A CLIMATE SOLUTIONS SPECIAL REPORT

In Hot Water – A Snapshot of the Northwest's Changing Climate

By Patrick Mazza

GLOBAL WARMING CAN SEEM SUCH A VAST AND COMPLEX ISSUE. It's global, after all. But when the prospective impacts of climate change are brought closer to home, its grave import becomes clear, because what we stand to lose comes into sharper focus. Between now and the middle of the coming century, climate change could impose harsh consequences on the Pacific Northwest. Scientifically credible scenarios show:

- Winters with substantially more rainfall, and summers with a larger number of extremely hot days.

continued on next page

- More frequent and destructive flooding and mudslides.
- A disrupted annual water cycle in which snowpack— on which the Columbia and other Northwest rivers depend during summer —shrinks by half.
- Droughts coming twice as frequently by 2020 and three times more often—three years out of every 10—by 2050.
- Salmon runs diminished or lost to an even greater degree than at present.
- Water shortages which choke hydroelectric power production and irrigated farms.
- Ski seasons and runs shortened as snowline retreats to higher elevations.
- Forest cover in Oregon and Washington sharply reduced, with forests retreating from the eastern slopes of the Cascades.
- More numerous and intense forest fires and pest infestations, bringing major shifts in tree species distribution across the Northwest.
- Human health impacts from worsened air pollution, increased heat waves and growth of disease-carrying insect populations.
- Rising seas which undermine coastal bluffs, cause landslides, drown highways and waterfronts, bring higher storm surges, and cover tidal marshes vital to fish and birds.

"We are really taking our climate to a new place..."

NATHAN MANTUA

"We are really taking our climate to a new place," University of Washington climate scientist Nathan Mantua says. "The rapid changes laid out by the scenario have not been experienced in this region probably for thousands of years."[1]

This paper briefly explains the scientific advances on which new regional scenarios of global warming are based. More importantly, it details how global warming threatens the Pacific Northwest economy, environment, and quality of life.[2]

Distilling The Danger From The Data

During the 19th century humanity learned how to generate electricity and to power vehicles with fossil fuels. These now dominant technologies may lead to huge climate impacts in the 21st century. Fortunately a set of newer technologies is sharpening our understanding of the climate. Satellites and high-resolution instruments now generate an unprecedented stream of data on planetary warming and its consequences.

But for understanding where the climate is heading, the most important new tool is the computer. The data processing revolution allows scientists to build increasingly realistic climate models. They are a form of virtual reality, an "Earth in a computer" that mimics the real one outside. Scientists test their models against the real world by building records of the past climate, either from instrumental readings or nature's record book written in tree rings, corals, sediments and ice layers. They run their models through the past to see if the computer climate roughly tracks with the real climate. Thus models can mimic the human-caused buildup of greenhouse gases that has already taken place and the way the climate has responded, then project how the climate might act under expected increases in greenhouse gases.[3] (For more about emerging global-climate-change science, see Climate Solutions' paper, *Global Warming Is Here: The Scientific Evidence.)*

Computer climate models, dealing with a hugely complex system, represent broad sketches of global conditions. But scientists are bringing models into sharper focus so they can project plausible impacts on specific regions. In Seattle, the National Oceanic and Atmospheric Administration and the University of Washington have created the Joint Institute for the Study of Atmosphere and Oceans. JISAO is developing detailed scenarios of Northwest climate change impacts. In Richland, Wash., scientists at Pacific Northwest National Laboratory (PNNL) are building Northwest models that paint some of the most finely grained regional climate change pictures available anywhere. The Environmental Change Research Group at the University of Oregon

Geography Department is also examining the regional dimensions of climate change.

Likely, Not Inevitable

This report is grounded on scenarios regarded by leading scientists and major scientific institutions as plausible. Often, a global warming outcome will be described as "likely." That does not mean inevitable. Partly this is because there are several sources of scientific uncertainty. First, we are still building our knowledge of the climate system. Second, much that we know still cannot be computer modeled. Third, the climate has natural variabilities that we only partly understand. Beyond the scientific aspects, there is a human factor—How the story comes out partly depends on us, on whether we take reasonable precautions to avert undesirable consequences.

The scenarios described in this paper envision the Northwest fallout in a world where carbon dioxide (CO_2), the major greenhouse gas, has doubled over present day levels. We are on course to reach that point sometime around 2050-2080.[4] Unless we very quickly move away from a fossil fuel-powered economy, we will not be able to moderate global warming's disastrous impacts here or anywhere.

In our paper, *Solutions to Global Warming: How the Northwest Can Lead a Clean Energy Revolution*, Climate Solutions has demonstrated that such a dramatic shift in energy technology is realistic, paralleling and fed by current revolutions in information, electronics and materials science. In this paper, we detail some of the likely outcomes of inaction, in the hope that a sharper focus on the perils will motivate the Northwest to take the lead and become a model for global warming solutions.

The Big Picture: Temperature And Precipitation

We cannot say for certain what global warming will do to the Pacific Northwest. But with temperatures globally expected to increase faster over the next 100 years than any time in the past 10,000, there are bound to be effects here at home.[5] Some may come as nasty surprises.

Over the past century, regional temperatures have already increased. The Northwest has warmed 0.5 deg F over the past century. Models show acceleration, with average regional temperatures galloping upwards nearly one deg F each decade over the next 50 years. JISAO's Climate Impacts Group applied seven global climate models to the Northwest. Averaged, they show an increase (including that which has already taken place) of 3 deg F by 2020 and 5 deg F by 2050.[6] And those averages imply an increase in the number of very hot days. Even if greenhouse emissions are stabilized by 2050, the climate is like a train that takes a long time to stop. Temperatures would climb even higher in subsequent decades.

L. Ruby Leung of PNNL has developed the most sharply focused regional climate model. The coarse-grained models usually used to simulate global climate do not have fine enough resolution to include key topographical features like the Cascades. The PNNL model, built on a detailed topographical map, gives climate projections for particular Northwest landscapes.[7] In general, it shows temperatures increasing fastest in mountain areas, which has serious implications for snowpack. That is covered in a following section.

Scenarios for future precipitation changes vary more widely than temperature projections. The general tendency of the seven global models used by JISAO is toward wetter winters and drier summers. At the extreme ends, models show winters with 22 percent more precipitation and summers with 26 percent less by 2050. Philip Mote of JISAO Climate Impacts Group says models overall suggest a nine percent increase in winter precipitation and a five percent decrease in the summer by sometime in mid-century.[8] Under any scenario, more heat brings more evaporation, which will make for drier summer conditions.

> *"It's easy to think of a one degree increase in temperature or a five percent increase in rainfall as inconsequential, but our studies of the past show that such changes have had astonishingly large impacts."*
>
> PHILIP MOTE

Critical Thresholds—Last Straws

While a few extra degrees might seem a pleasant prospect, especially on cold winter days, they threaten the region with more frequent, *Water is the defining element of this region, shaping our environment, economy, outlook and culture... If we disturb nature's free water delivery service it spells trouble.*

extreme weather events such as droughts, fires, floods and mudslides. For example, during El Niño, which is associated with sometimes severe dry spells in the Northwest, average winter temperatures go up by only 0.5 deg F.[9]

"It's easy to think of a one degree increase in temperature or a five percent increase in rainfall as inconsequential, but our studies of the past show that such changes have had astonishingly large impacts," notes Mote.[10]

The effect of the extra energy in a seemingly small warming can become the "last straw" that brings on an extreme event. In science, the moment the "camel's back breaks" is known as a critical threshold. A threshold event is the heavy rainstorm that sets a mudslide rolling, the river warming during a hot summer that kills salmon by the score, the dry spell that turns a forest into a tinderbox. Thresholds speed up and amplify changes. "Thresholds are important because they function as shortcuts to effects," notes JISAO Climate Impacts Group head Ed Miles.[11]

Climate change comes as an added stress on an already straining environment. Clearcutting, dams and development test the resiliency of forests, fisheries and other Northwest ecosystems. Global warming might push ecosystems across critical thresholds that amount to last straws for a number of species.

The Greatest Danger: A Disrupted Water Cycle

One way to grasp the significance of global warming for the Pacific Northwest is to ask, "How important is water here?" The answer is obvious—Water is the defining element of this region, shaping our environment, economy, outlook and culture. An alternate name for our place is Cascadia. Bioregional thinker David McCloskey says the name signifies the cascades of water rolling through the region in a great cycle encompassing ocean, sky, land and rivers.[12]

Pacific storms whisking in overhead write their signature across the landscape in the shape of the world's most expansive band of coastal temperate rainforests. An emblem of the Northwest, they grow taller and thicker than any other forests on the planet.

Water is the lifeblood of the iconic Northwest salmon. The runs depend on rivers well fed by rains and snow melting off white-capped peaks, another important symbol of the Pacific Northwest. Mountain streams also feed reservoirs supplying Seattle, Portland and other cities and towns with some of the purest drinking water around. Most of the Northwest's electricity is generated by water, and east of the Cascades one of the world's richest farming areas is watered by a vast irrigation network. The majority of Northwesterners live by water, in cities and towns on rivers and coasts.

We consider forests, salmon, snowcapped mountains and rivers abundant with water for our cities, power and farms to be enduring features of Northwest life. But each is dependent on arrival of the right amount and quality of water at the right time. If we disturb nature's free water delivery service, changing any of its three key aspects—quantity, quality and timing—it spells trouble. Such disruption is precisely what global warming threatens to bring home.

Of course, increasing temperatures will have some direct effects on the region. But the way warming might alter water flows is the greatest potential danger climate change poses for the Pacific Northwest. Much of this paper turns around the connection of global warming and a skewed water cycle.

If the climate develops in the way that scenarios suggest, it will mean that sometimes, particularly in winter and spring, there will be too much water, causing floods and mudslides. Often in late summer and fall there will be too little. Forests will dry out, becoming more vulnerable to catastrophic fires and disease outbreaks. Salmon will find new obstacles to spawning in swollen winter streams that wash out nests, as well as overheated summer streams with too little water. Low flows will also choke hydropower production and irrigated farms.

El Niño and other natural climate variations bring warm, dry spells to the Northwest every few years. These variations are regarded as dress rehearsals for global warming, which could

EL NIÑO'S DOUBLE WHAMMIES

In one sense, the Pacific Northwest goes through climate changes all the time, years and decades when the climate oscillates between wet and dry periods. Two climate variations have a major influence on the region: El Niño, which is supposed to come every few years, and the Pacific Decadal Oscillation, which tends to shift every 20-30 years or so.

Climate scientists look on these variations as dress rehearsals for human-caused climate change in the Northwest. For example, when El Niño rises in the central Pacific, the region experiences warmer than normal winters and springs. University of Washington climate scientist Dennis Lettenmaier says 21st century Northwest climate scenarios "essentially look like perpetual El Niños."[14]

The Pacific Decadal Oscillation, PDO, centers in the north Pacific. During its cool phase, PDO is associated with wetter, cooler Northwest weather. In the warm phase the Northwest becomes warmer and drier. Streamflows are reduced on the order of 15-20 percent.[15] A PDO warm phase, while distinct from El Niño, very much resembles its shorter -lived companion.

"Looking at the past, we find that persistent but small changes in temperature and precipitation associated with PDO have had dramatic changes on the incidence of droughts, floods, forest fires, and so on," notes Philip Mote of the JISAO Climate Impacts Group.[16]

If El Niño and PDO were influenced by global warming, it would have profound implications for the Northwest. El Niño and PDO warmings could possibly launch from a higher platform, making for even greater extremes.

El Niño is a release valve through which the Pacific periodically discharges heat buildups, and the past several decades of record atmospheric warming have also seen an unusual spate of El Niños. Those include the two strongest, in 1997-98 and 1982-83, and the longest, from 1990-95. Though El Niños are typically followed by La Ninas, the cool phase of the cycle, in recent decades El Niño has come far more often.

Global warming may well be pumping up El Niño by heating the sea surface. While this conclusion remains controversial among scientists, some leading researchers are making strong statements. El Niño research pioneer Kevin Trenberth, a climate analyst at the U.S. National Center for Atmospheric Research, has spent over two decades building statistical models of El Niño. His models indicate that odds are only one in 2,000 that purely natural causes are behind the recent surge of El Niños.[19]

"The main thing we can point to is global warming," Trenberth says. "I think El Niños are being changed by global warming."[20]

A computer climate modeling study done by the Geophysical Fluid Dynamics Laboratory at Princeton adds weight to that conclusion. Scientists determined that recent warming in the tropical Pacific, where El Niño originates, is unlikely to be purely a product of natural variations. "Instead, it is likely that a sustained thermal forcing, such as the increase in greenhouse gases in the atmosphere, has been at least partly responsible for the observed warming," they said.[21]

> *"The main thing we can point to is global warming, I think El Niños are being changed by global warming."*
>
> KEVIN TRENBERTH

Another new computer modeling study by researcher Mojib Latif of the Max Planck Institute for Meteorology projects that El Niño-like conditions will become essentially permanent by 2050 if the buildup of greenhouse gases is not arrested.[22]

As for any connection between global warming and the PDO, Nathan Mantua, a leading PDO researcher, says it remains unclear. "I think that if the tropical temperatures warm up in an El Niño-like way, it would tend to favor the warm phase of the PDO." Heat would be transmitted through "the atmospheric bridge between the tropics and higher latitudes."[23]

The PDO has been in its warm state since the late 1970s. Scientists speculate that it may be entering a cool, wet phase. That might temporarily mask drying that more frequent El Niños would bring to the Northwest. However, a future PDO dry phase perhaps beginning around 2020-30 would come to a far warmer world, potentially magnifying its impact on the Northwest.

For the Northwest, says JISAO's Climate Impacts Group, "How climate change might affect the frequency or intensity of these climatic oscillations remains an open, albeit critical, question."[24]

Halving of regional snowpack"is likely to be the most important of the consequences of global warming to the Northwest."

ROBERT FLEAGLE

make dry spells more intense by increasing evaporation and changing runoff patterns.

Water supply is already very much a zero-sum game in much of the Northwest—For someone to win, someone must lose. This is one reason why the salmon crisis on the Columbia has become so intractable. Meanwhile, growing populations and economies are expected to put even more pressure on regional water resources. In the context of these escalating demands, the "primary impact" of climate change in the Northwest "will be increased competition and conflict over access to water supply," Miles says.[13]

Snowpack: the Northwest's "White Gold"

We're all familiar with nature's water delivery "pipes"—the clouds that carry water from the ocean and drop it on the landscape. Less well known is the huge "reservoir" system through which nature stores water for our typically dry summers. This is the mountain snowpack, massive layers which annually bulk up with heavy winter precipitation.

While rivers west of the Cascades are primarily fed by rainfall, melting mountain snow sustains rivers east of the mountains during the dry season, particularly the mighty Columbia. More than a skier's delight, snowpack is a crucial element of Northwest life. Sixty percent of water flowing through Washington state began as melting snow.[25]

During the dry months streams and rivers gushing with snowmelt carry salmon and recharge groundwater beneath mountain forests. Snowmelt fills municipal reservoirs. The Pacific Northwest draws the majority of its electricity from hydroelectric dams that suck power from snowmelt-driven rivers. The region's seven million irrigated acres mostly rely on those rivers. For the Northwest, snowpack is white gold.

"A typical mid-winter storm deposits snow in the Columbia watershed that will be used in the summer for hydropower and irrigation and can be valued in many millions of dollars," notes

Washington's North Cascades

University of Washington atmospheric scientist Robert Fleagle.[26]

Global warming threatens to eliminate half the Northwest snowpack resource. This "is likely to be the most important of the consequences of global warming to the Northwest," Fleagle says. While Northwest winters are projected to have more precipitation they are also projected to be warmer. So less will fall as snow and more as rain. Snow that does accumulate will vanish more quickly—Nothing melts snow faster than rain. (Rain-on-snow is the source of most of the Northwest's severe floods, a topic covered in a following section.)

Warmer temperatures promise to elevate freezing levels. The PNNL model, with its detailed resolution of heights, shows average Cascades snowline rising from its current 3,000 feet to 4,100 feet by 2050-80.[27] More snow may pile up in regions where the temperature stays well below freezing, typically above 9,000 feet. But the loss of snowpack in far more extensive lower elevation areas is projected to more than cancel that out. The PNNL model shows the volume of water stored in Northwest snowpack shrinking 50 percent by 2050-80. In the scenario some areas near snowline see snowpack drop by up to 90 percent.[28] Many Northwest mountain areas in the 3,000-6,000-foot range become snow-free.

Only 40-60 percent of today's average March snowpack is projected to remain in most of the Cascades and interior eastside mountains of Oregon and Washington. The westside Oregon Cascades take an even harder hit—Most slopes retain 20 percent or less of current snowpack. (The somewhat higher Idaho and Montana Rockies lose 30 percent of snowpack overall.)[29] Because snow moderates heat by reflecting sunlight back to the sky, the albedo effect, a reduced snowpack alone can add 1 deg F to warming, Leung notes.[30]

With less snowpack, and warmer, rainier spring months, mountains are expected to lose their snow cover earlier in the year, making for earlier runoff. Eastside rivers such as the Columbia are expected to flow more like their rainfall-driven westside cousins. Rainfall-driven rivers also are likely to see flows increased in winter and decreased in summer.[31]

In the PNNL scenario for mid-century, runoff in Oregon and Washington will surge well above current levels through winter. Total annual streamflow will be higher but the peak will be sooner. In Oregon runoff will peak in March, instead of May as it does now. Around the beginning of April, it will dip below the present amount and remain significantly lower until September. Washington today experiences maximum runoff in May and June. The scenario shows it will tail off by early May, then stay lower all spring and summer.[32]

"Streamflow is reduced at the time you need it most, in July, and August," Leung notes. "This is the biggest problem in Washington and Oregon under doubled CO_2."[33]

"The earlier melt effectively lengthens the period between the end of snowmelt and the onset of fall rains," says Alan Hamlet, a JISAO streamflow expert. "In hydrologic terms this is like making summer several months longer than it is now."[34]

The Northwest experienced droughts in 1987-88 and 1992-94 which resulted in low streamflows, Hamlet notes. Among the consequences were $575 million in added expenses to Bonneville Power Administration in 1992-93, mandatory lawn watering restrictions in Seattle in 1992, and 1994 streamflows 10 percent below the target for salmon on the Columbia and 25 percent below on the Snake. Such severe low flow events are now expected four years out of every 40. By 2020, under a middle of the road climate scenario, odds are for eight drought years out of every 40, and by 2050, 12 out of 40. That represents a doubling of the risk in 20 years and tripling in 50.[35]

The human-made reservoirs behind Northwest dams hold an impressive amount of water. Over 100 reservoirs on the Columbia system can store about one-third of the river's annual flow. They catch winter-spring runoff for use in the dry summer and fall. But they are not equipped to store water from year to year, or to compensate for the loss of half the snowpack.

Reservoirs tend to run short when snowpack is low or the summer-fall dry spell lasts longer than usual. And in heavy runoff years, reservoirs fill to capacity, limiting their ability to control floods and forcing dam operators to

"The earlier melt effectively lengthens the period between the end of snowmelt and the onset of fall rains...In hydrologic terms this is like making summer several months longer than it is now."

ALAN HAMLET

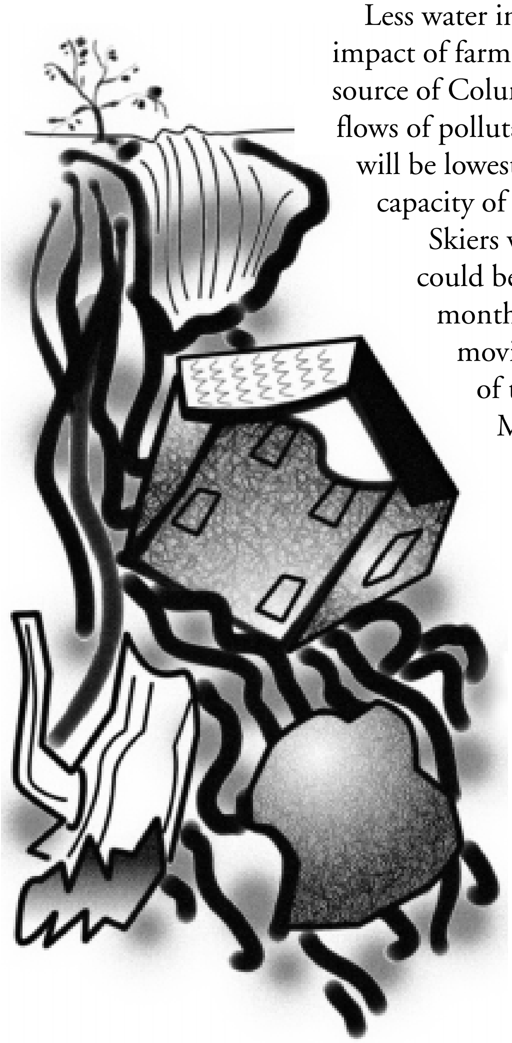
The severe storms, flooding and land slides seen over the past few years, still the exception, stand to become more the rule under global warming.

spill water early. Both these extremes are likely to be more frequent in a warming world. The region could be forced to build additional reservoirs at great economic and environmental cost. The best sites are dammed already.

One of the scenarios developed by JISAO, based on global modeling done by Max Planck Institute (MPI), projects that the Columbia-Snake hydrosystem, which now meets firm energy requirements 96 percent of the time, would slip down to 82 percent by 2050.[36] That signals large new regional investments in energy efficiency and generating capacity.

For irrigation, reliability drops even more. For example, the Upper Snake now reliably provides water to farmers 97 percent of the time. By 2020, that is expected to go down to 84 percent. The Middle Snake, now reliable only 86 percent of the time, drops to 70 percent.[37] The growing season may be longer, but water supplies could be severely constricted. Higher temperatures are likely to increase demand even as supply is decreasing. All this represents a substantial economic threat to farmers.

Less water in rivers will also multiply the impact of farm runoff, the largest nonpoint source of Columbia River pollution. Just when flows of pollutants are highest, flows of water will be lowest, limiting the pollution diluting capacity of the river.



Skiers would also suffer. The season could be abbreviated by around a month, Leung says. With snowlines moving higher, runs could stop short of the base of current chair lifts.[38] Most ski areas are located near current snowlines where snowpack losses are expected to be highest. Among the most vulnerable are resorts on Snoqualmie Pass in Washington, on Vancouver's north shore in British Columbia, and in Oregon's Blue Mountains.[39]

Floods And Mudslides: A Stormy Outlook

In February 1996 a "pineapple express" storm shot out of the tropical Pacific directly at the Pacific Northwest, hosing down Cascades snowpack with warm water. Rapid melt rumbled downwards, overwhelming streams and rivers. Within days, rivers over much of Oregon and Southwest Washington were beyond flood stage. The Columbia rode near the top of its immense levees. Just beyond the embankment and now below river level was Portland International Airport. Concern about a levee break was so great that incoming jetliners turned back and Oregon National Guard F-16s thundered off to higher ground. Meanwhile, landslides in the Oregon Cascades muddied water supplies to Portland and Salem. Slides also severed major routes including Interstate 5 and 84.

That was only a warm-up for the deadly '96-97 winter storm season. From October on, heavy rains drenched the Northwest. Some areas were hit by record floods. Overall, the Northwest sustained around $3 billion in damages.[40]

The severe storms, flooding and slides seen over the past few years, still the exception, stand to become more the rule under global warming. Commenting on the '96-97 storms, National Climatic Data Center Chief Scientist Thomas Karl said they were "an example of the type of weather patterns that would be expected to become more frequent and yield an increase in precipitation extremes as the climate continues to warm."[41]

Rivers west of the Cascades that are driven primarily by rainfall are likely to flood more often. Rivers east of the Cascades now not known for flooding could become a threat. Notes University of Washington hydrology expert Dennis Lettenmaier, "The possibility of substantial increases in flood flows may, given present reservoir storage, represent serious risk to life and property, particularly in the densely populated lower Columbia River flood plain."[42]

By increasing evaporation from the oceans, global warming is creating a steamier atmosphere more prone to intense rainstorms. Dr. Gerhard Berz, head of the Geoscience Research

Group at Munich Reinsurance, the world's largest reinsurance company, says, "There is no longer any doubt to us that a warming of the atmosphere and the oceans is causing an increased likelihood of storms, tidal waves, hailstorms, floods and other extreme events."[43]

The NCDC has already documented a 10-percent increase in precipitation and a 20-percent increase in extreme precipitation events over the U.S. this century.[44] The study shows rainfall increasing over 20 percent since 1900 at a number of Oregon Cascades and Western Washington weather stations.[45] "I would say the climate is responding to greenhouse gases," Karl told *the New York Times*.

Because of our unstable landscape, an increase in extreme rainfalls represents a special concern for Northwesterners. The Northwest, particularly Western Oregon and Western Washington, is one the most slide-prone reaches of the U.S. And it is precisely during or shortly after drenching storms when landslides are most likely to occur.[46]

"The big driver for slides is intense rainfall," notes University of Washington slide expert David Montgomery. "If we get a storm where we have more than 2 to 3 inches of rain in a day, we'll start to see some sliding."[47]

The incredible rains of winter '96-97 caused mudslides which buried families near Roseburg, Ore. and on Bainbridge Island, Wash. Slides demolished dozens of homes from Stafford, Calif. to Myrtle Creek, Ore. to the Magnolia Bluffs of Seattle overlooking Puget Sound. In some cases, clearcuts turned hillsides into loaded guns. In others, people built in the geological line of fire. But it was heavy storms that pulled the trigger.

Slides returned in winter '98-99, when many Northwest precipitation records were broken. From the Oregon Coast to Hood Canal, mudflows blocked major highways. Slide danger forced evacuation of around 20 homes on the Puget Sound north of Olympia.

This all underscores that much of the Northwest landscape is a geological newborn, a product of events that took place around 14,000 years ago at the end of the last ice age. The Columbia Gorge we know today was carved then by massive flooding that also shaped Eastern Washington and the Willamette Valley. Mile-high glaciers which dug the Puget Sound left behind mounds of deposits in the form of hills and bluffs. One-third of Puget Sound coastline, 660 miles, is lined by bluffs subject to retreat.[48] It's the nature of nature to eventually wear things down, and natural forces have only begun working on the Northwest's fresh landscape.

The Magnolia Bluffs are a case study in instability. Walking among the broken homes still hanging to the slopes requires care. Slide-opened gashes in the ground expose a sandy mush that instantly sucks boots down to the lip. It seems as if the whole hillside is a thinly concealed pudding. It isn't hard to imagine why the mile of bluff-hugging Perkins Lane leading up to the barricaded Magnolia disaster site was festooned with seven "For Sale" signs one January day two years after the slides.

Meanwhile, a Kelso, Wash. subdivision built on a slide reawakened by recent deluges is slowly going down, creating the largest single destruction of homes by landslide in U.S. history, 98 already gone and 37 more threatened. A half-mile away another reborn slide threatens similar devastation. Portland's West Hills have also experiencing regular landsliding during recent heavy rainstorms. Slides are

This all underscores that much of the Northwest landscape is a geological newborn...If heavy rainfalls become more commonplace, our particularly vulnerable region will face regular recurrences of destructive slides.

Intense rainfalls in winter '96-97 unleashed landslides which destroyed many Northwest homes such as this one in Seattle. Such storms coud become more common under global warming. *Photo by David McCloskey*

> *"Can Pacific salmon adapt to new climatic regimes?... Populations that are presently stressed by occupying unhealthy, marginal or fragmented habitat will likely face more acute threats of extinction..."*
>
> ROBERT FRANCIS

endemic to the Northwest's mushy landscape. Humans who have dared to thickly populate it are vulnerable to the consequences.

In many ways, what we see as placid everyday landforms are really a record of past catastrophes in temporary freeze-frame. The landscape does the greater part of its changing during extreme events such as storms. If heavy rainfalls become more commonplace, our particularly vulnerable region will face regular recurrences of destructive slides that muddy waters, cut off highways, shatter homes and kill people.

Fish In Hot Water: Rivers And Streams

During summer 1998 the world's greatest salmon river offered a glimpse into the global warming future. Over the previous winter in British Columbia's Fraser River watershed, precipitation was in the normal range. Snowpack on which the river depends for year-round flow piled up in the mountains. But temperatures, warmer than usual, caused an early melt and runoff. On its heels came a very hot and dry summer.

The results were some of the lowest water flows ever recorded on the Fraser, as well as some of the highest water temperatures. The river became a hostile environment for salmon, which died by the tens of thousands. B.C. fisheries managers were forced to suspend the commercial season for hard-hit sockeye, a species that especially needs cool water.[49]

Some, but not necessarily all, of those salmon-killing conditions were an outcome of the 1997-98 El Niño. They were also the conditions a 1994 Environment Canada report predicted for the Fraser River under global warming. The devastating consequences salmon experienced in 1998 were resonant with those forecast by the report.[50]

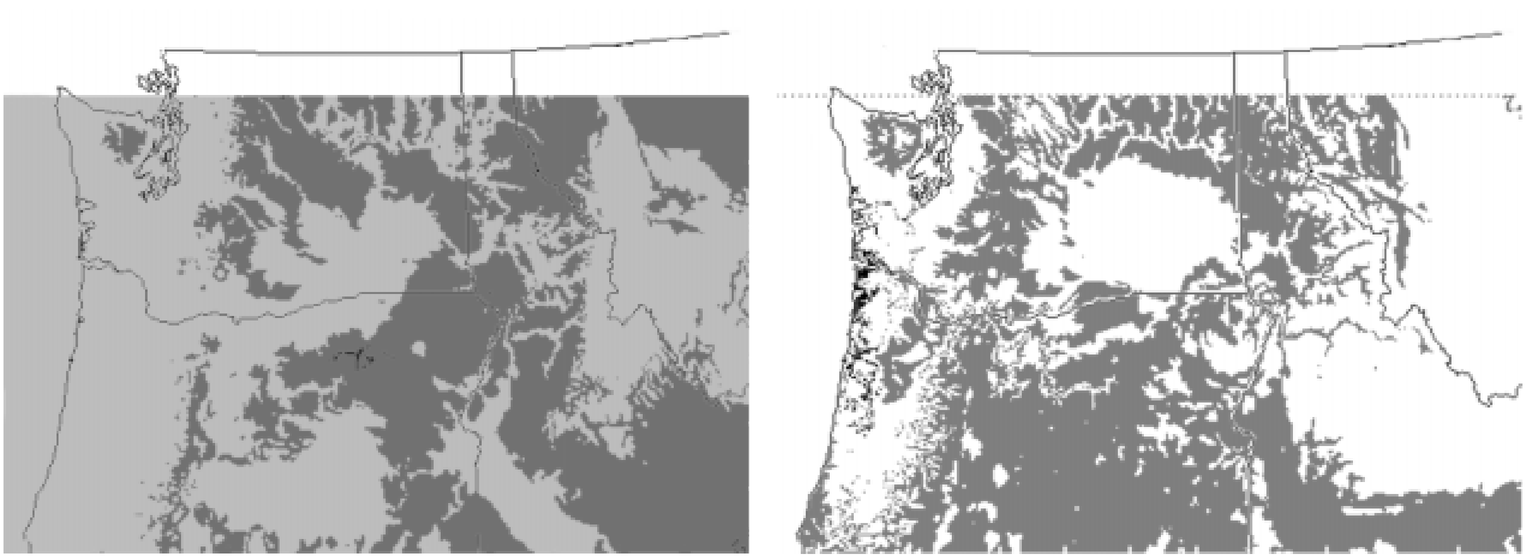
Salmon love cool water. It's good for them. It keeps down diseases. It's rich in dissolved oxygen. It lets the cold-blooded salmon turn their metabolic rate down low so they can make the most efficient use of oxygen and stored fat on their perilous upriver journey. Warm water makes them work harder, carries more patho-

Changes for the Northwest predicted by computer model for doubling of CO_2

Source: Pacific Northwest National Laboratory

Annual Mean Surface Temperature Change (F) — Percent Change Snowwater

2 - 3.5 | 3.5 - 5.5 — 10-50% | 150% or greater



gens and parasites and supplies less oxygen. No wonder that salmon generally seek out the coolest spots in rivers, or that the 1998 Fraser was so deadly.

Many fish stand to be affected by warming waters, particularly other cold loving species such as trout. What happens to the salmon can be regarded as an indicator for what many other species will face.

The next major regional river south of the Fraser, the Columbia, was once the greatest salmon stream on Earth. The radical drop in Columbia salmon runs is another global warming preview.

"On the Columbia we've done our own climate change experiment with the dams," says Nathan Mantua, who studies climate impacts on salmon.[51]

The dams both slowed flows and warmed up the river, two conditions likely to become more common in Northwest rivers and streams under global warming. Climate change is expected to amplify human impacts. Reduced summer flows would make salmon migration far more difficult. Slower moving rivers with less water would be inclined to heat up, multiplying the effect of a warming atmosphere.

In the MPI scenario used by JISAO, streamflows at McNary Dam, now adequate for fish only 85 percent of the time under standards set by the National Marine Fisheries Service, reach those benchmarks only 76 percent of the time in 2020. Reliability for hitting streamflow targets at Lower Granite plummets from 81 percent now to 47 percent in 20 years.[52]

Higher winter runoff may help with some salmon migrations. But if it comes too fast as scouring floods it will tear up redds, the nests where female salmon plant their eggs.

Robert C. Francis of the University of Washington Fisheries Research Institute, writing with Mantua, notes that human-caused global warming is "expected to lead to rapid changes in the climate system over the next few decades and centuries. Can Pacific salmon adapt to new climatic regimes?....Populations that are presently stressed by occupying unhealthy, marginal or fragmented habitat will likely face more acute threats of extinction..."[53]

"How fast can salmon adapt? Salmon have shown remarkable resilience, but they have been under attack by development," Mantua notes. "It seems unlikely they will respond well to a rapidly warming climate."[54]

Global warming raises the bar for habitat restoration efforts. It underscores the urgent necessity of bringing back a landscape friendly to salmon to as great a degree as possible, to mitigate stresses salmon are likely to experience from a warming climate.

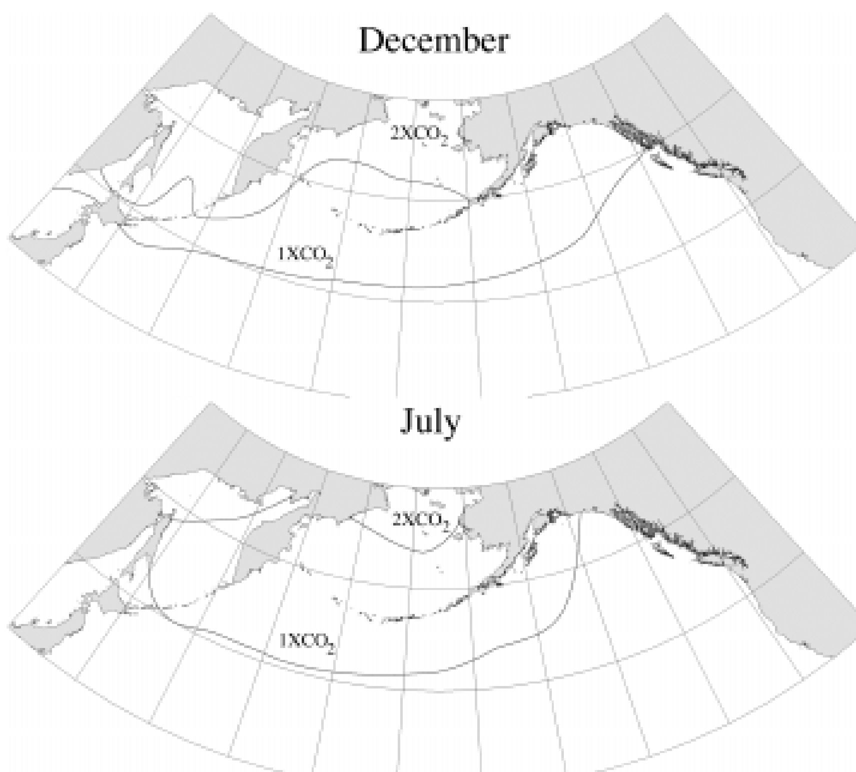
"The eastern Pacific may begin to lose its salmon range within 20-30 years."

DAVID WELCH

Fish In Hot Water Pacific

Perhaps the most troubling portent for the salmon is the expected rise in temperatures where they spend most of their lives and do most of their growing, the surface layer of the North Pacific.

A team led by David Welch of Fisheries Canada found there are maximum sea surface temperatures beyond which salmon will not range, except to return to their spawning streams. The lines identified as 1XCO2 show where that thermal barrier is today. The lines marked as 2XCO2 show where the barrier is projected to move under a doubled carbon dioxide atmosphere expected for approximately 2050. The barriers vary by season.



"We're seeing huge changes in the atmosphere and oceans in the 1990s...The response of our salmon populations is not at all encouraging."

DAVID WELCH

David Welch, a biological oceanographer, heads Fisheries Canada's high seas salmon research program at the Pacific Biological Station in Nanaimo, B.C. Welch led a team which looked back at four decades of North Pacific salmon data. Correlating seasons and locations salmon were found with sea surface temperature records in a more precise fashion than had ever been done before, Welch's team made a fresh discovery. They found there are extremely sharp thermal barriers that limit salmon distribution.[55]

For the same reason salmon favor cool water in rivers, they like cold water at sea. Welch discovered that the oceanic range of the salmon stops roughly where sea surface temperature reaches 45 deg F in the winter and 59 deg F at the peak of summer.

"What we've shown that people previously had not realized is there was a really strong effect of temperature on where salmon will not go," Welch says. "We showed there was an extremely sharp effect on limiting distribution. There was always this thermal wall." He says this is true of all salmon species. "60,000 genetically different populations all responding the same way—That says something. Not exceeding these temperatures must be very important for salmon."[56]

Welch notes salmon must maintain a balance between the amount of energy they burn and the amount they can gain from food. He theorizes that is why the thermal barrier varies by season. Summer, with greater food supplies, lets salmon swim into warmer water and keep up their fighting weight even though they expend more energy.

If Welch is correct, sea surface temperature increases well within global warming scenarios for the North Pacific will wall salmon out.

"The really perturbing thing to us," Welch says, "is where these sharp limits would be in 60 years time under doubled CO_2. They do not exist in the Pacific Ocean at all. They are up in the Bering Sea."[57]

The eastern Pacific may begin to lose its salmon range within 20-30 years, he says.[58] Since salmon spend most of their time in surface layers, Welch does not expect them to move to cooler, deeper water.

Salmon are hard-wired to return where they spawned. They would still jump the thermal barrier to migrate back along the coast to Northwest rivers and streams. But metabolically drained by hotter water, they would return with less stored energy for their final upstream run. (Salmon do not feed once they return to rivers.) They would have less capacity to stand the increasingly harsh stream conditions. And they would lay fewer eggs, further diminishing odds for survival.

A new Northwest Power Planning Council scientific study says one possible reason Columbia-Snake salmon runs are failing is that salmon expend their energy jumping hurdles placed in their way by dams. By the time they reach spawning grounds, they may be too worn out to reproduce.[59] If global warming further diminishes salmon energy reserves, it remains an open question whether runs can survive.

"We're seeing huge changes in the atmosphere and oceans in the 1990s," Welch notes. "We're seeing sharp declines in salmon survival, with fat reserves down by as much as 20 percent in the 1997 Fraser sockeye run. The climatic changes are consistent with the early stages of global warming. The response of our salmon populations is not at all encouraging."[60]

Welch's team believes that if data for other species is subjected to the same kind of finely-grained analysis they gave the salmon, similar thermal barriers might be discovered: "...other cold-blooded organisms may also express similar distributional responses to temperature that have so far gone unnoticed..."[61]

Of course, a warming ocean brings other species north. The warm seas of 1997 produced some unusual and bizarre fish catches off the coasts of Oregon and Washington—mahi-mahi, marlin, barracuda, tropical lizard fish, species that usually stay far to the south. Commercial fishermen in Newport, Ore. were selling albacore tuna dockside, instead of the usual salmon.

Warm-water fish such as albacore, mackerel and sardines stand to become more common off the Northwest coast if global warming drives up ocean temperatures. But sharply diminished or perhaps gone would be the region's iconic salmon.

Broken Links In The Food Chain

What is troubling Pacific salmon has implications for many ocean species. An oceanic shift that comes with El Niño is regarded as a foreshadowing of what might become normal conditions under global warming.

Winds normally mix surface layers with deeper, cooler, nutrient-rich waters. This upwelling feeds microscopic plankton, the base of the food chain. But when surface waters warm, they expand and effectively seal off the upwelling. Though sealing normally happens every spring and summer, global warming could perpetuate this condition for longer periods, as happens in an El Niño. Deprived of the upwelling, the food chain would collapse from the bottom up, beginning with plankton. Seabirds, marine mammals and salmon would follow. And all have been troubled by extended ocean warming during recent El Niños.

"Seabirds are quite sensitive indicators of ocean conditions," Welch notes. "They have shown large-scale changes off the West Coast through the 1990s."[62]

On the coast from Oregon to Vancouver Island in recent years, dead shearwaters have been drifting onshore with flight muscles atrophied, no fat, and blood in the stomach, classic signs of starvation. At the north end of Vancouver Island, nesting grounds to some of the world's largest seabird populations, researchers have been finding 50 percent of nests abandoned.[63]

On the Oregon Coast, major diebacks of common murres have been observed by scientists at the Hatfield Marine Science Center in Newport. In 1993 they witnessed a coastwide abandonment of nests, "unprecedented from our experience," notes David Pitkin, a U.S. Fish and Wildlife Service wildlife biologist based at the center. Scientists there have been monitoring Oregon Coast seabird numbers since the late 1980s. In summer 1996, a 4.5-mile beach survey turned up 122 dead murres. "That was quite striking. It represented a die-off of certainly thousands of birds." Similar reports up and down the Oregon coast revealed the die-off was widespread.

Reduced upwelling is "probably the broken link in this chain," Pitkin says. Common murres eat all kinds of small fish, can dive 600 feet, and range up to 40 miles from shore. They are a good indicator for the health of the food chain. "If it doesn't bode well for the common murre, it doesn't bode well for a lot of other species."[64]

Shearwater

Sea surface temperatures along the Northwest coast reached record levels in 1997. By late summer, they hit peaks with a chance of occurring due to purely natural causes once every 10,000 years.[65] Those temperatures indicated trouble in the food chain.

Common Murre

Apparently connected to a sealing of the surface layers, phytoplankton blooms of a kind never before recorded in the Bering Sea spread in 1997 and 1998. The blooms of coccolithophore, a species of plankton associated with low nutrient conditions, painted huge whitish-blue patches visible from space. Meanwhile zooplankton growth vital to the food chain was off. That may have contributed to a high rate of shearwater deaths.

Alaska Bristol Bay salmon runs unexpectedly declined in 1997-98. Predicted to be average to high, they instead were the lowest since the 1970s, notes Vera Alexander of the University of Alaska School of Fisheries and Ocean Sciences. That is also thought tied to ocean food chain breakages.[66] It is clear that a warming Pacific does not augur well for many marine species or people who depend on them.

Global warming is likely to increase the frequency and intensity of forest disturbances such as pest and disease outbreaks, and wildfires.

Forests: Outrun By Climate Change

The signature forests of the Northwest are known by their longevity—They're old growth. They are survivors, having long endured droughts, drenchings and windstorms. They have taken repeated hits from fire, disease and pests. As JISAO'S Ed Miles notes, "Mature trees tend to be long-lived and can survive long periods of marginal climate."[67]

As Northwest forests face global warming, "Responses will be slow and muted, especially for older forests, because they are relatively tolerant to change and can adapt somewhat to new environments," pioneering ancient forest scientist Jerry Franklin says.[68]

Douglas fir, which requires a winter chilling, will likely vanish from the Coast Range of Southern Oregon and Northern California under expected warming.

Old forests not only absorb climate change better—Northwest old growth forests also sequester immense amounts of carbon—Some hold more carbon per acre than any other ecosystem on earth. Cutting forests on a short-rotation basis actually puts more carbon into the atmosphere than leaving the equivalent acreage in old growth.[69]

Global warming is likely to increase the frequency and intensity of disturbances such as pest and disease outbreaks, and wildfires. This is where climate change is expected to have the greatest impact on Northwest forests, young and old.[70] During such disturbances the normal, slow pace of forest change drastically accelerates. Forests that otherwise might remain the same for centuries undergo dramatic shifts. Whole, new species communities can take root. Scientists studying pollen embedded in geologic layers have detected radical reordering of forest communities, brought on by catastrophic events that took place as climate was shifting. This is the likely scenario for future species shifts.

With warming temperatures, forests will become generally drier during summers because increased evaporation will wring out soils. Dryness will help promote fires. In a warming world, forest fires can be expected to burn more frequently and with greater intensity. For instance, large stand-replacing fires have come to the Central Washington Cascades every four centuries. Under global warming, they can be anticipated every century.[71] One hundred years of suppressing natural fires adds to the danger. Many Northwest forests are choked with thick growth just waiting for a spark. A climate swinging between extremes sets up further troubles. Heavy rainfalls feed growth of underbrush. Then warm, dry spells turn that underbrush into a tinderbox.

A hotter climate will be more friendly for insects which infest tree stands. Some insect species might be able to birth more generations each year. Aphids could climb to elevations currently too cold for them, to attack trees with little resistance such as subalpine fir.[72] And trees in general, when stressed by thirst and heat, are more susceptible to pests and disease.

In many Northwest forests, such as those on the Olympic Peninsula, severe windstorms are the prime stand-replacing catastrophes. Northwesterners remember the Columbus Day 1962 windstorm as an event that downed millions of trees. Scientists as yet cannot say if global warming will promote such fierce windstorms in the region. But the southeast Alaska coast has seen gale-force wind days double in number during the warming of the past 20 years.[73]

Every forest reflects its own particular place. Each is an adaptation to a certain pattern of temperature and precipitation. With warmer temperatures moving north, forests will find themselves in places where conditions are unlike those in which they originally grew. Tree species already living on the fringes of their range, facing global warming's added stress and disturbances, are expected to decline or disappear across wide areas. The more dry, southern and inland the forest is, the more susceptible it will be to change.

Both Washington and Oregon could lose 15-25 percent of total forest cover, mostly conifers on the drying lower east slopes of the Cascades.[74] They would be replaced by sagebrush steppe and grassland. For instance, one scenario shows the eastside Central Oregon Cascades, now 60 percent forested, losing half that cover in a 4.5 deg F warming.[75] The east slopes of the Washington Cascades are also projected to lose half their forests in a 5 deg F warming.[76] Those temperature increases are expected around 2050-80.

However, University of Oregon climate researcher Patrick Bartlein says, "The loss of forests east of the Cascades may not be a foregone conclusion." That is due to the fertilizing effect of increased atmospheric CO_2 on tree growth, he explains. Newer models that better account for this effect are giving forests stronger odds, Bartlein says.[77]

Temperature alone is expected to impact a major Northwest tree species. Douglas fir, which requires a winter chilling, will likely vanish from the Coast Range of Southern Oregon and Northern California under expected warming.[78]

As the geography of climate changes, forests will attempt to follow. But tree species typically "migrate" six-tenths of a mile each year. Climate will be moving twice as fast or faster.[79] Forests will often be blocked by human developments. Changing ecosystems will need new kinds of seedlings, but prospective parents will be left behind. Some species adapted to special conditions, such as the Port Orford cedar, might go extinct.

"Forest ecosystems are not expected to shift as intact communities," notes Miles.[80]

Trees could find new habitat at higher elevations that are now covered by snowpack and alpine meadows. But the flowered meadows Northwesterners have come to love in places such as Paradise on Mount Rainier are at risk. Subalpine forest is already invading meadows in the Cascades and Olympics, and threatens to entirely displace them from the westside of the Cascades in Oregon.[81]

Even though trees will find some new places to grow, the net effect of global warming in the Northwest could be forests diminished in extent, outrun by a climate changing faster than their ability to adapt.

Trouble For the Human Species

Human beings are no more exempt from global warming impacts than forests, fish and birds. A number of potential threats face us.

For urban areas, hotter temperatures mean more of those smoggy skies Seattle, Portland and other cities often encounter during hot summer days. Bright sunlight and high temperatures feed creation of ground-level ozone, a key component of smog which inflames lungs and worsens respiratory illnesses. More ozone will not only push cities further over the line—It also will hurt crops and wild plants.[82]

Drier summers could elevate pollen counts, making life more miserable for asthma and hay fever sufferers. An increase in summer heat waves, already observed in recent decades across the U.S., poses dangers to vulnerable populations such as the elderly.[83]

Warmer temperatures also encourages growth of disease-carrying insect populations. Lyme disease carried by ticks could increase in Oregon and forms of mosquito-born encephalitis could spread north from California.[84] Both diseases cause long-term damage to the human nervous system.

All along the coast, warmer water could also mean an increase in health threats such as disease carrying algal blooms, "red tides." They appeared in Washington state waters in 1989, '90 and '91. Algal blooms, which are already reaching epidemic status around the world, cause paralytic shellfish poisoning. Ocean warming potentially menaces Northwest shellfish fisheries, particularly the valuable oyster farms of the Willapa Bay, and the people who eat their products.

Where the Ocean Meets the Land

If El Niño is a dress rehearsal for global warming, then a crucial scene in the play unfolded during the 1997-98 El Niño when an upscale development on an eroding coastal bluff at Oceanside, Ore. threatened to slide into the Pacific. El Niños typically push the ocean up 2-10 inches in the Northwest. Higher tides and storm surges eat at the base of coastal cliffs. Over the winter months this is exactly what was happening beneath The Capes. When the danger became apparent, 34 homeowners including former Oregon Sen. Mark Hatfield were red-tagged out of their dwellings. The threat later receded, but four homes closest to the edge were still posted no-entry a year later.

Just a few inches of ocean might not sound like much. But they can represent a threshold, one of those "last straws," that set off big and

Hotter temperatures mean more of those smoggy skies Seattle, Portland and other cities often encounter during hot summer days.

Olympia is perhaps the most vulnerable place in the Puget Sound area to sea level rises. Large areas of downtown would be inundated by 2100 under current projections.

sometimes hairy changes. Those are in prospect. Elevated ocean levels that lap at the Northwest coast for short periods during El Niños are projected to become business as usual over the next century. As a permanent condition, their effects will be compounded.

Because of both melting glacier ice and the expansion of water as it warms, world sea levels have already risen 4-10 inches over the past century. Three inches more are expected by 2020, 8 by 2050 and 20 by 2100. Those are "best guess" estimates—High end is around three feet.[85] In any case, sea levels will continue rising for hundreds of years while higher temperatures melt ice caps and work their way through the deep oceans.

As the ocean increasingly crowds coastal bluffs, chances for landslides will increase. If global warming brings more intense rainfalls, turning hillsides into muck, those odds will multiply. The Capes exemplified that. Storms from above and sea from below together conspired to undermine bluffs.

Small rises in sea level add height to tides and significantly boost storm surges. Starting from a higher platform, surges can flood more turf. A 75-year storm a century from now will be able to do the kind of damage a 100-year storm does today.[86] Flooding could spread far inland when higher surges and tides back up rivers gorged with storm runoff. Low-elevation river valleys in the Puget Sound and along the Oregon Coast might be especially hard hit.

Olympia at high tide

Rising waters will busily chomp away at beaches. The sandy edges of Oregon and Southwest Washington that have shaped so many pleasant days and contemplative moments are at risk of severe erosion. They already experience temporary setbacks during El Niños. Diminished extent could become more the normal condition. Coastline and beaches on inland straits from Puget Sound to the Fraser River delta are also at high risk of erosion.[87] Northwesterners of the future might find narrower sandy stretches on which to play, think, read and gaze.

As seas rise some land will also be rising but other places will be sinking. It's the natural course of geological history. For the British Columbia coast, the upward push of the earth will cancel out as much as 16 inches of climbing waters. But the Puget Sound is settling by six inches per century in Seattle, nine around Tacoma, and five around Olympia.[88] Put 20 inches more water on top, and some areas around the Sound are clearly in a precarious position.

"Olympia is perhaps the most vulnerable place in the Puget Sound area to sea level rises," notes JISAO's Philip Mote. "Large areas of downtown would be inundated by 2100 under current projections of sea-level rise without substantial investment in building dikes."[89]

Coastal communities from Raymond and South Bend in Washington to Tillamook, Cannon Beach and Coos Bay in Oregon, as well as coast-hugging highways, are vulnerable to rising waters. Even a one-foot rise will force a costly realignment of Oregon Highway 101, disrupting businesses and forcing people to move.[90]

A special concern surrounding sea level rise is tidal marshes, whose contribution to biological productivity is far out of proportion to their size. They are food and shelter for wildlife including oysters, clams, ducks, geese, salmon, herring and smelt. In Western Washington alone, coastal wetlands play a vital part in the lives of 212 animal species.[91] Development has already eliminated vast reaches of the marshes. Rising sea levels could take out much of what remains. If water ascends only 13 inches in particularly vulnerable Puget Sound, 40 percent of its tidal flats would go permanently under the wave.[92] Oregon's coastal marshes, now limited to Coos and Tillamook Bays, could drown under a 1-3-foot rise.[93]

With higher tides and storm surges undermining banks, property owners will feel driven to armor even more shoreline. Already, for example, human alterations line 52 percent of central Puget Sound shores.[94] Besides huge economic costs, the ecological price of bulkheading what remains would be considerable. Wetlands pinched between rising waters and bulkheads would find no place to move. Shores would lose plant life, wildlife corridors, spawning areas, and logs and debris that create wildlife habitat. A more biologically impoverished coastline, with fewer salmon, shellfish and birds, would result. For wildlife and fisheries, it would be bad news.

Humans are already putting intense pressure on coastal ecosystems through armoring, wetland filling, logging, agriculture, dredging, exotic species introductions and other disturbances. Climate change piles on yet more stress.

Conclusion

Wetter winters and hotter summers...Fewer salmon...More forest fires and less forest cover...A disrupted water cycle with snowpack cut in half...Too much water in rivers in winter...More floods and mudslides...Too little water in summer...An increase in drought years...A squeeze on hydropower and farmers...Shortened ski seasons...Drowned highways, waterfronts and tidal marshes...More heat waves, air pollution and disease-carrying insects...None of these outcomes are what we want. Yet all are what we potentially face in the disrupted climate of the next century.

The damages global warming might inflict on the Pacific Northwest constitute a call to action and leadership. Part of the challenge will be adaptation. The Northwest is likely to experience a degree of negative impacts. A range of public policies must take likely climate change into account, from comprehensive water conservation, to increased focus on slide and flooding hazards in land use and transportation plans, to added emphasis on salmon recovery.

But we cannot stop at adaptation. In a way, we are in a paradoxical situation, for our region is vulnerable to circumstances far beyond our control. Yet if we want to save much of what we value about the Northwest, we must find a way to alter global trajectories. Our corner of the world clearly cannot do much to slow global warming, at least on our own. But we can play a leadership role far out of proportion to our numbers or geographic extent. It is said that with a sufficient fulcrum, one might move a whole world. Perhaps the Pacific Northwest, leading by example in and export of practical and profitable solutions to global warming, might tip the scales toward a worldwide response equal to the challenge.

Really, we are not so small. As an independent nation our economic region would rank as the 10th largest economy in the world.[95] From software to aerospace, coffee to microbrew to music, we are leaders in technology and culture. Our budding clean energy industry is already on the global map. We are also a center for environmental policy innovation. The Northwest has mounted world-recognized efforts in urban growth management and ecosystem-based protection of forest and watersheds, areas with important ramifications for climate change. We possess all the raw materials needed to craft a regional global warming strategy that provides a leading-edge model for the world.

We possess all the raw materials needed to craft a regional global warming strategy that provides a leading-edge model for the world.

So far, we are not there. To some extent, the Northwest thinks regionally in terms of the hydroelectric system and related issues such as salmon and flood control. But we have barely begun to grapple with climate change on any level. As Ed Miles of the JISAO Climate Impacts Group notes, "There is now very little regional capacity to plan in response to climate variability and none with respect to climate change."[96] A warming world and disrupted climate do not give us the option of continuing that status quo.

The first step is to build regional self-awareness of both the perils we face, and the opportunities. For as the vast issue of global warming and its potential impacts is most readily comprehended on a regional scale, so are the solutions. Though national and global responses are utterly crucial, it will be at the bioregional scale where "the rubber meets the road," where changes take visible shape:

- where clean energy sources such as wind turbines, solar photovoltaic panels and hydrogen fuel cells are employed.
- where homes, stores, offices and factories are constructed and retrofitted for maximum energy efficiency.

The foundation is in place for a comprehensive regional climate change initiative

- where neighborhoods, downtowns and town centers are revitalized and rebuilt so sprawl is constrained and the need for travel is minimized.
- where climate-friendly transportation systems emphasize buses, trains, car and van pools, bicycles, walking, telecommuting and clean-fuel vehicles.
- where farmers and foresters grow carbon reservoirs that lock up greenhouse gases in trees, crops and soils, and harvest biofuels that add no net greenhouse gases to the atmosphere.

Each of these transformations represents substantial opportunities for economic prosperity as well as environmental gain. In most of these areas, the Northwest already has models on the ground. The foundation is in place for a comprehensive regional climate change initiative bringing together large and small businesses, state and local government agencies, educational and research institutions, labor, and environmental and other nonprofit groups. Pulling together at the regional level, combining our resources, skills and knowledge, we can generate sufficient critical mass to create a Northwest climate change agenda that carries global significance.

For the sake of our future and our children's future, and all the elements of Northwest nature we have come to treasure and rely upon, we must together consider both adaptation to a changing climate and innovative actions to avert the more dangerous scenarios. If we can clearly understand there are potentially bleak outcomes, we can also become a leader in global warming solutions and help the world navigate one of the coming century's greatest challenges. With clarity, vision and purpose, this role is well within our grasp.

We wish to thank our reviewers:

Professor Patrick J. Bartlein,
Dept. of Geography, University of Oregon

Richard Gammon,
Professor of Chemistry and Oceanography,
University of Washington

Dr. L. Ruby Leung,
Senior Research Scientist,
Pacific Northwest National Laboratory

Nathan Mantua, Ph D.,
Dept. of Atmospheric Sciences,
University of Washington

David McCloskey, Ph.D.,
Ecological Studies Program,
Seattle Univerity

Philip Mote, Ph D.,
JISAO/SMA Climate Impacts Group,
University of Washington

Dr. David Welch,
Fisheries & Oceans Canada,
Nanaimo, B.C.

References

[1]personal communication

[2]For purposes of this paper, Pacific Northwest generally refers to Washington, Oregon and British Columbia.

[3]Trenberth, Kevin E., The use and abuse of climate models, *Nature*, Vol386, March 11, 1997, p131-3

[4]Leung, L. Ruby, Regional climate model results, Washington State Senate workshop on climate change, March 26, 1999, http://tao.atmos.washington.edu/PNWimpacts

[5]Climate Change State of Knowledge, Office of Science and Technology Policy, October 1997, p9

[6]Mote, Philip, Climate model scenarios for the Northwest, Washington State Senate workshop on climate change, March 26, 1999, http://tao.atmos.washington.edu/PNWimpacts

[7]Leung, L.R. and Ghan, S.J., Pacific Northwest Climate Sensitivity Simulated by a Regional Climate Model Driven by a GCM. PART II: 2xCO_2 Simulations, Pacific Northwest National Laboratory, Richland, Wash., Fig14c

[8]Mote, Climate model scenarios

[9]Mote, Climate model scenarios

[10]personal communication

[11]Miles, Edward L.; Hamlet, Alan; Snover, Amy, Summarizing the Integrated Assessment: Approach and Findings, July 20, 1998, Joint Institute for the Study of Atmosphere Climate Impacts Group, University of Washington, p15

[12]McCloskey, David, Cascadia, in *Futures by Design: The Practice of Ecological Planning*, ed. by Doug Aberley, New Society Publishers, 1994, p98-105

[13]Miles and Hamlet,p9

[14]OSTP/USGCRP Regional Workshop on the Impacts of Global Climate Change on the Pacific Northwest Final Report, July 31, 1997, pC5

[15]Miles, Edward L.; Hamlet, Alan; Snover, Amy; Summarizing the Integrated Assessment: Approach and Findings, July 20, 1998, Joint Institute for the Study of Atmosphere Climate Impacts Group, University of Washington, p14

[16]personal communication

[17]Miles and Hamlet, p16

[18]Joint Institute for the Study of Atmosphere and Oceans, El Niño Impacts on the Pacific Northwest, http://tao.atmos.washington.edu

[19]Trenberth, K.E. and Hoar, T.J., The 1990-95 El Niño-Southern Oscillation Event: Longest on Record, *Geophysical Research Letters*, vol23, No1, Jan. 1, 1996, p 57-60

[20]personal communication

[21]Knutson, T.R. and Manabe, S., Model Assessment of Decadal Variability and Trends in the Tropical Pacific Ocean, *Journal of Climate*, Sept. 1998, p2273-96

[22]Associated Press, Global warming might make El Niño-like conditions permanent, April 22, 1999; and http://www.cnn.com/NATURE/9904/22/global.warming.ap/index.html

[23]personal communication

[24]Miles and Hamlet, p23

[25]Preparing for an Uncertain Climate, Vol. 1, U.S. Congress/Office of Technology Assessment, 1993, p227

[26]Doherty, Sarah; Roth, Rhys; Snover, Amy; Global Warming and the Pacific Northwest: a profile of the vulnerabilities of our region to global climate change, Atmosphere Alliance, July 1997, p6

[27]Leung, State Senate Workshop

[28]Leung and Ghan, Abstract

[29]Leung and Ghan, Fig14d

[30]Leung and Ghan, p16

[31]Miles and Hamlet, p24

[32]Leung and Ghan, Fig13

[33]Leung, personal communication

[34]Hamlet, Alan F., Climate Change in the Columbia River Basin, Washington State Senate workshop on climate change, March 26, 1999, http://tao.atmos.washington.edu/PNWimpacts

[35]Hamlet

[36]Miles and Hamlet, p26

[37]ibid

[38]personal communication

[39]ibid, and Ryan, John, *Over Our Heads: A Local Look at Global Climate*, Northwest Environment Watch, 1997, p14

[40]Climate Change State of Knowledge, p14

[41]Global Warming and Change in Flood Potential, Tom Karl, National Climatic Data Center, Jan. 6, 1997, http://www.ncdc.noaa/gov/rcsg/flooding/gwcfp.html

[42]Lettenmaier, D.P.; R.N. Palmer; A.W. Wood; "The Implications of Global Warming for U.S. Water Resources," April 1996, in press, cited in Doherty, p8

[43]Finance in the Greenhouse, Issue I, Nov. 1996

[44]B*ulletin of the American Meteorological Society*, v77, Feb. 19, 1996, p279-92

[45]U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Climate Change and Washington, Sept. 1997; Climate Change and Oregon, Sept. 1998

[46]Bell, Brenda, The Liquid Earth, *The Atlantic Monthly*, Jan. 1999, p58-72; hazards map, p71

[47]S*eattle Post-Intelligencer*, "Record rains putting mud on the move," Feb. 8, 1999, pA1

[48]Bell, p. 62

[49]Fraser River Environmental Watch Report, 1998, Fisheries and Oceans Canada, various editions, July-August 1998, cited in Last Call: The Will to Save the Pacific Salmon, David Suzuki Foundation, Sept. 1998, p7

[50]Levy, David, Potential Impacts of Global Warming on Salmon Production in the Fraser River Watershed, Environment Canada Climate Change Digest CCD 94-04, p1

[51]personal communication

[52]Miles and Hamlet, p26

[53]Francis, R.C; N.J. Mantua; S.R. Hare, Climate and Extinction Risk for Salmon Populations of the Northeast Pacific, in conclusion, http://tao.atmos.washington.edu/PNWimpacts/REPORTS/extinctions.html

[54]personal communication

[55]Welch, D.W. et al, Thermal limits and ocean migrations of sockeye salmon (Oncorhynchus nerka): long-term consequences of global warming, *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 55, 1998, p937-48; Welch, D.W. et al, Upper thermal limits on the oceanic distribution of Pacific salmon (Oncorhynchus spp.) in the spring, *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 52, 1995, p489-503; Welch, D.W. et al, Thermal limits on the ocean distribution of Steelhead Trout (Oncorhynchus mykiss), *NPAFC Bulletin* No. 1, 1998, p 396-404; Williams, Nigel, Temperature Rise Could Squeeze Salmon, *Science*, vol. 280, May 29, 1998, p1349

[56]personal communication

[57]ibid

[58]ibid

[59]*Seattle Post-Intelligencer*, Salmon may be too pooped to spawn, Feb. 5, 1999, pC10

[60]personal communication

[61]Welch, *Canadian Journal of Fisheries and Aquatic Sciences*, 1998, p947

[62]personal communication

[63]ibid

[64]personal communication

[65]Last Call: The Will to Save the Pacific Salmon, David Suzuki Foundation, Sept. 1998, p13; David Welch, personal communication

[66]personal communication

[67]Miles and Hamlet, p28

[68]OSTP/USGCRP Regional Workshop on the Impacts of Global Climate Change on the Pacific Northwest Final Report, July 31, 1997, pc-7

[69]ibid, pC-8

[70]Miles and Hamlet, p27-28

[71]Franklin, J.F. et al, Effects of global climatic change on forests in northwestern North America, 1991 *Northwest Environmental Journal* 7, p233-54

[72]ibid

[73]Juday, Glenn, Observed Climate Change in Alaska: The Early Consequences of Global Warming, US Global Change Research Program Seminar Series, Dec. 8, 1997

[74]U.S. Environmental Protection Agency, Climate Change and Washington, Climate Change and Oregon

[75]Franklin et al

[76]Mote, Philip, Impacts of climate change on Washington's forests, salmon, coasts, and human health, Washington State Senate workshop on climate change,, March 26, 1999, http://tao.atmos.washington.edu/PNWimpacts

[77]personal communication

[78]Leverenz, J.W. and Lev, D.J., Effects of carbon dioxide-induced changes on the natural ranges of six commercial tree species in the western United States, in *The Greenhouse Effect: Climate Change and US Forests*, ed. by Shands, W.E. and Joffman, J.S., Conservation Foundation, Washington, D.C., 1997

[79]Doherty, p17

[80]Miles and Hamlet, p27

[81]Franklin et al

[82]U.S. Environmental Protection Agency, Climate Change and Washington

[83]Gaffen, Dian J. & Ross, Rebecca, J., Increased summertime heat stress in the US, *Nature*, Vol. 396, Dec. 10, 1998, p. 629-30

[84]U.S. Environmental Protection Agency, Climate Change and Oregon

[85]Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change*, Summary for Policymakers

[86]Ryan, p29

[87]Doherty, p11

[88]Ryan, p28

[89]Mote, Philip, Impacts of climate change on Washington's forests, salmon, coasts, and human health

[90]"Sea Level Rise," Washington State Department of Ecology, Washington Coastal Zone Management, November 1996; Oregon Task Force on Global Warming, *Report to the Governor and Legislature, Part One: Possible Impacts on Oregon from Global Warming*, June 1990

[91]Washington State Department of Ecology, 1988 Washington Wetlands Study Report, Olympia, Wash.

[92]Park, R.A. et al, Potential effects of sea level rise on Puget Sound wetlands, Geocarto Int., 113, 8(4)99-110

[93]U.S. Environmental Protection Agency, Climate Change and Oregon

[94]*Seattle Post-Intelligencer*, A salmon fight—on the beach, March 18, 1999, pA1

[95]Schell, Paul and Hamer, John, What is the Future of Cascadia?, *Discovery Institute Inquiry*, May 28, 1993. The authors refer to the five U.S. states and two Canadian provinces that make up the Pacific Northwest Economic Region.

[96]Miles and Hamlet, p49

Climate Solutions is dedicated to stopping global warming at the earliest point possible by helping the Pacific Northwest to become a world leader in practical and profitable solutions.

Our work is made possible by contributions from hundreds of individual members and grants from the W. Alton Jones, Turner, and Bullitt Foundations.

This report is published in collaboration with the Washington State Dept. of Community, Trade and Economic Development, the Washington State University Energy Program, and the Northwest Council on Climate Change, with support from the U.S. Environmental Protection Agency's Office of Policy, Planning and Evaluation.

For additional copies of this report, or for a list of publications on global warming and solutions, contact:

Climate Solutions
a project of the Earth Island Institute
610 E 4th Ave
Olympia, Washington 98501

phone .... (360) 352-1763
fax .... (360) 943-4977
email .... info@climatesolutions.org

www.climatesolutions.org

Design by Steve Barrett

Climate Solutions
a project of the Earth Island Institute
610 E. 4th Ave
Olympia, Washington 98501 USA

Non-Profit Org.
U.S. Postage
PAID
Olympia, WA
Permit #771