
EFFECS OF GLOBAL WARMING ON
SNOWPACK IN THE COLORADO RIVER
BASIN

By Michael Powers

CONTENTS

Introduction.....	3
Methodology.....	4
Immediate Effects on Snowpack.....	5
Effects of Global Warming on Microbial Communities.....	8
Effects of Global Warming on Snow Runoff and Water Supply.....	10
Effects of Global Warming on Mountain Wildlife.....	15
Conclusions.....	21
Works Cited.....	23

INTRODUCTION

The Colorado River Basin is highly dependent upon the snowpack contained in its mountains. It is a key component in the area's hydrological cycle, providing water to the region during sensitive times of the year. The snow satisfies many of the region's economic as well as recreational demands. This is not just an important resource for the people that live there, but also for the wildlife in the region as well. This dependency makes it crucial to understand how a changing climate will affect the mountain snowpack.

Snowfall in the Colorado Basin is contained mostly in the high altitude mountainous regions such as the Rocky Mountains. While these areas are generally isolated they are the source of many of the basin's larger rivers. While the regions of the Colorado Basin which receive snowfall only account for 15% of the total basin area, it accounts for about 85% of the total basin runoff.

Arkansas, Colorado and Rio Grande Basin Mountain Snowpack as of February 1, 2009

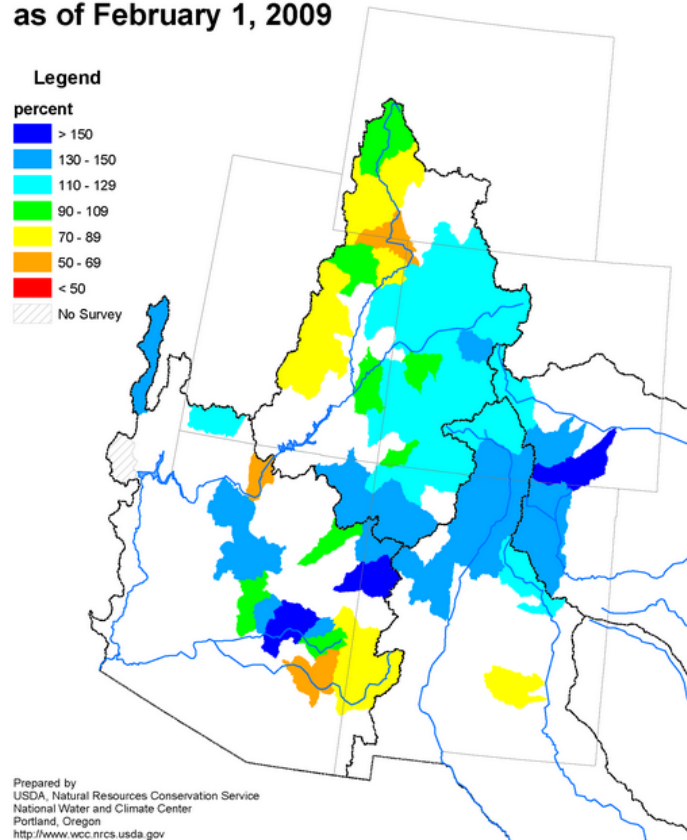


FIGURE 1: SNOW FALL IN COLORADO RIVER BASIN AS A PERCENTAGE OF THE AVERAGE

METHODOLOGY

This is a research based report. Information on global warming effects in the Colorado Basin as well as other parts of the world in similar situations was gathered. These sources came primarily through scientific journals to ensure that the information was accurate. This information was then compiled to create a realistic description of the problems faced by the Snowpack in the Colorado Basin. This report is that compilation.

IMMEDIATE EFFECTS ON SNOWPACK

Since this mountain snowpack provides such a disproportionate amount of runoff to the surrounding regions it is important to understand how the snowpack is changing in response to changes in its environment. It is generally expected that the current warming trend would correspond to an overall decrease in snowpack. While this may be the case for lower altitude regions, which are warmer and therefore more sensitive to temperature change, it is not the case for higher altitude areas. The lower altitude areas are more often near the melting point, and slight temperature fluctuations can lead to a thaw. In the higher regions, however, the temperature is generally much further below freezing, and an increase in temperature by a few degrees is not enough to cause melting.

The higher altitude regions, which account for the majority of snowpack in the Colorado Basin, are more sensitive to changes in precipitation amounts. It is therefore important to understand current precipitation trends in these areas. A study performed by Mote et al. (2005) investigated snowpack and precipitation trends and how they corresponded to changes in average temperature. They found that the overall increase in average temperature in the Colorado River Basin has brought about an overall increase in precipitation. This increase in precipitation also brought increased snowpack in most of the area.

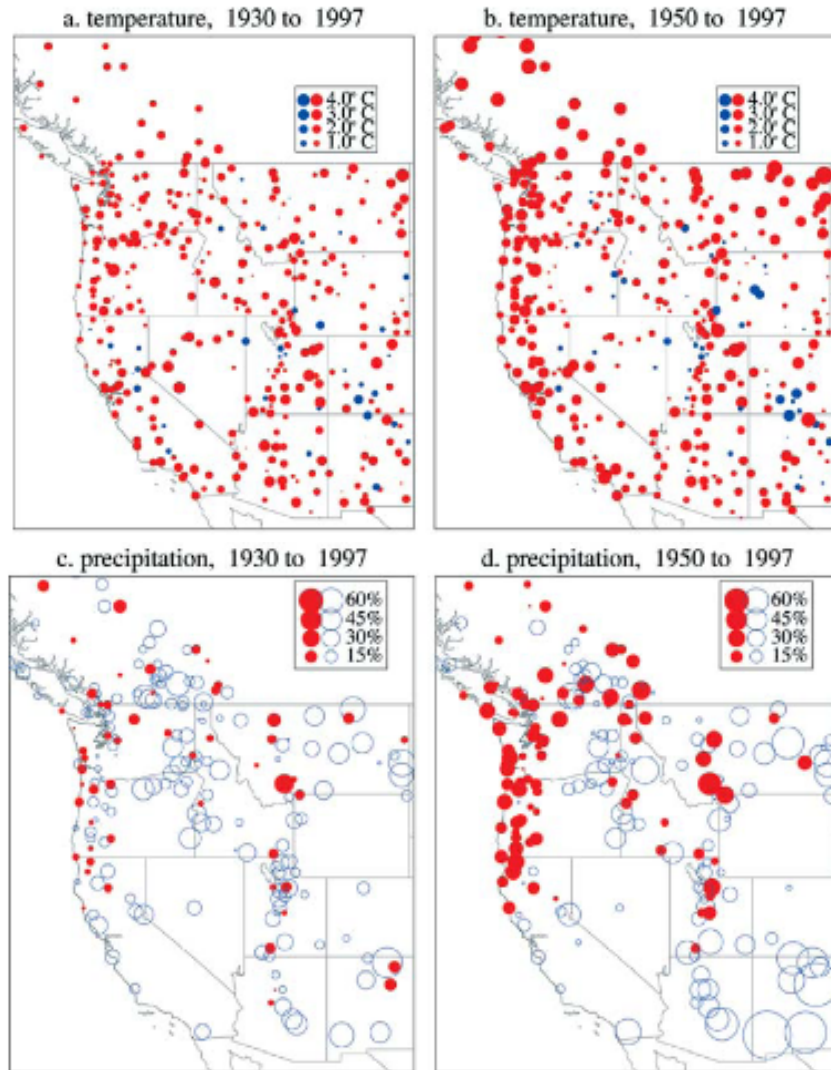


FIG. 6. Linear trends in Nov–Mar (a), (b) temperature and (c), (d) total precipitation over the period indicated. For temperature, negative trends are indicated by blue circles, and positive trends by red circles; values are given in degrees per century. For precipitation, trends are given as a percentage of the starting value (1930 or 1950), and positive trends are shown as blue circles.

FIGURE 2: TEMPERATURE AND PRECIPITATION TRENDS IN WESTERN NORTH AMERICA (MOTE ET AL., 2005). FIGURE 6 AT [HTTP://WWW.LIVINGRIVERS.ORG/PDFS/LRLIBRARY/CLIMATEDOCS/MOTEHAMLETCLARKLETTENMAIER.PDF](http://www.livingrivers.org/pdfs/lrlibrary/climatedocs/motehamletclarklettenmaier.pdf)

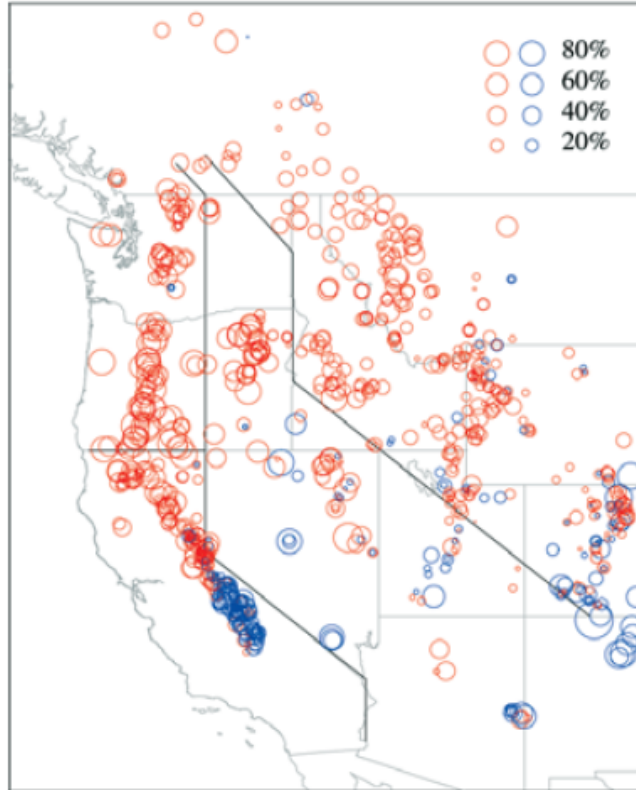


FIGURE 3: TREND IN SWE FOR WESTERN UNITED STATES (MOTE ET. AL, 2005). FIGURE 1 AT [HTTP://WWW.LIVINGRIVERS.ORG/PDFs/LRLIBRARY/CLIMATEDOCS/MOTEHAMLETCLARKLETTENMAIER.PDF](http://www.livingrivers.org/PDFs/LRLIBRARY/CLIMATEDOCS/MOTEHAMLETCLARKLETTENMAIER.PDF)

The above figure shows the changes in snow water equivalent (SWE) between the years of 1950 and 1997. Blue circles correspond to an increase in snow water equivalent, while red circles correspond with a decrease. It can be seen that while most other regions observed a decrease, the Colorado Basin area mostly observed an increase. This is due to the fact that snowfall in the basin is contained mostly in higher altitude areas which are more resistant to temperature fluctuations.

Increasing amounts of snowpack does not mean that these regions are immune to effects of global warming however. Increasing temperature combined with more precipitation can cause

serious problems for the Colorado Basin. These effects will be explored in the following sections.

EFFECTS OF GLOBAL WARMING ON MICROBIAL COMMUNITIES

Contained beneath the snow of the Colorado Basin is a layer of frozen ground. The layer of soil which freezes in the winter only to thaw out again in the warmer months is known as the active layer. In areas that are cold enough there is another layer below this which never fully thaws out. This is known as permafrost. As the average temperature of an area rises, these layers will decrease in size and duration. This has the potential to create lasting atmospheric effects.

Permafrost contains a very large pool of carbon which is currently inactive. These underground carbon pools can be created through different mechanisms. The first of these involves layers of carbon rich matter building upon each other, which causes the ground to slowly rise. The bottom layers then freeze and become permafrost. This is known as syngenetic permafrost growth. One cause of this is the growing of mosses or peat on top of each other. Each year a new layer of growth will cover the next one, causing a slow accumulation of organic carbon matter. As this happens the material on the bottom becomes incorporated into the active layer and eventually the permafrost. Build up in this manner can result in accumulation of about 0.5 millimeters a year (Schuur et al., 2000). This effect generally only occurs in poorly drained areas that support large amounts of mosses, and therefore is not likely in the more barren high altitude regions of Colorado. A more likely cause of syngenetic permafrost growth is the deposit of silt and minerals on an area over time. These deposits can come from aeolian sedimentation, or mineral deposits caused by the erosion of earth by the wind. They can also come from

alluvial sedimentation, or mineral deposits caused by erosion of the earth due to liquid. This effect can lead to ground surface build up of about 0.7 millimeters per year (Schuur et al., 2000). This is a much more likely cause of carbon pools in the Colorado area due to the exposure of the mountains as well as its glacial history.

These carbon pools are extremely large. In the upper hemisphere alone, there is estimated to be over 1672 petagrams of carbon (Schuur et al., 2008). This amount is more than double the carbon that is currently available in the atmosphere (Schuur et al., 2000). The quantities of carbon contained within permafrost are extremely large, and should not be ignored. If such large quantities of carbon were to become active there could be far reaching consequences.

As yearly temperatures increase more and more portions of what was formerly permafrost will begin to thaw for at least part of the year and become active layer. This is known as active layer thickening. If regions of permafrost thaw out the carbon that was previously stored in them become more readily available as an energy source to microbes that live in soil. Microbe activity can increase by more than an order of magnitude once the temperature rises above the freezing point of water. If these regions thaw they can support large microbial communities which will break down the carbon and release gases in return. This gas is usually carbon dioxide or methane, both of which are green house gases. Carbon dioxide alone makes up 83.8% of current green house gas emissions, and methane makes up 8.6% (Energy Information Administration, 2008). These chemicals already make up the vast majority of atmospheric greenhouse gases. If the extremely large source of carbon is tapped then an extremely large increase in greenhouse gas emissions could occur.

The yearly increase in temperature is aided by the increase in winter precipitation seen in the Colorado basin. A recent study has shown that snowfall in the Colorado Basin has increased from 1042 cm to 1239 cm between the years of 1997 and 1999 (Inouye et al., 2000). This increased snowfall helps to insulate the ground below it. The air temperature above the snow layer may fall well below freezing, but the snow at ground level will still remain around the 0° C mark. This effect helps keep the ground from re-freezing as much as it would if it were exposed directly to the air. As yearly snowfall increases, the ground becomes more insulated from the cold air, and allows for the ground to thaw more deeply than in previous years. This effect helps to exaggerate the active layer thickening that is already occurring as a response to global warming.

The release of greenhouse gases as a response to increased temperatures is a dangerous effect. The greenhouse gases which are released will help aid the current trend of global warming. The increased temperatures will then aid active layer thickening. This creates a positive feedback loop that will exaggerate current global warming trends.

EFFECTS OF GLOBAL WARMING ON SNOW RUNOFF AND WATER SUPPLY

Water is an extremely important and scarce resource in the Colorado Basin. The Colorado River alone supplies water to over 25 million people, irrigation to 3.5 million acres of farmland, and is used to generate over 12.2 trillion kilowatts of electric power (Hooton, 2008). These areas rely on this runoff to provide a sufficient amount of water to their population. This

region is already struggling to provide enough water to its residents. In 2008 Lake Powell was at 45% capacity and Lake Mead was at 50% capacity (Hooton, 2008). If the current trend climate change and current rate of water usage continues there is a 50% chance that lake Mead will be completely dry by 2021 (Hooton, 2008). The Colorado Basin area is clearly very sensitive to any change in water supply that might occur.

Snowmelt runoff is an extremely large source of water for the Colorado Basin. It is also a very efficient source of water. The thin mountain soil that this snow falls on does not absorb much water, and therefore not much snow is lost as it melts and runs down the mountain. As a result it supplies a disproportionate amount of water. A significant portion of rainfall at lower altitudes, especially during the summer months, does not reach streams and aquifers. Plants in the area will use some of this rainfall almost immediately. Nearly all of the rest will then be lost to evaporation, which is intensified by the warm ground on which it lands (Committee on the Scientific Bases of Colorado River Basin Water Management, 2007). A total of about 90% of stream flow to the Colorado River comes from snowmelt in the upper basin (Hooton, 2008). It is therefore obvious that any changes to runoff due to snow melt can have very serious consequences.

Snowmelt also provides water to Colorado Basin during critical parts of the year. Precipitation during the winter time is stored on the mountains only to melt later in the year when temperatures are warmer. Water is in greater demand during the warmer parts of the year, due largely to agriculture. This effect of saving water until these later months means that water is naturally stored until it is needed the most. Rainfall in the warmer, lower altitude regions can supply water to the region during the less demanding winters.

Warmer climates cause the snow to melt faster. This causes a redistribution of snowmelt runoff throughout the year. An increased amount of runoff is seen in the early spring months of April and May, but less is seen towards the end of the snowmelt season in June and July. A study performed by Katwijk et al. (1990) used a computer model to determine the change in distribution of snowmelt runoff for a 1°, 2° and 3° C change in temperature in the Rio Grande basin. This study found a 2.7%, 8.3%, and 14.3% increase in total runoff respectively. When applied to the Illecewaet basin, they found a 4.5%, 11.1%, and 16.3% increase in total runoff. While total runoff increased in both cases, this is due to a dramatic increase in runoff that is experienced earlier in the year.

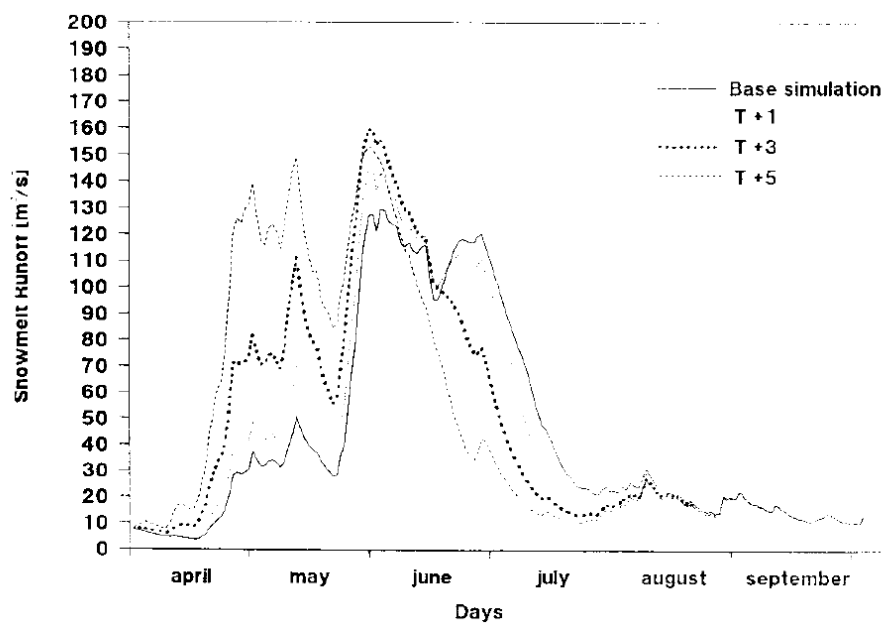


FIGURE 4: CHANGE IN RUNOFF WITH TEMPERATURE IN RIO GRANDE BASIN (KATWIJK ET AL. 1990)

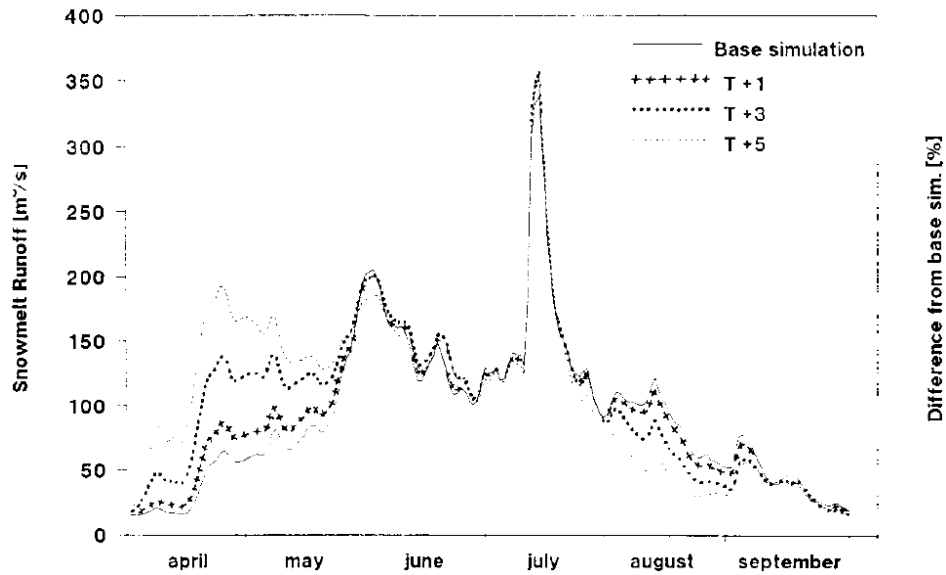


FIGURE 5: CHANGE IN RUNOFF WITH TEMPERATURE IN ILLECILLEWAET BASIN (KATWIJK ET AL. 1990)

Warming temperatures also have an effect on the amount of precipitation the region receives, and therefore the amount of runoff it receives as well. While the amount of change in precipitation this area will receive is widely debated, most figures range between -10% and +10%. Katwijk et al. (1990) also modeled the predicted change in runoff due to this effect in the Rio Grande and Illecewaet basins.

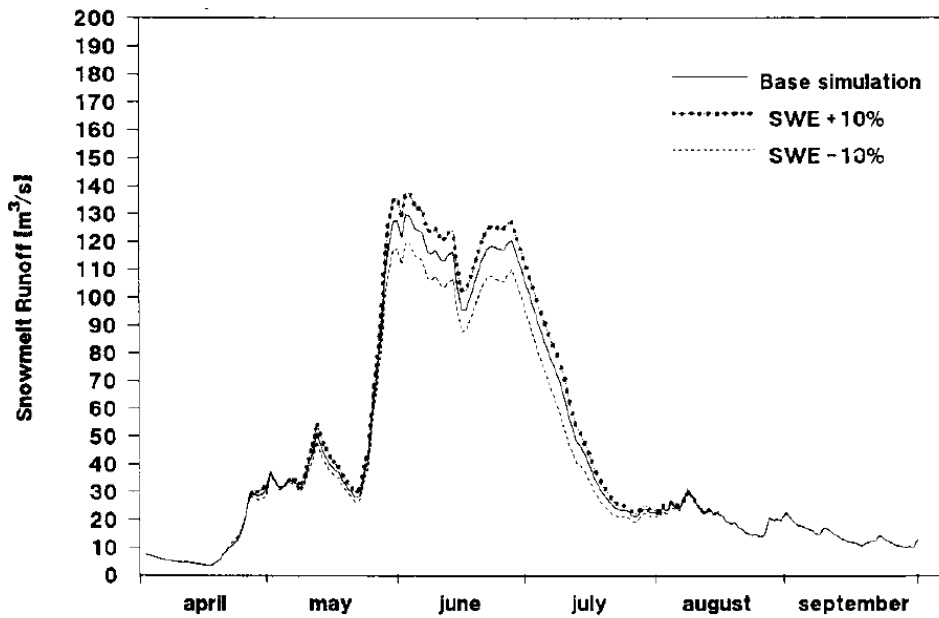


FIGURE 6: COMPARISON OF -10% AND +10% CHANGE IN SNOW ACCUMULATION FOR RIO GRANDE BASIN (KATWIJK ET AL. 1990)

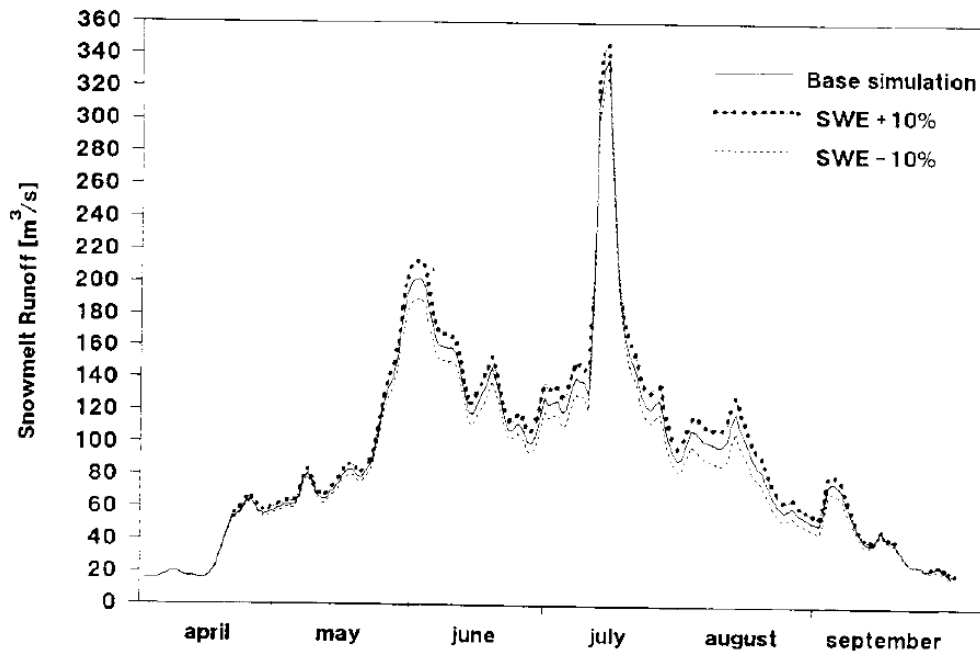


FIGURE 7: COMPARISON OF -10% AND +10% CHANGE IN SNOW ACCUMULATION FOR ILLECILLEWAET BASIN (KATWIJK ET AL. 1990)

The above figures illustrate that the effects of increased precipitation on seasonal runoff are not nearly as strong as those due directly to increased temperature. This redistribution of runoff can still have profound effects on the surrounding area, however.

The dramatic increase in precipitation seen earlier in the year can stress the existing facilities intended to store this water which were not designed to handle this new higher rate of flow. The demand for this water is also low at this point in the year. Storage areas may already be filled to capacity and unable to store this water. This can lead to a loss in potential water reserves that will be needed later in the year. Current water storage systems may need to be upgraded in order to handle this and prevent a water shortage from occurring in later months.

The agricultural industry in the Colorado Basin depends almost entirely on water reserves. Almost 90% of water used in the state goes towards agriculture (CRWULA.org). The agricultural industry is not just a source of food. The state also relies on it as an economic boon. About \$6.3 billion a year is generated by the agriculture industry in Colorado (Gillentine, 2008). The area is a large producer of fruit, and wheat as well as wine. A water shortage has the potential to cause severe economic problems, as well as national shortages of certain commodities.

EFFECTS OF GLOBAL WARMING ON MOUNTAIN WILDLIFE

Changes in snowpack as a result of global warming can have serious consequences on animals which live in these areas. The snowpack provides a habitat for animals which depend on it for shelter and protection. In lower altitude regions increased temperatures can cause the total

disappearance of ground snow, and therefore the destruction of habitat for snow dwelling animals.

Higher regions whose snowpack are not immediately threatened by increased temperatures are not immune to habitat destruction either. In these areas, small animals live in the subnivean layer during the winter. This region is between the snow layer and the ground. The area receives the heat that is stored in the ground, but is protected from the cold air by the insulating layer of snow. As a result the snow here softens and can even melt away. This region is often inhabited by smaller animals because it provides excellent protection from the cold as well as larger predators which cannot fit in this region. The ground is quite often exposed in these areas so animals can access what remains of plants which can be used for food. As climate changes, so does the subnivean layer. These changes can pose a threat to the small mammals which live in this region.

This area is only suitable as a habitat as long as there is snow soft enough to burrow through. Kausrud et al. (2008) demonstrated that snow hardness can be determined from changes in temperature throughout the winter. Warmer winters are associated with increased precipitation, which in the mountains come in the form of snowfall. A study by Inouye et al. (2000) determined that between the years of 1997 and 1999 alone yearly total snowfall values increased from 1042 cm to 1239 cm. This would seem beneficial for animals which rely on this snow layer, but this is not the case.

Increased precipitation corresponds with increased humidity. This means that there is more free water available in the atmosphere as well as within the snowpack itself. Increased availability of free water brings increased heat loss and risk of flooding along with it. These

factors all pose serious threats to animals which live in an area as constrained as the subnivean layer.

Increased humidity and free water also allows ice to form more easily in this cold environment. If water in its liquid form is available in the warmer subnivean layer, it can easily freeze into ice if the temperature drops below freezing. When ice can form more easily the snow layer becomes harder. This creates the potential for the snow to become too hard for subnivean species to be able to burrow through, thus rendering the area inhospitable to these animals.

One mountain becoming inhospitable to subnivean animals can wreak havoc on the population even if there are other mountains nearby which would be suitable. Each high altitude habitat is islanded by the surrounding low altitude area. If a mountain area becomes unsuitable for subnivean species, they do not have a nearby habitat to migrate to. In order to reach another suitable area they must migrate down their mountain, through a valley and up another mountain in order to reach another suitable area. This is very dangerous. Subnivean animals rely on the snow above them for protection from both the elements and predators. When they leave this shelter they are relatively defenseless and can easily fall prey to predatory species. Losing the shelter provided by the snow also exposes them to the elements. Many may die when exposed to the harsh mountain climates.

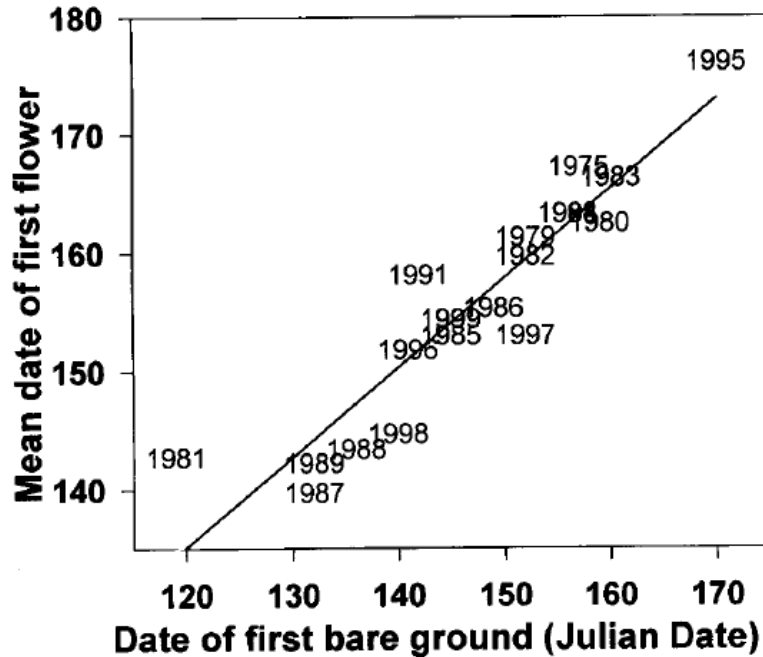
This effect is evident in the *Ochotona Princeps*, or American Pika. Destruction of this animal's habitat has been observed. According to Science Daily (2004) a 2003 study performed as a follow up to studies performed in the mid and late 1990s demonstrated a severe loss of habitat for the American Pika. Only 5 out of the 7 sites that were studied still supported Pika

populations in 2003 (Science Daily, 2008). Destruction of this animal's habitat is a real phenomenon which is having an effect on its population.

As temperatures increase, larger and larger regions may become unusable to subnivean animals through the above mechanisms. This destruction of habitat can cause serious risks to animal these animal populations, and therefore to the ecosystem as a whole.

An interesting effect of higher temperatures corresponding to increased snow fall is the quickness with which the snow melts. A study by Inouye et al. (2000) has determined that the first date at which bare ground is observed in the spring has not changed significantly between the years of 1975 and 2000. They study was performed in Gothic, CO in the West Elk mountains at an elevation of 2945 m. The reason for this is that the two effects help to cancel each other out. Higher temperatures will most certainly cause the snow to melt faster, but now there is more of it. This results in the snow taking approximately the same amount of time to melt as it had previously taken. This may first appear to be a non issue, but it can cause problems within the wildlife community. Different species use different factors to determine their activity, and snow melt no longer corresponding to the same temperature can have a serious effect on animal species.

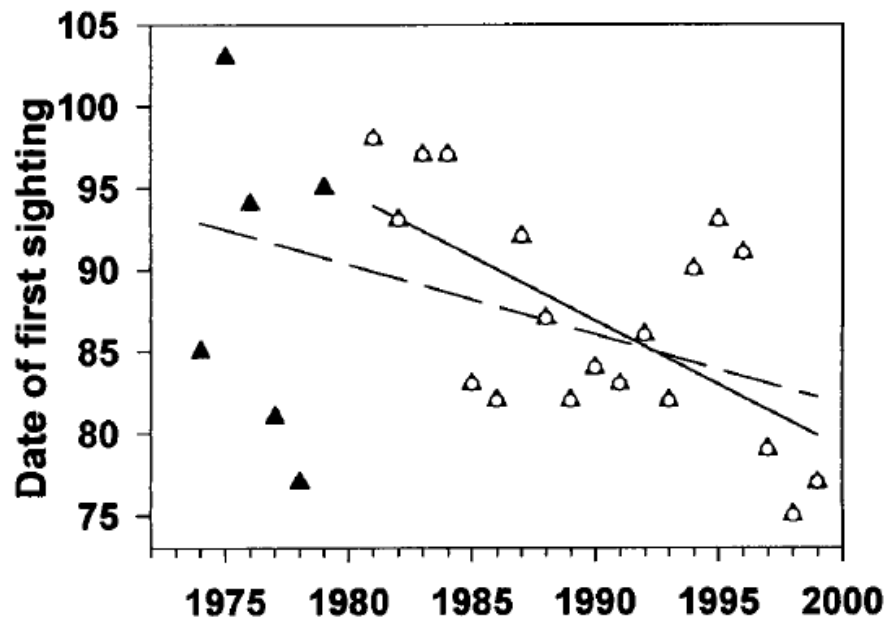
With the exception of a few wildflower species the growing season in these areas does not fully begin until the snow has melted. The melting of snow is a useful indicator for determining plant phenology for the spring and summer. A good demonstration of this is the plant *Mertensia fusiformis*. This plant will reliably flower between 7 and 14 days after the snow has melted (Inouye et al., 2000). The graph below shows a similar strong correlation between the date of first bare ground and the date of first flowering of the related plant *Mertensia ciliata*.



© THE NATIONAL ACADEMY OF SCIENCES

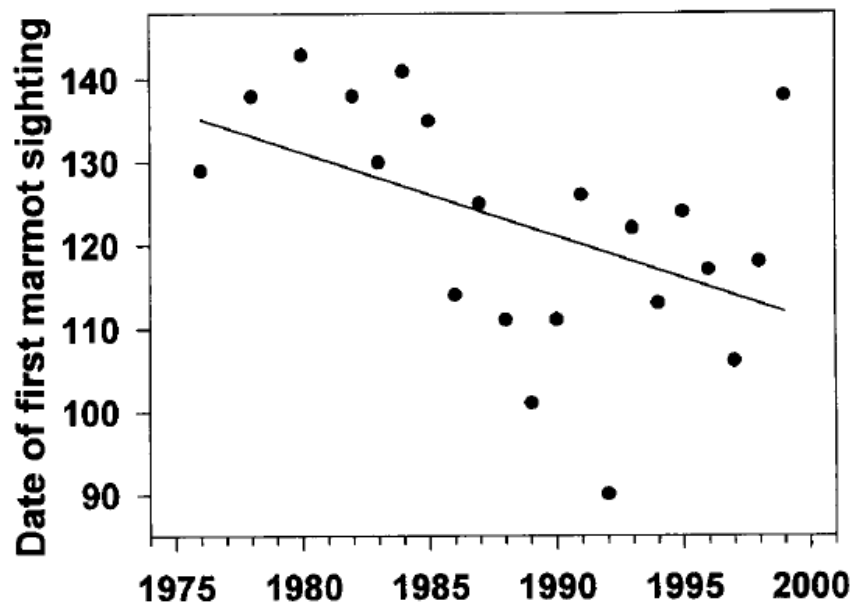
FIGURE 8: DATE OF FIRST BARE GROUND VS. DATE OF FIRST FLOWERING OF *MARTENSIA CILIATA*
(INOUE ET AL., 2000)

Animals, on the other hand generally use temperature as an indicator for migration or emergence from hibernation. The current warming trend means that animal species will be arriving earlier in the year. The same study by Inouye et al. (2000) has observed both earlier emergence from hibernation in as well as migration to these areas. Upon studying the American Robin (*Turdus migratorius*) as well as the yellow-bellied marmot (*Marmota flaviventris*) they found a trend towards an earlier date of first sighting in both cases.



© THE NATIONAL ACADEMY OF SCIENCES

FIGURE 9: DATE OF FIRST SIGHTING OF THE AMERICAN ROBIN FROM 1974 TO 1999. SOLID TRIANGLE AND DASHED LINE REPRESENT DATA FROM 1974 TO 1980. A HOLLOW TRIANGLE AND A SOLID LINE REPRESENT DATA FROM 1981 TO 1999 (INOUE ET AL., 2000).



© THE NATIONAL ACADEMY OF SCIENCES

FIGURE 10: DATE OF FIRST SIGHTING OF THE MARMOT FROM 1976 TO 1999 (INOUE ET AL., 2000)

It is now apparent that plant life has been returning to these mountainous areas later where as animal life has been returning earlier. This can cause problems for the animals which rely on plants as a source of food. Inouye et al. (2000) have determined that there is now 57 cm more snow on the ground when marmots emerge from hibernation than there was upon emergence 23 years ago. This means that these animals have to wait increasingly longer to find available food. For flying species this is not as much as an issue because they can fly back down to lower altitudes and warmer climates until food is available. Ground animals such as the marmot which cannot migrate so easily will have to wait an increasingly longer time for food to become available to them. This places them at a greater risk for starvation.

Migrants such as the robin may not face this threat, but they do face a similar one. If food is not available to them at the higher altitudes they will spend more time in the lower altitude areas. Inouye et al. (2000) have found that robins are waiting 18 days longer for food then they had to 19 years ago. This will place an increased amount of stress on the lower regions which are supplying food to them during those times. These regions are only capable of producing so much food, so this extra stress could eventually cause the robins to run out of food.

CONCLUSIONS

The snowpack contained within the Colorado River Basin is quite sensitive to climate change. Global warming has the potential to affect the quality of life in the area as well as its economic welfare as its hydrologic processes are changed. Rising temperatures can endanger more than just human life, however. Animals are placed at an even greater danger as their habitats and ecosystems are threatened. There is also the possibility of experiencing a positive

feedback loop from global warming. Microbes will be able to live in previously inhabitable environments and produce even more greenhouse gases. This can exacerbate the current problem of global warming.

Global warming can have serious effects in the snow covered regions of the Colorado River Basin which we do not yet fully understand. Care and study should be taken to understand and prevent the negative effects that can come about due to increased temperatures.

WORKS CITED

“Agriculture”. Colorado River Water Users Association. 2007.

<<http://www.crwua.org/coloradoriver/riveruses/index.cfm?action=agriculture>>.

Colorado River Basin: Paleo – Present – Future. (November, 2008).

“Greenhouse Gases, Climate Change, and Energy”. Energy Information Administration. 2008.

<<http://www.eia.doe.gov/bookshelf/brochures/greenhouse/Chapter1.htm>>.

Barott, K. L., Lipson, D. A., Oechel, W. C. “A Positive Feedback Loop For Global Warming:

Methane Production And Microbial Diversity In Arctic Soils”. American Geophysical

Union (2008).

Inouye et al. “Climate Change is Affecting Altitudinal Migrants and Hibernating Species”.

Proceedings of the National Academy of Sciences of the United States of America 97

(2000).

Katwijk, Victor F. van, and Rango, Al. “Climate Change Effects on Snowmelt Hydrology of

Western North American Mountain Basins”. IEEE Transactions on Geoscience and

Remote Sensing 28.5 (1990): 970-974.

Kausrud, Kyrre L. et al. “Linking Climate Change to Lemming Cycles”. Nature 456 (2008): 93-

98.

Mote, Philip W., Hamlet, Alan F., Clark, Martyn P., and Lettenmaier, Dennis P. “Declining Mountain Snowpack in Western North America”. American Meteorological Society (Jan, 2005): 39-49.

Schuur, Edward A. G. et al. “Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle”. BioScience 58.8 (2008): 701-714.