SECTION 1
Making Sense of Climate Change Projections

Globally, greenhouse gas concentrations have risen substantially as a result of human activities, and have been a primary driver of warming. To make projections of future climate, scientists use "what if" scenarios of plausible future greenhouse gas emissions to drive computer model simulations of the earth's climate. There are multiple greenhouse gas scenarios, numerous global climate models – each constructed slightly differently – and multiple techniques for "downscaling" coarse global model projections to local scales. The many possible combinations of scenarios, models, and downscaling techniques are used to estimate a range of possible future climates. The range reflects some of the important unknowns regarding future choices in energy and technology, and in our understanding of the climate system. As scientists develop new scenarios or improve models and downscaling procedures, projections are periodically updated. This section describes the ingredients for making climate projections, and provides the context for comparing results from the two most recent international climate science reports (IPCC 2007[1] and 2013[2]).

Projections of Future Climate

How much and how fast climate changes[A] occur depends on both the amount of future greenhouse gas emissions and how the climate changes in response to those emissions. Irreducible uncertainty in both future greenhouse gas emissions and the climate system's response means that projections of future climate will always be represented by a range of plausible outcomes.

- *Since it is impossible to predict the exact amount of greenhouse gas emissions resulting from future human activities,* scientists use greenhouse gas scenarios to represent a range of different future conditions.
- *We cannot know which scenario is most likely.* Since we are unable to predict the future, we cannot say with certainty which greenhouse gas scenario is most likely to occur.
- *It is important to consider a range of potential outcomes.* There is no "best" scenario, and the appropriate range of scenarios depends on the specific climate impact

A In this report, the terms "climate change" and "global warming" are used interchangeably to refer to the human-induced (or "anthropogenic") changes brought on by increasing atmospheric concentrations of greenhouse gases.

under consideration. Deciding which scenario(s) to use involves clarifying how climate affects a particular decision and what level of risk is acceptable.

- *Projections will continue to be updated over time.* As the science of climate change progresses, new greenhouse gas scenarios and updated climate models will inevitably replace the current climate projections.

Greenhouse Gas Scenarios

New greenhouse gas scenarios used in IPCC 2013[2,3] range from an extremely low scenario involving aggressive emissions reductions to a high "business as usual" scenario with substantial continued growth in greenhouse gases. Although these scenarios were developed using a different methodology and span a wider range of possible 21st century emissions, many are similar to greenhouse gas scenarios used in previous assessments (Table 1-1, Figures 1-1 and 1-2).[B,C,4]

- *The previous scenarios have close analogues in the newer scenarios*. For example, the A1B scenario – used in many Pacific Northwest impacts assessments – is similar to the newer RCP 6.0 scenario by 2100, though closer to the RCP 8.5 scenario at mid-century.

- *In both sets of scenarios, the high end is a "business as usual" scenario (RCP 8.5, SRES A1FI)* in which emissions of greenhouse gases continue to increase until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels. It is unlikely that 21st century emissions will exceed these "business as usual" scenarios: both were selected to represent the upper end of plausible future emissions.

- *The newer scenarios include an aggressive mitigation scenario (RCP 2.6),* which would require about a 50% reduction in global emissions by 2050 relative to 1990 levels, and near or below zero net emissions in the final decades of the 21st century. One recent study estimates that 41% (range: 24% to 59%) of total global emissions projected for 2010-2060 under the RCP 2.6 scenario are already "committed", given the anticipated lifetime of existing fossil-fuel infrastructure.[D,5,6]

[B] The latest scenarios, used in the 2013 IPCC report, are referred to as Representative Concentration Pathways (RCPs; Van Vuuren et al. 2011[3]). The previous greenhouse gas scenarios, used in the 2001 and 2007 IPCC reports, are described in the Special Report on Emissions Scenarios (SRES; Nakicenovic et al. 2000[C]).

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

[D] The study considered emissions from *existing* infrastructure, comparing these to emissions projected by greenhouse gas scenarios for 2010 through 2060. The estimates do not account for additional emissions from new fossil-fuel infrastructure that may be installed after 2010.

- *All scenarios result in similar warming until about mid-century.* Prior to mid-century, projected changes in global climate are largely driven by the warming that is "in the pipeline" – warming to which we are already committed given past emissions of greenhouse gases. In contrast, warming after mid-century is strongly dependent on the amount of greenhouse gases emitted in the coming decades.

- *Greenhouse gas scenarios are consistent with recent global emissions.* Globally, greenhouse gas emissions are higher and increasing more rapidly since 2000 than during the 1990s (Figure 1-1).[2]

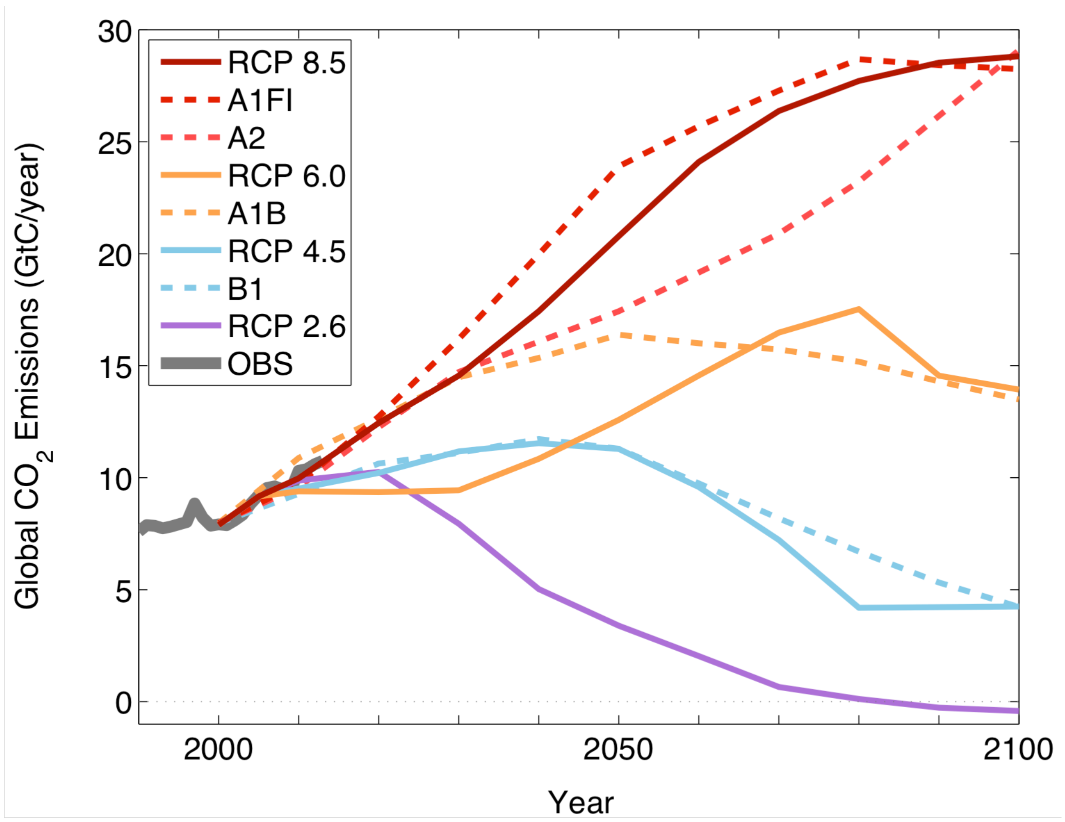

Figure 1-1. Future greenhouse gas scenarios range from aggressive reductions to large increases in greenhouse gas emissions. The figure shows annual global CO_2 emissions in gigatons of carbon (GtC). Though not the only greenhouse gas, CO_2 emissions are the dominant driver of human-caused warming. Actual emissions for 1990-2010 are shown in grey. Annual emissions projected for 2005-2100 are shown in color for two generations of greenhouse gas scenarios: the current scenarios (solid lines), and those from the previous generation (dashed lines). Similar scenarios are plotted using similar colors. Year-to-year emissions of greenhouse gases, as shown in this graph, accumulate in the atmosphere and cause CO_2 concentrations to rise, as shown in Figure 1-2. Scenarios with higher emissions cause atmospheric concentrations to rise rapidly, while lower scenarios cause concentrations to rise more slowly or decline. *Figure source: Based on data from Le Quéré et al. 2015,[7] IPCC 2007,[1] and IPCC 2013[2] (available at: http://dx.doi.org/10.5194/essdd-7-521-2014, http://tntcat.iiasa.ac.at:8787/RcpDb,[3] and http://sedac.ciesin.columbia.edu/ddc/sres/[4]).*

Table 1-1. Previous greenhouse gas scenarios have close analogues in the new scenarios.

Current scenarios[2,3]	***Scenario characteristics***	***Comparison to previous scenarios*** [1,4]	***Description used in this report***
RCP 2.6	An extremely low scenario that reflects aggressive greenhouse gas reduction and sequestration efforts	No analogue in previous scenarios	"Very Low"
RCP 4.5	A low scenario in which greenhouse gas emissions stabilize by mid-century and fall sharply thereafter	Very close to B1 by 2100, but higher emissions at mid-century	"Low"
RCP 6.0	A medium scenario in which greenhouse gas emissions increase gradually until stabilizing in the final decades of the 21st century	Similar to A1B by 2100, but closer to B1 at mid-century	"Moderate"
RCP 8.5	A high scenario that assumes continued increases in greenhouse gas emissions until the end of the 21st century	Nearly identical to A1FI[E]	"High"

Global Climate Models

New climate change projections (IPCC 2013) also use new versions of the Global Climate Models (GCMs) developed to simulate changes in the Earth's climate. More models were used to develop the new projections, and they are improved relative to previous models.[8,9]

- *Global Climate Models (GCMs) are designed to represent the processes controlling Earth's climate.* These models incorporate the state-of-the-art in climate science. As a result, they are periodically updated as the science progresses.

- *It is important to consider a range of projections among multiple different climate models.* Each model simulates the earth's climate using a different set of approaches. As a result, each provides a unique estimate of the response of the climate to greenhouse gas emissions. In addition, the timing and sequence of natural variability (e.g., El Niño) is unpredictable, and will therefore be unique for each climate model simulation. For a given greenhouse gas scenario, the range among climate model projections encompasses both the range due to different climate models and due to natural variability. Since it is not known which projection is most accurate, a range of projections must be considered.

- *The range among climate model projections may not encompass the full range of potential future climate changes.* For a given greenhouse gas scenario, the range among climate model simulations provides an estimate of the uncertainty in projections. However, we cannot rule out the possibility that future changes in

[E] The A2 greenhouse gas scenario is between the RCP 6.0 and 8.5 scenarios.

climate will be outside of the range projected by climate models.[10]

- *New climate models project similar climate changes for the same amount of greenhouse gas emissions.* Differences between the changes projected for the 2007 and 2013 IPCC reports are mostly due to differences in greenhouse gas scenarios: both sets of models project about the same amount of warming for similar greenhouse gas emissions (Figure 1-3).[8,11,12]

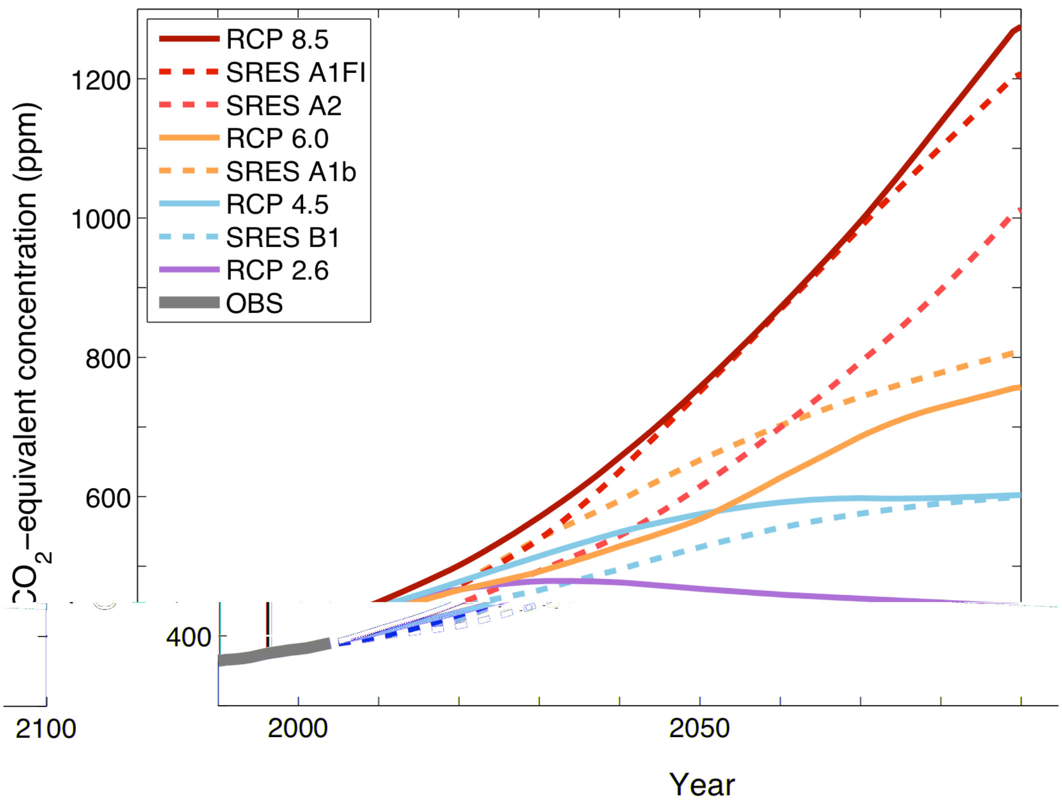

Figure 1-2. All scenarios project continued growth in atmospheric levels of greenhouse gases for the next few decades. The figure shows the equivalent CO_2 concentration, in parts per million (ppm), for each greenhouse gas scenario. CO_2-Equivalent is a measure that accounts for the global warming impact of all atmospheric greenhouse gases. Observed concentrations for 1990-2005 are shown in grey. Projected concentrations for 2005-2100 are shown in color for two generations of greenhouse gas scenarios: the current scenarios (solid lines), and those from the previous generation (dashed lines). Similar scenarios are plotted using similar colors. *Figure source: Based on data used in IPCC 2007[1] and IPCC 2013[2] (http://tntcat.iiasa.ac.at:8787/RcpDb[3] and http://sedac.ciesin.columbia.edu/ddc/sres/[C]).*

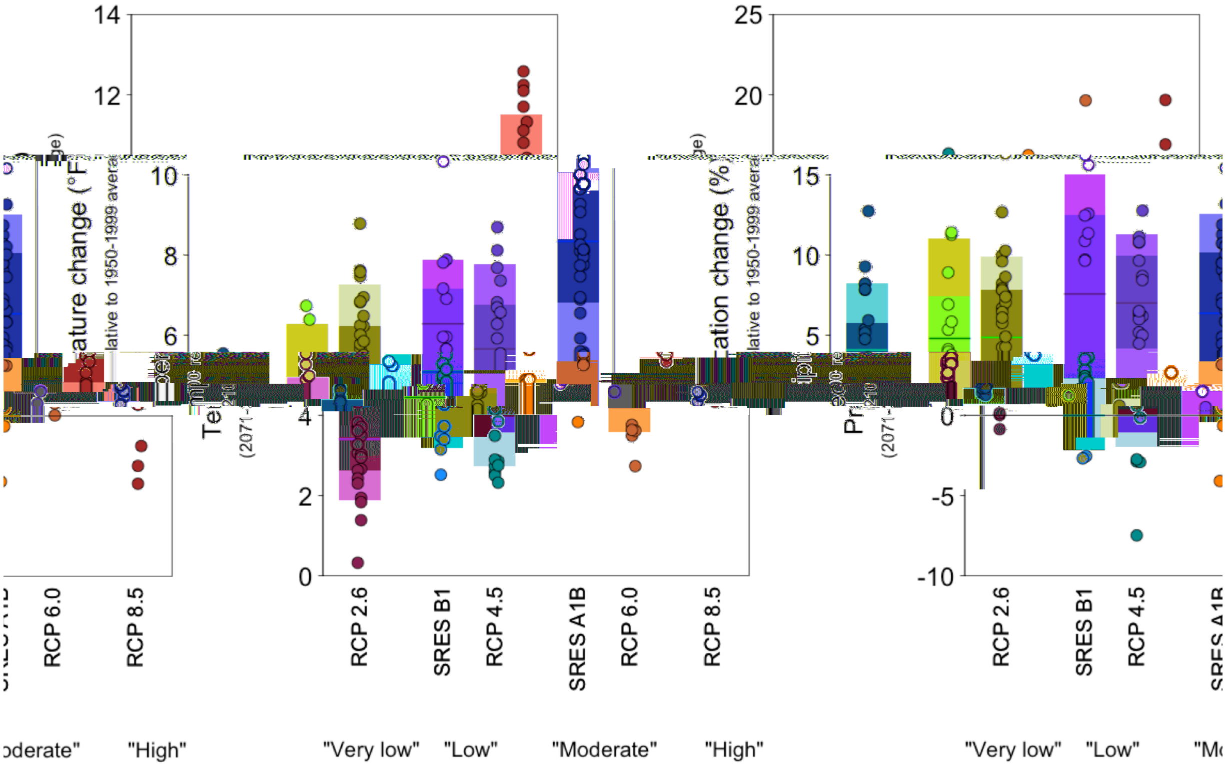

Figure 1-3. Differences in the change projected for the Puget Sound region by the current (IPCC 2013[2]) and previous (IPCC 2007[1]) global climate model simulations are primarily due to differences among greenhouse gas scenarios. Projected changes are shown for average annual temperature (left) and precipitation (right) for the Puget Sound region (46.5°-49.5°N, 123.5°-120.5°W) for the 2080s (2071-2100, relative to 1950-1999). Projections include all four new scenarios: RCP 2.6 ("very low"), 4.5 ("low"), 6.0 ("moderate"), and 8.5 ("high"), along with the two previous scenarios used in many regional impacts assessments: B1 ("low") and A1B ("moderate"). Individual climate model projections for each greenhouse gas scenario are shown using colored dots. Boxes show the average projected change (in °F for temperature and percent change for precipitation), along with the 10th, 25th, 75th, and 90th percentile values among all climate model projections. The black horizontal line on the precipitation graph denotes zero change. *Figure source: Based on climate projections used in the IPCC 2013 report.[2] and Figures 2.5b and 2.6 of Mote et al., 2013.[13]*

Downscaling

Climate change impacts are often assessed by first "downscaling" coarse resolution global model projections to local scales. Global Climate Models (GCMs) simulate changes at coarse spatial scales (~50-100 miles from one grid cell to the next), and therefore do not adequately represent local-scale weather and climate patterns.

- *Downscaled climate projections translate coarse resolution global model projections to a level of detail that is more relevant to management and decision-making.* This increased resolution (usually about 5 to 10 miles from one grid cell to the next) often provides a better representation of local climate, but also entails additional assumptions, which means that different approaches can give different results.

- *"Statistical downscaling" uses observed relationships between weather observations and coarse-scale GCM weather patterns.* An advantage of statistical downscaling is that it is inexpensive to implement. A disadvantage is that it does not capture the local-scale processes that can alter the response to warming at any particular location.

- *"Dynamical downscaling" uses a physical model, such as a regional climate model (RCM), which is driven by coarse-resolution GCM weather patterns.* An advantage of dynamical downscaling is that the model can capture important local-scale changes that cannot be represented with a statistical approach. A disadvantage is that it is expensive to implement, although RCM simulations are becoming increasingly feasible.

Implications for Puget Sound Climate Impacts Assessments

Impacts assessments that are based on the previous set of projections (IPCC 2007[1]) are likely very similar to those based on the newer projections (IPCC 2013[2]). New climate models project similar warming for the same amount of greenhouse gas emissions, and all scenarios result in similar warming until about mid-century. Although the current projections include a very low greenhouse gas scenario, this may not be achievable given the anticipated lifetime of existing fossil fuel infrastructure. The primary distinction between the current and previous projections is that the high-end scenario in the newer projections includes a much greater increase in greenhouse gas concentrations over the course of the 21st century. Although this does not affect projections for mid-century, the high-end projections for the end of the 21st century are substantially warmer in the newer projections.

- *Projected climate changes in the Puget Sound region are similar for current (IPCC 2013[2]) and previous (IPCC 2007[1]) scenarios of medium and low greenhouse gas emissions.* The Washington Climate Change Impacts Assessment (WACCIA)[14] and many other regional climate impact studies used the B1 and A1B greenhouse gas scenarios.[15,16] These are comparable to RCP 4.5 and RCP 6.0, respectively, at the end of the century, in terms of both greenhouse gas concentrations (Table 1-1, Figure 1-2) and resultant changes in climate projected for the Puget Sound region (Figure 1-3).

- *Newer scenarios for very low and high greenhouse gas emissions result in a wider range in projected late-century warming for the Puget Sound region.* Previous regional assessments have typically considered a narrower range of greenhouse gas scenarios.

- The newer scenarios include an aggressive greenhouse gas mitigation scenario (RCP 2.6), which assumes much lower emissions than in other scenarios. The older projections do not include a comparable scenario. Recent research shows that nearly half of the total greenhouse gas emissions projected under this scenario are already committed, given the anticipated lifetime of existing fossil-fuel infrastructure.[5,6]

- The highest scenarios commonly used in many previous climate impacts assessments (A1B, A2) are much lower than the high-end scenario in the current projections (RCP 8.5). It is unlikely that 21st century emissions will exceed the RCP 8.5 scenario: it was selected to represent the high end of plausible future emissions.

- *The importance of differences between the current and previous climate change projections will depend on the specific impact under consideration and the sensitivity of the decision being made.* For example, projected changes in annual average temperature are likely to differ by less than 1°F under similar greenhouse gas scenarios from IPCC 2007 and 2013, while projected changes in annual average precipitation are likely to differ by only a few percentage points (see Section 2, Figure 2-2). Other differences between the scenarios have not yet been explored.

- *Most existing climate change impacts assessments are based on statistical downscaling.* This means that some projections may change as dynamically downscaled simulations become more widely available. Although some comparisons have been made,[17] there has been no comprehensive assessment of the differences in projections between statistical and dynamical downscaling approaches.

This Report

In this report, the specific greenhouse gas scenarios and the number of climate models used are listed for each projection. Whenever possible, we report the range among projections. In addition, the future time frame of each projection is listed, along with the historical period to which it is compared (e.g., 1970-1999). Unless otherwise noted, all projections are based on a statistical downscaling of global model projections.

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