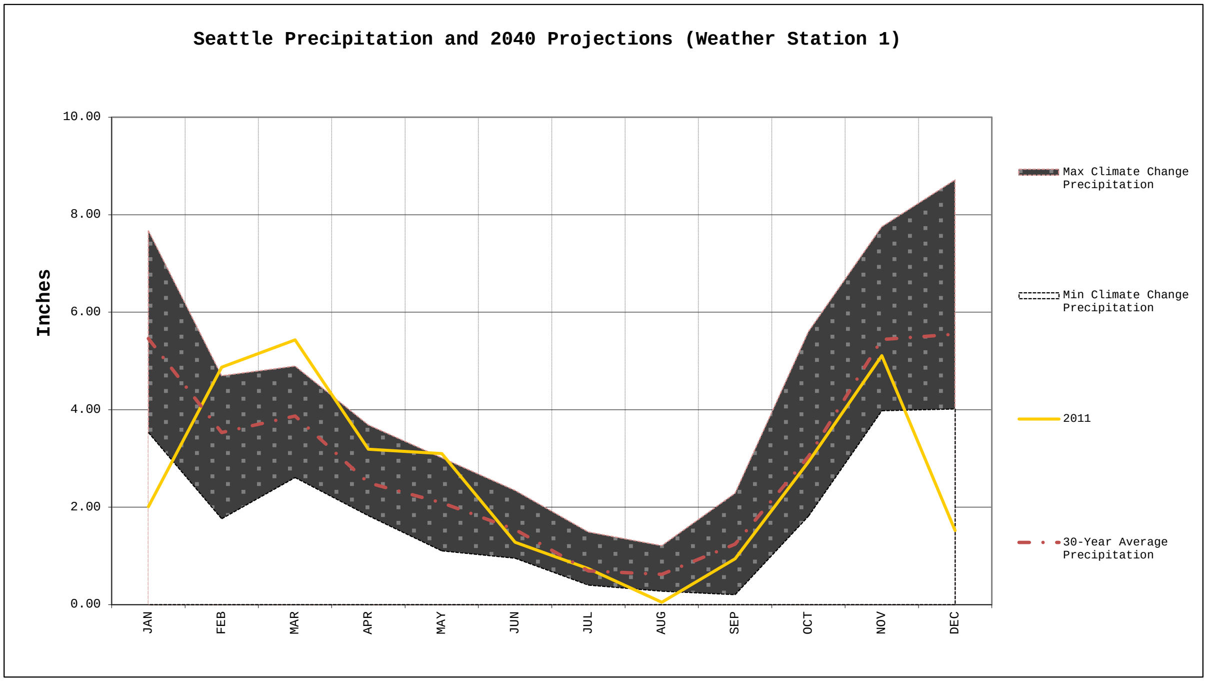


Table 17. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections – Weather Station 1, 2011

		Weather Station 1		**Climate Change Projections**			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2011	January	46	2.01	47.24	50.94	1.79	2.25
	February	40	4.87	41.43	45.13	4.33	5.45
	March	45	5.43	46.92	50.62	4.83	6.08
	April	46	3.19	47.13	50.83	2.84	3.57
	May	52	3.10	53.76	57.46	2.76	3.47
	June	59	1.28	60.13	63.83	1.14	1.43
	July	62	0.74	63.89	67.59	0.66	0.83
	August	65	0.05	66.31	70.01	0.04	0.06
	September	64	0.94	65.33	69.03	0.84	1.05
	October	52	2.93	53.73	57.43	2.61	3.28
	November	44	5.11	45.27	48.97	4.55	5.72
	December	41	1.52	42.40	46.10	1.35	1.70

WEATHER STATION 2:

Figure 25. Seattle Temperature and 2040 Projections - Weather Station 2, 2009 - 2011

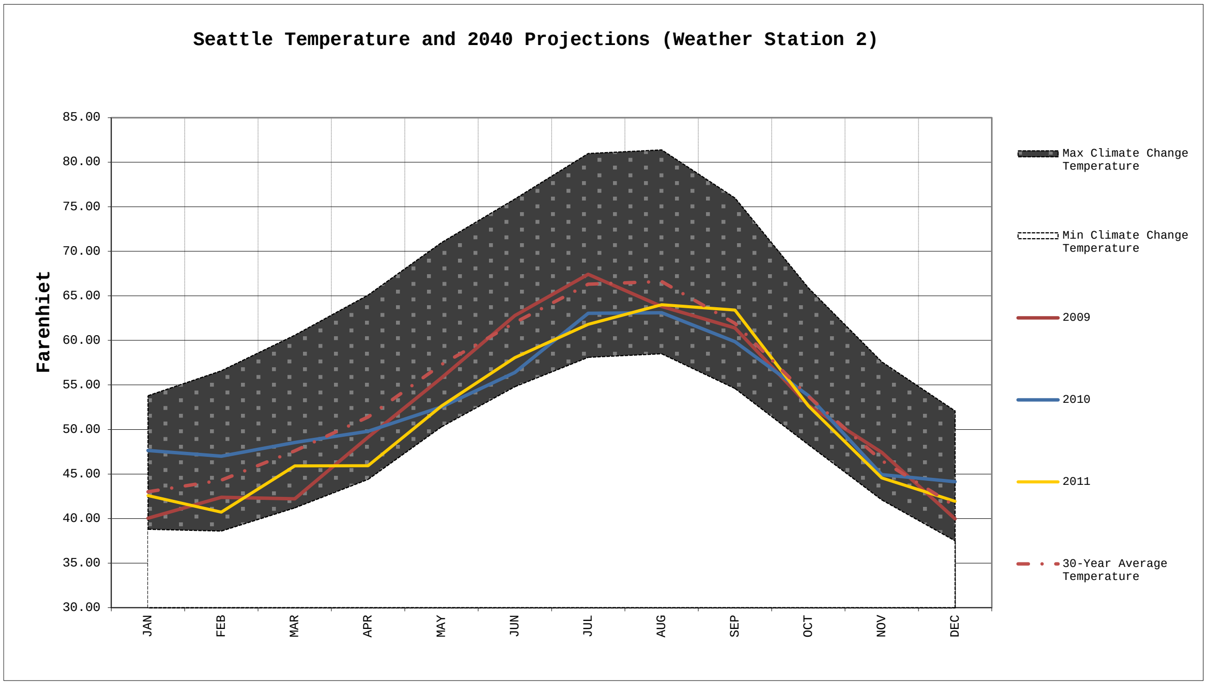


Figure 26. Seattle Precipitation and 2040 Projections - Weather Station 2, 2009 - 2011

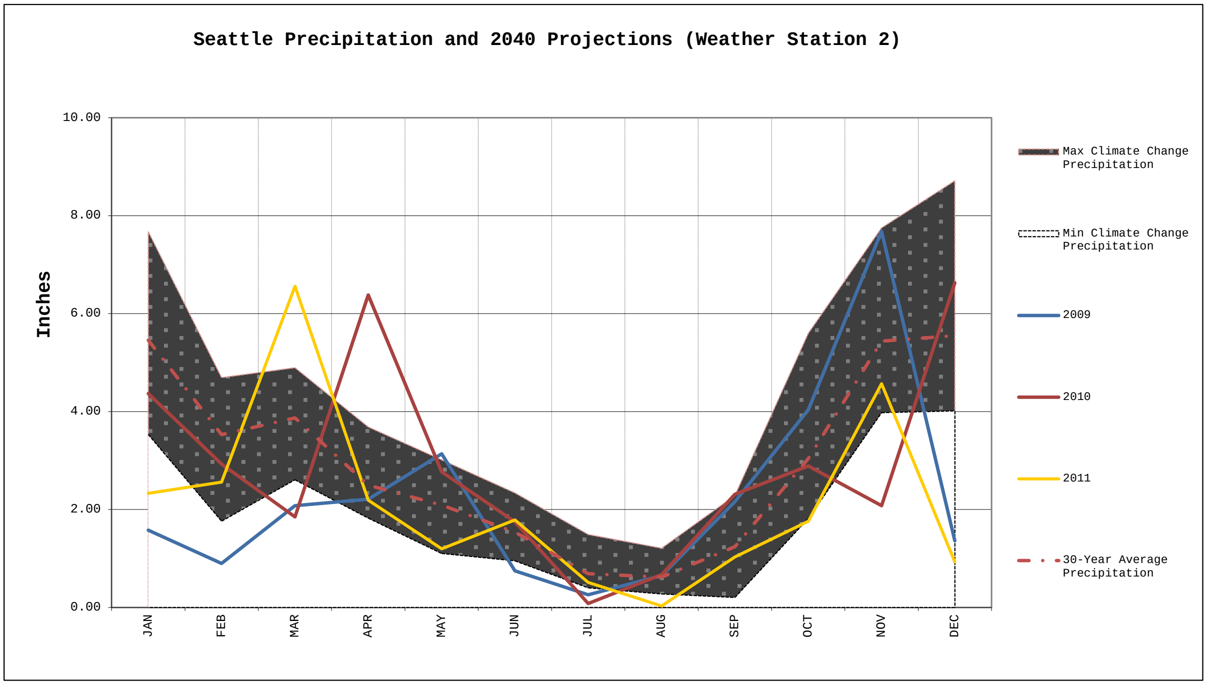


Table 18. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 2, 2009 - 2011

		Weather Station 2		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2009	January	40	1.58	41.53	45.23	1.41	1.77
	February	42	0.90	43.89	47.59	0.80	1.01
	March	42	2.08	43.73	47.43	1.85	2.33
	April	49	2.21	50.63	54.33	1.97	2.48
	May	56	3.14	57.31	61.01	2.79	3.52
	June	63	0.75	64.29	67.99	0.67	0.84
	July	67	0.26	68.92	72.62	0.23	0.29
	August	64	0.65	65.31	69.01	0.58	0.73
	September	61	2.16	62.90	66.60	1.92	2.42
	October	53	4.04	54.21	57.91	3.60	4.52
	November	47	7.68	48.93	52.63	6.84	8.60
	December	40	1.36	41.47	45.17	1.21	1.52
2010	January	48	4.37	49.15	52.85	3.89	4.89
	February	47	2.93	48.50	52.20	2.61	3.28
	March	49	1.85	50.03	53.73	1.65	2.07
	April	50	6.38	51.30	55.00	5.68	7.15
	May	53	2.77	54.03	57.73	2.47	3.10
	June	56	1.75	57.89	61.59	1.56	1.96
	July	63	0.08	64.53	68.23	0.07	0.09
	August	63	0.67	64.60	68.30	0.60	0.75
	September	60	2.31	61.36	65.06	2.06	2.59
	October	54	2.89	55.30	59.00	2.57	3.24
	November	45	2.08	46.43	50.13	1.85	2.33
	December	44	6.63	45.63	49.33	5.90	7.43
2011	January	43	2.33	44.08	47.78	2.07	2.61
	February	41	2.56	42.21	45.91	2.28	2.87
	March	46	6.56	47.40	51.10	5.84	7.35
	April	46	2.19	47.43	51.13	1.95	2.45
	May	53	1.20	54.15	57.85	1.07	1.34
	June	58	1.79	59.57	63.27	1.59	2.00
	July	62	0.51	63.31	67.01	0.45	0.57
	August	64	0.03	65.50	69.20	0.03	0.03
	September	63	1.03	64.90	68.60	0.92	1.15
	October	53	1.76	54.15	57.85	1.57	1.97
	November	45	4.57	46.07	49.77	4.07	5.12
	December	42	0.93	43.44	47.14	0.83	1.04

WEATHER STATION 3:

Figure 27. Seattle Temperature and 2040 Projections - Weather Station 3, 2008 - 2011

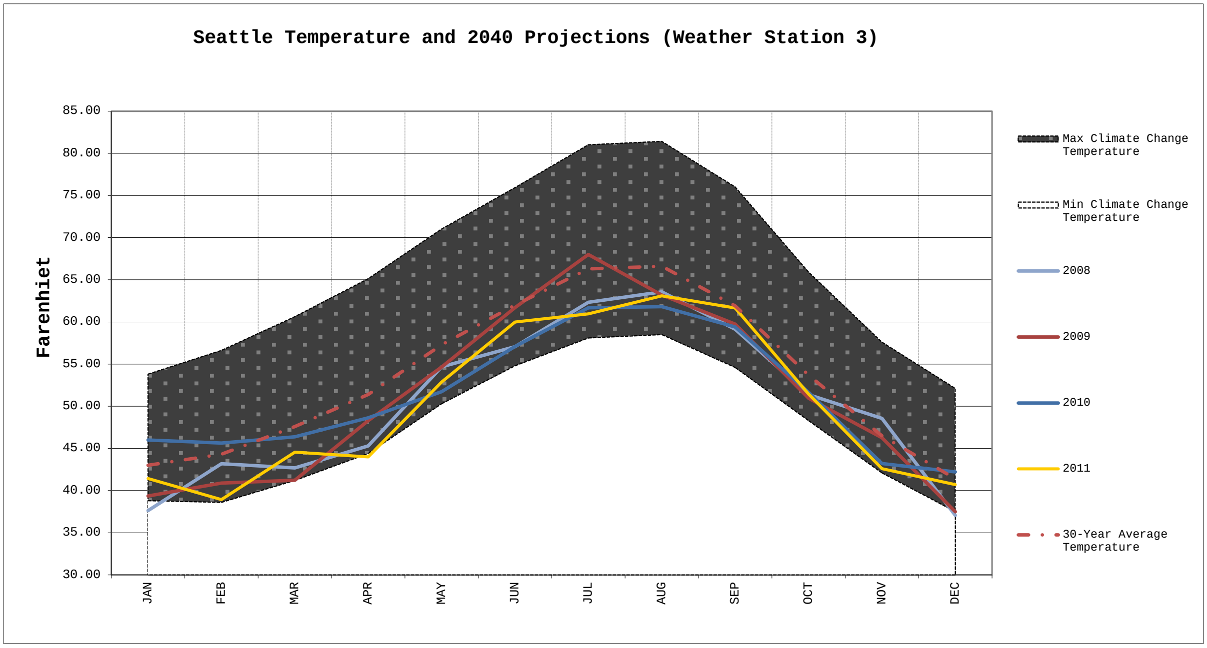


Figure 28. Seattle Precipitation and 2040 Projections - Weather Station 3, 2008 - 2011

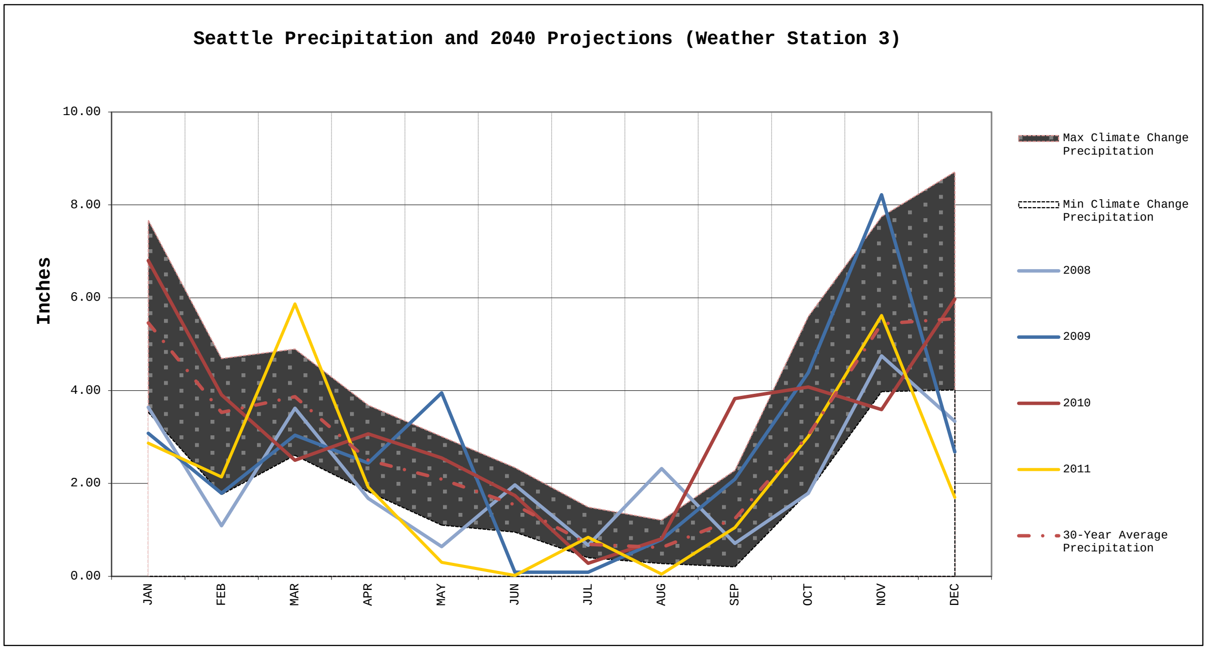


Table 19. Seatte Temperature and Precipitation Numbers and 2040 Climate Change Projections – Weather Station 3, 2008 - 2011

		Weather Station 3		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2008	January	38	3.64	39.13	42.83	3.24	4.08
	February	43	1.09	44.67	48.37	0.97	1.22
	March	43	3.62	44.18	47.88	3.22	4.05
	April	45	1.68	46.80	50.50	1.50	1.88
	May	55	0.64	56.18	59.88	0.57	0.72
	June	57	1.97	58.57	62.27	1.75	2.21
	July	62	0.67	63.82	67.52	0.60	0.75
	August	64	2.32	65.08	68.78	2.06	2.60
	September	59	0.71	60.63	64.33	0.63	0.80
	October	51	1.79	52.88	56.58	1.59	2.00
	November	49	4.75	50.07	53.77	4.23	5.32
	December	37	3.34	38.57	42.27	2.97	3.74
2009	January	39	3.08	40.85	44.55	2.74	3.45
	February	41	1.79	42.39	46.09	1.59	2.00
	March	41	3.04	42.73	46.43	2.71	3.40
	April	48	2.44	49.80	53.50	2.17	2.73
	May	55	3.95	56.17	59.87	3.52	4.42
	June	62	0.09	63.20	66.90	0.08	0.10
	July	68	0.09	69.50	73.20	0.08	0.10
	August	63	0.79	64.69	68.39	0.70	0.88
	September	60	2.09	61.23	64.93	1.86	2.34
	October	51	4.39	52.44	56.14	3.91	4.92
	November	46	8.22	47.77	51.47	7.32	9.21
	December	37	2.68	38.98	42.68	2.39	3.00
2010	January	46	6.80	47.50	51.20	6.05	7.62
	February	46	3.91	47.14	50.84	3.48	4.38
	March	46	2.50	47.89	51.59	2.23	2.80
	April	49	3.07	50.13	53.83	2.73	3.44
	May	52	2.55	53.24	56.94	2.27	2.86
	June	57	1.74	58.60	62.30	1.55	1.95
	July	62	0.28	63.18	66.88	0.25	0.31
	August	62	0.81	63.31	67.01	0.72	0.91
	September	59	3.83	60.90	64.60	3.41	4.29
	October	52	4.08	53.15	56.85	3.63	4.57
	November	43	3.59	44.70	48.40	3.20	4.02
	December	42	5.97	43.73	47.43	5.31	6.69
2011	January	41	2.87	42.92	46.62	2.55	3.21
	February	39	2.14	40.43	44.13	1.90	2.40
	March	45	5.87	46.05	49.75	5.22	6.57
	April	44	1.92	45.50	49.20	1.71	2.15
	May	53	0.30	54.38	58.08	0.27	0.34
	June	60	0.02	61.50	65.20	0.02	0.02
	July	61	0.84	62.47	66.17	0.75	0.94
	August	63	0.05	64.60	68.30	0.04	0.06

	September	62	1.05	63.17	66.87	0.93	1.18
	October	51	3.01	52.94	56.64	2.68	3.37
	November	43	5.62	44.10	47.80	5.00	6.29
	December	41	1.70	42.20	45.90	1.51	1.90

WEATHER STATION 4:

Figure 29. Seattle Temperature and 2040 Projections - Weather Station 4, 2011

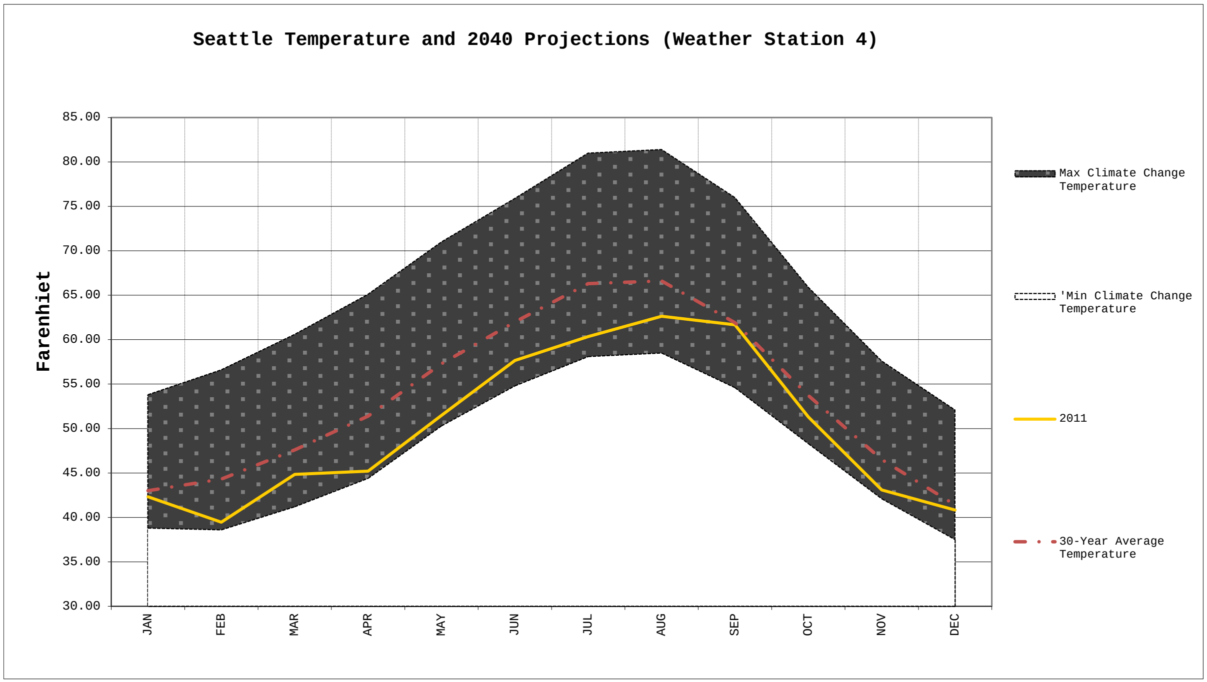


Figure 30. Seattle Precipitation and 2040 Projections - Weather Station 4, 2011

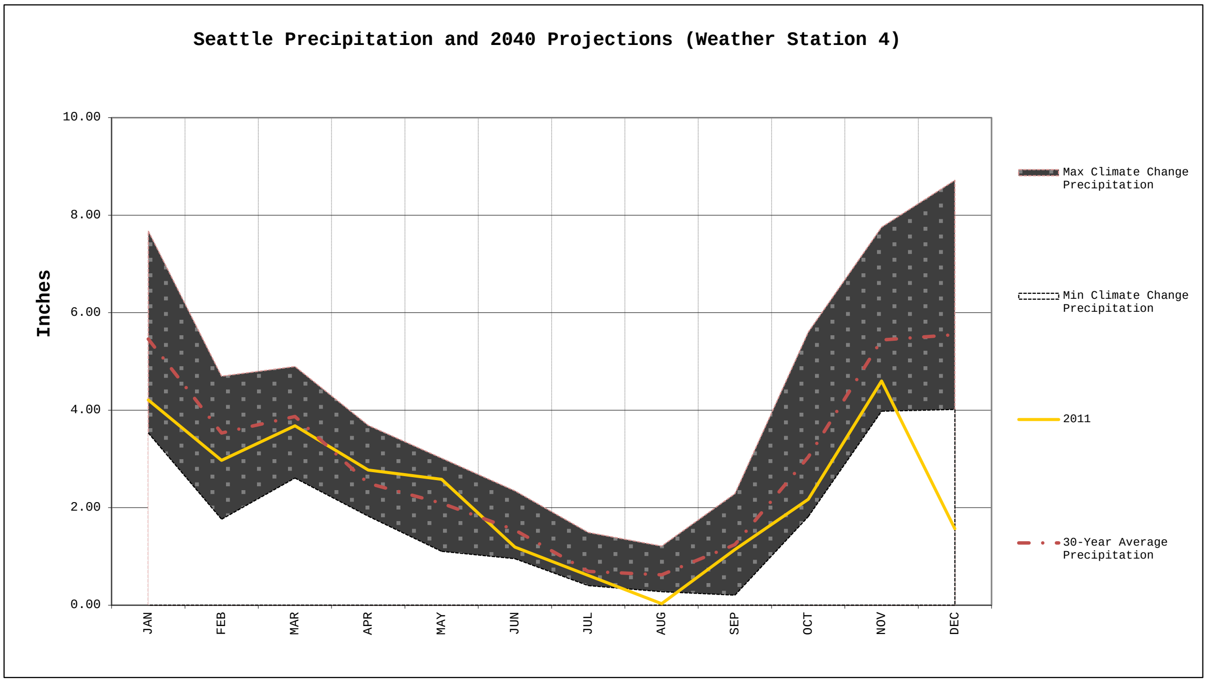


Table 20. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 4, 2001

		Weather Station 4		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2011	January	42	4.21	43.82	47.52	3.75	4.72
	February	39	2.97	40.96	44.66	2.64	3.33
	March	45	3.68	46.34	50.04	3.28	4.12
	April	45	2.77	46.70	50.40	2.47	3.10
	May	51	2.58	52.98	56.68	2.30	2.89
	June	58	1.19	59.16	62.86	1.06	1.33
	July	60	0.61	61.85	65.55	0.54	0.68
	August	63	0.03	64.15	67.85	0.03	0.03
	September	62	1.14	63.17	66.87	1.01	1.28
	October	51	2.17	52.79	56.49	1.93	2.43
	November	43	4.60	44.60	48.30	4.09	5.15
	December	41	1.57	42.34	46.04	1.40	1.76

WEATHER STATION 5:

Figure 31. Seattle Temperature and 2040 Projections – Weather Station 5, 2009 - 2011

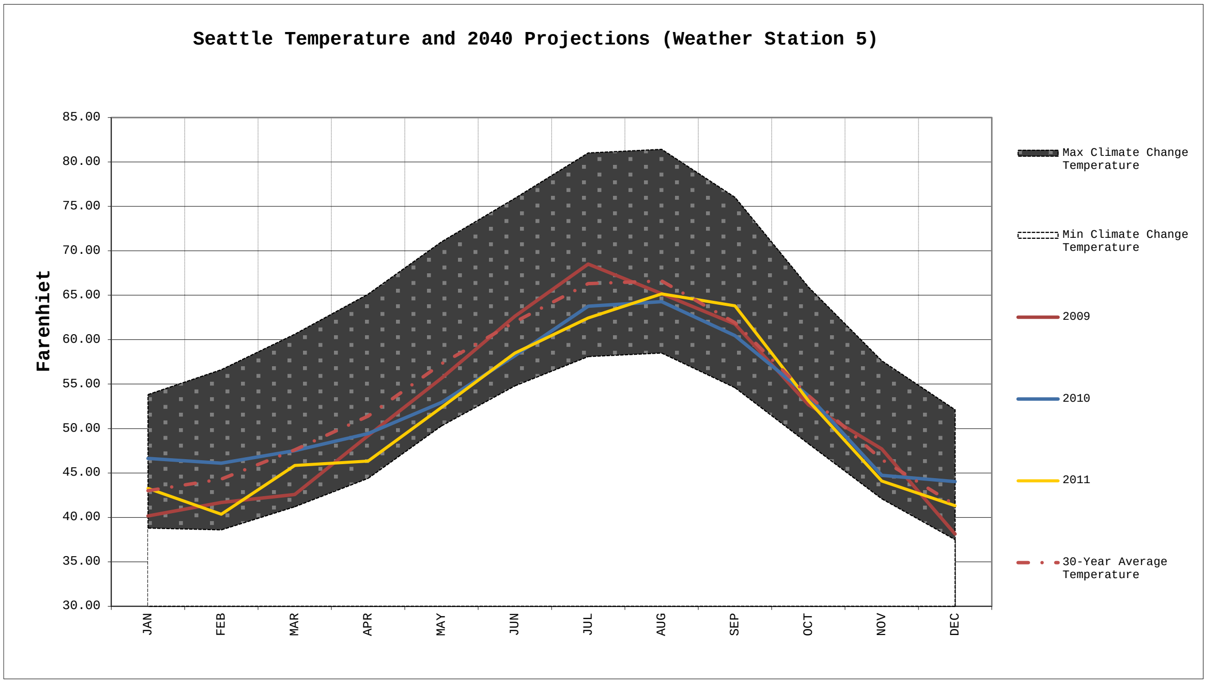


Figure 32. Seattle Precipitation and 2040 Projections - Weather Station 6, 2009 - 2011

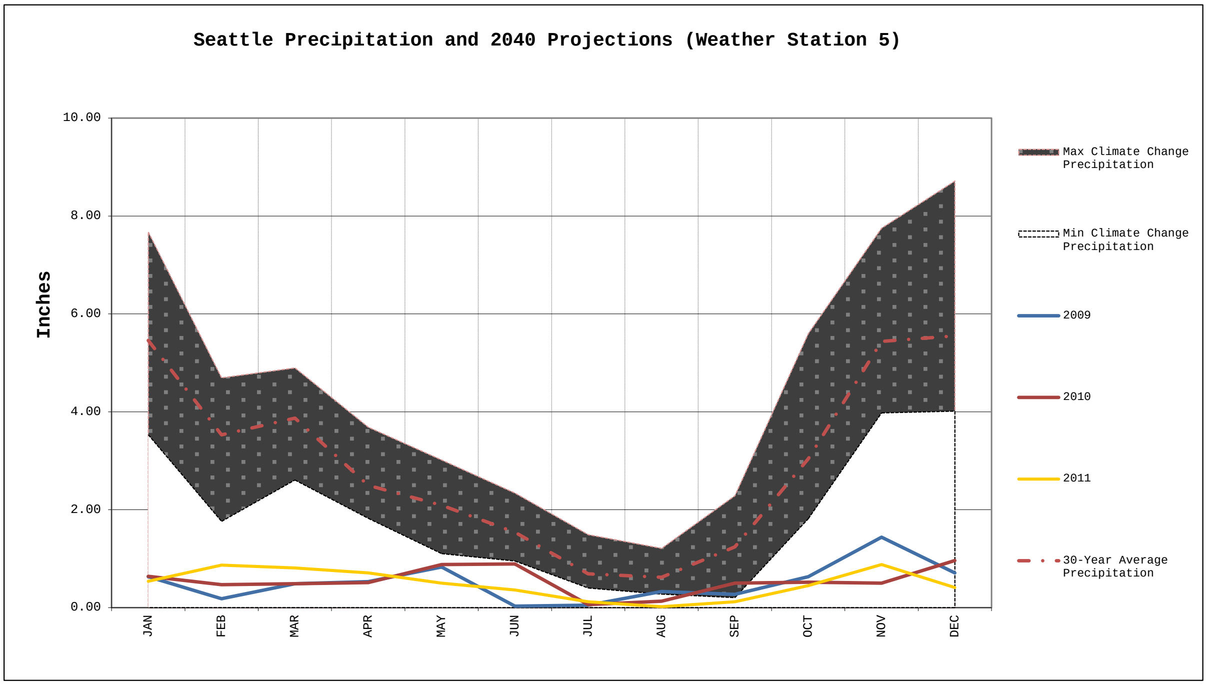


Table 21. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projection, Weather Station 5, 2009 - 2011

		Weather Station 5		Climate Change Projection			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project - PREC Min	High CC Project - PREC Max
2009	January	40	0.63	41.66	45.36	0.56	0.71
	February	42	0.18	43.18	46.88	0.16	0.20
	March	43	0.49	44.08	47.78	0.44	0.55
	April	49	0.53	50.70	54.40	0.47	0.59
	May	56	0.83	57.18	60.88	0.74	0.93
	June	63	0.03	64.13	67.83	0.03	0.03
	July	69	0.05	70.02	73.72	0.04	0.06
	August	65	0.33	66.67	70.37	0.29	0.37
	September	62	0.27	63.27	66.97	0.24	0.30
	October	53	0.63	54.18	57.88	0.56	0.71
	November	48	1.44	49.20	52.90	1.28	1.61
	December	38	0.71	39.63	43.33	0.63	0.80
2010	January	47	0.64	48.15	51.85	0.57	0.72
	February	46	0.47	47.61	51.31	0.42	0.53
	March	48	0.49	49.02	52.72	0.44	0.55
	April	49	0.51	50.93	54.63	0.45	0.57
	May	53	0.88	54.44	58.14	0.78	0.99
	June	58	0.89	59.70	63.40	0.79	1.00
	July	64	0.06	65.27	68.97	0.05	0.07
	August	64	0.13	65.79	69.49	0.12	0.15
	September	60	0.50	61.95	65.65	0.45	0.56
	October	54	0.52	55.18	58.88	0.46	0.58
	November	45	0.50	46.23	49.93	0.45	0.56
	December	44	0.96	45.53	49.23	0.85	1.08
2011	January	43	0.54	44.76	48.46	0.48	0.60
	February	40	0.87	41.86	45.56	0.77	0.97
	March	46	0.81	47.34	51.04	0.72	0.91
	April	46	0.71	47.83	51.53	0.63	0.80
	May	52	0.50	53.89	57.59	0.45	0.56
	June	59	0.36	60.00	63.70	0.32	0.40
	July	62	0.12	63.95	67.65	0.11	0.13
	August	65	0.02	66.66	70.36	0.02	0.02
	September	64	0.12	65.30	69.00	0.11	0.13
	October	53	0.45	54.63	58.33	0.40	0.50
	November	44	0.88	45.60	49.30	0.78	0.99
	December	41	0.41	42.82	46.52	0.36	0.46

WEATHER STATION 6:

Figure 33. Seattle Temperature and 2040 Projections - Weather Station 6, 2011

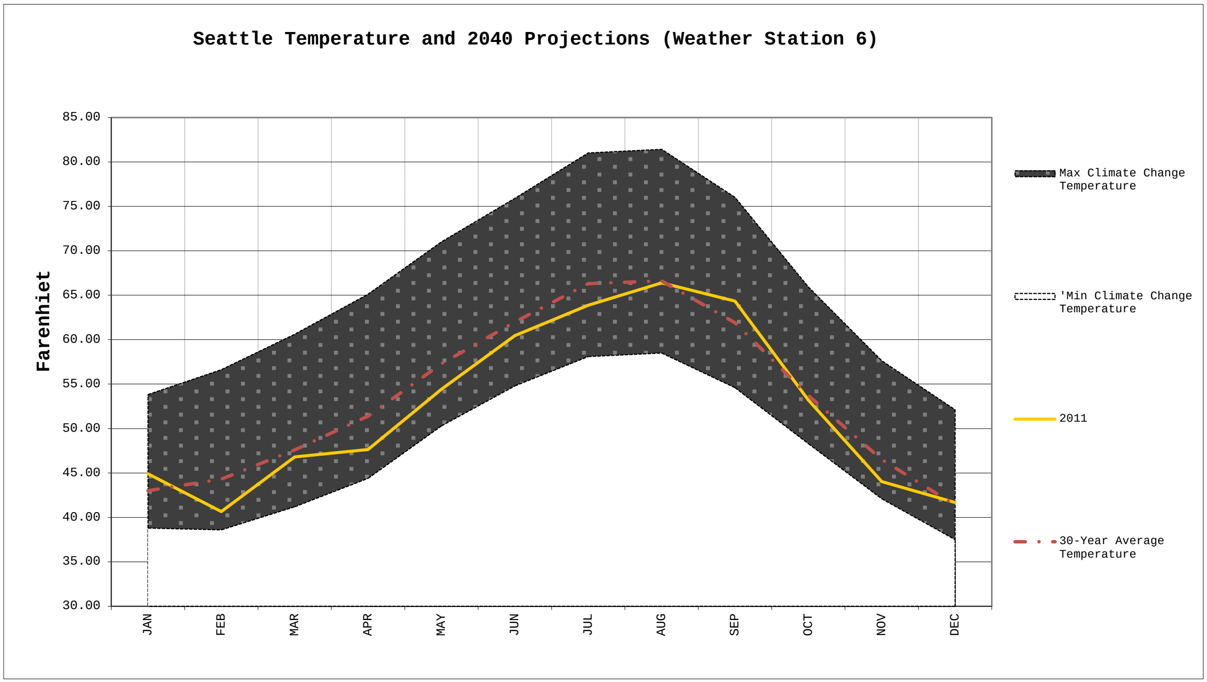


Figure 34. Seattle Precipitation and 2040 Projections - Weather Station 6, 2011

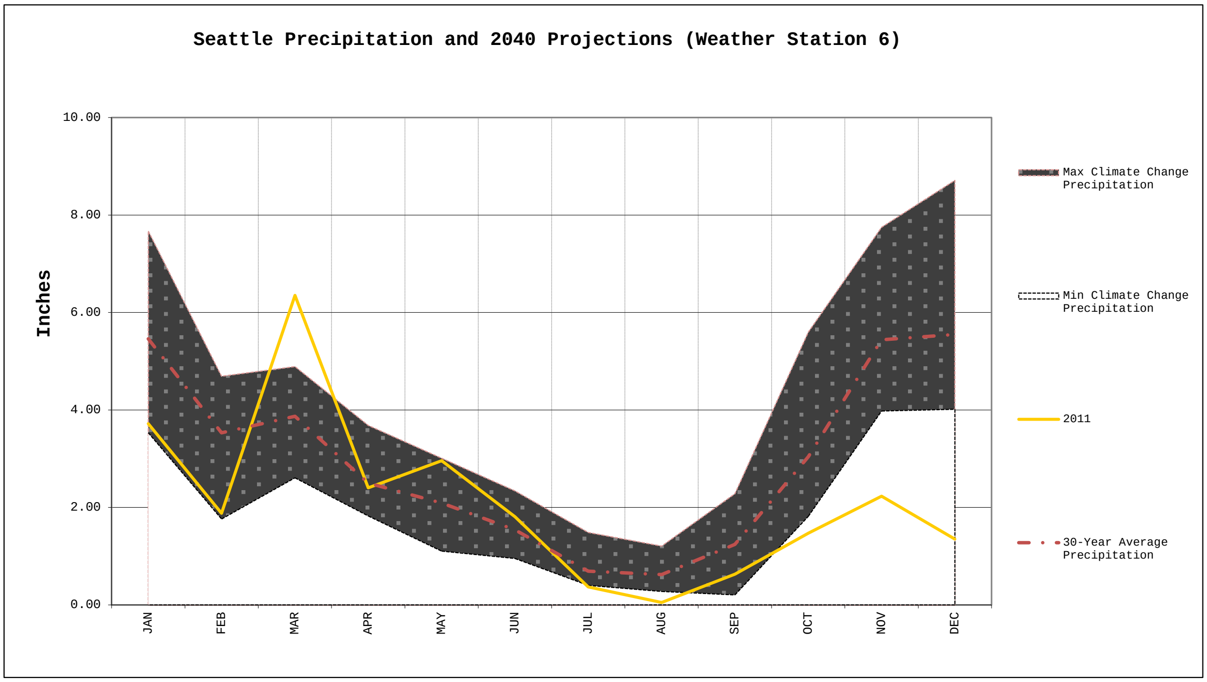


Table 22. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 6, 2011

		Weather Station 6		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2011	January	45	3.72	46.41	50.11	3.31	4.17
	February	41	1.88	42.17	45.87	1.67	2.11
	March	47	6.35	48.30	52.00	5.65	7.11
	April	48	2.40	49.13	52.83	2.14	2.69
	May	54	2.96	55.93	59.63	2.63	3.32
	June	60	1.81	61.95	65.65	1.61	2.03
	July	64	0.37	65.38	69.08	0.33	0.41
	August	66	0.05	67.89	71.59	0.04	0.06
	September	64	0.63	65.83	69.53	0.56	0.71
	October	53	1.47	54.69	58.39	1.31	1.65
	November	44	2.23	45.53	49.23	1.98	2.50
	December	42	1.35	43.18	46.88	1.20	1.51

WEATHER STATION 7:

Figure 35. Seattle Temperature and 2040 Projections - Weather Station 7, 2004 - 2007, 2010 - 2011

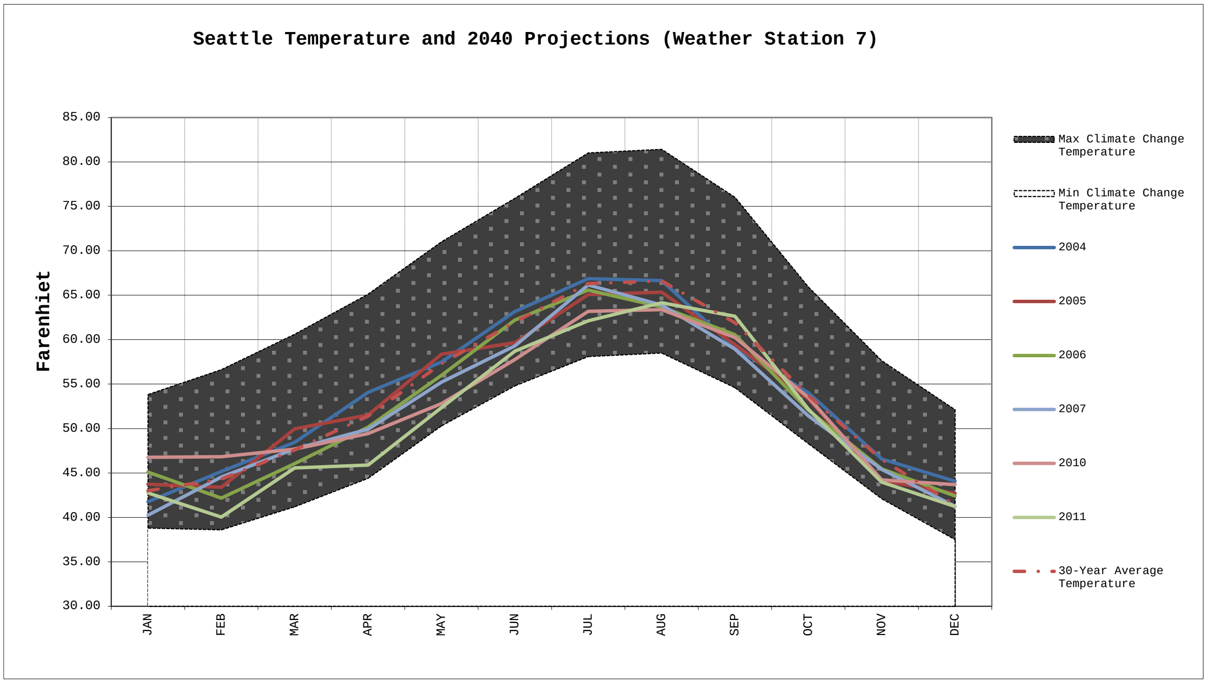


Figure 36. Seattle Temperature and 2040 Projections - Weather Station 7, 2004 - 2007, 2010 - 2011

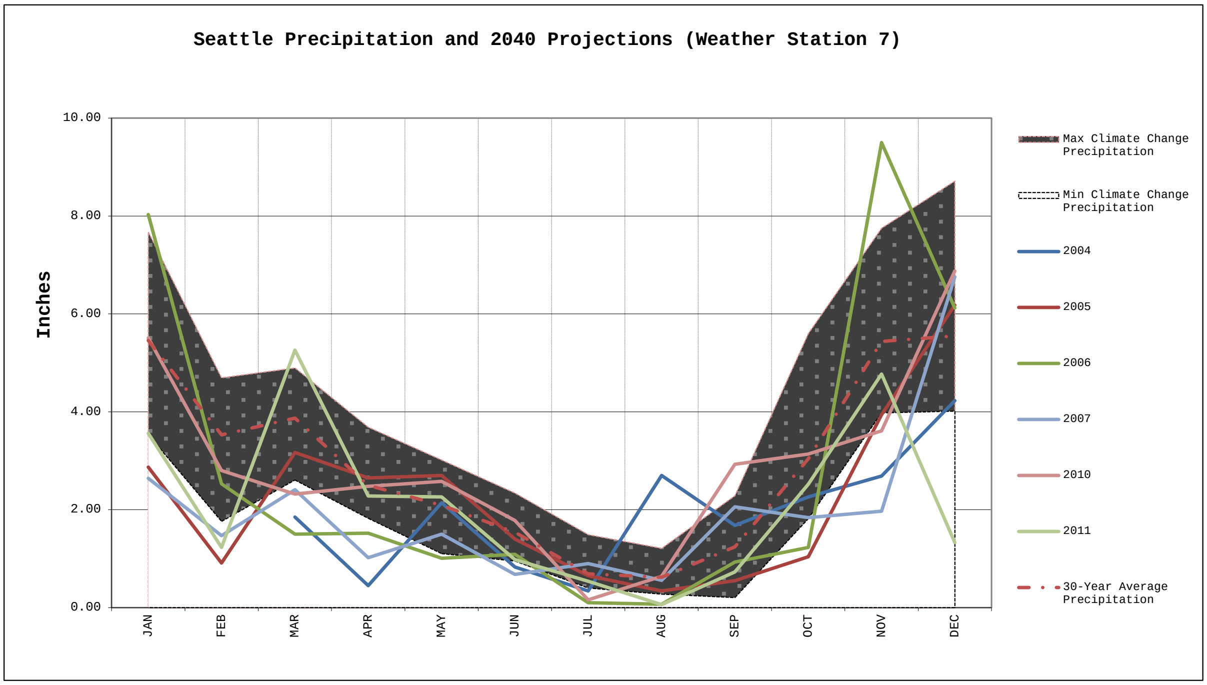


Table 23. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 7, 2004 - 2007, 2010 - 2011

		Weather Station 7		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2004	January	42		43.27	46.97	0.00	0.00
	February	45		46.67	50.37	0.00	0.00
	March	48	1.85	49.95	53.65	1.65	2.07
	April	54	0.45	55.57	59.27	0.40	0.50
	May	57	2.14	58.98	62.68	1.90	2.40
	June	63	0.83	64.67	68.37	0.74	0.93
	July	67	0.34	68.37	72.07	0.30	0.38
	August	67	2.70	68.15	71.85	2.40	3.02
	September	59	1.68	60.60	64.30	1.50	1.88
	October	54	2.26	55.53	59.23	2.01	2.53
	November	47	2.69	48.07	51.77	2.39	3.01
	December	44	4.23	45.57	49.27	3.76	4.74
2005	January	44	2.87	45.24	48.94	2.55	3.21
	February	43	0.91	44.89	48.59	0.81	1.02
	March	50	3.17	51.47	55.17	2.82	3.55
	April	52	2.65	53.03	56.73	2.36	2.97
	May	58	2.70	59.85	63.55	2.40	3.02
	June	60	1.40	61.17	64.87	1.25	1.57
	July	65	0.65	66.56	70.26	0.58	0.73
	August	65	0.34	66.85	70.55	0.30	0.38
	September	59	0.55	60.95	64.65	0.49	0.62
	October	53	1.04	54.83	58.53	0.93	1.16
	November	44	3.94	45.63	49.33	3.51	4.41
	December	43	6.18	44.21	47.91	5.50	6.92
2006	January	45	8.03	46.60	50.30	7.15	8.99
	February	42	2.53	43.68	47.38	2.25	2.83
	March	46	1.50	47.56	51.26	1.34	1.68
	April	50	1.52	51.67	55.37	1.35	1.70
	May	56	1.01	57.50	61.20	0.90	1.13
	June	62	1.09	63.70	67.40	0.97	1.22
	July	66	0.10	67.08	70.78	0.09	0.11
	August	64	0.07	65.18	68.88	0.06	0.08
	September	61	0.93	62.07	65.77	0.83	1.04
	October	52	1.23	53.56	57.26	1.09	1.38
	November	45	9.50	46.97	50.67	8.46	10.64
	December	42	6.12	43.90	47.60	5.45	6.85
2007	January	40	2.64	41.76	45.46	2.35	2.96
	February	45	1.47	46.04	49.74	1.31	1.65
	March	48	2.41	49.21	52.91	2.14	2.70
	April	50	1.02	51.43	55.13	0.91	1.14
	May	55	1.50	56.73	60.43	1.34	1.68
	June	59	0.68	60.80	64.50	0.61	0.76
	July	66	0.90	67.66	71.36	0.80	1.01
	August	64	0.56	65.40	69.10	0.50	0.63
	September	59	2.06	60.43	64.13	1.83	2.31

	October	51	1.84	52.92	56.62	1.64	2.06
	November	45	1.97	46.90	50.60	1.75	2.21
	December	41	6.76	42.76	46.46	6.02	7.57
2010	January	47	5.51	48.27	51.97	4.90	6.17
	February	47	2.80	48.32	52.02	2.49	3.14
	March	48	2.32	49.18	52.88	2.06	2.60
	April	49	2.48	50.93	54.63	2.21	2.78
	May	53	2.58	54.31	58.01	2.30	2.89
	June	58	1.78	59.27	62.97	1.58	1.99
	July	63	0.16	64.69	68.39	0.14	0.18
	August	63	0.64	64.89	68.59	0.57	0.72
	September	60	2.93	61.73	65.43	2.61	3.28
	October	53	3.14	54.98	58.68	2.79	3.52
	November	44	3.61	45.73	49.43	3.21	4.04
	December	44	6.88	45.20	48.90	6.12	7.71
2011	January	43	3.56	44.24	47.94	3.17	3.99
	February	40	1.23	41.54	45.24	1.09	1.38
	March	46	5.26	47.08	50.78	4.68	5.89
	April	46	2.28	47.40	51.10	2.03	2.55
	May	52	2.26	53.85	57.55	2.01	2.53
	June	59	0.98	60.20	63.90	0.87	1.10
	July	62	0.54	63.63	67.33	0.48	0.60
	August	64	0.06	65.66	69.36	0.05	0.07
	September	63	0.73	64.13	67.83	0.65	0.82
	October	52	2.52	53.66	57.36	2.24	2.82
	November	44	4.77	45.47	49.17	4.25	5.34
	December	41	1.33	42.73	46.43	1.18	1.49

WEATHER STATION 8:

Figure 37. Seattle Temperature and 2040 Projections - Weather Station 8, 2010 - 2011

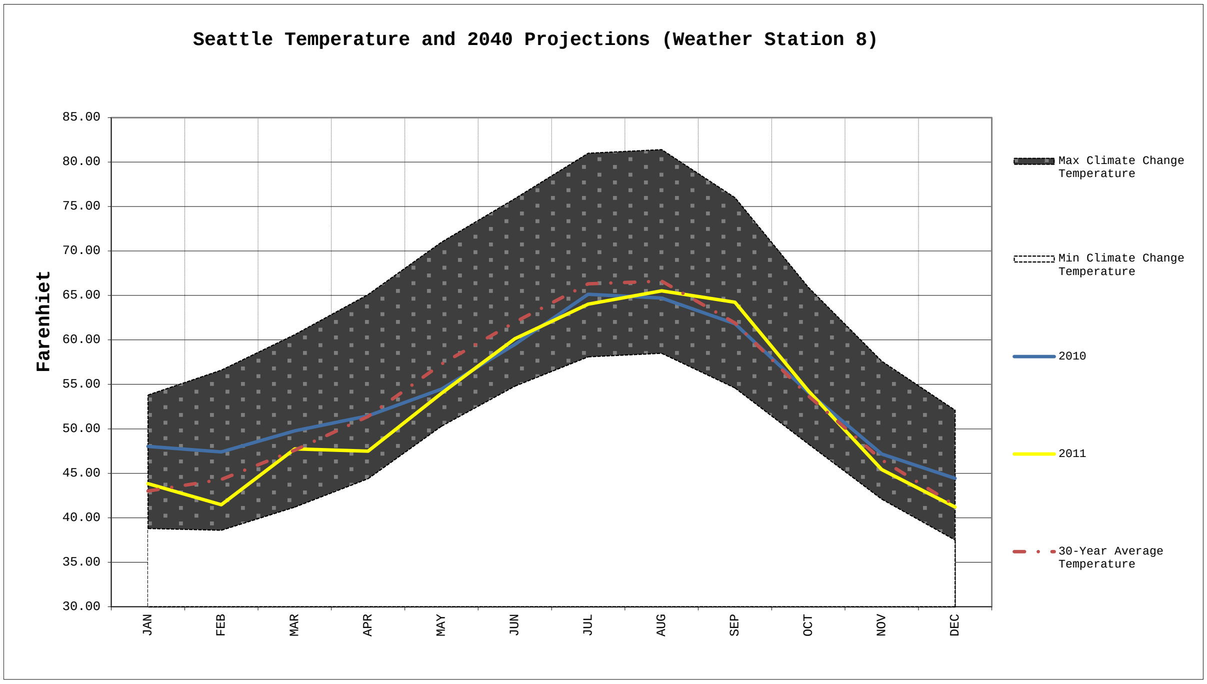


Figure 38. Seattle Precipitation and 2040 Projections - Weather Station 8, 2010 - 2011

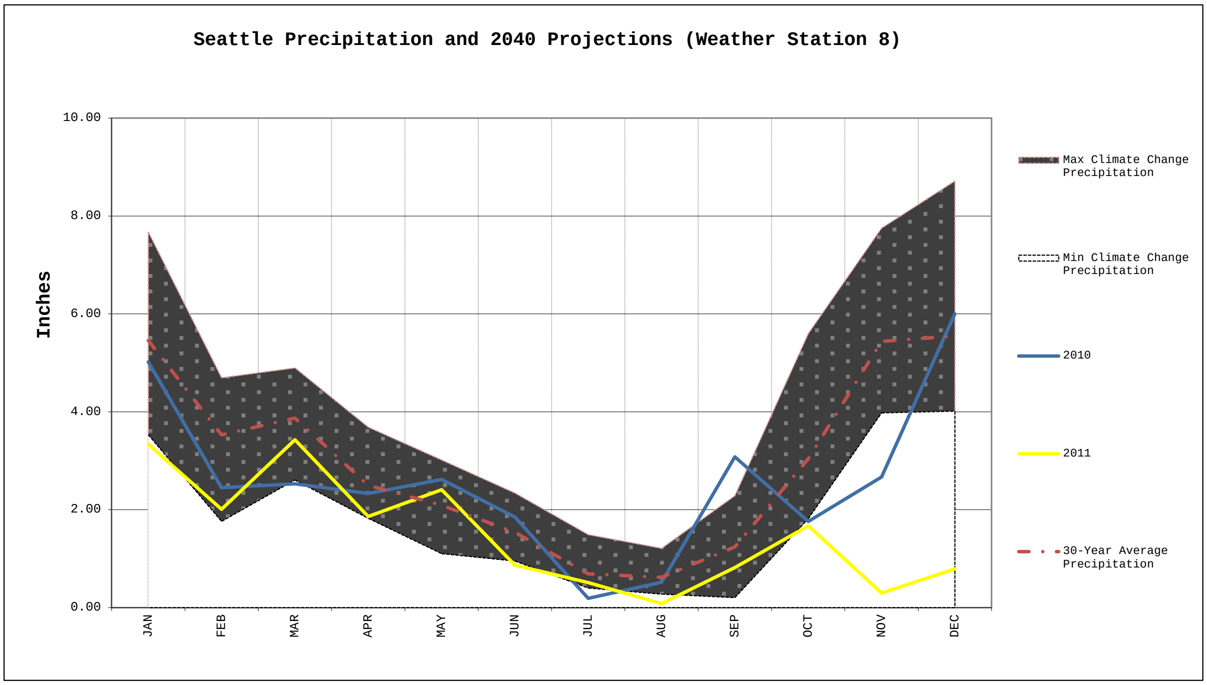


Table 24. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 8, 2010 - 2011

		Weather Station 8		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2010	January	48	5.02	49.53	53.23	4.47	5.62
	February	47	2.45	48.90	52.60	2.18	2.74
	March	50	2.53	51.28	54.98	2.25	2.83
	April	51	2.33	52.96	56.66	2.07	2.61
	May	54	2.62	55.98	59.68	2.33	2.93
	June	60	1.85	61.00	64.70	1.65	2.07
	July	65	0.19	66.63	70.33	0.17	0.21
	August	65	0.52	66.20	69.90	0.46	0.58
	September	62	3.08	63.33	67.03	2.74	3.45
	October	54	1.76	55.59	59.29	1.57	1.97
	November	47	2.67	48.67	52.37	2.38	2.99
	December	44	6.00	45.93	49.63	5.34	6.72
2011	January	44	3.34	45.34	49.04	2.97	3.74
	February	41	2.01	42.98	46.68	1.79	2.25
	March	48	3.43	49.24	52.94	3.05	3.84
	April	48	1.86	49.00	52.70	1.66	2.08
	May	54	2.41	55.50	59.20	2.14	2.70
	June	60	0.87	61.63	65.33	0.77	0.97
	July	64	0.51	65.53	69.23	0.45	0.57
	August	66	0.08	67.02	70.72	0.07	0.09
	September	64	0.82	65.73	69.43	0.73	0.92
	October	54	1.67	55.76	59.46	1.49	1.87
	November	45	0.30	46.92	50.62	0.27	0.34
	December	41	0.79	42.71	46.41	0.70	0.88

WEATHER STATION 9:

Figure 39. Seattle Temperature and 2040 Projections - Weather Station 9, 2010 - 2011

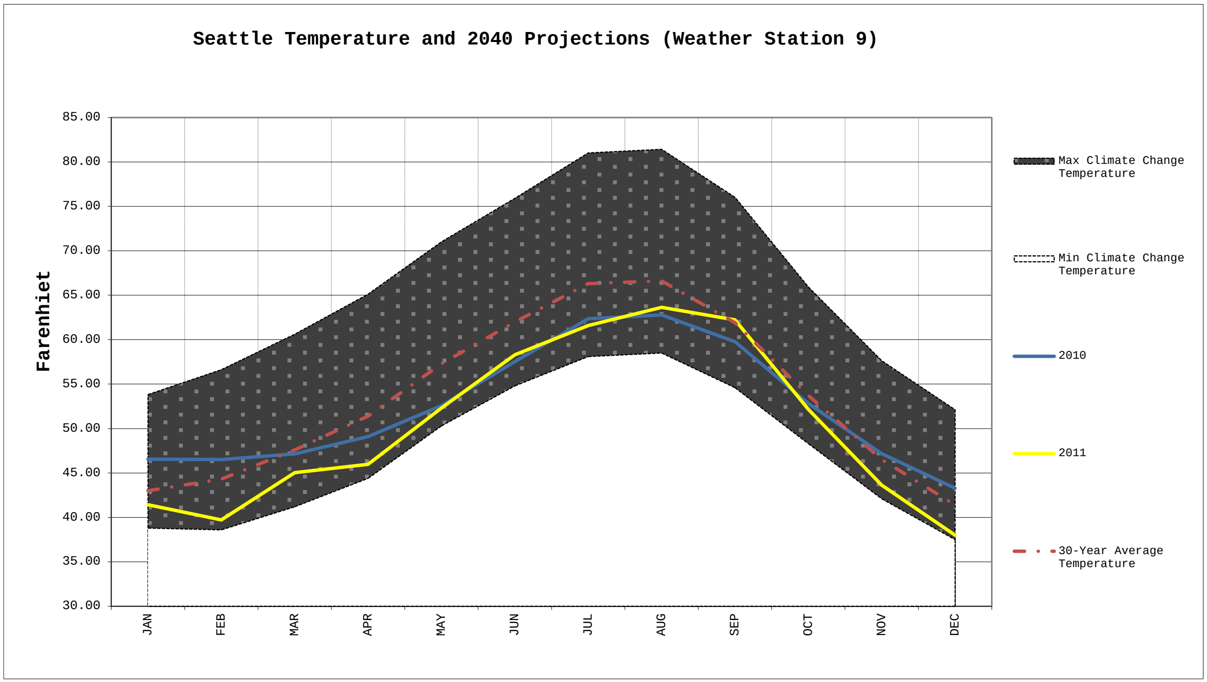


Figure 40. Seattle Precipitation and 2040 Projections - Weather Station 9, 2010 - 2011

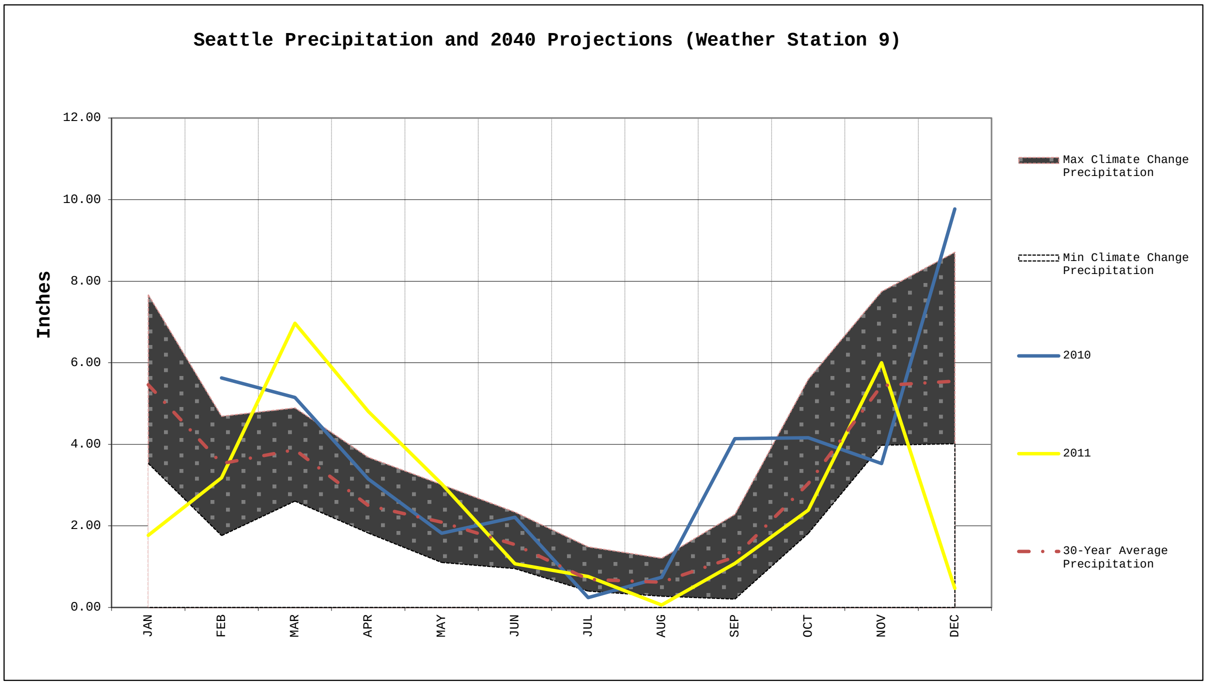


Table 25. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 9, 2010 - 2011

		Weather Station 9		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2010	January	47		48.05	51.75	0.00	0.00
	February	47	5.63	48.02	51.72	5.01	6.31
	March	47	5.15	48.66	52.36	4.58	5.77
	April	49	3.15	50.60	54.30	2.80	3.53
	May	53	1.82	54.08	57.78	1.62	2.04
	June	58	2.21	59.03	62.73	1.97	2.48
	July	62	0.24	63.85	67.55	0.21	0.27
	August	63	0.74	64.27	67.97	0.66	0.83
	September	60	4.14	61.27	64.97	3.68	4.64
	October	53	4.16	54.31	58.01	3.70	4.66
	November	47	3.53	48.67	52.37	3.14	3.95
	December	43	9.77	44.79	48.49	8.70	10.94
2011	January	41	1.77	42.92	46.62	1.58	1.98
	February	40	3.18	41.23	44.93	2.83	3.56
	March	45	6.97	46.54	50.24	6.20	7.81
	April	46	4.81	47.47	51.17	4.28	5.39
	May	52	3.03	53.82	57.52	2.70	3.39
	June	58	1.07	59.80	63.50	0.95	1.20
	July	62	0.76	63.08	66.78	0.68	0.85
	August	64	0.06	65.15	68.85	0.05	0.07
	September	62	1.08	63.73	67.43	0.96	1.21
	October	52	2.39	53.64	57.34	2.13	2.68
	November	44	6.00	45.13	48.83	5.34	6.72
	December	38	0.47	39.50	43.20	0.42	0.53

WEATHER STATION 10:

Figure 41. Seattle Temperature and 2040 Projections - Weather Station 10, 2008 - 2011

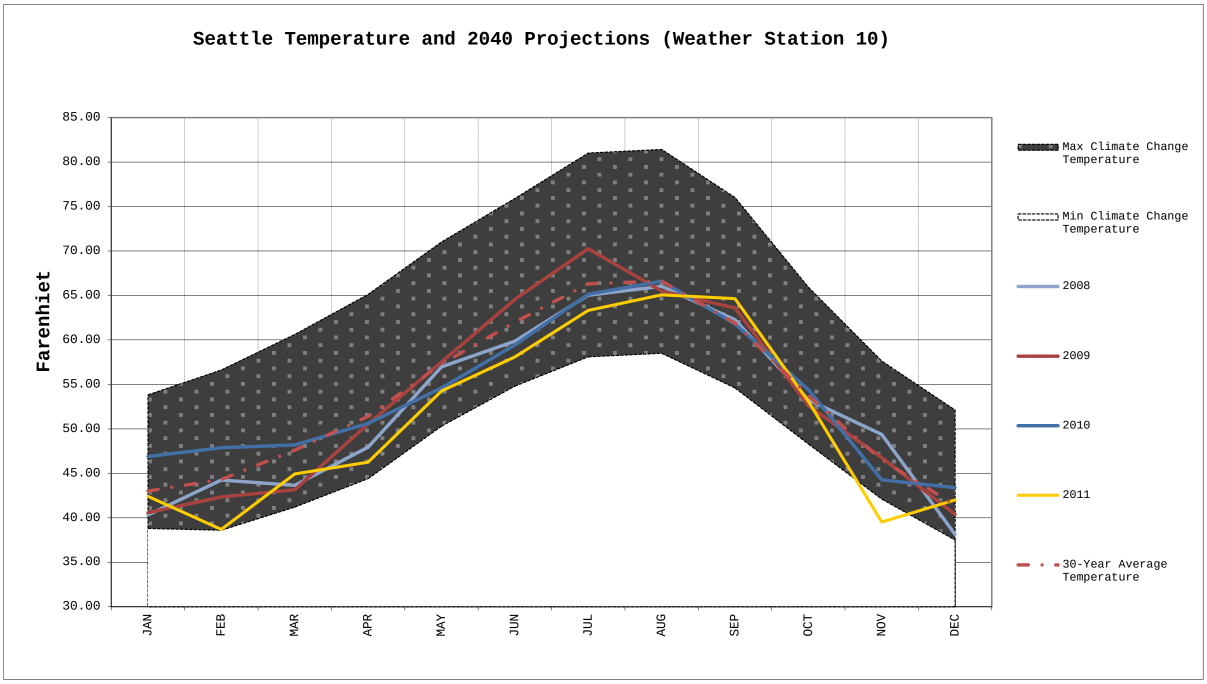


Figure 42. Seattle Precipitation and 2040 Projections - Weather Station 10, 2008 - 2011

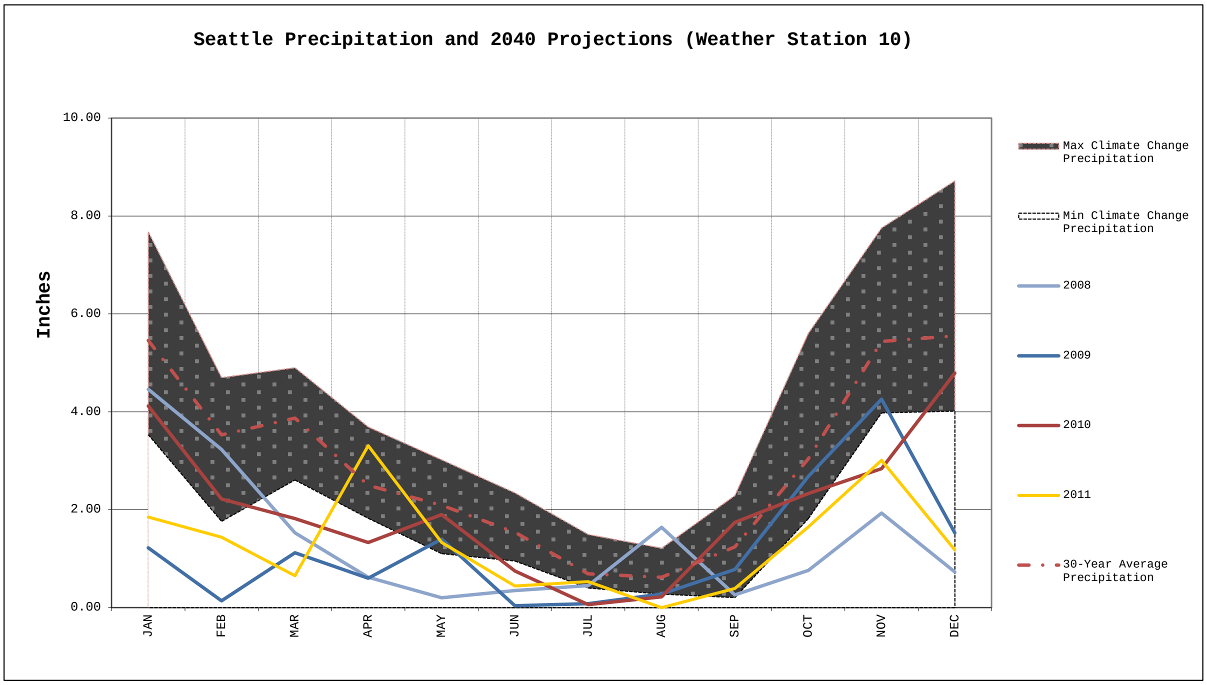


Table 26. Seattle Temperature and Precipitation and 2040 Climate Change Projections, 2008 - 2011

		Weather Station 10		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2008	January	40	4.46	41.82	45.52	3.97	5.00
	February	44	3.23	45.75	49.45	2.87	3.62
	March	44	1.53	45.15	48.85	1.36	1.71
	April	48	0.62	49.43	53.13	0.55	0.69
	May	57	0.20	58.47	62.17	0.18	0.22
	June	60	0.35	61.35	65.05	0.31	0.39
	July	65	0.45	66.53	70.23	0.40	0.50
	August	66	1.64	67.53	71.23	1.46	1.84
	September	62	0.26	63.78	67.48	0.23	0.29
	October	53	0.76	54.76	58.46	0.68	0.85
	November	49	1.93	50.88	54.58	1.72	2.16
	December	38	0.73	39.63	43.33	0.65	0.82
2009	January	41	1.22	42.07	45.77	1.09	1.37
	February	42	0.14	43.85	47.55	0.12	0.16
	March	43	1.12	44.66	48.36	1.00	1.25
	April	51	0.60	52.06	55.76	0.53	0.67
	May	58	1.40	59.04	62.74	1.25	1.57
	June	65	0.04	66.07	69.77	0.04	0.04
	July	70	0.08	71.77	75.47	0.07	0.09
	August	66	0.28	67.00	70.70	0.25	0.31
	September	64	0.78	65.09	68.79	0.69	0.87
	October	53	2.68	54.09	57.79	2.39	3.00
	November	47	4.26	48.27	51.97	3.79	4.77
	December	40	1.53	41.89	45.59	1.36	1.71
2010	January	47	4.12	48.40	52.10	3.67	4.61
	February	48	2.22	49.38	53.08	1.98	2.49
	March	48	1.82	49.71	53.41	1.62	2.04
	April	51	1.33	52.11	55.81	1.18	1.49
	May	55	1.90	56.11	59.81	1.69	2.13
	June	59	0.75	60.92	64.62	0.67	0.84
	July	65	0.06	66.63	70.33	0.05	0.07
	August	67	0.22	68.10	71.80	0.20	0.25
	September	62	1.74	63.30	67.00	1.55	1.95
	October	54	2.33	55.89	59.59	2.07	2.61
	November	44	2.84	45.77	49.47	2.53	3.18
	December	43	4.79	44.89	48.59	4.26	5.36
2011	January	42	1.85	43.92	47.62	1.65	2.07
	February	39	1.44	40.20	43.90	1.28	1.61
	March	45	0.65	46.44	50.14	0.58	0.73
	April	46	3.31	47.76	51.46	2.95	3.71
	May	54	1.33	55.76	59.46	1.18	1.49
	June	58	0.44	59.58	63.28	0.39	0.49
	July	63	0.53	64.81	68.51	0.47	0.59
	August	65	0.00	66.58	70.28	0.00	0.00

	September	65	0.39	66.14	69.84	0.35	0.44
	October	53	1.65	54.58	58.28	1.47	1.85
	November	40	3.01	41.03	44.73	2.68	3.37
	December	42	1.18	43.50	47.20	1.05	1.32

WEATHER STATION 11:

Figure 43. Seattle Temperature and 2040 Projections - Weather Station 11, 2009 - 2011

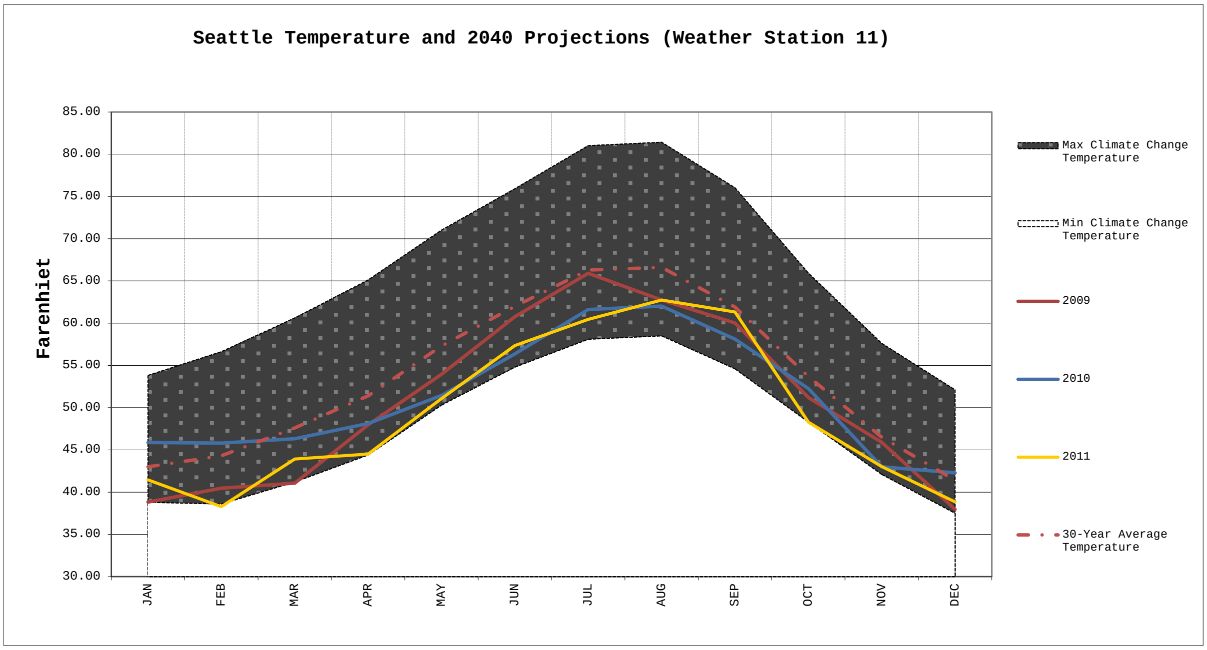


Figure 44. Seattle Precipitation and 2040 Projections - Weather Station 11, 2009 - 2011

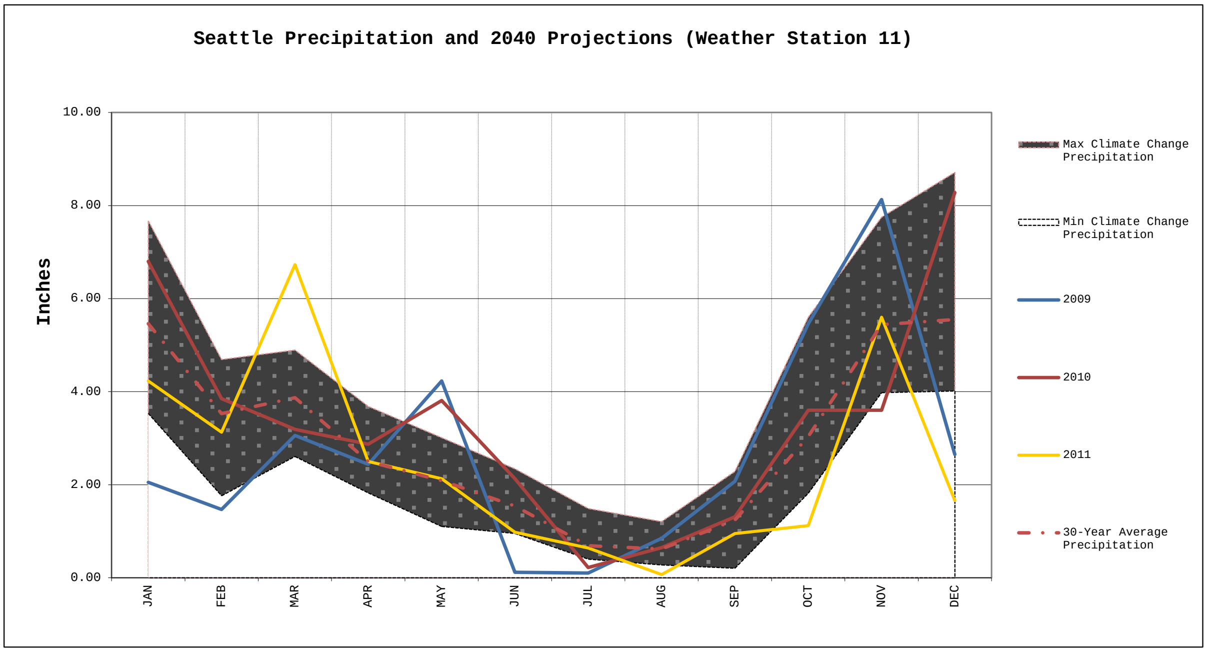


Table 27. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 11, 2009 - 2011

		Weather Station 11		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2009	January	39	2	40.33	44.03	1.82	2.30
	February	40	1	41.96	45.66	1.31	1.65
	March	41	3	42.56	46.26	2.72	3.43
	April	48	2	49.47	53.17	2.17	2.73
	May	54	4	55.47	59.17	3.76	4.74
	June	61	0	62.27	65.97	0.11	0.13
	July	66	0	67.40	71.10	0.09	0.11
	August	63	1	64.24	67.94	0.76	0.95
	September	60	2	61.53	65.23	1.84	2.32
	October	51	5	52.69	56.39	4.86	6.12
	November	46	8	47.40	51.10	7.24	9.11
	December	38	3	39.47	43.17	2.36	2.97
2010	January	46	7	47.37	51.07	6.05	7.62
	February	46	4	47.32	51.02	3.43	4.31
	March	46	3	47.82	51.52	2.84	3.57
	April	48	3	49.63	53.33	2.55	3.21
	May	51	4	52.95	56.65	3.39	4.27
	June	56	2	57.87	61.57	1.90	2.39
	July	62	0	63.11	66.81	0.20	0.25
	August	62	1	63.53	67.23	0.58	0.73
	September	58	1	59.61	63.31	1.17	1.47
	October	52	4	53.76	57.46	3.20	4.03
	November	43	4	44.50	48.20	3.20	4.03
	December	42	8	43.79	47.49	7.37	9.27
2011	January	41	4	42.95	46.65	3.76	4.74
	February	38	3	39.79	43.49	2.79	3.51
	March	44	7	45.44	49.14	5.99	7.54
	April	45	3	46.00	49.70	2.23	2.80
	May	51	2	52.60	56.30	1.90	2.39
	June	57	1	58.84	62.54	0.87	1.10
	July	60	1	61.95	65.65	0.57	0.72
	August	63	0	64.24	67.94	0.06	0.08
	September	61	1	62.83	66.53	0.85	1.06
	October	48	1	49.79	53.49	1.00	1.25
	November	43	6	44.53	48.23	4.98	6.27
	December	39	2	40.34	44.04	1.48	1.86

WEATHER STATION 12:

Figure 45. Seattle Temperature and 2040 Projections - Weather Station 12, 2010 - 2011

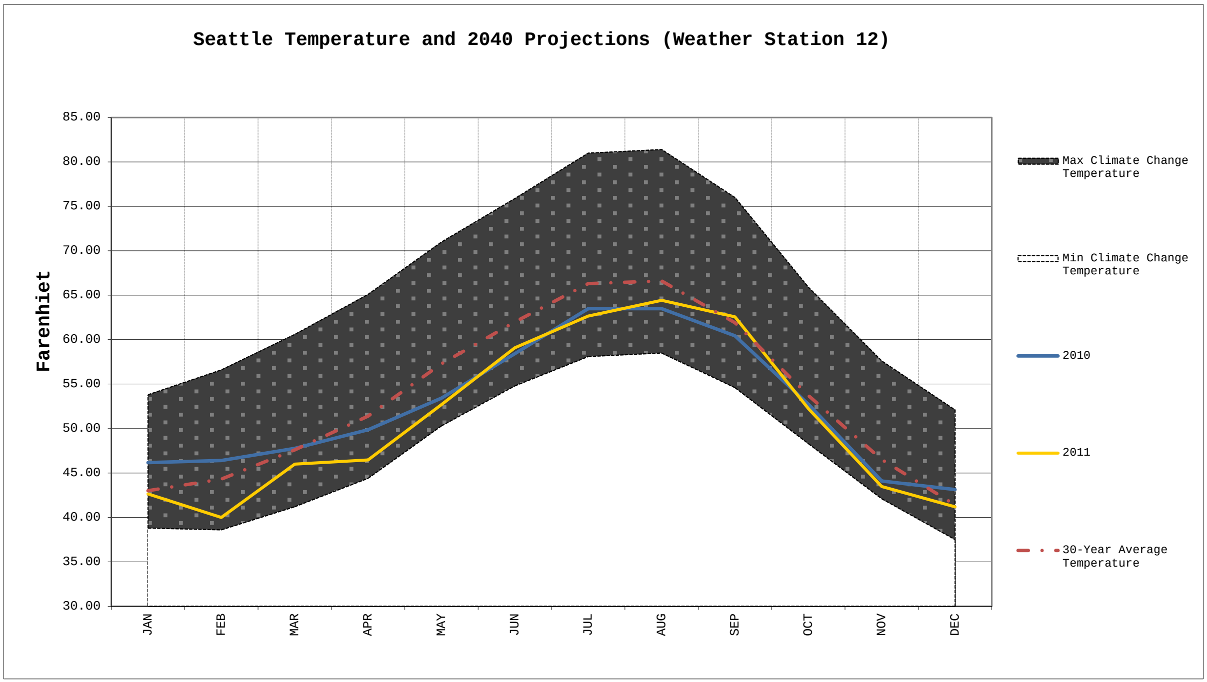


Figure 46. Seattle Precipitation and 2040 Projections - Weather Station 12, 2010 - 2011

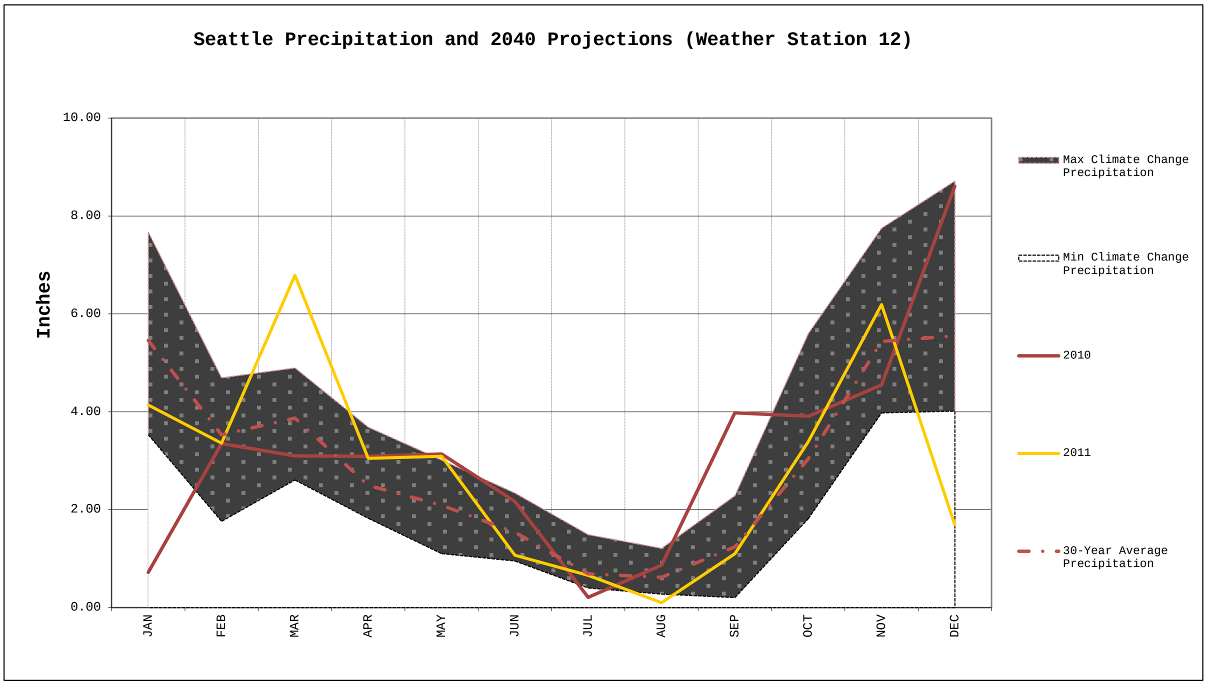


Table 28. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 12, 2010 - 2011

		Weather Station 12		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2010	January	46	0.72	47.67	51.37	0.64	0.81
	February	46	3.35	47.89	51.59	2.98	3.75
	March	48	3.10	49.27	52.97	2.76	3.47
	April	50	3.09	51.37	55.07	2.75	3.46
	May	53	3.14	54.92	58.62	2.79	3.52
	June	58	2.17	59.93	63.63	1.93	2.43
	July	63	0.21	64.98	68.68	0.19	0.24
	August	63	0.87	64.98	68.68	0.77	0.97
	September	60	3.98	61.93	65.63	3.54	4.46
	October	53	3.91	54.23	57.93	3.48	4.38
	November	44	4.55	45.60	49.30	4.05	5.10
	December	43	8.61	44.63	48.33	7.66	9.64
2011	January	43	4.14	44.15	47.85	3.68	4.64
	February	40	3.36	41.50	45.20	2.99	3.76
	March	46	6.79	47.50	51.20	6.04	7.60
	April	46	3.05	47.97	51.67	2.71	3.42
	May	53	3.09	54.21	57.91	2.75	3.46
	June	59	1.07	60.60	64.30	0.95	1.20
	July	63	0.66	64.15	67.85	0.59	0.74
	August	64	0.10	65.92	69.62	0.09	0.11
	September	63	1.10	64.07	67.77	0.98	1.23
	October	52	3.39	53.73	57.43	3.02	3.80
	November	43	6.19	44.97	48.67	5.51	6.93
	December	41	1.69	42.69	46.39	1.50	1.89

WEATHER STATION 13:

Figure 47. Seattle Temperature and 2040 Projections - Weather Station 13, 2004 - 2011

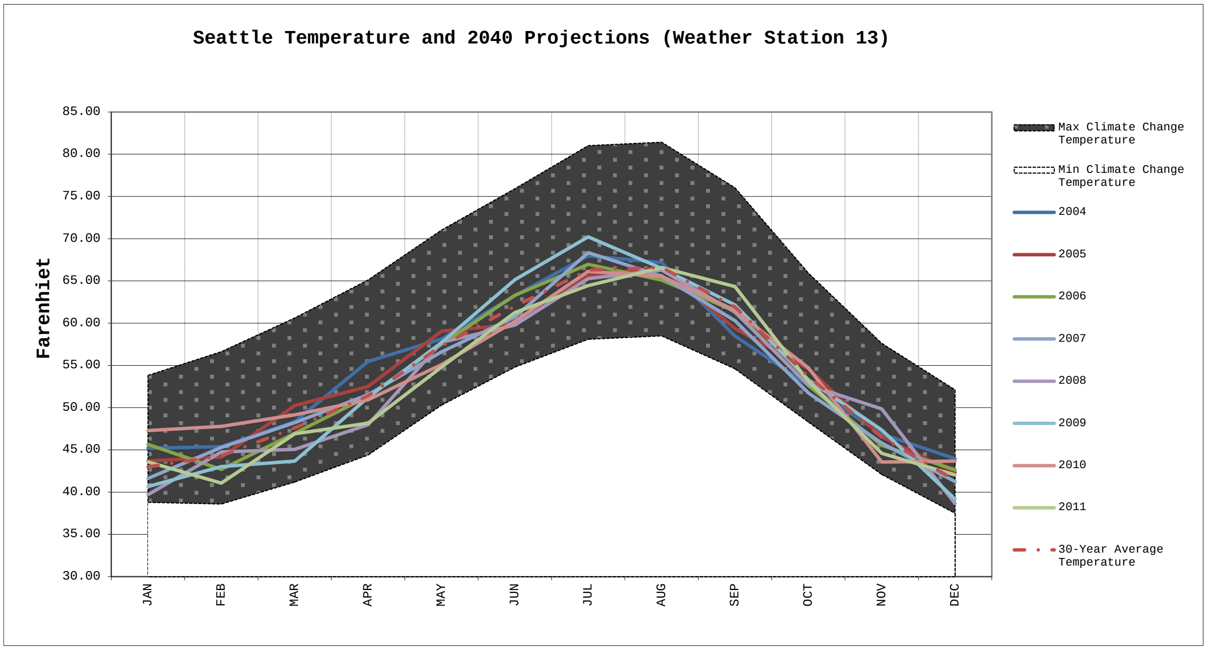


Figure 48. Seattle Precipitation and 2040 Projections, Weather Station 13, 2004 - 2011

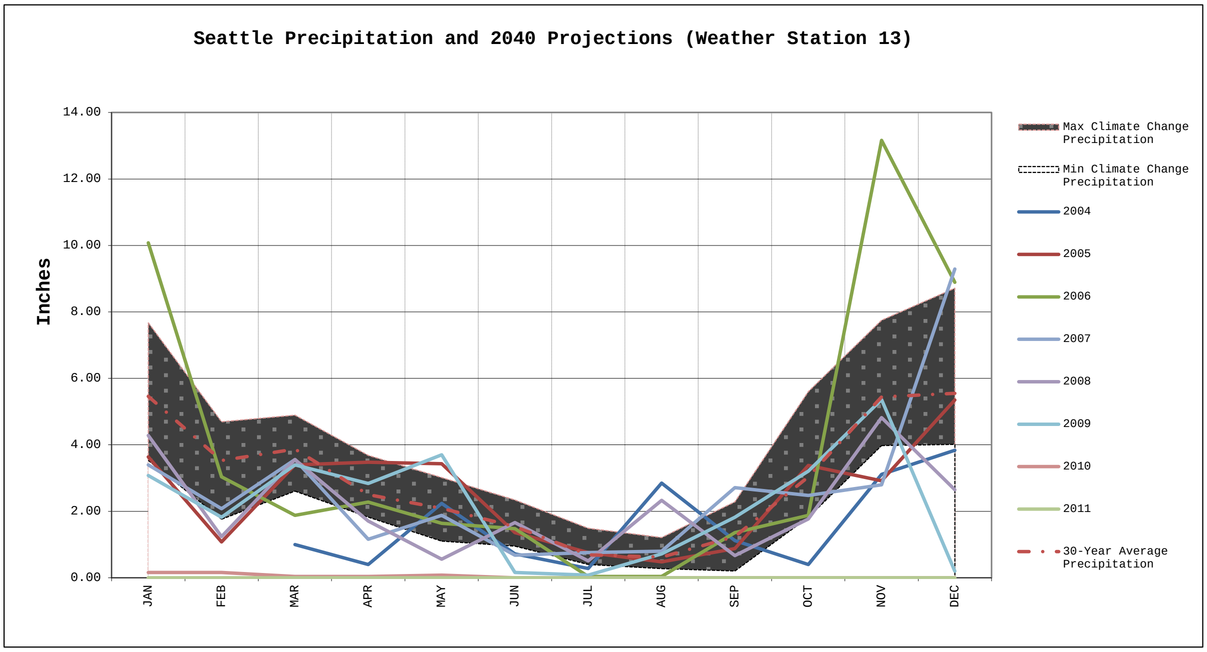


Table 29. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 13, 2004 - 2011

		Weather Station 13		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2004	January	45		46.70	50.40	0.00	0.00
	February	45		46.88	50.58	0.00	0.00
	March	48	1.00	49.84	53.54	0.89	1.12
	April	55	0.40	56.96	60.66	0.36	0.45
	May	58	2.24	59.63	63.33	1.99	2.51
	June	63	0.72	64.77	68.47	0.64	0.81
	July	68	0.28	69.47	73.17	0.25	0.31
	August	67	2.85	68.66	72.36	2.54	3.19
	September	58	1.12	59.98	63.68	1.00	1.25
	October	53	0.40	54.15	57.85	0.36	0.45
	November	47	3.11	48.37	52.07	2.77	3.48
	December	44	3.84	45.47	49.17	3.42	4.30
2005	January	44	3.64	45.21	48.91	3.24	4.08
	February	44	1.08	45.64	49.34	0.96	1.21
	March	50	3.40	51.76	55.46	3.03	3.81
	April	53	3.48	54.00	57.70	3.10	3.90
	May	59	3.43	60.56	64.26	3.05	3.84
	June	60	1.36	61.34	65.04	1.21	1.52
	July	66	0.76	67.16	70.86	0.68	0.85
	August	67	0.48	68.08	71.78	0.43	0.54
	September	59	0.88	60.87	64.57	0.78	0.99
	October	55	3.38	56.08	59.78	3.01	3.79
	November	47	2.92	48.05	51.75	2.60	3.27
	December	42	5.35	43.82	47.52	4.76	5.99
2006	January	46	10.08	47.15	50.85	8.97	11.29
	February	43	3.04	44.18	47.88	2.71	3.40
	March	47	1.88	48.47	52.17	1.67	2.11
	April	51	2.28	52.83	56.53	2.03	2.55
	May	58	1.64	59.02	62.72	1.46	1.84
	June	63	1.48	64.80	68.50	1.32	1.66
	July	67	0.04	68.47	72.17	0.04	0.04
	August	65	0.04	66.60	70.30	0.04	0.04
	September	61	1.36	62.93	66.63	1.21	1.52
	October	53	1.88	54.11	57.81	1.67	2.11
	November	46	13.16	47.03	50.73	11.71	14.74
	December	43	8.89	44.15	47.85	7.91	9.96
2007	January	42	3.40	43.14	46.84	3.03	3.81
	February	45	2.08	46.79	50.49	1.85	2.33
	March	48	3.56	49.73	53.43	3.17	3.99
	April	52	1.16	53.03	56.73	1.03	1.30
	May	57	1.88	58.11	61.81	1.67	2.11
	June	61	0.68	62.25	65.95	0.61	0.76
	July	68	0.76	69.84	73.54	0.68	0.85
	August	66	0.80	67.08	70.78	0.71	0.90
	September	60	2.71	61.80	65.50	2.41	3.04

	October	52	2.48	53.24	56.94	2.21	2.78
	November	46	2.80	47.30	51.00	2.49	3.14
	December	41	9.29	42.76	46.46	8.27	10.40
2008	January	40	4.28	41.21	44.91	3.81	4.79
	February	45	1.24	46.26	49.96	1.10	1.39
	March	45	3.56	46.56	50.26	3.17	3.99
	April	48	1.71	49.50	53.20	1.52	1.92
	May	58	0.56	59.24	62.94	0.50	0.63
	June	60	1.66	61.27	64.97	1.48	1.86
	July	65	0.51	66.79	70.49	0.45	0.57
	August	66	2.33	67.79	71.49	2.07	2.61
	September	61	0.67	62.80	66.50	0.60	0.75
	October	53	1.77	54.18	57.88	1.58	1.98
	November	50	4.82	51.35	55.05	4.29	5.40
	December	39	2.65	40.15	43.85	2.36	2.97
2009	January	41	3.08	42.18	45.88	2.74	3.45
	February	43	1.82	44.54	48.24	1.62	2.04
	March	44	3.40	45.18	48.88	3.03	3.81
	April	51	2.84	52.73	56.43	2.53	3.18
	May	58	3.70	59.21	62.91	3.29	4.14
	June	65	0.16	66.63	70.33	0.14	0.18
	July	70	0.08	71.73	75.43	0.07	0.09
	August	66	0.72	67.98	71.68	0.64	0.81
	September	62	1.82	63.67	67.37	1.62	2.04
	October	53	3.21	54.79	58.49	2.86	3.60
	November	47	5.36	48.87	52.57	4.77	6.00
	December	39	0.20	40.69	44.39	0.18	0.22
2010	January	47	0.16	48.79	52.49	0.14	0.18
	February	48	0.16	49.29	52.99	0.14	0.18
	March	49	0.04	50.66	54.36	0.04	0.04
	April	51	0.04	52.43	56.13	0.04	0.04
	May	55	0.08	56.60	60.30	0.07	0.09
	June	60	0.00	61.73	65.43	0.00	0.00
	July	66	0.00	67.63	71.33	0.00	0.00
	August	66	0.00	67.05	70.75	0.00	0.00
	September	62	0.00	63.03	66.73	0.00	0.00
	October	55	0.00	56.19	59.89	0.00	0.00
	November	44	0.00	45.06	48.76	0.00	0.00
	December	44	0.00	45.18	48.88	0.00	0.00
2011	January	44	0.00	45.09	48.79	0.00	0.00
	February	41	0.00	42.57	46.27	0.00	0.00
	March	47	0.00	48.40	52.10	0.00	0.00
	April	48	0.00	49.67	53.37	0.00	0.00
	May	55	0.00	56.31	60.01	0.00	0.00
	June	61	0.00	62.77	66.47	0.00	0.00
	July	64	0.00	65.95	69.65	0.00	0.00
	August	67	0.00	68.08	71.78	0.00	0.00
	September	64	0.00	65.83	69.53	0.00	0.00
	October	53	0.00	54.60	58.30	0.00	0.00
	November	45	0.00	46.10	49.80	0.00	0.00
	December	42	0.00	43.53	47.23	0.00	0.00

WEATHER STATION 14:

Figure 49. Seattle Temperature and 2040 Projections - Weather Station 14, 2009 - 2011

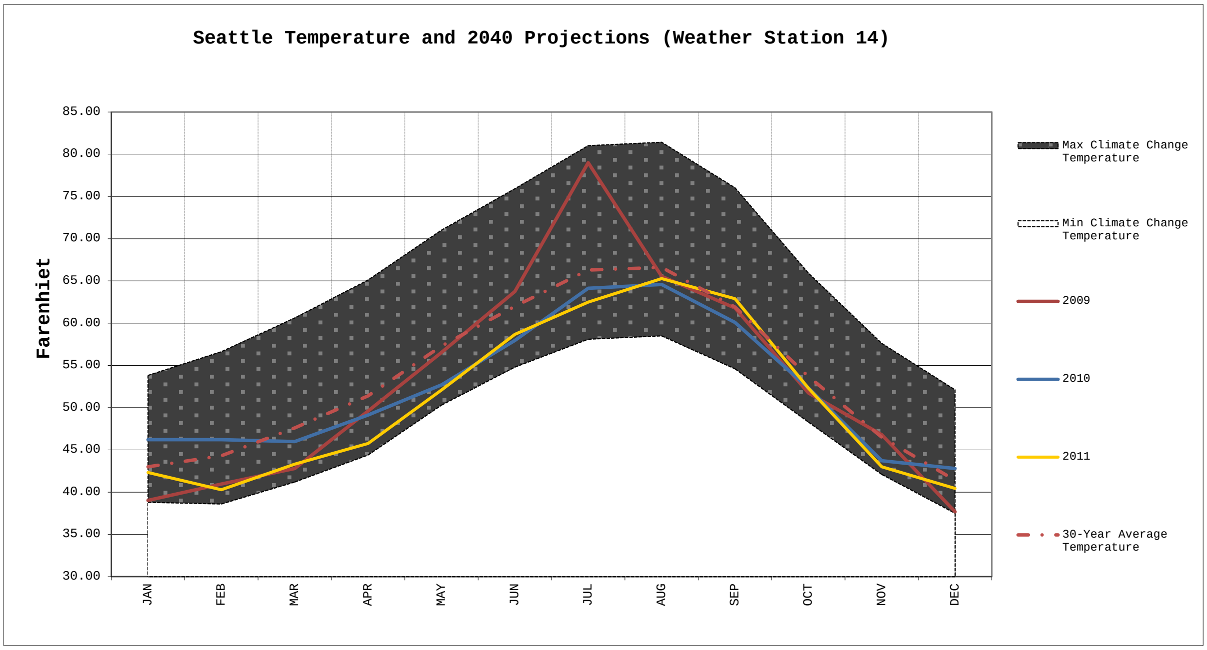


Figure 50. Seattle Precipitation and 2040 Projections - Weather Station 14, 2009 - 2011

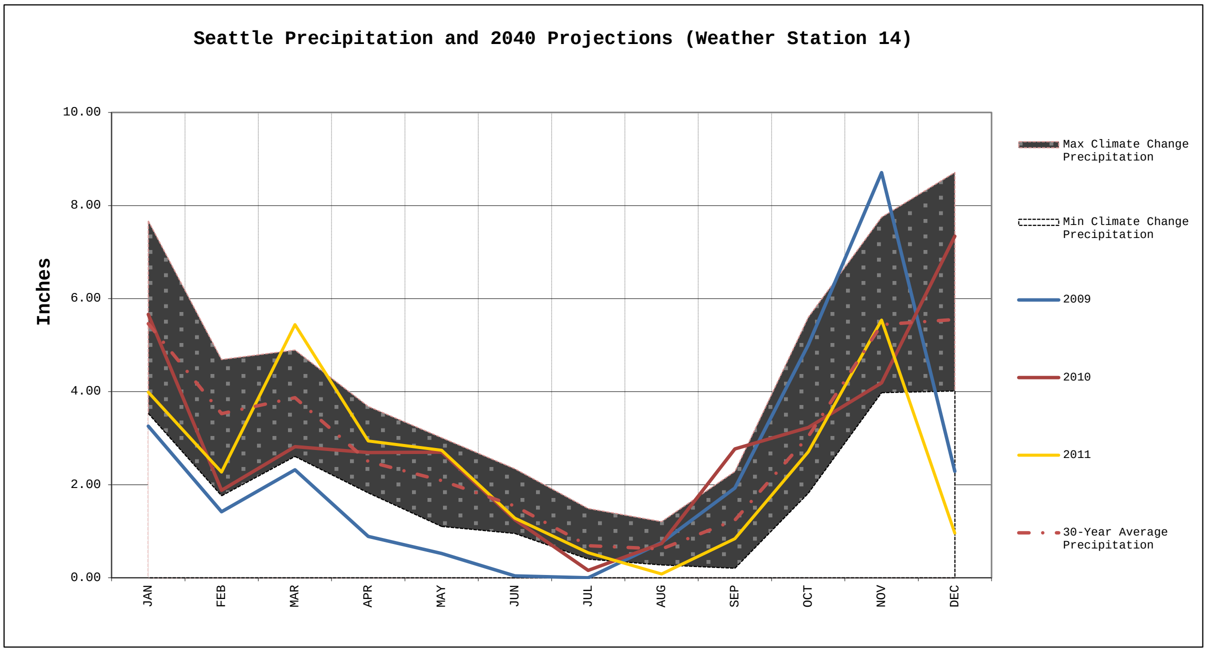


Table 30. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 14, 2009 - 2011

		Weather Station 14		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2009	January	39	3.26	40.53	44.23	2.90	3.65
	February	41	1.42	42.46	46.16	1.26	1.59
	March	43	2.32	44.31	48.01	2.06	2.60
	April	50	0.89	51.10	54.80	0.79	1.00
	May	57	0.52	58.05	61.75	0.46	0.58
	June	64	0.04	65.26	68.96	0.04	0.04
	July	79	0.00	80.50	84.20	0.00	0.00
	August	66	0.76	67.05	70.75	0.68	0.85
	September	62	1.93	63.29	66.99	1.72	2.16
	October	52	5.01	53.24	56.94	4.46	5.61
	November	47	8.71	48.30	52.00	7.75	9.76
	December	38	2.29	39.18	42.88	2.04	2.56
2010	January	46	5.66	47.73	51.43	5.04	6.34
	February	46	1.88	47.72	51.42	1.67	2.11
	March	46	2.82	47.50	51.20	2.51	3.16
	April	49	2.69	50.63	54.33	2.39	3.01
	May	53	2.70	54.21	57.91	2.40	3.02
	June	58	1.25	59.45	63.15	1.11	1.40
	July	64	0.16	65.63	69.33	0.14	0.18
	August	65	0.74	66.08	69.78	0.66	0.83
	September	60	2.77	61.59	65.29	2.47	3.10
	October	52	3.23	53.82	57.52	2.87	3.62
	November	44	4.19	45.23	48.93	3.73	4.69
	December	43	7.34	44.31	48.01	6.53	8.22
2011	January	42	3.99	43.82	47.52	3.55	4.47
	February	40	2.27	41.80	45.50	2.02	2.54
	March	43	5.44	44.82	48.52	4.84	6.09
	April	46	2.94	47.27	50.97	2.62	3.29
	May	52	2.74	53.60	57.30	2.44	3.07
	June	59	1.28	60.17	63.87	1.14	1.43
	July	62	0.54	63.98	67.68	0.48	0.60
	August	65	0.08	66.78	70.48	0.07	0.09
	September	63	0.84	64.40	68.10	0.75	0.94
	October	52	2.71	53.79	57.49	2.41	3.04
	November	43	5.54	44.50	48.20	4.93	6.20
	December	40	0.96	41.95	45.65	0.85	1.08

WEATHER STATION 15:

Figure 51. Seattle Temperature and 2040 Projections - Weather Station 15, 2011

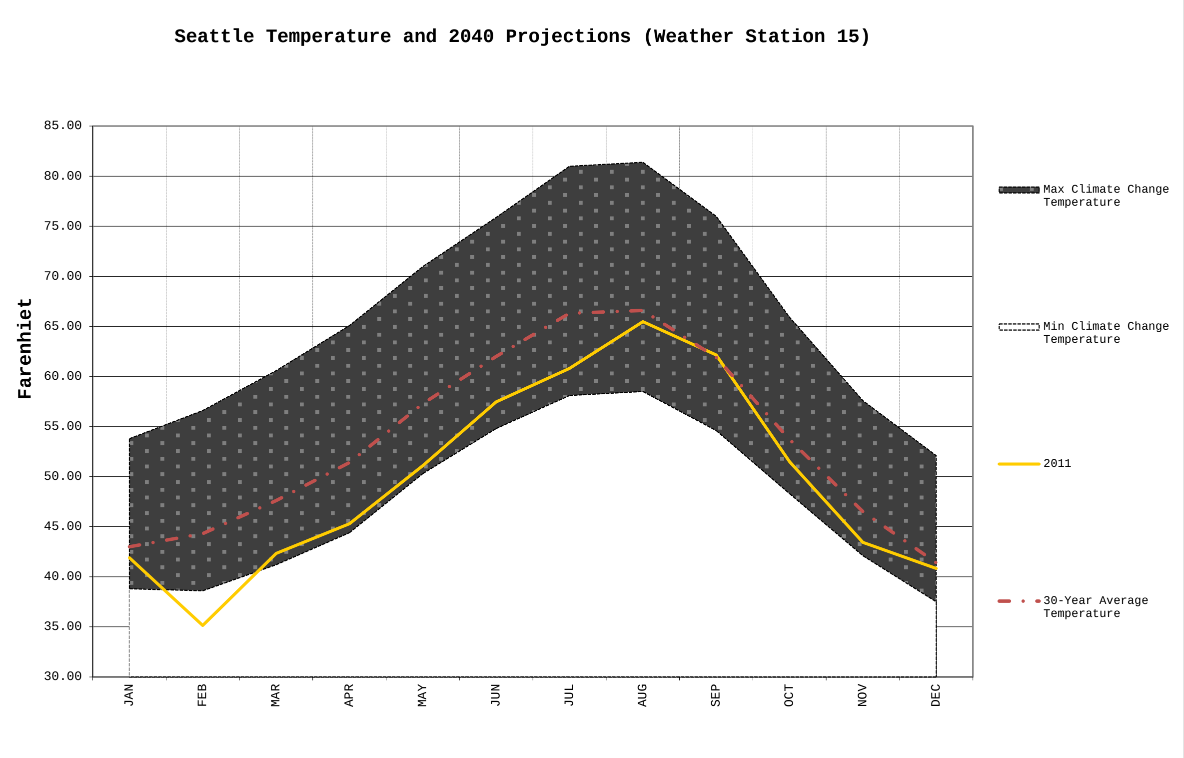


Figure 52. Seattle Precipitation and 2040 Projections - Weather Station 15, 2011

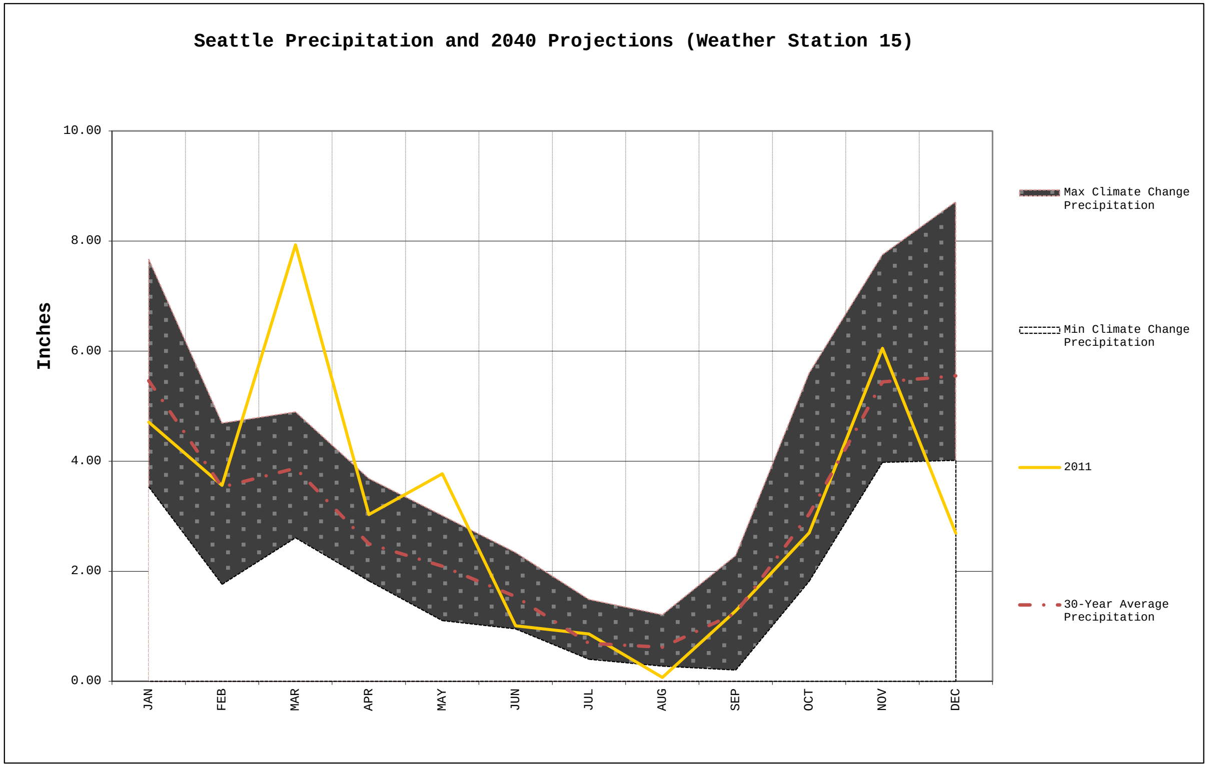


Table 31. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 15, 2011

		Weather Station 15		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2011	January	42	4.71	43.40	47.10	4.19	5.28
	February	35	3.56	36.64	40.34	3.17	3.99
	March	42	7.93	43.82	47.52	7.06	8.88
	April	45	3.03	46.79	50.49	2.70	3.39
	May	51	3.77	52.60	56.30	3.36	4.22
	June	57	1.01	58.96	62.66	0.90	1.13
	July	61	0.86	62.31	66.01	0.77	0.96
	August	65	0.07	66.98	70.68	0.06	0.08
	September	62	1.28	63.65	67.35	1.14	1.43
	October	51	2.70	52.98	56.68	2.40	3.02
	November	43	6.05	44.93	48.63	5.38	6.78
	December	41	2.69	42.34	46.04	2.39	3.01

WEATHER STATION 16:

Figure 53. Seattle Temperature and 2040 Projections - Weather Station 16, 2010 - 2011

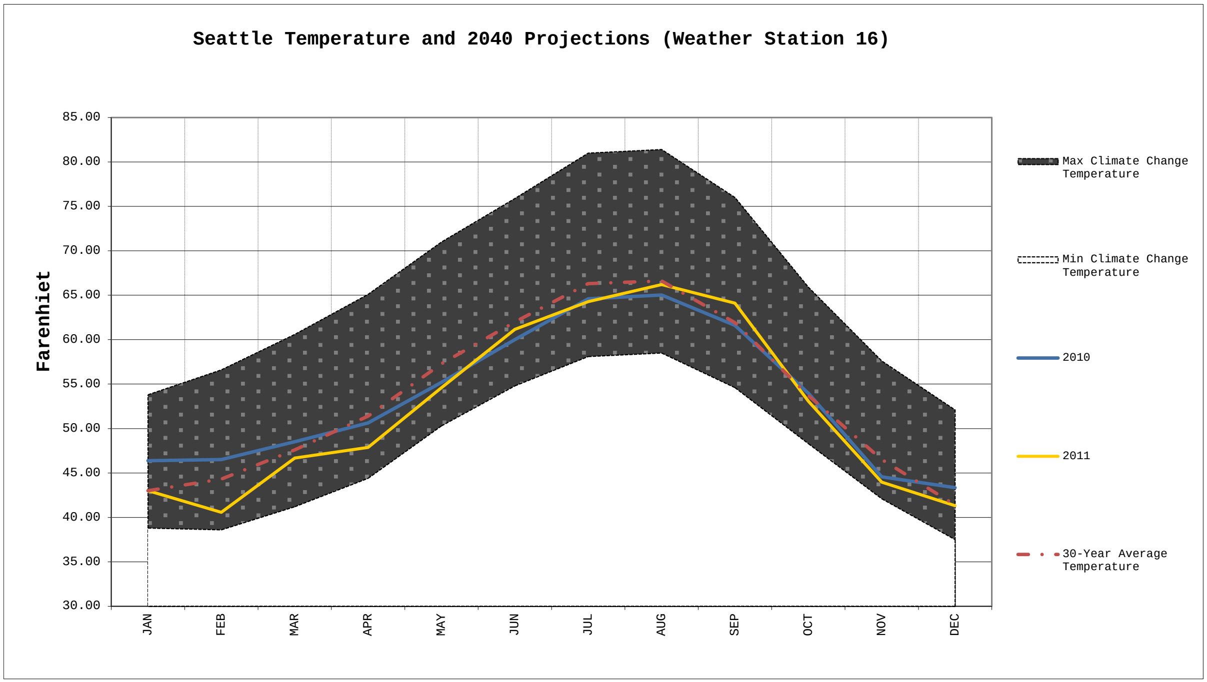


Figure 54. Seattle Precipitation and 2040 Projections - Weather Station 17, 2010 - 2011

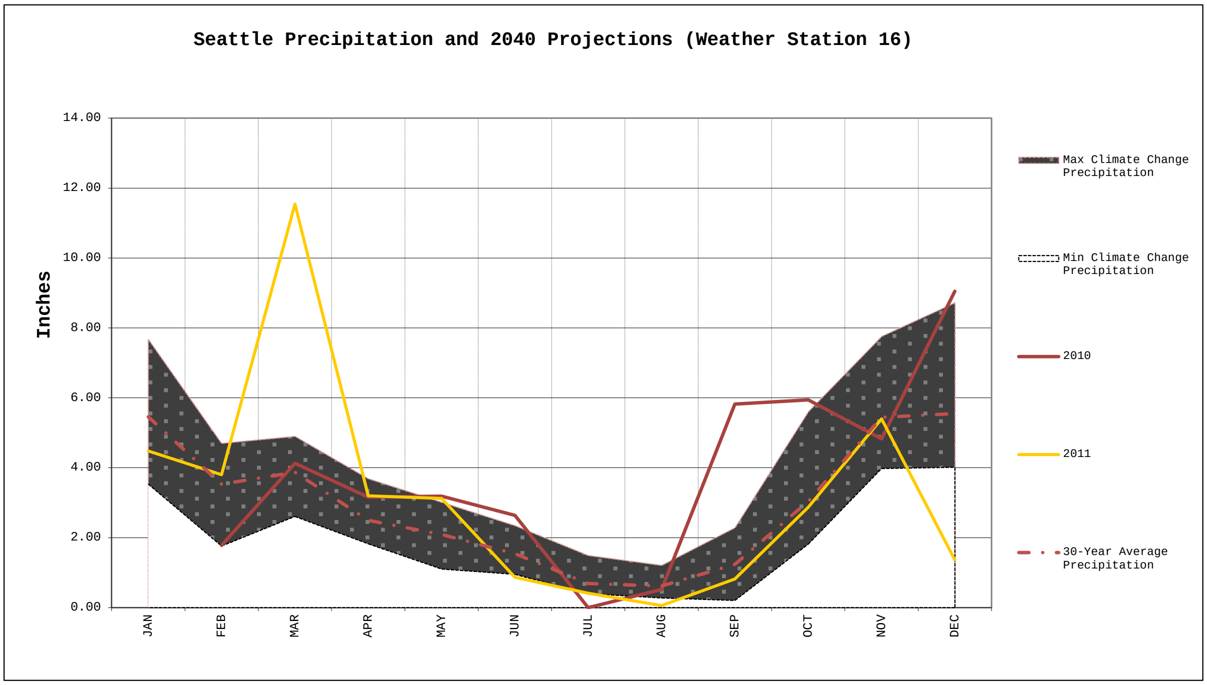


Table 32. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 16, 2010 - 2011

		Weather Station 16		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2010	January	46		47.89	51.59	0.00	0.00
	February	47	1.78	48.00	51.70	1.58	1.99
	March	49	4.13	50.02	53.72	3.68	4.63
	April	51	3.16	52.13	55.83	2.81	3.54
	May	55	3.19	56.69	60.39	2.84	3.57
	June	60	2.64	61.50	65.20	2.35	2.96
	July	65	0.00	66.11	69.81	0.00	0.00
	August	65	0.52	66.54	70.24	0.46	0.58
	September	62	5.82	63.10	66.80	5.18	6.52
	October	54	5.94	55.47	59.17	5.29	6.65
	November	45	4.83	46.07	49.77	4.30	5.41
	December	43	9.05	44.85	48.55	8.05	10.14
2011	January	43	4.48	44.50	48.20	3.99	5.02
	February	41	3.80	42.07	45.77	3.38	4.26
	March	47	11.54	48.18	51.88	10.27	12.92
	April	48	3.20	49.37	53.07	2.85	3.58
	May	55	3.12	56.11	59.81	2.78	3.49
	June	61	0.87	62.65	66.35	0.77	0.97
	July	64	0.41	65.79	69.49	0.36	0.46
	August	66	0.06	67.69	71.39	0.05	0.07
	September	64	0.82	65.60	69.30	0.73	0.92
	October	53	2.87	54.56	58.26	2.55	3.21
	November	44	5.40	45.47	49.17	4.81	6.05
	December	41	1.37	42.82	46.52	1.22	1.53

WEATHER STATION 17:

Figure 55. Seattle Temperature and 2040 Projections - Weather Station 17, 2010 - 2011

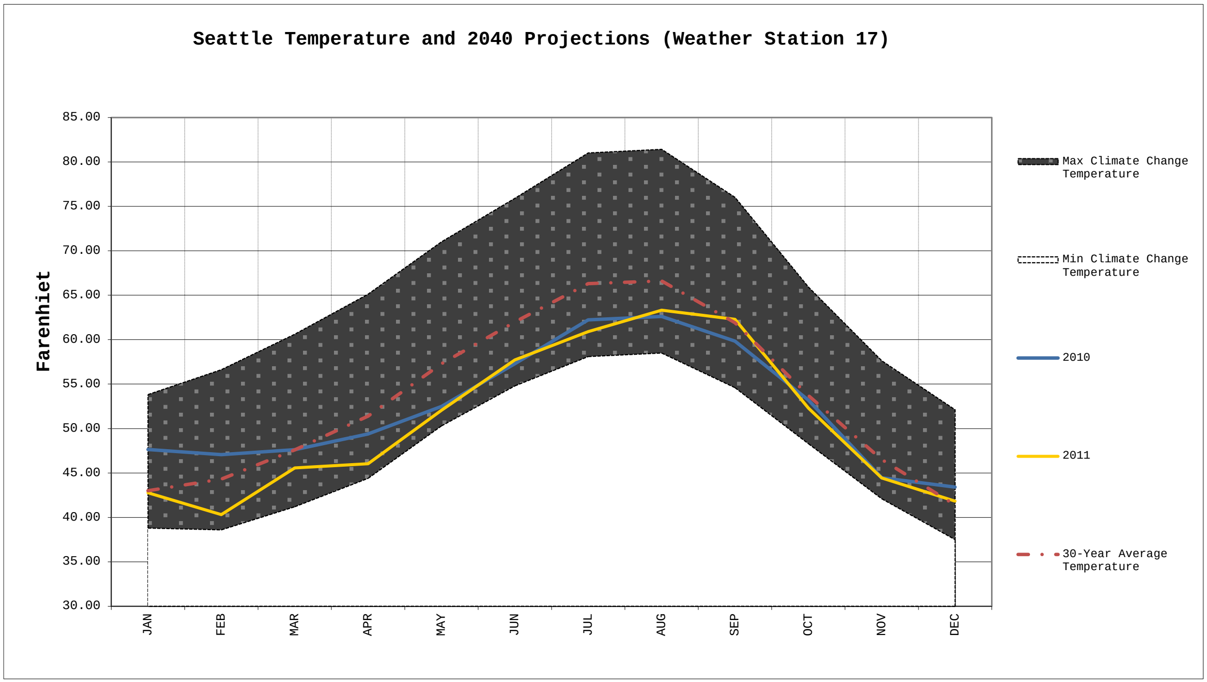


Figure 56. Seattle Precipitation and 2040 Projections - Weather Station 17, 2010 - 2011

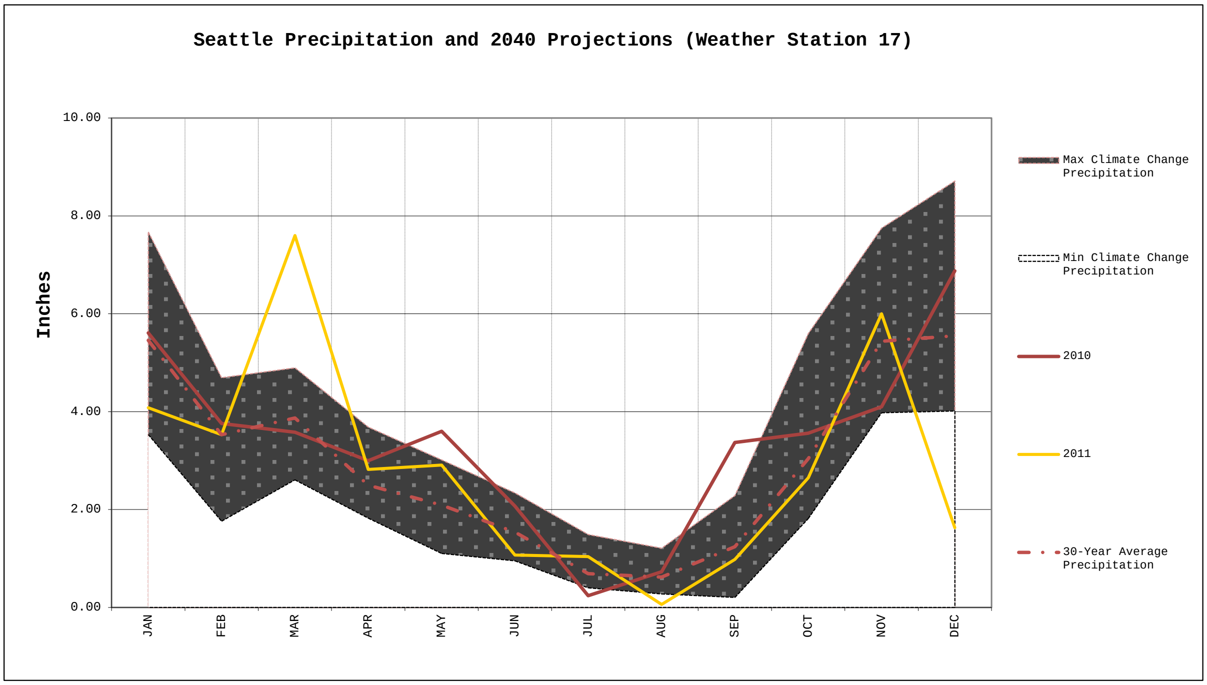


Table 33. Seattle Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 17, 2010 - 2011

		Weather Station 17		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2010	January	48	5.61	49.14	52.84	4.99	6.28
	February	47	3.76	48.57	52.27	3.35	4.21
	March	48	3.58	49.11	52.81	3.19	4.01
	April	49	3.00	50.90	54.60	2.67	3.36
	May	52	3.60	53.98	57.68	3.20	4.03
	June	57	2.07	58.80	62.50	1.84	2.32
	July	62	0.24	63.73	67.43	0.21	0.27
	August	63	0.73	64.11	67.81	0.65	0.82
	September	60	3.37	61.33	65.03	3.00	3.77
	October	53	3.56	54.70	58.40	3.17	3.99
	November	44	4.10	45.97	49.67	3.65	4.59
	December	43	6.88	44.91	48.61	6.12	7.71
2011	January	43	4.08	44.27	47.97	3.63	4.57
	February	40	3.53	41.82	45.52	3.14	3.95
	March	46	7.60	47.08	50.78	6.76	8.51
	April	46	2.82	47.53	51.23	2.51	3.16
	May	52	2.91	53.56	57.26	2.59	3.26
	June	58	1.07	59.23	62.93	0.95	1.20
	July	61	1.04	62.40	66.10	0.93	1.16
	August	63	0.06	64.82	68.52	0.05	0.07
	September	62	0.98	63.80	67.50	0.87	1.10
	October	52	2.65	53.79	57.49	2.36	2.97
	November	44	6.00	45.93	49.63	5.34	6.72
	December	42	1.63	43.34	47.04	1.45	1.83

Appendix C: Everett UHI Tables and Graphs

WEATHER STATION 1:

Figure 57. Everett Temperature and 2040 Projections - Weather Station 1, 2009 - 2011

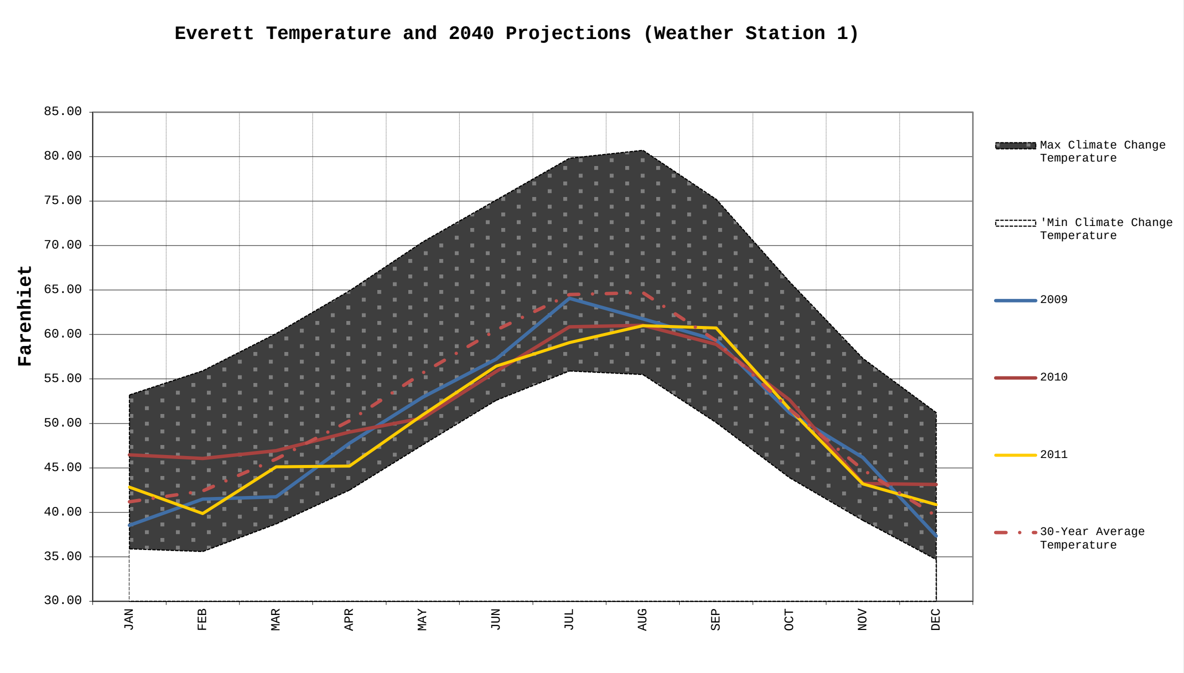


Figure 58. Everett Precipitation and 2040 Projections - Weather Station 1, 2009 - 2011

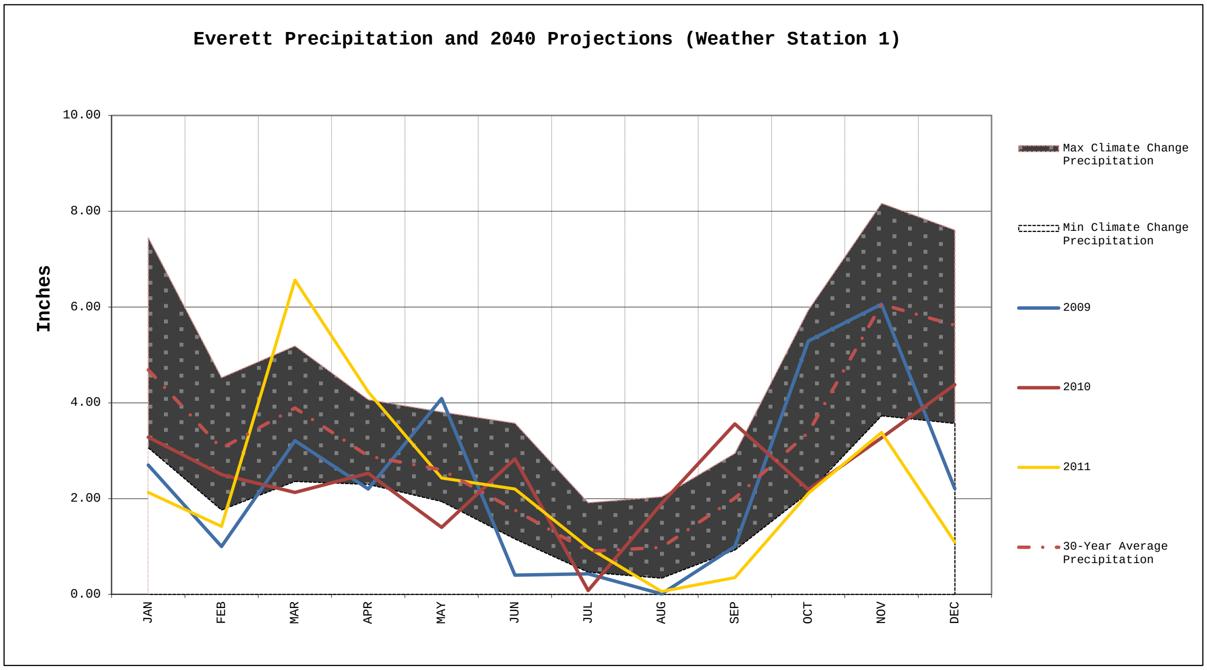


Table 34. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 1, 2009 - 2011

		Weather Station 1		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2009	January	39	2.70	40.05	43.75	2.40	3.02
	February	42	1.00	43.00	46.70	0.89	1.12
	March	42	3.21	43.24	46.94	2.86	3.60
	April	48	2.20	49.27	52.97	1.96	2.46
	May	53	4.09	54.47	58.17	3.64	4.58
	June	57	0.40	58.72	62.42	0.36	0.45
	July	64	0.43	65.56	69.26	0.38	0.48
	August	62	0.01	63.26	66.96	0.01	0.01
	September	59	1.00	60.87	64.57	0.89	1.12
	October	51	5.29	52.69	56.39	4.71	5.92
	November	46	6.06	47.67	51.37	5.39	6.79
	December	37	2.21	38.85	42.55	1.97	2.48
2010	January	46	3.28	47.97	51.67	2.92	3.67
	February	46	2.50	47.57	51.27	2.23	2.80
	March	47	2.13	48.44	52.14	1.90	2.39
	April	49	2.53	50.53	54.23	2.25	2.83
	May	51	1.40	52.12	55.82	1.25	1.57
	June	56	2.83	57.33	61.03	2.52	3.17
	July	61	0.08	62.37	66.07	0.07	0.09
	August	61	1.90	62.53	66.23	1.69	2.13
	September	59	3.56	60.40	64.10	3.17	3.99
	October	53	2.19	54.15	57.85	1.95	2.45
	November	43	3.27	44.73	48.43	2.91	3.66
	December	43	4.38	44.63	48.33	3.90	4.91
2011	January	43	2.13	44.34	48.04	1.90	2.39
	February	40	1.42	41.36	45.06	1.26	1.59
	March	45	6.56	46.63	50.33	5.84	7.35
	April	45	4.23	46.70	50.40	3.76	4.74
	May	51	2.43	52.47	56.17	2.16	2.72
	June	56	2.20	57.93	61.63	1.96	2.46
	July	59	0.98	60.60	64.30	0.87	1.10
	August	61	0.06	62.50	66.20	0.05	0.07
	September	61	0.35	62.23	65.93	0.31	0.39
	October	52	2.11	53.11	56.81	1.88	2.36
	November	43	3.38	44.70	48.40	3.01	3.79
	December	41	1.09	42.37	46.07	0.97	1.22

WEATHER STATION 2:

Figure 59. Everett Temperature and 2040 Projections - Weather Station 2, 2011

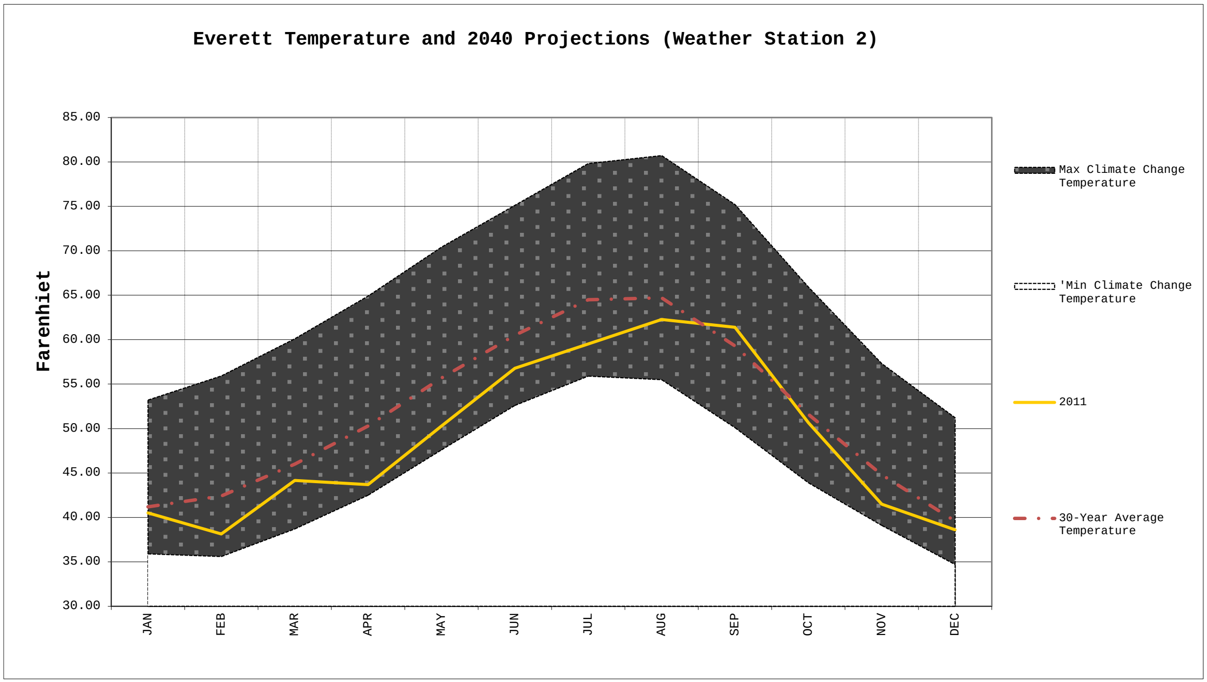


Figure 60. Everett Precipitation and 2040 Projections - Weather Station 2, 2011

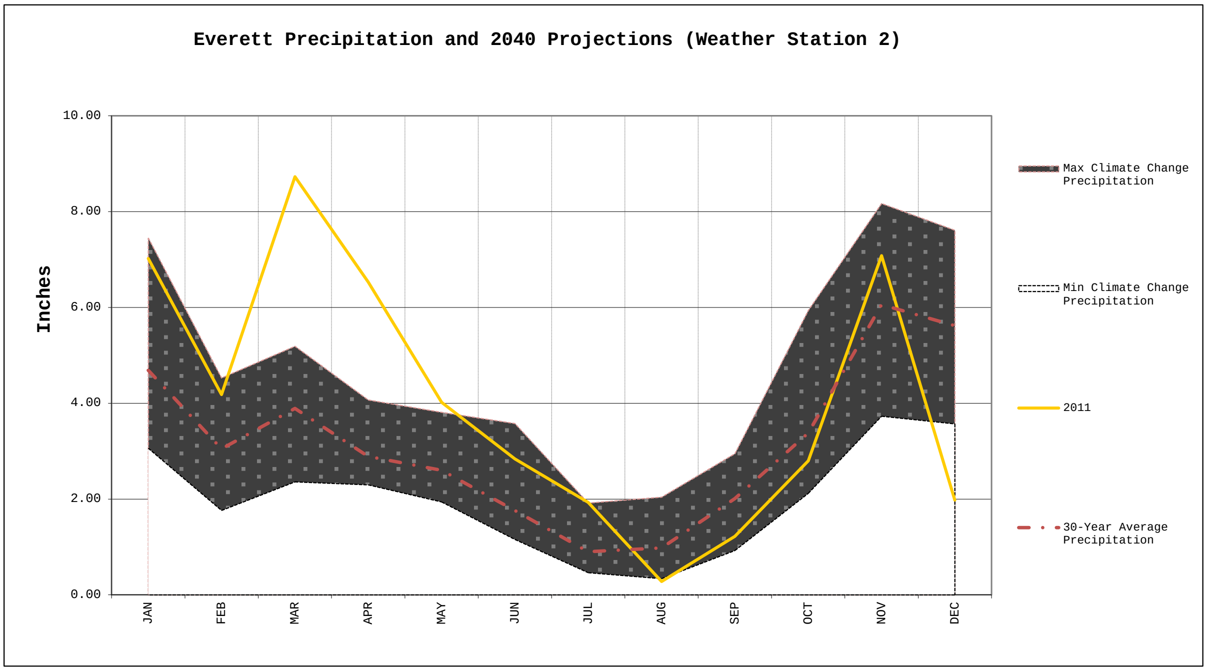


Table 35. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 2, 2011

		Weather Station 2		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2011	January	41	7.02	42.02	45.72	6.25	7.86
	February	38	4.18	39.64	43.34	3.72	4.68
	March	44	8.73	45.66	49.36	7.77	9.78
	April	44	6.53	45.20	48.90	5.81	7.31
	May	50	4.02	51.79	55.49	3.58	4.50
	June	57	2.84	58.29	61.99	2.53	3.18
	July	60	1.93	61.02	64.72	1.72	2.16
	August	62	0.28	63.77	67.47	0.25	0.31
	September	61	1.22	62.90	66.60	1.09	1.37
	October	51	2.80	52.14	55.84	2.49	3.14
	November	42	7.08	43.00	46.70	6.30	7.93
	December	39	1.98	40.11	43.81	1.76	2.22

WEATHER STATION 3:

Figure 61. Everett Temperature and 2040 Projections - Weather Station 3, 2010 - 2011

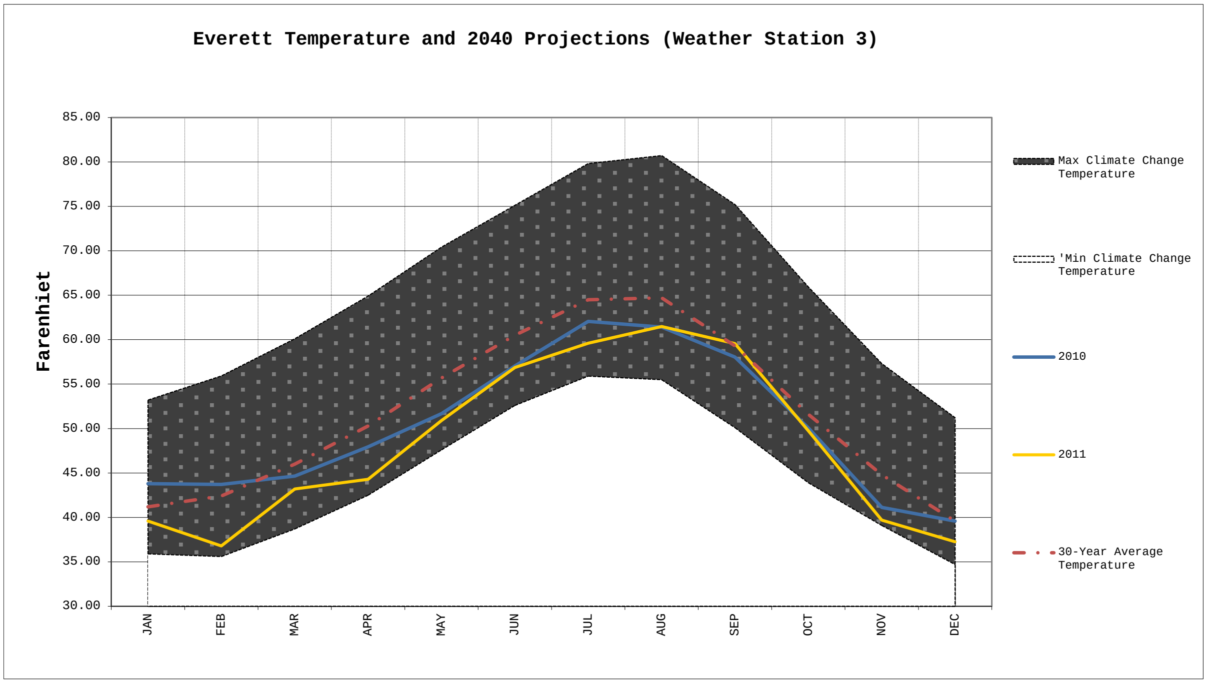


Figure 62. Everett Precipitation and 2040 Projections - Weather Station 3, 2010 - 2011

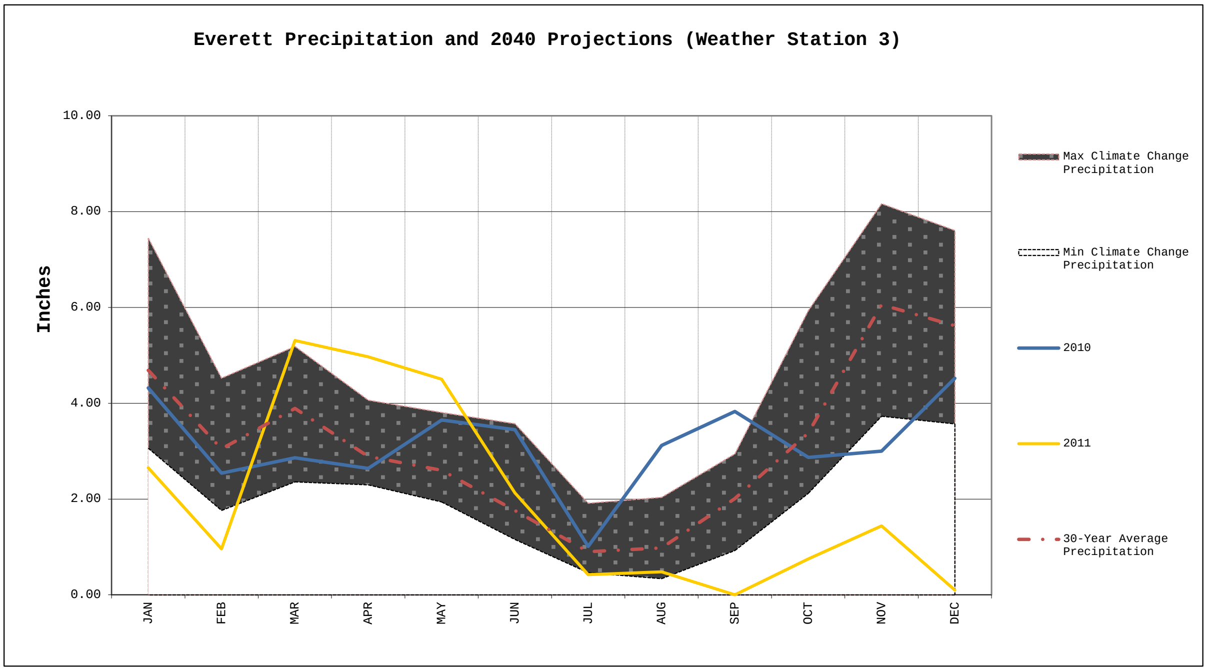


Table 36. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 3, 2010 - 2011

		Weather Station 3		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2010	January	44	4.32	45.31	49.01	3.84	4.84
	February	44	2.54	45.21	48.91	2.26	2.84
	March	45	2.86	46.15	49.85	2.55	3.20
	April	48	2.64	49.43	53.13	2.35	2.96
	May	52	3.65	53.18	56.88	3.25	4.09
	June	57	3.45	58.53	62.23	3.07	3.86
	July	62	1.01	63.56	67.26	0.90	1.13
	August	61	3.12	62.92	66.62	2.78	3.49
	September	58	3.83	59.53	63.23	3.41	4.29
	October	50	2.87	51.56	55.26	2.55	3.21
	November	41	3.00	42.63	46.33	2.67	3.36
	December	40	4.52	41.08	44.78	4.02	5.06
2011	January	40	2.65	41.08	44.78	2.36	2.97
	February	37	0.96	38.29	41.99	0.85	1.08
	March	43	5.31	44.69	48.39	4.73	5.95
	April	44	4.97	45.79	49.49	4.42	5.57
	May	51	4.50	52.40	56.10	4.01	5.04
	June	57	2.13	58.37	62.07	1.90	2.39
	July	60	0.42	61.11	64.81	0.37	0.47
	August	61	0.48	62.98	66.68	0.43	0.54
	September	60	0.00	61.07	64.77	0.00	0.00
	October	50	0.75	51.24	54.94	0.67	0.84
	November	40	1.44	41.20	44.90	1.28	1.61
	December	37	0.10	38.76	42.46	0.09	0.11

WEATHER STATION 4:

Figure 63. Everett Temperature and 2040 Projections - Weather Station 4, 2009 - 2011

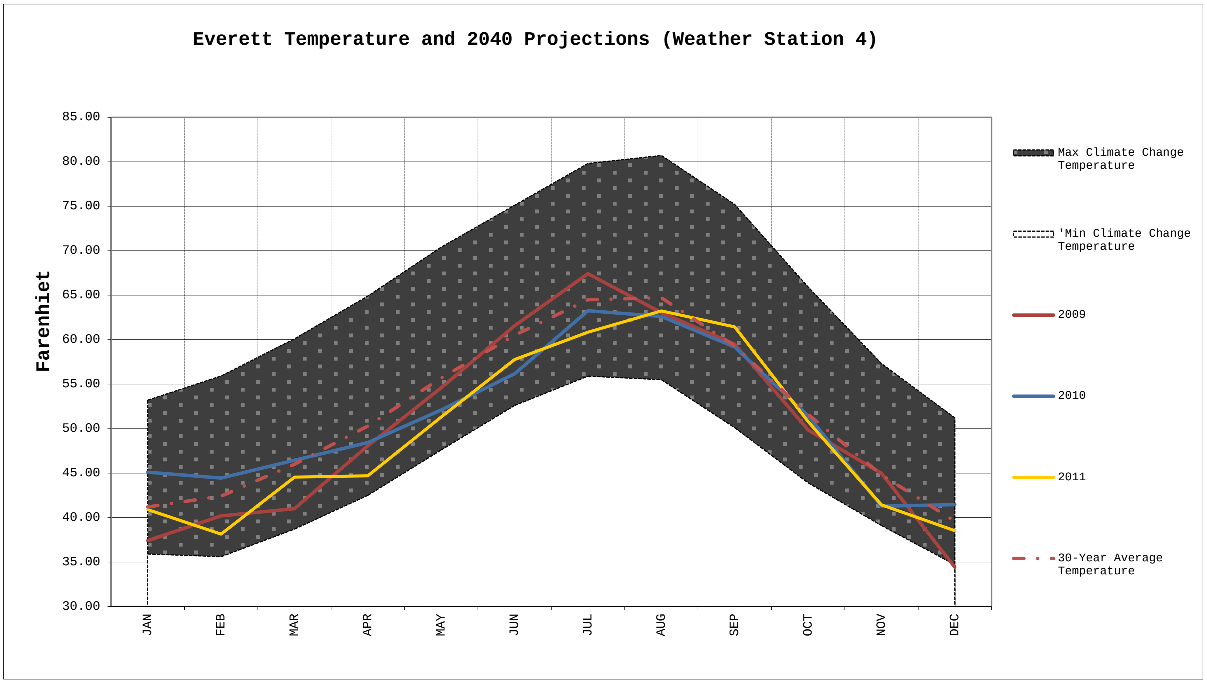


Figure 64. Everett Precipitation and 2040 Projections - Weather Station 4, 2009 - 2011

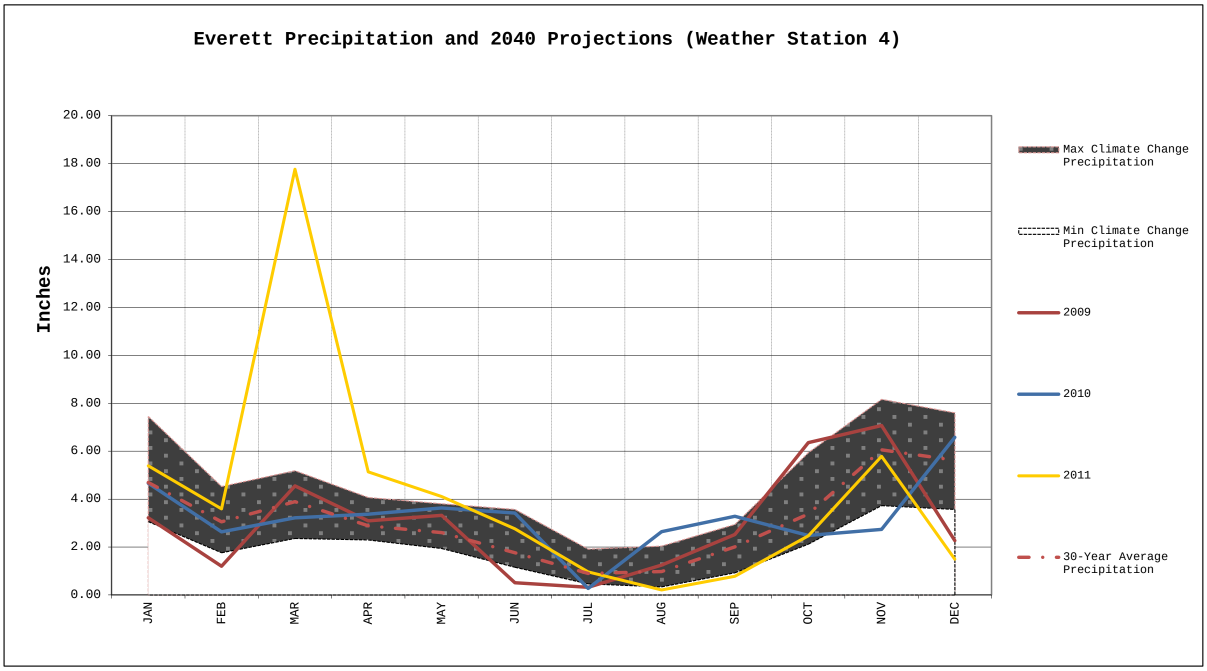


Table 37. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 4, 2009 - 2011

		Weather Station 4		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2009	January	37	3.22	38.92	42.62	2.87	3.61
	February	40	1.20	41.68	45.38	1.07	1.34
	March	41	4.55	42.50	46.20	4.05	5.10
	April	48	3.09	49.57	53.27	2.75	3.46
	May	55	3.32	56.11	59.81	2.95	3.72
	June	62	0.51	63.07	66.77	0.45	0.57
	July	67	0.32	68.92	72.62	0.28	0.36
	August	63	1.25	64.53	68.23	1.11	1.40
	September	60	2.52	61.00	64.70	2.24	2.82
	October	50	6.36	51.34	55.04	5.66	7.12
	November	45	7.07	46.47	50.17	6.29	7.92
	December	34	2.27	35.92	39.62	2.02	2.54
2010	January	45	4.66	46.60	50.30	4.15	5.22
	February	44	2.63	45.93	49.63	2.34	2.95
	March	46	3.22	47.95	51.65	2.87	3.61
	April	48	3.37	49.93	53.63	3.00	3.77
	May	52	3.63	53.60	57.30	3.23	4.07
	June	56	3.42	57.66	61.36	3.04	3.83
	July	63	0.27	64.76	68.46	0.24	0.30
	August	63	2.64	64.11	67.81	2.35	2.96
	September	59	3.28	60.67	64.37	2.92	3.67
	October	51	2.48	52.92	56.62	2.21	2.78
	November	41	2.74	42.77	46.47	2.44	3.07
	December	41	6.58	42.95	46.65	5.86	7.37
2011	January	41	5.39	42.40	46.10	4.80	6.04
	February	38	3.59	39.64	43.34	3.20	4.02
	March	45	17.77	46.05	49.75	15.82	19.90
	April	45	5.14	46.20	49.90	4.57	5.76
	May	51	4.11	52.82	56.52	3.66	4.60
	June	58	2.76	59.27	62.97	2.46	3.09
	July	61	0.96	62.34	66.04	0.85	1.08
	August	63	0.21	64.73	68.43	0.19	0.24
	September	61	0.78	62.93	66.63	0.69	0.87
	October	51	2.47	52.27	55.97	2.20	2.77
	November	41	5.79	42.93	46.63	5.15	6.48
	December	39	1.49	40.02	43.72	1.33	1.67

WEATHER STATION 5:

Figure 65. Everett Temperature and 2040 Projections - Weather Station 5, 2004 - 2011

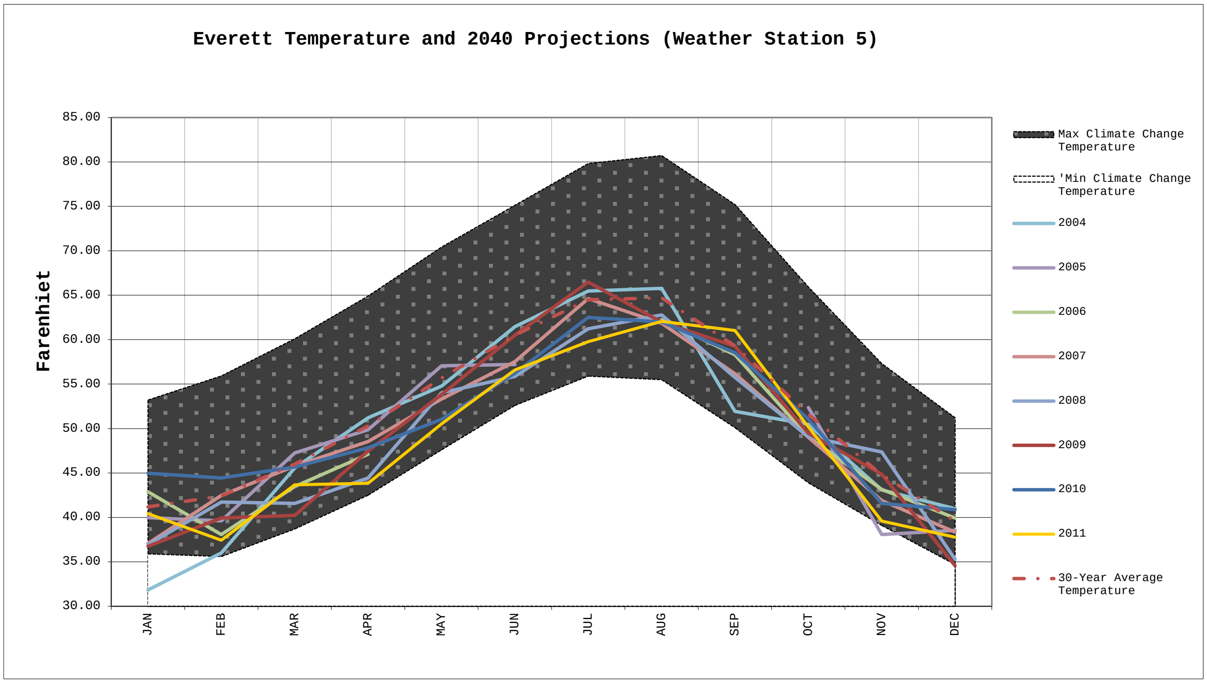


Figure 66. Everett Precipitation and 2040 Projections - Weather Station 5, 2004 - 2011

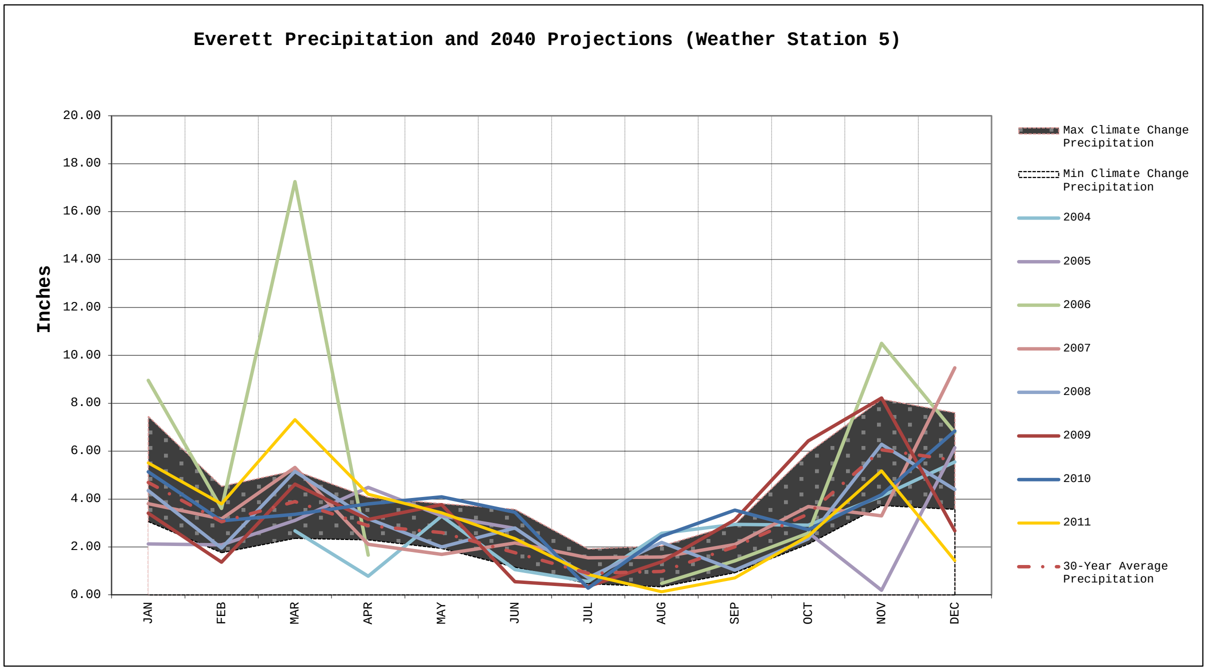


Table 38. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 5, 2004 - 2011

		Weather Station 5		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2004	January	32		33.34	37.04	0.00	0.00
	February	36		37.50	41.20	0.00	0.00
	March	46	2.67	47.08	50.78	2.38	2.99
	April	51	0.78	52.70	56.40	0.69	0.87
	May	55	3.29	56.27	59.97	2.93	3.68
	June	61	1.06	62.97	66.67	0.94	1.19
	July	65	0.56	66.98	70.68	0.50	0.63
	August	66	2.57	67.27	70.97	2.29	2.88
	September	52	2.94	53.43	57.13	2.62	3.29
	October	50	2.91	51.95	55.65	2.59	3.26
	November	43	4.12	44.60	48.30	3.67	4.61
	December	41	5.55	42.47	46.17	4.94	6.22
2005	January	40	2.13	41.47	45.17	1.90	2.39
	February	40	2.09	41.11	44.81	1.86	2.34
	March	47	3.11	48.76	52.46	2.77	3.48
	April	50	4.49	51.37	55.07	4.00	5.03
	May	57	3.30	58.56	62.26	2.94	3.70
	June	57	2.78	58.70	62.40	2.47	3.11
	July			1.50	5.20	0.00	0.00
	August	65	0.25	66.90	70.60	0.22	0.28
	September			1.50	5.20	0.00	0.00
	October	52	2.60	53.86	57.56	2.31	2.91
	November	38	0.20	39.57	43.27	0.17	0.22
	December	39	6.14	40.05	43.75	5.46	6.88
2006	January	43	8.96	44.39	48.09	7.97	10.04
	February	38	3.61	39.57	43.27	3.21	4.04
	March	43	17.25	44.97	48.67	15.35	19.32
	April	47	1.66	48.62	52.32	1.48	1.86
	May			1.50	5.20	0.00	0.00
	June			1.50	5.20	0.00	0.00
	July			1.50	5.20	0.00	0.00
	August	62	0.48	63.73	67.43	0.43	0.54
	September	58	1.42	59.80	63.50	1.26	1.59
	October	49	2.58	50.53	54.23	2.30	2.89
	November	43	10.50	44.67	48.37	9.35	11.76
	December	40	6.78	41.44	45.14	6.03	7.59
2007	January	37	3.81	38.56	42.26	3.39	4.27
	February	42	3.17	43.96	47.66	2.82	3.55
	March	46	5.32	47.27	50.97	4.73	5.96
	April	49	2.11	50.03	53.73	1.88	2.36
	May	53	1.69	54.82	58.52	1.50	1.89
	June	58	2.17	59.03	62.73	1.93	2.43
	July	65	1.55	66.11	69.81	1.38	1.74
	August	62	1.58	63.34	67.04	1.41	1.77
	September	56	2.10	57.67	61.37	1.87	2.35

	October	49	3.69	50.50	54.20	3.28	4.13
	November	42	3.30	43.40	47.10	2.94	3.70
	December	38	9.48	39.85	43.55	8.44	10.62
2008	January	37	4.35	38.44	42.14	3.87	4.87
	February	42	1.95	43.22	46.92	1.74	2.18
	March	42	5.15	43.08	46.78	4.58	5.77
	April	44	3.18	45.94	49.64	2.83	3.56
	May	54	2.00	55.53	59.23	1.78	2.24
	June	56	2.79	57.37	61.07	2.48	3.12
	July	61	0.72	62.73	66.43	0.64	0.81
	August	63	2.19	64.27	67.97	1.95	2.45
	September	56	1.03	57.27	60.97	0.92	1.15
	October	49	2.34	50.56	54.26	2.08	2.62
	November	47	6.29	48.87	52.57	5.60	7.04
	December	35	4.40	36.79	40.49	3.92	4.93
2009	January	37	3.41	38.24	41.94	3.03	3.82
	February	40	1.37	41.43	45.13	1.22	1.53
	March	40	4.62	41.73	45.43	4.11	5.17
	April	47	3.15	48.97	52.67	2.80	3.53
	May	54	3.77	55.34	59.04	3.36	4.22
	June	61	0.55	62.00	65.70	0.49	0.62
	July	66	0.35	67.98	71.68	0.31	0.39
	August	62	1.38	63.46	67.16	1.23	1.55
	September	59	3.13	60.77	64.47	2.79	3.51
	October	49	6.43	50.95	54.65	5.72	7.20
	November	45	8.22	46.37	50.07	7.32	9.21
	December	35	2.67	36.08	39.78	2.38	2.99
2010	January	45	5.14	46.47	50.17	4.57	5.76
	February	44	3.09	45.93	49.63	2.75	3.46
	March	46	3.36	47.18	50.88	2.99	3.76
	April	48	3.80	49.33	53.03	3.38	4.26
	May	51	4.09	52.53	56.23	3.64	4.58
	June	56	3.45	57.73	61.43	3.07	3.86
	July	63	0.28	64.02	67.72	0.25	0.31
	August	62	2.45	63.50	67.20	2.18	2.74
	September	59	3.54	60.03	63.73	3.15	3.96
	October	51	2.72	52.53	56.23	2.42	3.05
	November	42	4.18	43.07	46.77	3.72	4.68
	December	41	6.84	42.37	46.07	6.09	7.66
2011	January	40	5.51	41.92	45.62	4.90	6.17
	February	37	3.80	38.93	42.63	3.38	4.26
	March	44	7.32	45.18	48.88	6.51	8.20
	April	44	4.20	45.33	49.03	3.74	4.70
	May	51	3.43	52.02	55.72	3.05	3.84
	June	57	2.35	58.10	61.80	2.09	2.63
	July	60	0.85	61.27	64.97	0.76	0.95
	August	62	0.13	63.56	67.26	0.12	0.15
	September	61	0.71	62.53	66.23	0.63	0.80
	October	50	2.46	51.66	55.36	2.19	2.76
	November	40	5.18	41.09	44.79	4.61	5.80
	December	38	1.43	39.27	42.97	1.27	1.60

WEATHER STATION 6:

Figure 67. Everett Temperature and 2040 Projections - Weather Station 6, 2007 - 2011

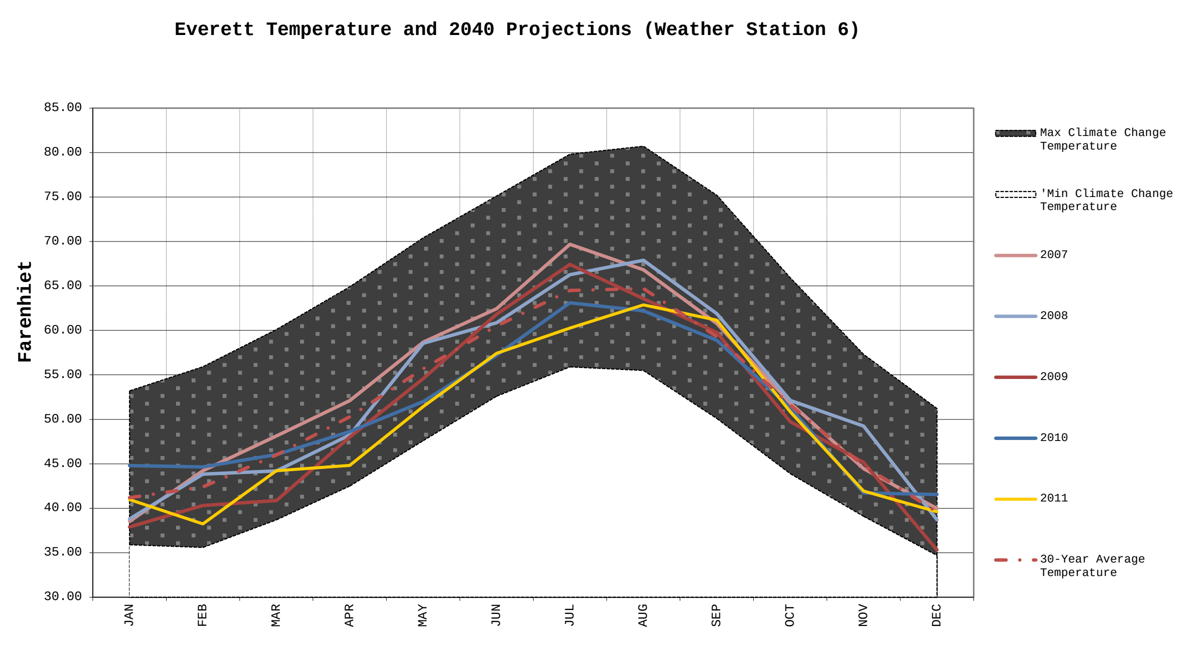


Figure 68. Everett Precipitation and 2040 Projections - Weather Station 6, 2007 - 2011

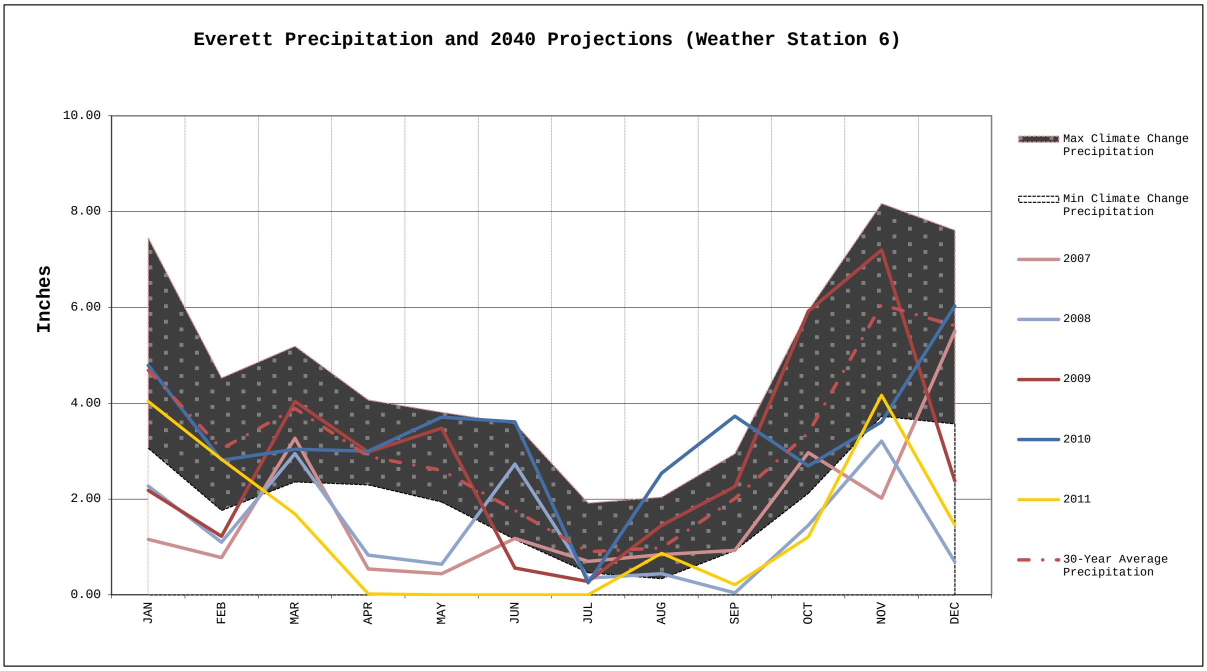


Table 39. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 6, 2007 - 2011

		Weather Station 6		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2007	January	39	1.16	40.02	43.72	1.03	1.30
	February	44	0.78	45.71	49.41	0.69	0.87
	March	48	3.27	49.64	53.34	2.91	3.66
	April	52	0.54	53.60	57.30	0.48	0.60
	May	59	0.44	60.18	63.88	0.39	0.49
	June	62	1.18	63.95	67.65	1.05	1.32
	July	70	0.70	71.19	74.89	0.62	0.78
	August	67	0.84	68.32	72.02	0.75	0.94
	September	61	0.93	62.29	65.99	0.83	1.04
	October	52	2.97	53.34	57.04	2.64	3.33
	November	44	2.02	45.97	49.67	1.80	2.26
	December	40	5.50	41.47	45.17	4.90	6.16
2008	January	39	2.27	40.31	44.01	2.02	2.54
	February	44	1.10	45.34	49.04	0.98	1.23
	March	44	2.95	45.69	49.39	2.63	3.30
	April	48	0.83	49.73	53.43	0.74	0.93
	May	59	0.64	60.05	63.75	0.57	0.72
	June	61	2.73	62.37	66.07	2.43	3.06
	July	66	0.35	67.78	71.48	0.31	0.39
	August	68	0.44	69.39	73.09	0.39	0.49
	September	62	0.04	63.38	67.08	0.04	0.04
	October	52	1.45	53.63	57.33	1.29	1.62
	November	49	3.21	50.73	54.43	2.86	3.60
	December	39	0.69	40.21	43.91	0.61	0.77
2009	January	38	2.18	39.40	43.10	1.94	2.44
	February	40	1.22	41.82	45.52	1.09	1.37
	March	41	4.04	42.37	46.07	3.60	4.52
	April	48	2.98	49.50	53.20	2.65	3.34
	May	55	3.48	56.08	59.78	3.10	3.90
	June	62	0.56	63.33	67.03	0.50	0.63
	July	67	0.28	68.92	72.62	0.25	0.31
	August	64	1.45	65.08	68.78	1.29	1.62
	September	60	2.26	61.27	64.97	2.01	2.53
	October	50	5.92	51.24	54.94	5.27	6.63
	November	45	7.20	46.67	50.37	6.41	8.06
	December	35	2.38	36.82	40.52	2.12	2.67
2010	January	45	4.79	46.31	50.01	4.26	5.36
	February	45	2.81	46.14	49.84	2.50	3.15
	March	46	3.04	47.53	51.23	2.71	3.40
	April	49	3.00	50.13	53.83	2.67	3.36
	May	52	3.71	53.50	57.20	3.30	4.16
	June	57	3.61	58.70	62.40	3.21	4.04
	July	63	0.25	64.60	68.30	0.22	0.28
	August	62	2.54	63.70	67.40	2.26	2.84
	September	59	3.73	60.40	64.10	3.32	4.18

	October	51	2.69	52.82	56.52	2.39	3.01
	November	42	3.61	43.23	46.93	3.21	4.04
	December	42	6.03	43.05	46.75	5.37	6.75
2011	January	41	4.04	42.47	46.17	3.60	4.52
	February	38	2.83	39.75	43.45	2.52	3.17
	March	44	1.69	45.73	49.43	1.50	1.89
	April	45	0.02	46.33	50.03	0.02	0.02
	May	51	0.00	52.95	56.65	0.00	0.00
	June	57	0.00	58.93	62.63	0.00	0.00
	July	60	0.00	61.76	65.46	0.00	0.00
	August	63	0.87	64.37	68.07	0.77	0.97
	September	61	0.21	62.67	66.37	0.19	0.24
	October	51	1.21	52.34	56.04	1.08	1.36
	November	42	4.17	43.43	47.13	3.71	4.67
	December	40	1.46	41.11	44.81	1.30	1.64

WEATHER STATION 7:

Figure 69. Everett Temperature and 2040 Projections - Weather Station 7, 2008 - 2011

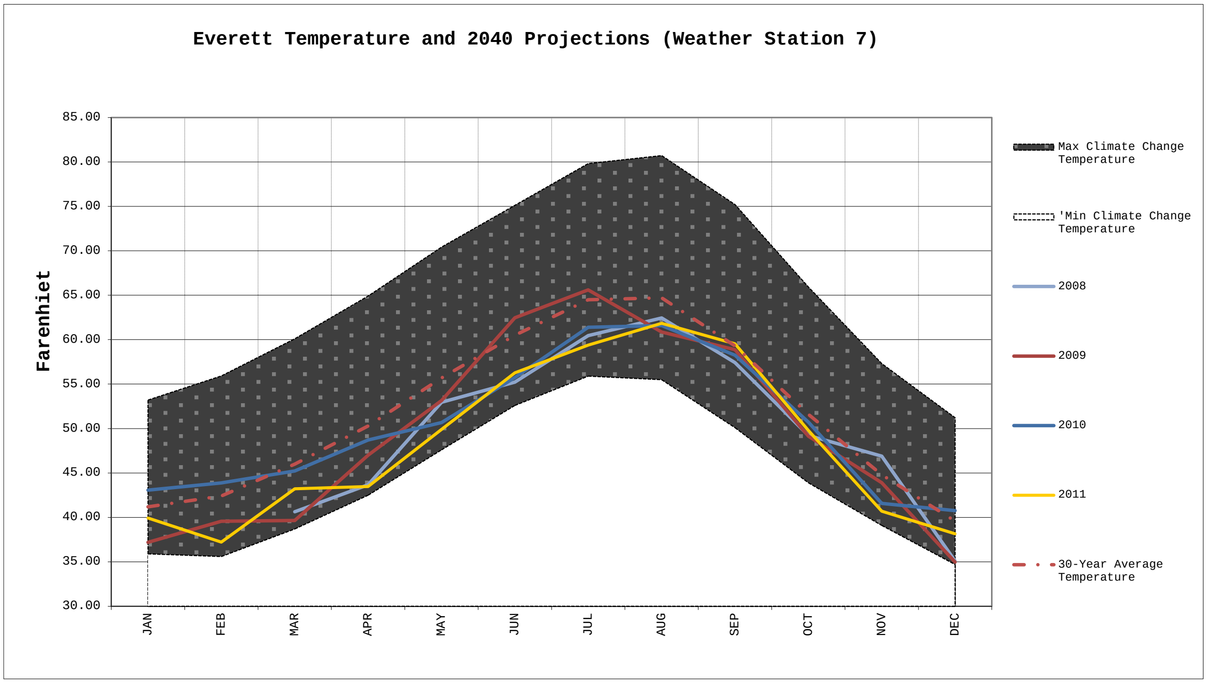


Figure 70. Everett Precipitation and 2040 Projections - Weather Station 7, 2008 - 2011

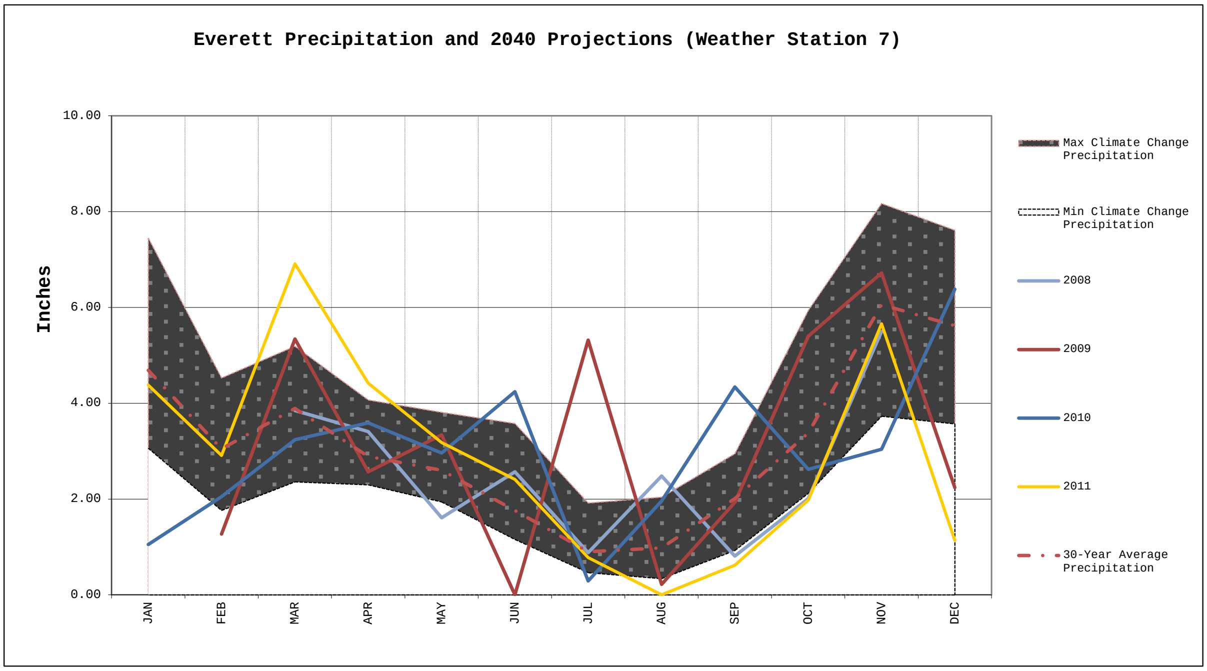


Table 40. Everett Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 7, 2008 - 2010

		Weather Station 7		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PREC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2008	January			1.50	5.20	0.00	0.00
	February			1.50	5.20	0.00	0.00
	March	41	3.85	42.14	45.84	3.43	4.31
	April	44	3.41	45.17	48.87	3.03	3.82
	May	53	1.61	54.47	58.17	1.43	1.80
	June	55	2.57	56.73	60.43	2.29	2.88
	July	60	0.88	61.95	65.65	0.78	0.99
	August	62	2.48	63.95	67.65	2.21	2.78
	September	57	0.81	58.93	62.63	0.72	0.91
	October	49	2.01	50.73	54.43	1.79	2.25
	November	47	5.50	48.40	52.10	4.90	6.16
	December	35		36.60	40.30	0.00	0.00
2009	January	37		38.69	42.39	0.00	0.00
	February	40	1.27	41.07	44.77	1.13	1.42
	March	40	5.34	41.15	44.85	4.75	5.98
	April	47	2.57	48.50	52.20	2.29	2.88
	May	53	3.34	54.66	58.36	2.97	3.74
	June	62	0.00	63.97	67.67	0.00	0.00
	July	66	5.32	67.11	70.81	4.73	5.96
	August	61	0.22	62.37	66.07	0.20	0.25
	September	59	1.93	60.37	64.07	1.72	2.16
	October	49	5.40	50.63	54.33	4.81	6.05
	November	44	6.72	45.40	49.10	5.98	7.53
	December	35	2.24	36.47	40.17	1.99	2.51
2010	January	43	1.05	44.56	48.26	0.93	1.18
	February	44	2.05	45.39	49.09	1.82	2.30
	March	45	3.24	46.73	50.43	2.88	3.63
	April	49	3.59	50.20	53.90	3.20	4.02
	May	51	2.96	52.17	55.87	2.63	3.32
	June	56	4.24	57.23	60.93	3.77	4.75
	July	61	0.29	62.89	66.59	0.26	0.32
	August	62	1.96	63.08	66.78	1.74	2.20
	September	58	4.34	59.77	63.47	3.86	4.86
	October	51	2.62	52.21	55.91	2.33	2.93
	November	42	3.04	43.07	46.77	2.71	3.40
	December	41	6.38	42.27	45.97	5.68	7.15
2011	January	40	4.38	41.44	45.14	3.90	4.91
	February	37	2.91	38.71	42.41	2.59	3.26
	March	43	6.91	44.73	48.43	6.15	7.74
	April	43	4.42	44.97	48.67	3.93	4.95
	May	50	3.18	51.40	55.10	2.83	3.56
	June	56	2.41	57.77	61.47	2.14	2.70
	July	59	0.78	60.89	64.59	0.69	0.87
	August	62	0.00	63.35	67.05	0.00	0.00

	September	60	0.62	61.04	64.74	0.55	0.69
	October	50	1.98	51.27	54.97	1.76	2.22
	November	41	5.66	42.20	45.90	5.04	6.34
	December	38	1.14	39.66	43.36	1.01	1.28

Appendix D: Snoqualmie UHI Tables and Graphs

WEATHER STATION 1:

Figure 71. Snoqualmie Temperature and 2040 Projections - Weather Station 1, 2009 - 2011

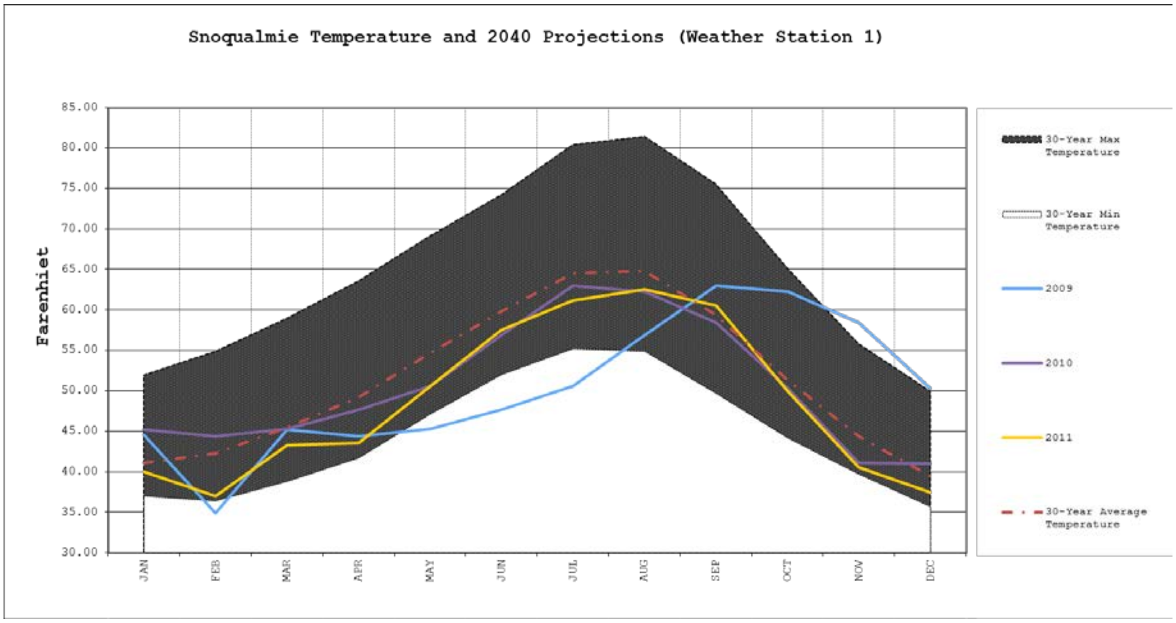


Figure 72. Snoqualmie Precipitation and 2040 Projections - Weather Station 1, 2009 - 2011

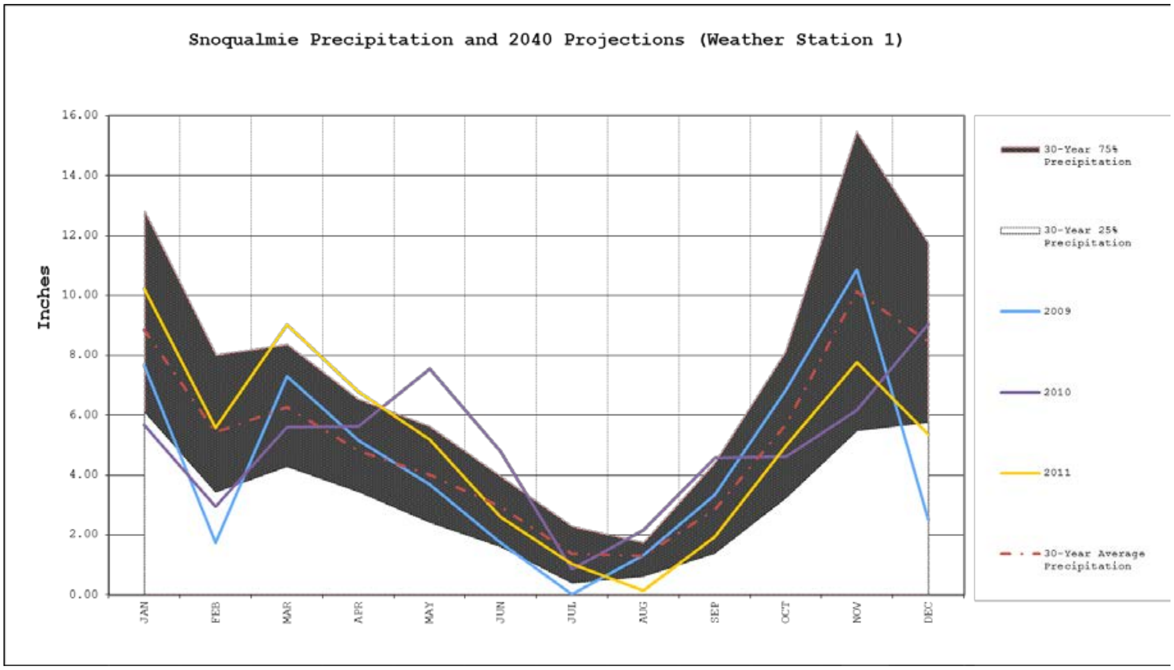


Table 41. Snoqualmie Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 1, 2009 - 2011

		Weather Station 1		**Climate Change Projections**			
		NORMAL - AVG TEMP	NOMRAL - AVG PERC	Low CC Project -temp Min	High CC Project -temp Max	Low CC Project -PREC Min	High CC Project - PREC Max
2009	January	37	8	38.21	41.91	6.83	8.59
	February	40	2	41.32	45.02	1.55	1.95
	March	40	7	41.18	44.88	6.50	8.18
	April	47	5	48.47	52.17	4.60	5.79
	May	56	4	57.05	60.75	3.28	4.13
	June	63	2	64.03	67.73	1.55	1.95
	July	69	0	70.79	74.49	0.02	0.02
	August	65	1	66.98	70.68	1.17	1.47
	September	61	3	62.23	65.93	2.96	3.73
	October	50	7	51.53	55.23	6.10	7.67
	November	45	11	46.10	49.80	9.67	12.16
	December	35	2	36.40	40.10	2.22	2.79
2010	January	45	6	46.66	50.36	5.05	6.35
	February	44	3	45.86	49.56	2.62	3.29
	March	45	6	46.82	50.52	4.99	6.28
	April	48	6	49.13	52.83	5.00	6.29
	May	51	8	52.05	55.75	6.72	8.46
	June	57	5	58.37	62.07	4.26	5.36
	July	63	1	64.50	68.20	0.76	0.95
	August	62	2	63.79	67.49	1.91	2.41
	September	58	5	59.97	63.67	4.06	5.11
	October	50	5	51.79	55.49	4.12	5.19
	November	41	6	42.60	46.30	5.48	6.90
	December	41	9	42.47	46.17	8.05	10.12
2011	January	40	10	41.53	45.23	9.11	11.47
	February	37	6	38.46	42.16	4.96	6.24
	March	43	9	44.79	48.49	8.04	10.11
	April	44	7	45.03	48.73	6.04	7.60
	May	51	5	52.05	55.75	4.61	5.80
	June	57	3	58.97	62.67	2.31	2.91
	July	61	1	62.69	66.39	0.92	1.15
	August	63	0	64.05	67.75	0.12	0.16
	September	61	2	62.00	65.70	1.73	2.17
	October	50	5	51.47	55.17	4.43	5.58
	November	41	8	42.03	45.73	6.91	8.69
	December	37	5	38.95	42.65	4.77	6.00

WEATHER STATION 2:

Figure 73. Snoqualmie Temperature and 2040 Projections - Weather Station 2, 2011

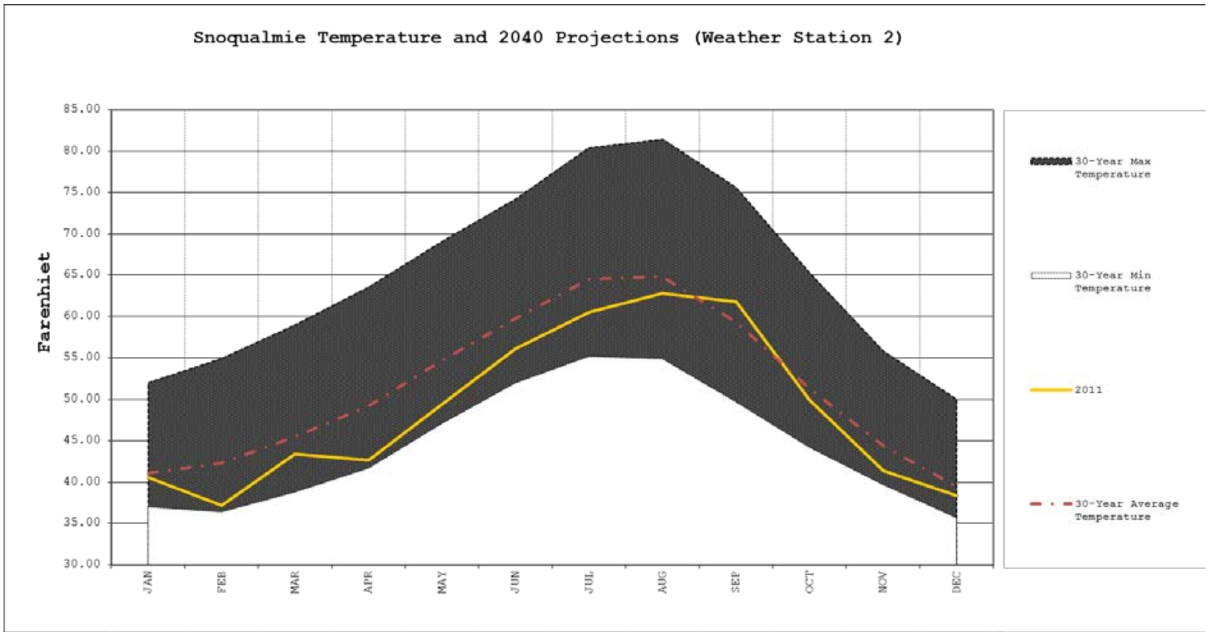


Figure 74. Snoqualmie Precipitation and 2040 Projections - Weather Station 2, 2011

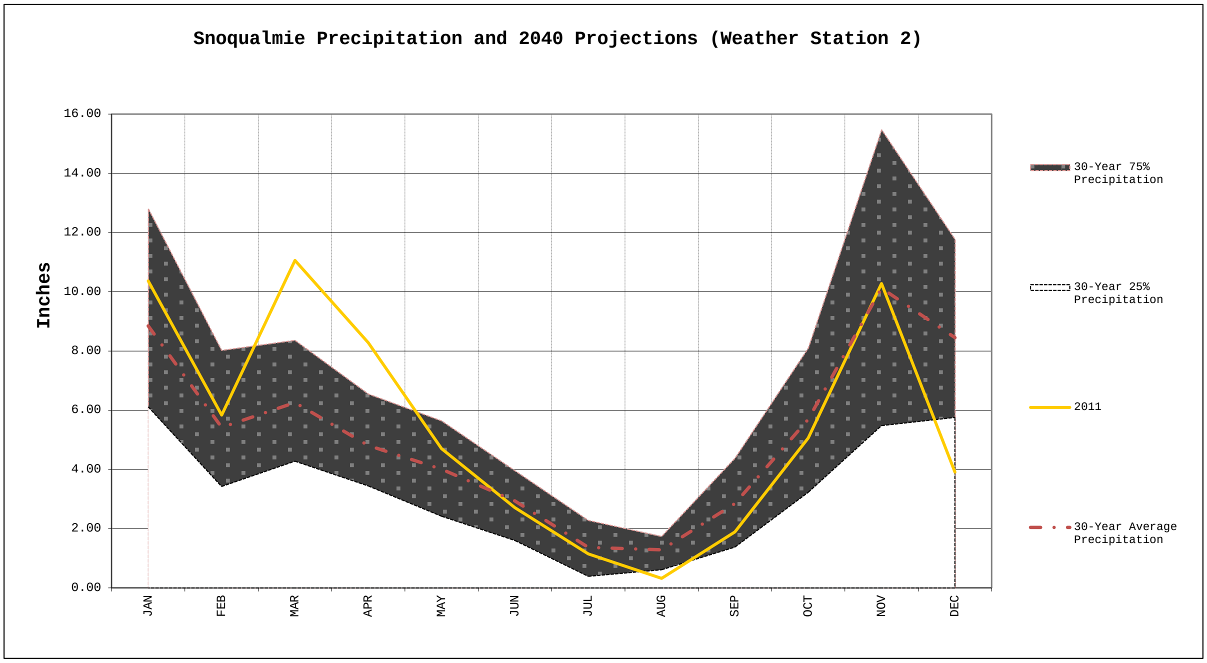


Table 42. Snoqualmie Temperature and Precipitation Numbers and 2040 Climate Change Projections, 2011

		Weather Station 2		Climate Change Projections			
		NORMAL - AVG TEMP	NOMRAL - AVG PERC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project - PREC Min	High CC Project - PREC Max
2011	January	41	10	42.08	45.78	9.23	11.61
	February	37	6	38.64	42.34	5.20	6.54
	March	43	11	44.85	48.55	9.84	12.39
	April	43	8	44.13	47.83	7.37	9.27
	May	49	5	50.89	54.59	4.18	5.26
	June	56	3	57.63	61.33	2.41	3.04
	July	61	1	62.02	65.72	1.02	1.29
	August	63	0	64.27	67.97	0.28	0.36
	September	62	2	63.33	67.03	1.68	2.12
	October	50	5	51.47	55.17	4.50	5.67
	November	41	10	42.87	46.57	9.15	11.51
	December	38	4	39.82	43.52	3.48	4.38

WEATHER STATION 3:

Figure 75. Snoqualmie Temperature and 2040 Projections - Weather Station 3, 2009 - 2011

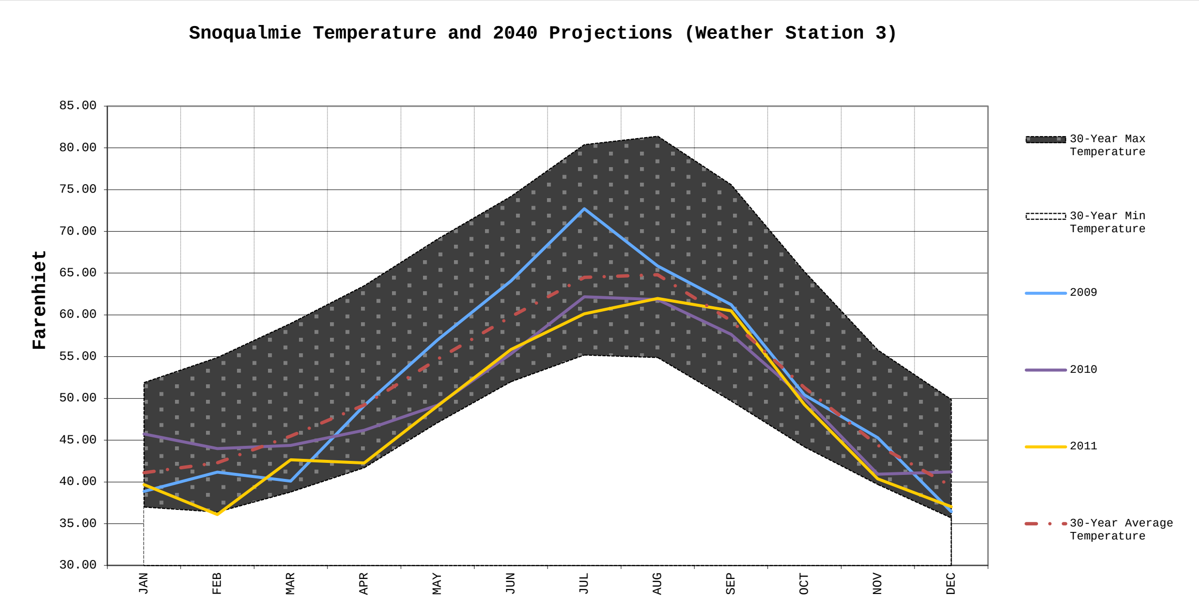
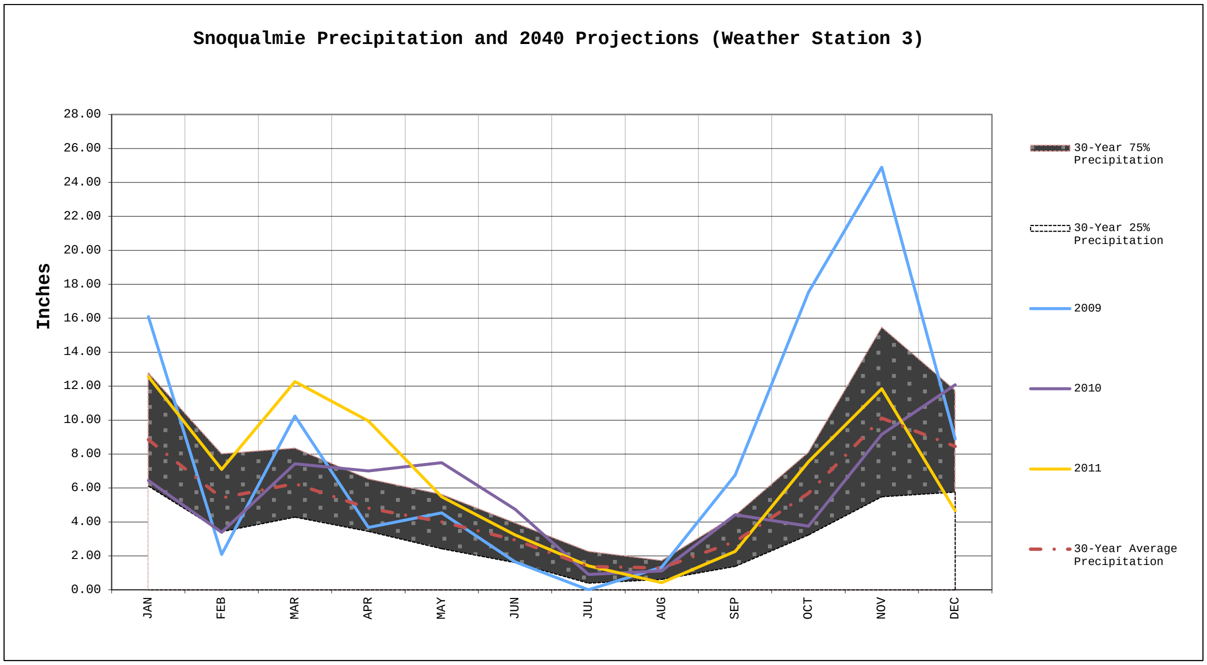


Figure 76. Snoqualmie Precipitation and 2040 Projections - Weather Station 3, 2009 - 2011



sTable 43. Snoqualmie Temperature and Precipitation Numbers and 2040 Climate Change Projections - Weather Station 3, 2009 - 2011

		Weather Station 3		**Climate Change Projections**			
		NORMAL - AVG TEMP	NOMRAL - AVG PERC	Low CC Project - Temp Min	High CC Project - Temp Max	Low CC Project - PREC Min	High CC Project - PREC Max
2009	January	39	16	40.37	44.07	14.32	18.02
	February	41	2	42.68	46.38	1.86	2.34
	March	40	10	41.60	45.30	9.11	11.47
	April	49	4	50.63	54.33	3.27	4.11
	May	57	5	58.50	62.20	4.03	5.07
	June	64	2	65.57	69.27	1.47	1.85
	July	73	0	74.20	77.90	0.00	0.00
	August	66	1	67.37	71.07	1.19	1.50
	September	61	7	62.73	66.43	6.02	7.57
	October	50	18	51.92	55.62	15.60	19.63
	November	45	25	46.80	50.50	22.15	27.88
	December	36	9	37.95	41.65	7.91	9.96
2010	January	46	6	47.24	50.94	5.73	7.21
	February	44	3	45.50	49.20	3.02	3.80
	March	44	7	45.89	49.59	6.61	8.32
	April	46	7	47.70	51.40	6.24	7.85
	May	49	7	50.69	54.39	6.67	8.39
	June	55	5	56.83	60.53	4.22	5.31
	July	62	1	63.66	67.36	0.81	1.02
	August	62	1	63.34	67.04	1.00	1.25
	September	58	4	59.17	62.87	3.93	4.95
	October	50	4	51.50	55.20	3.34	4.20
	November	41	9	42.43	46.13	8.15	10.26
	December	41	12	42.69	46.39	10.75	13.53
2011	January	40	13	41.18	44.88	11.18	14.07
	February	36	7	37.61	41.31	6.31	7.94
	March	43	12	44.15	47.85	10.92	13.74
	April	42	10	43.77	47.47	8.86	11.14
	May	49	5	50.60	54.30	4.88	6.14
	June	56	3	57.37	61.07	2.87	3.62
	July	60	1	61.63	65.33	1.25	1.58
	August	62	0	63.47	67.17	0.37	0.47
	September	61	2	62.00	65.70	2.01	2.53
	October	49	8	50.76	54.46	6.72	8.46
	November	40	12	41.87	45.57	10.55	13.27
	December	37	5	38.53	42.23	4.15	5.22