MONTANA'S CHANGING CLIMATE

By

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Today, the word climate change has taken on many meanings. In the early 1970's, many scientists were suggesting that we were entering another ice age. Temperatures were cooling and precipitation was increasing. Then the trend reversed in the early 1970's, and scientists started to advocate that global warming was occurring as temperatures were increasing and precipitation decreasing. In the 1990's, there were some cooling of temperatures, so the scientist changed the name to climate change so they could incorporate almost any type of climatic change. The concentration of CO_2 was entered as the cause of warming but as time progressed, it was considered the cause of all climate change. Now, many consider all climate change as a result of increasing CO_2 even though there are changes related to natural conditions. Also, many scientists just report on recent records to show the increase in temperature and decrease in precipitation. In reality, climate is changing almost every year as seen in the annual variation of snow water equivalent, precipitation, temperature and stream flow. When you look at long term records, they indicate different results. In general, precipitation was high in the late 1890's then decreasing to the 1930's, up again until the 1970's and down again to the present time. See Figures 1, 2, and 3 to see how using a shorter record can make it appear that things are getting much worse when the longer records show that the current trends are not that unusual.

If CO_2 causes warming, and if it was shown that we were moving toward cooler temperatures and possibly a return to another "little ice age", would everyone be required to let their cars idle in their driveways for an hour every night to increase the CO_2 levels to help stave off the new ice age?

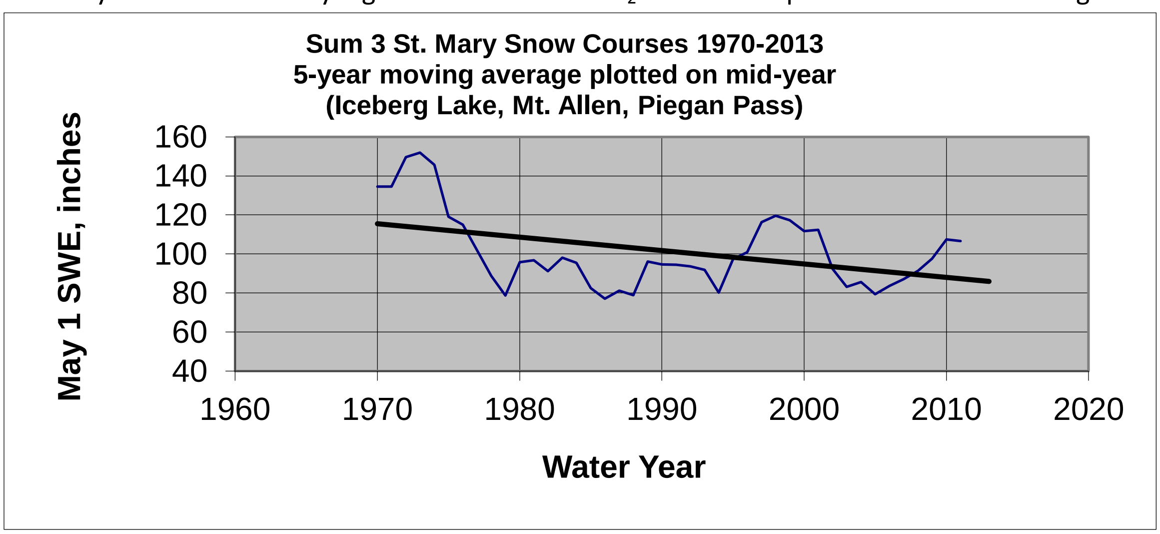


Figure 1. SWE at three snow courses in Glacier National Park for the period 1970-2013 which is similar to the period that SNOTEL sites have been providing data. This graph suggests the water stored in the snowpack has decreased by about 30 percent over the past 40 years.

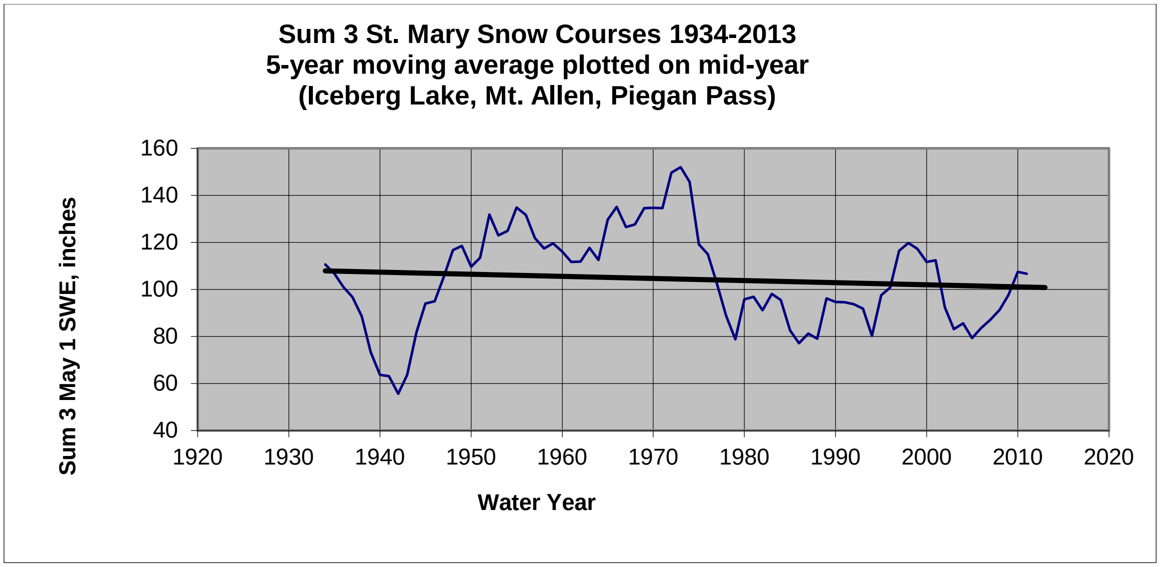


Figure 2. SWE at three snow courses in Glacier National Park for the period 1934-2013 which is similar to the period that snow course sites have been providing data. This graph suggests the water stored in the snowpack has decreased by about 8 percent over the past 80 years.

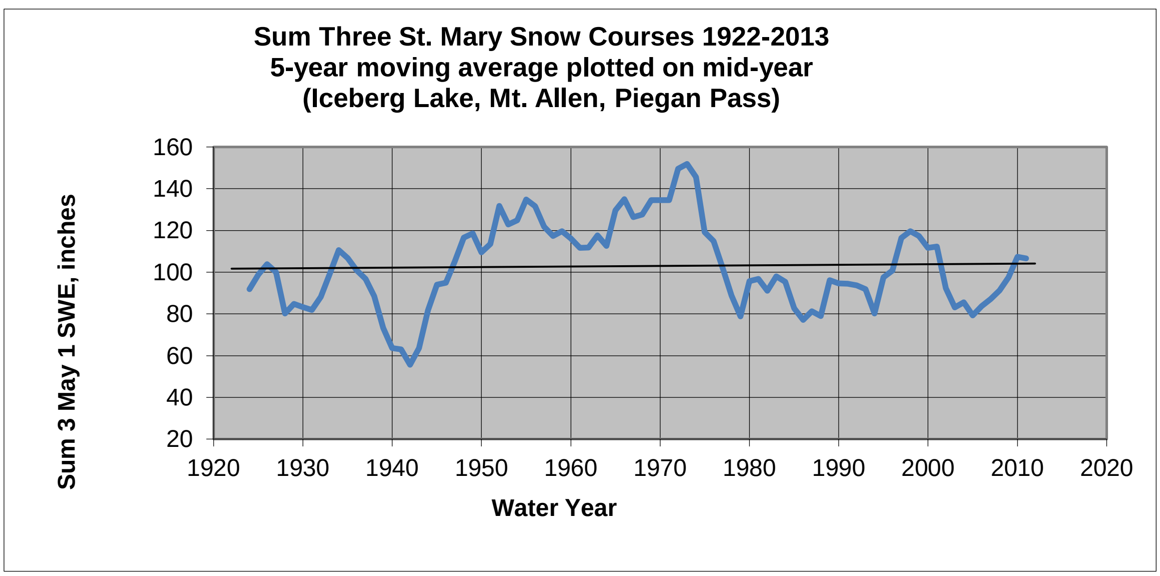


Figure 3. SWE at three snow courses in Glacier National Park for the period 1922-2013 which is the longest record for measuring water content at snow courses in Montana. This graph suggests the water stored in the snowpack has increased by about 3 percent over the past 90 years.

Most CO_2 data comes from Mauna Loa Observatory in Hawaii. If the atmosphere is a $100 bill, the current level of CO_2 contained in the atmosphere is equivalent to about 4 cents. The earth's atmosphere is primarily oxygen and nitrogen.

If temperatures in Gallatin Drainage are increased by 2^0F, melt will occur three days earlier and growing season will be advanced by 7 to 8 days. Figure 4 shows how melt rates change with the season. Other drainages in Montana have similar melt rates.

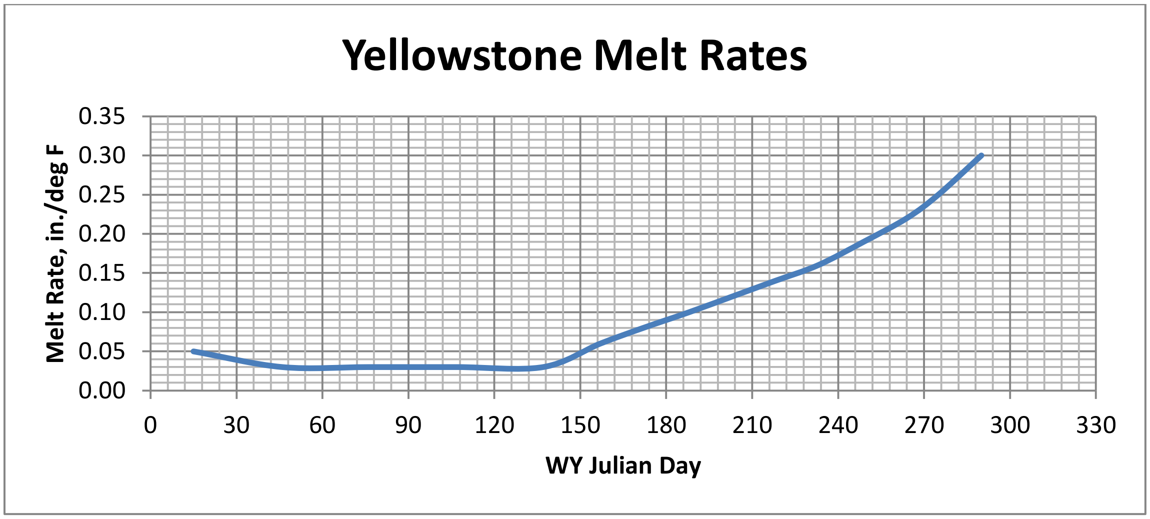


Figure 4. Melt rates change throughout the season. Advancing warmer temperatures will melt less snow than same temperatures do later in the season. Water Year (WY) begins on October 1.

Precipitation occurs by different patterns at different elevations. Higher elevations receive most of their precipitation during the winter months while lower elevations receive most of their precipitation in the spring. Figure 5 shows distribution of monthly precipitation at different elevation sites in the west side of the Bitterroot River drainage. Other Montana drainages have similar precipitation patterns. Weather systems that determine mountain snowpack are different from those that bring spring precipitation to the valleys.

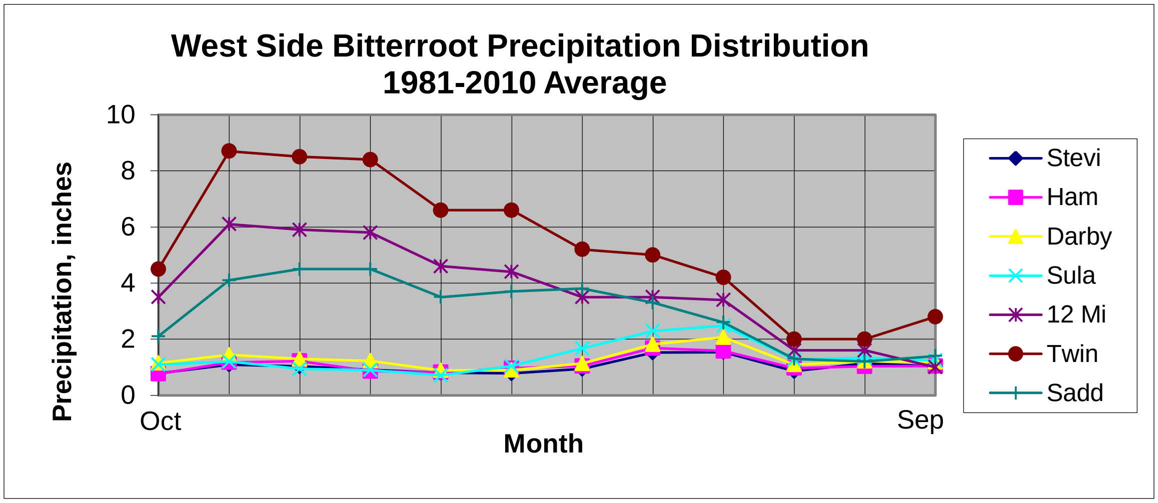


Figure 5. Distribution of annual precipitation for West Side of Bitterroot River drainage. Winter precipitation is greatest in higher elevations while valley areas receive most of their precipitation in the spring months.

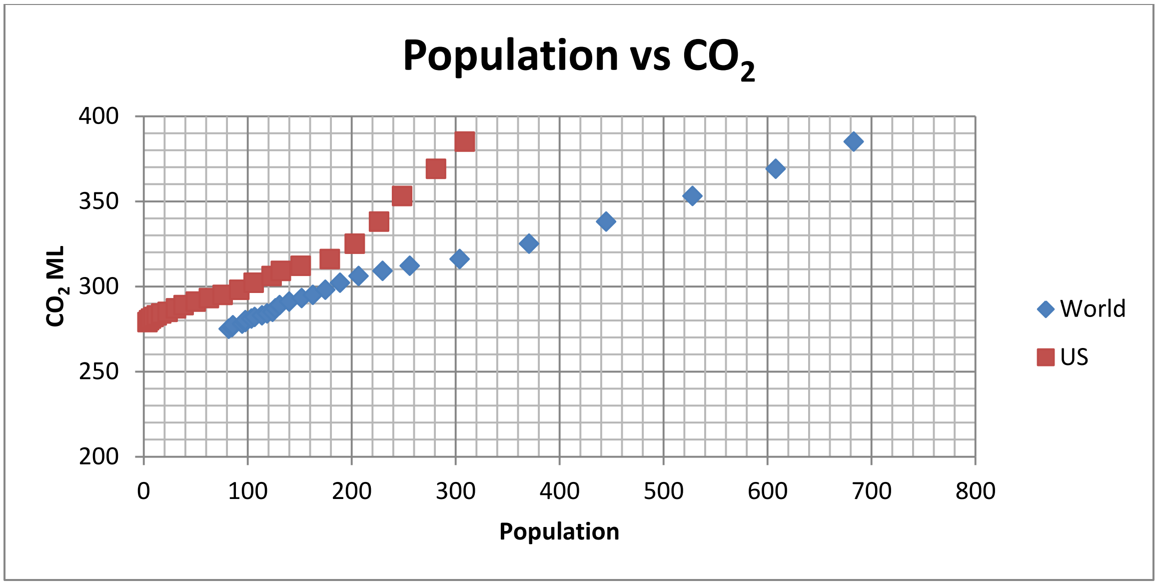


Figure 6. Population of United States and World plotted against the CO_2 concentrations. It may be necessary to see a reduction in population in order to see a decrease in the concentration of CO_2.

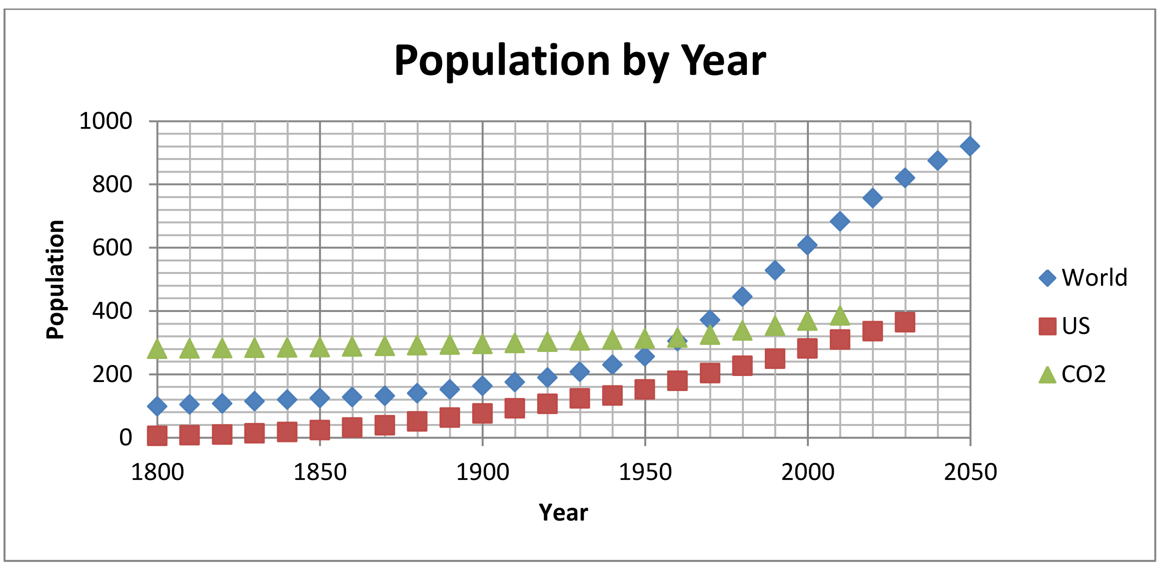


Figure 7. Population index for US and World plotted against CO_2 concentrations. US population has doubled in past 60 years while World population has doubled in past 45 years.

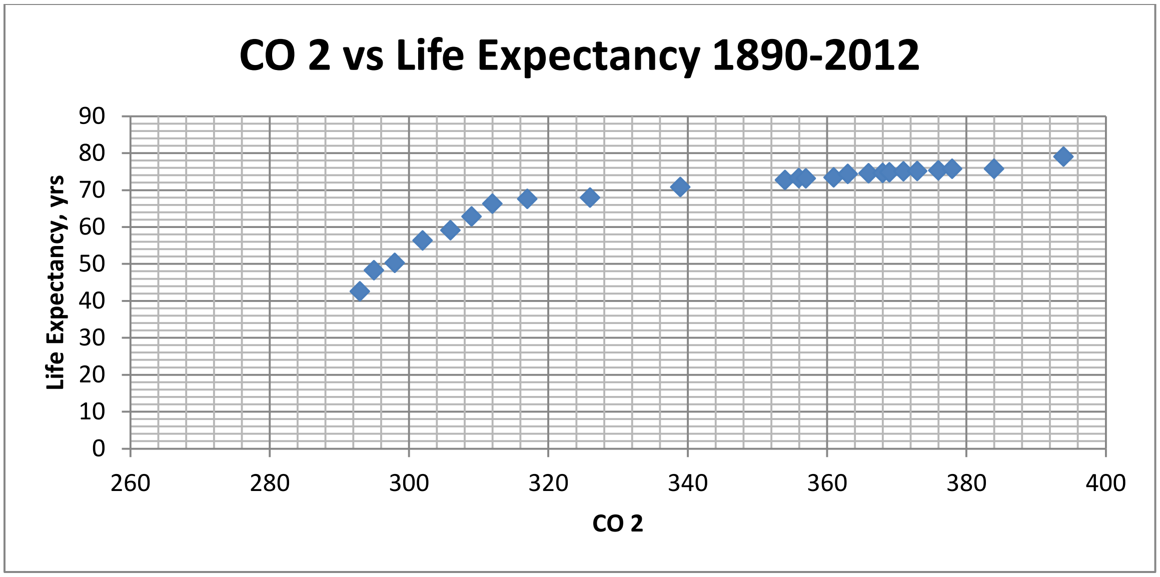


Figure 8. With the life expectancy increasing, each person is increasing the amount of CO_2 being produced by the energy needed to satisfy the needs of individuals.

CO_2 concentrations are related to population as shown in Figures 6 and 7 and longer life spans are also contributing as seen in Figure 8. Using solar or wind energy can reduce the advance of CO_2 but uncontrolled population growth soon negates any reductions. In order to hold the concentrations at their present level or to reduce the present level will require some form of population reduction. Presently, this does not seem to be a viable alternative and concentrations will probably increase at near the present rate. Some of the money currently being used to develop alternate energy sources which will only delay the rate of increase might be better spent on developing methods helping people adapt to warmer climates and/or holding down population gains.

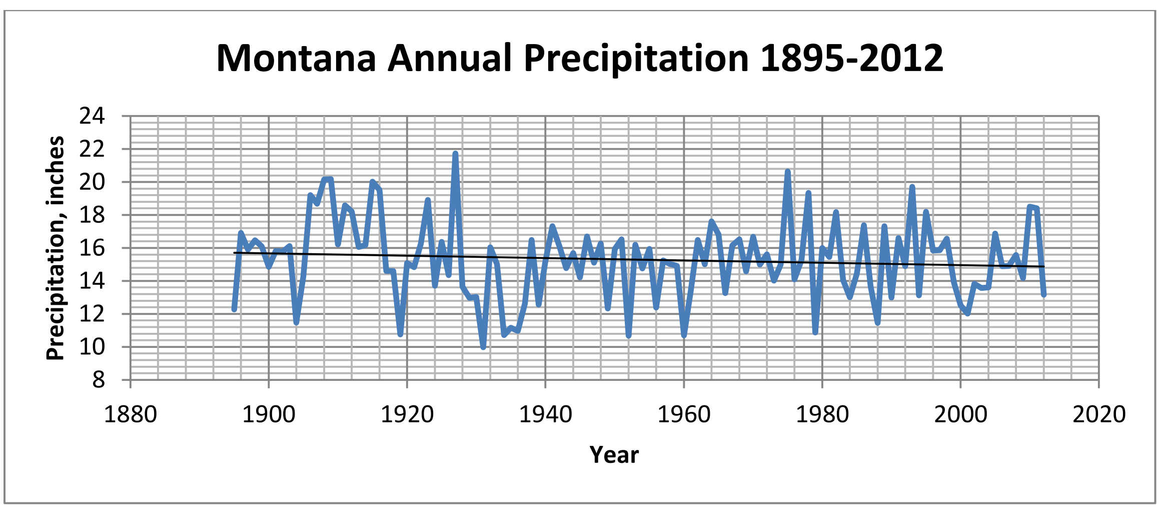


Figure 9. Statewide valley annual precipitation has decreased slightly over the past 115 years. Variation from year to year can be large with trends toward 10 to 30 year periods of increasing or decreasing precipitation. Data is from NOAA's Climate at a Glance.

Annual precipitation in the valley locations was highest during the early 1900's, then decreasing into the mid-1930's, increasing into the mid 1940's and then trending about uniform until the present but with larger variation between individual years. Mountain precipitation does not always pattern that occurring in the valleys. Mountainous areas are subject to orographic effects and temperature inversions not common in valley areas.

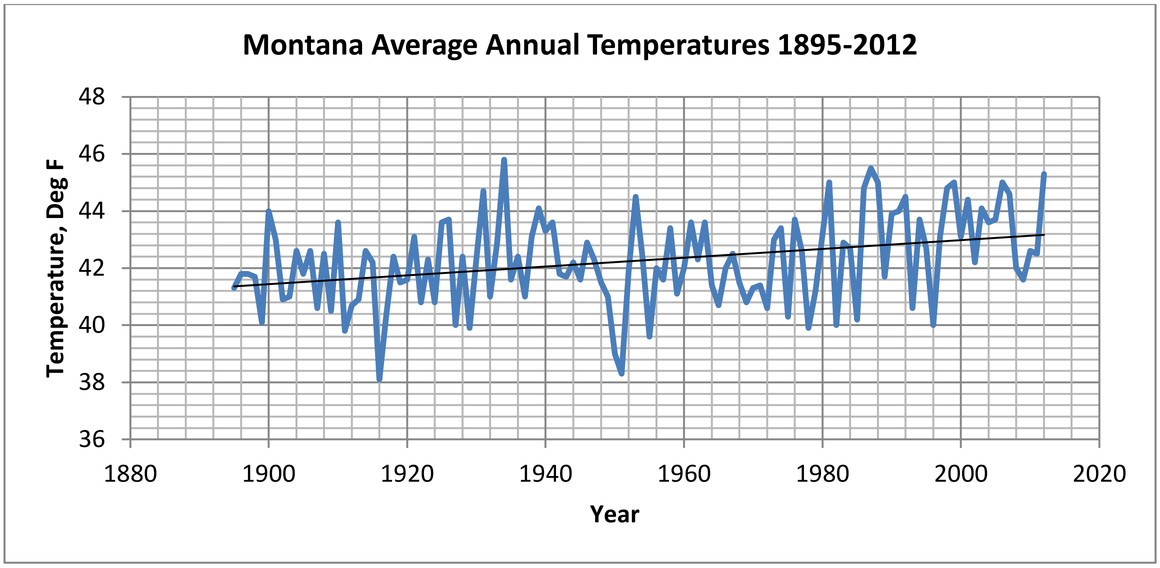


Figure 10. Statewide valley average annual temperature trends show about 2^{0}F increase over the past 115 years with large variations from year to year. The average annual temperature in 1934 is still the warmest year on record for Montana. There are periods of warm years and periods with a series of cooler years. Data is from NOAA's Climate at a Glance.

Annual temperature was trending lower from 1900 to 1920, then upward to 1940, then downward to 1950, then upward to the 1990's, downward into the late 1990's and then upward to 2000, similar from 2000 through 2010 and then dropping to present. With CO_2 increasing through this entire period, it is impossible to determine whether temperatures are going to increase or decrease over 10 to 20 year periods by relating temperatures to CO_2. Other factors affecting temperatures are in play.

Currently, temperatures at Death Valley are threatening the record of 134 ^{0}F established on July 10, 1914. If recent hot temperatures are a result of Global Warming caused by CO_2, then one need's to question -- What was the CO_2 concentration in 1914? Are there other factors that caused this location to set the record that has stood for nearly 100 years?

Averages are made up of both below and above the average values. There are roughly the same number of above average situations as there are those that are below average. It is not unusual to have long-term records of natural events such as stream flow, snow pack, precipitation to have varied from less than 40 percent of the 30-year average to 160 percent average or for historic daily temperatures to have varied by 60 to 90 degrees F from highest to lowest recorded temperature on any given day at a given location. It is not unusual for annual temperatures to have a spread of about 120 to 140 degrees F at any given station. Plants and animals now existing in specific areas have been able to adapt to these changes. Those that cannot adapt are generally not present unless artificial environments have been created.

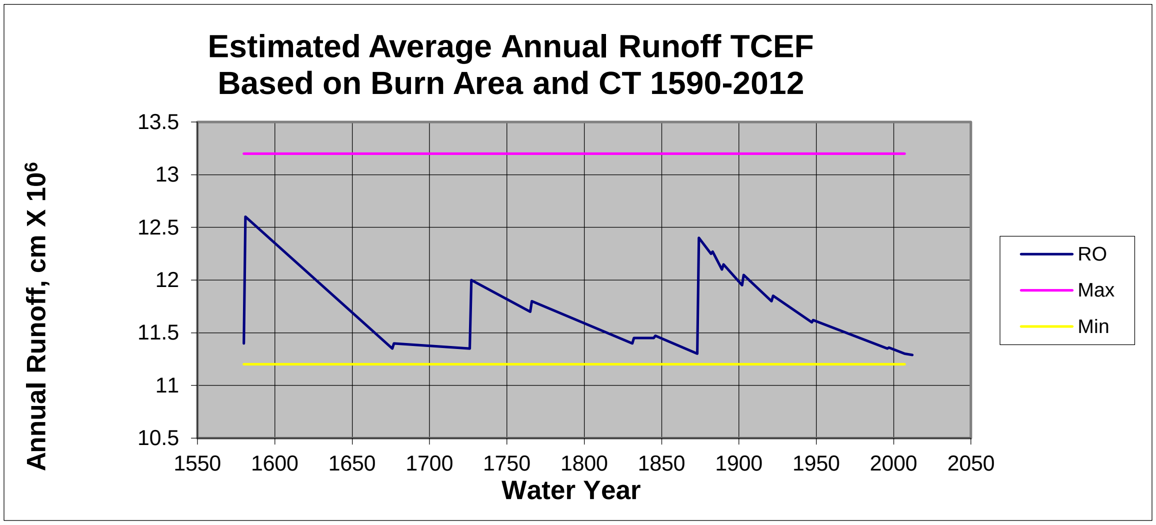


Figure 11. Fire has been a constant on forested watersheds. Fires increase the runoff from snow-fed watersheds and then the runoff declines as the trees re-grow and snow and rain are intercepted and sublimated from the forest canopy. If all of the timber was removed, the runoff would be near the Max line. The Min line represents the runoff if the entire watershed was mature forest. Major fires have occurred about every century with the potential for another major fire being not too far in the future. Changes shown are those that would occur under constant temperature and precipitation conditions and reflect only changes due to fire. There does not appear to be any relationship between historic fire frequency and CO_2 concentrations. Data is from Tenderfoot Experimental Forest in Central Montana.

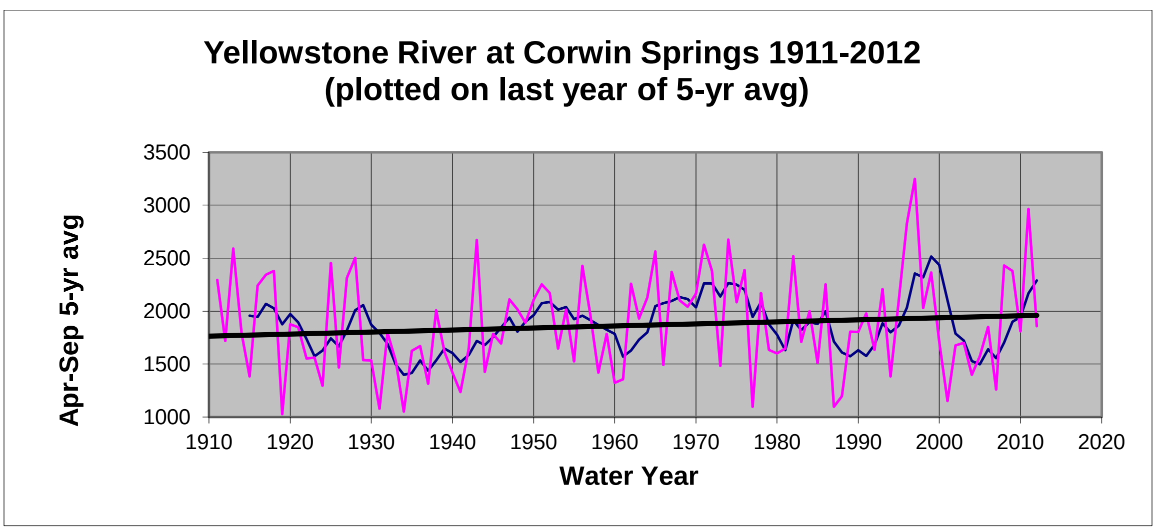


Figure 12. Spring and summer runoff trends have increased over the past century at many Montana rivers. There are many periods where runoff has increased or decreased because of changing snow packs and spring precipitation. Red lines show individual years while blue lines show 5-year moving averages.

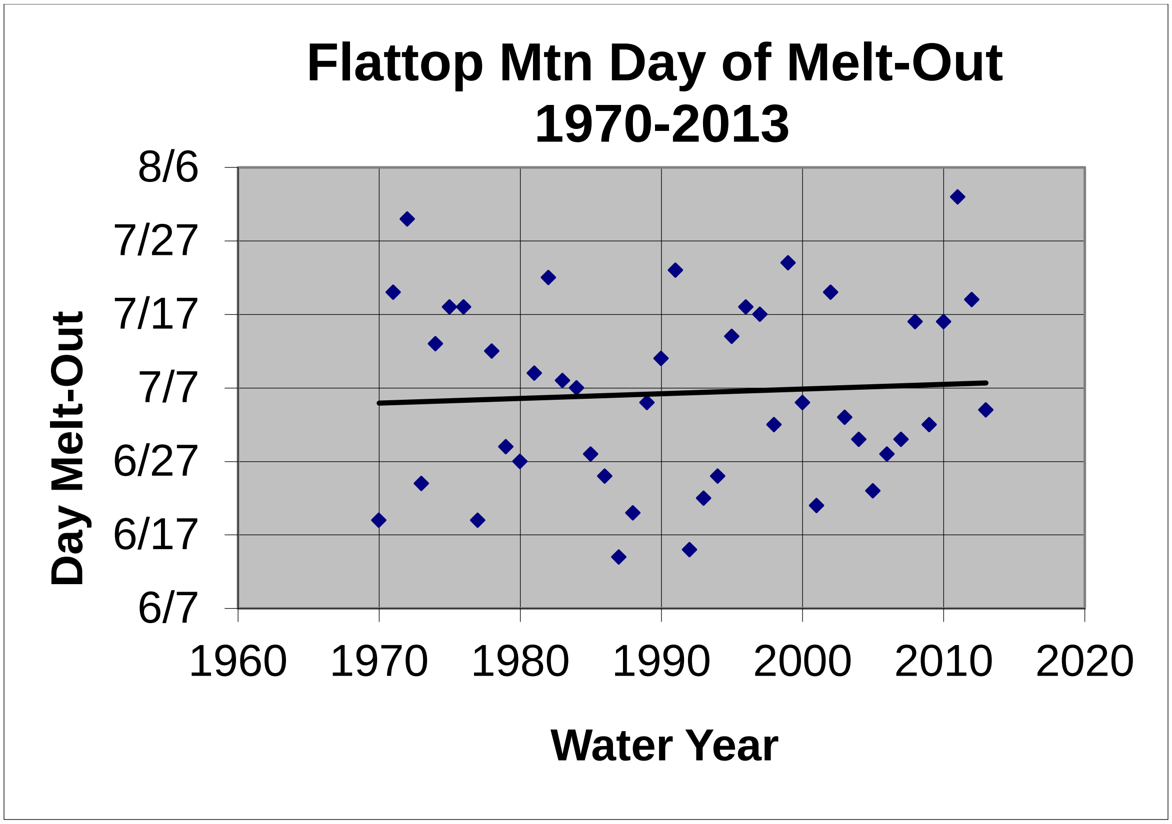


Figure 13. The dates of most hydrologic and climatic events in Montana vary by 6 to 8 weeks. Even though the recent trend has been for earlier melt-out, 2011 was the latest day of melt-out for the period of record.

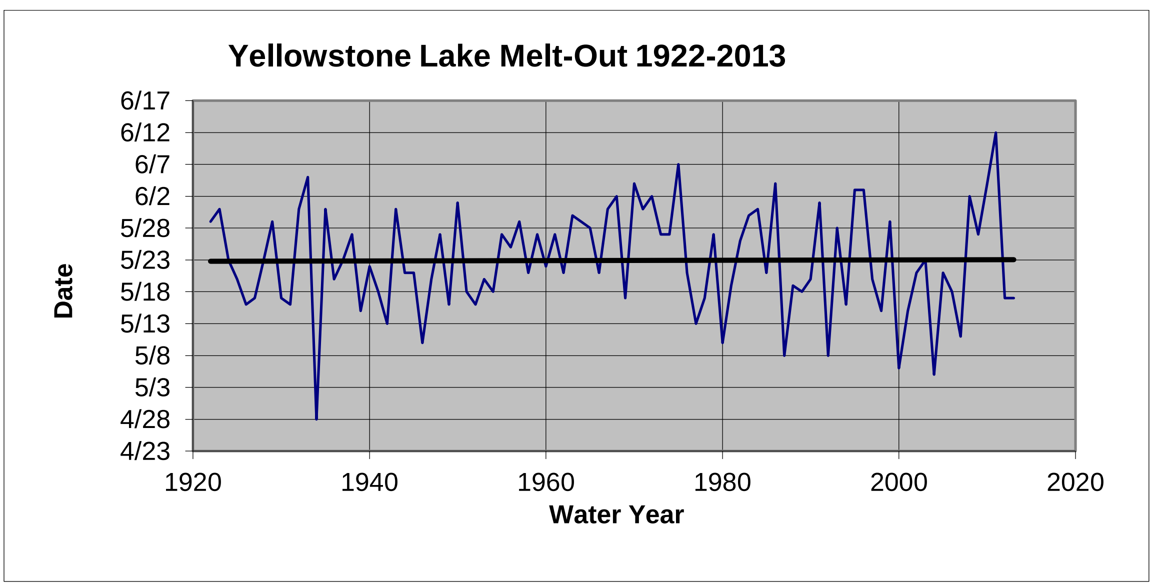


Figure 14. The day ice melts out at Yellowstone Lake has occurred over a 7 week time spread during the past 90 years with no trend toward either an earlier or later melt-out date. The earliest melt-out occurred in 1934 with the latest date in 2011.

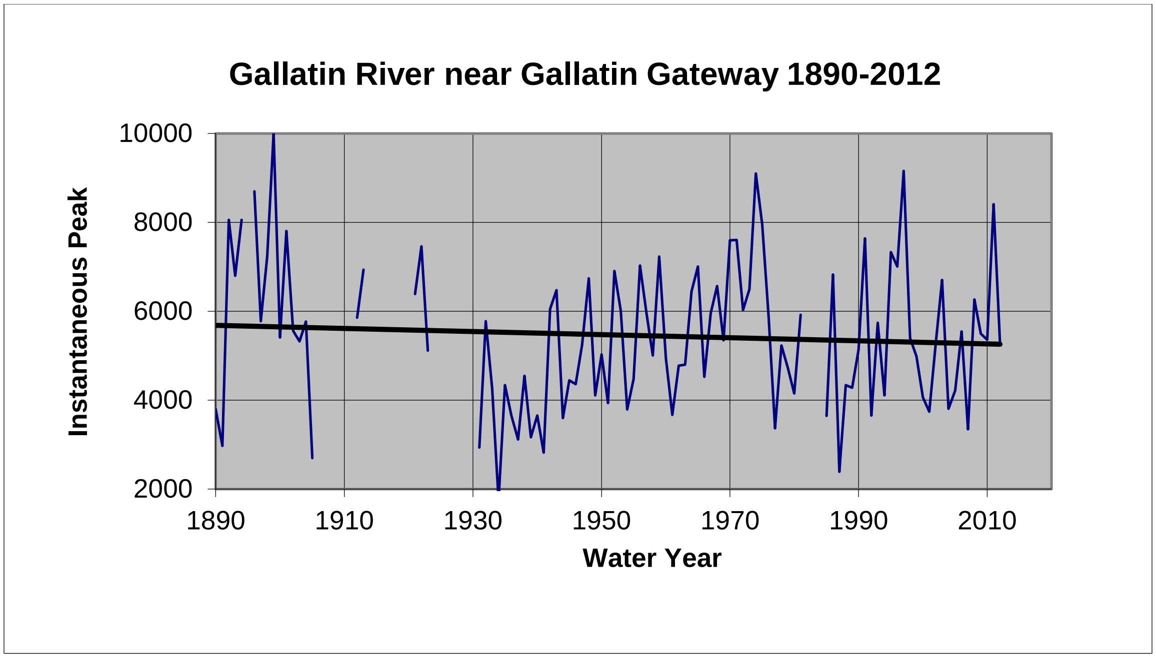


Figure 15. Instantaneous peak flows have been trending toward slightly lower peaks but 3 of the 4 highest peaks have occurred since the 1970's on the Gallatin River near Gallatin Gateway.

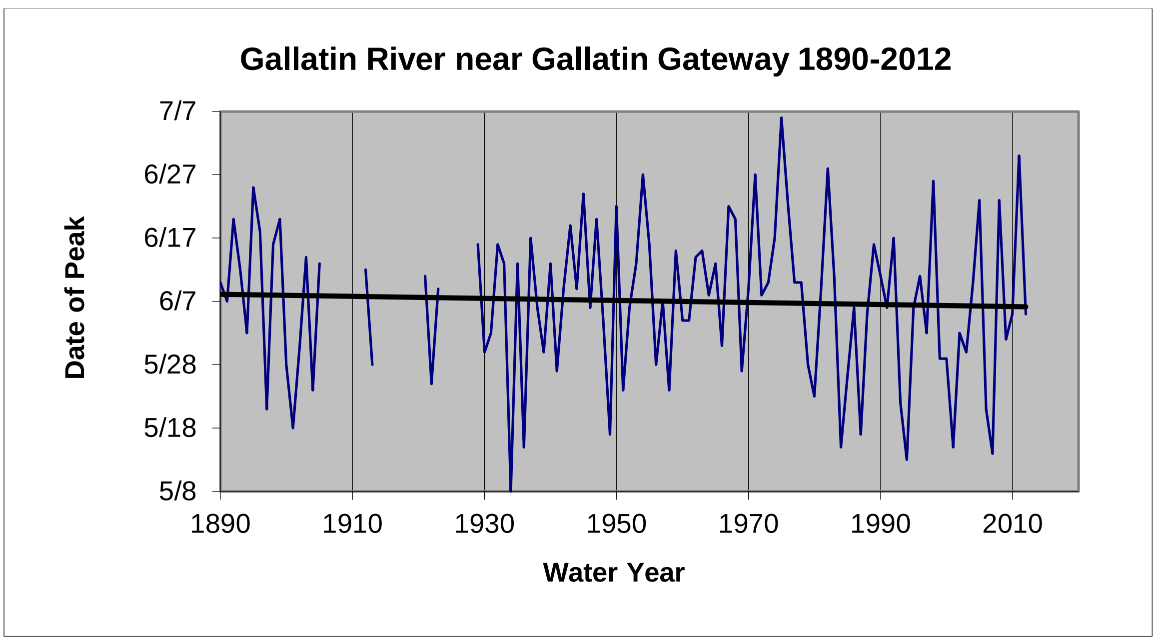


Figure 16. The date of the annual peak flow is trending toward a few days earlier but historically it has occurred over about a seven weeks spread.

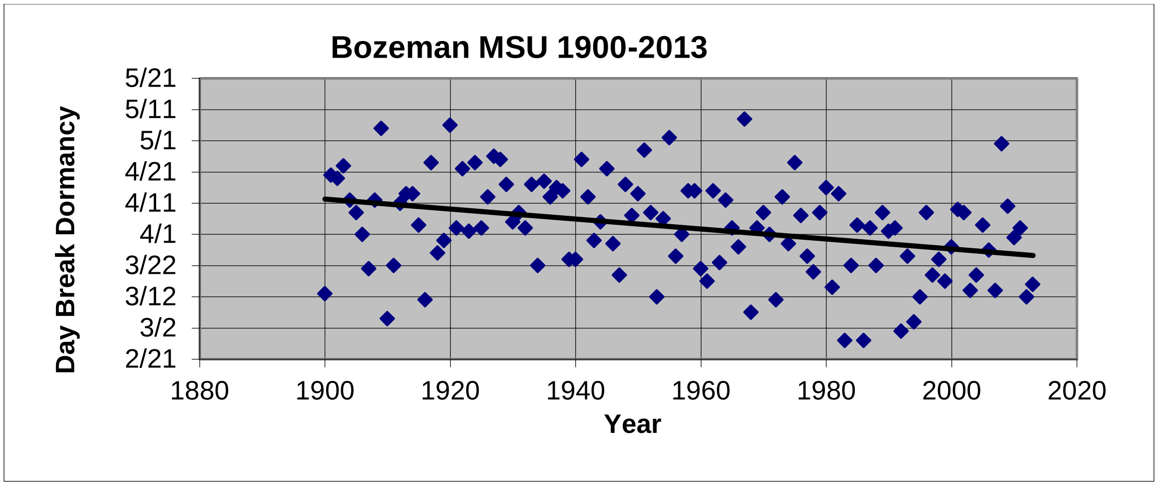


Figure 17. Day plants break dormancy has shifted about 16 days earlier over the past 110 years. (Based on average daily temperatures above 41^{0}F which is considered to be biological zero). The earliest date when plants broke dormancy was February 27 and latest date was May 8.

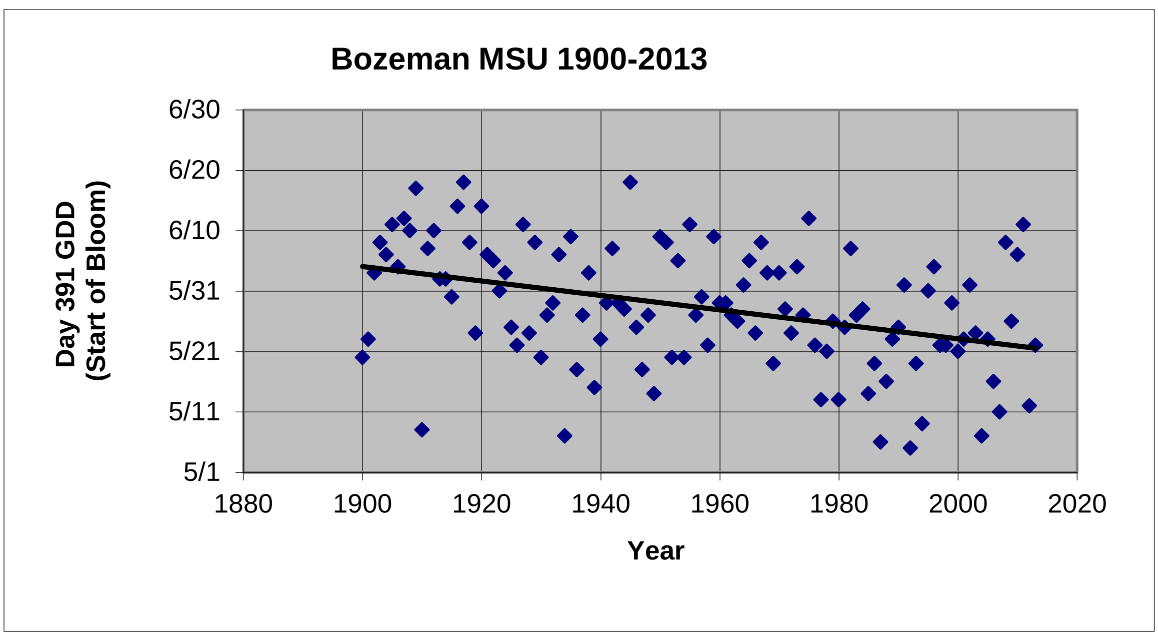


Figure 18. Day Lilacs reach full bloom in Bozeman, MT has shifted forward about 13 days over the past 110 years. (Growing Degree-Days based on average daily temperatures above 41^{0}F which is considered biological zero). Joe Caprio, former State Climatologist, used day of Lilac bloom to determine length of growing seasons across Montana. The earliest date that the Growing Degree-Days reached 391(^{0}F) was May 5 and latest date was June 18.

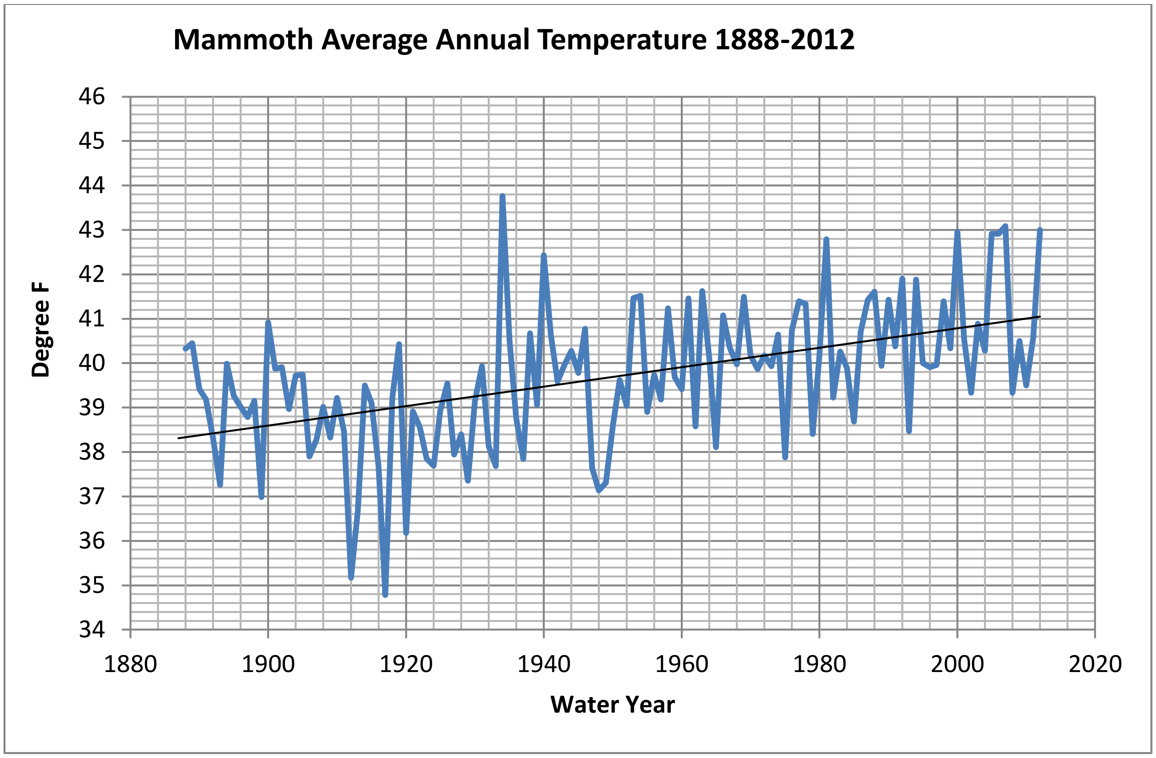


Figure 19. Yellowstone Park (Mammoth) average annual temperatures have increase about 2.6 ^{0}F over the past 120 years. The highest average annual temperature was in 1934 and the coldest year was 1917.

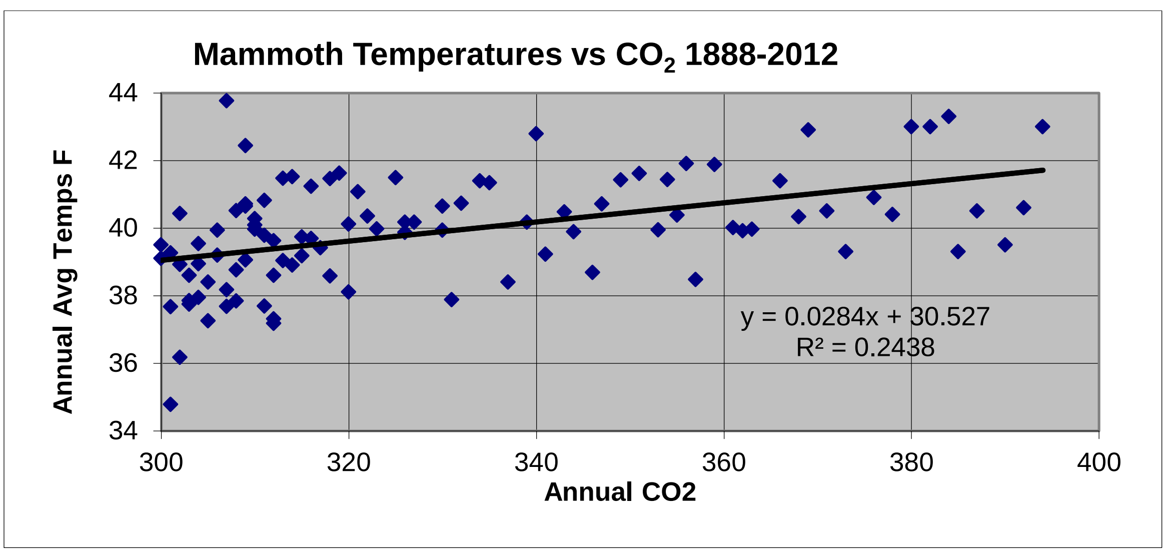


Figure 20. Average annual Water Year temperatures at Yellowstone Park (Mammoth) have a poor correlation with CO_2 concentrations even though there is an upward trend suggesting increased temperatures with increasing CO_2.

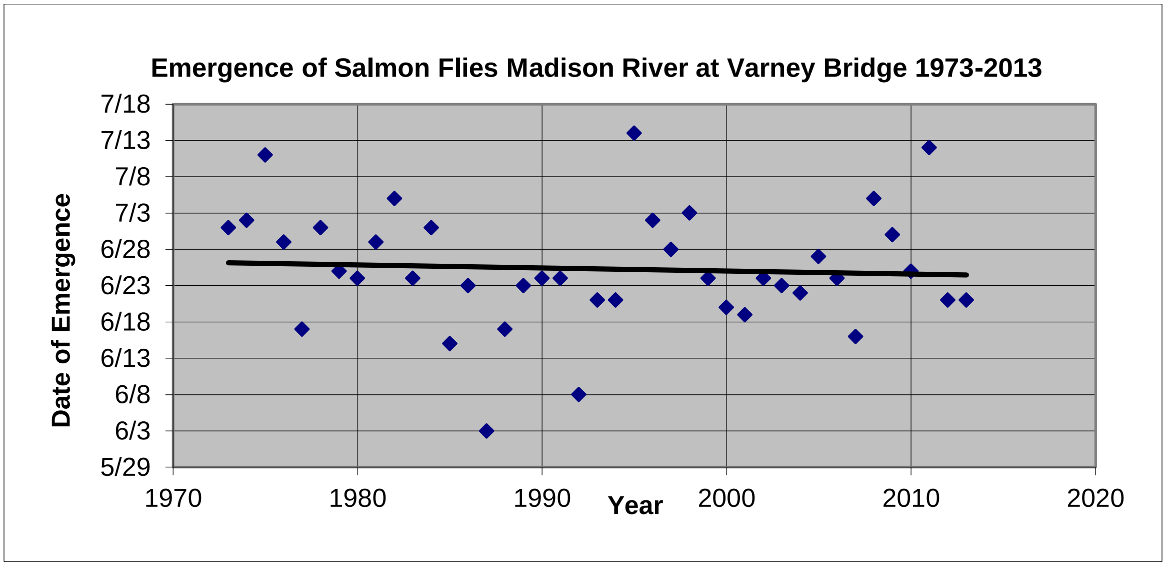


Figure 21. There is a good correlation between day snow melts at SNOTEL sites (which is related to stream temperatures) and day salmon flies emerge at Varney Bridge. Over the past 40 years, the trend has shown the day of emergence has moved about one day earlier. The day of emergence has varied over nearly a six week period with the earliest being June 3 and the latest July 14.

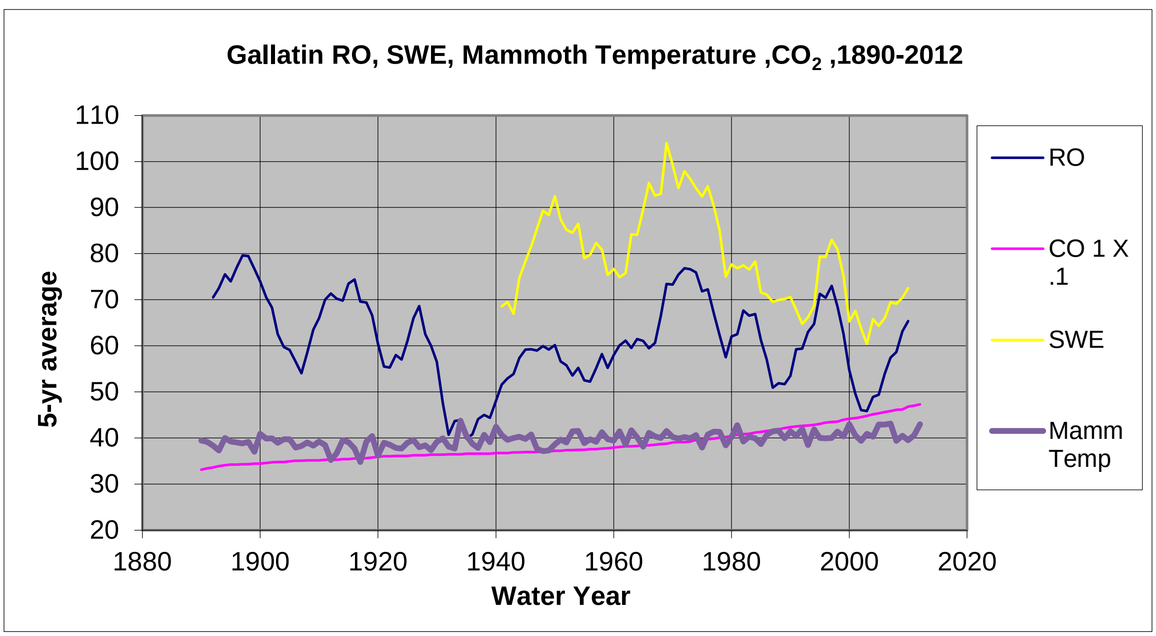


Figure 22. Comparison of annual runoff for the Gallatin River near Gallatin Gateway, April 1 SWE in the Gallatin River drainage, CO_2 concentration and Mammoth average annual temperature over past 120 + years.

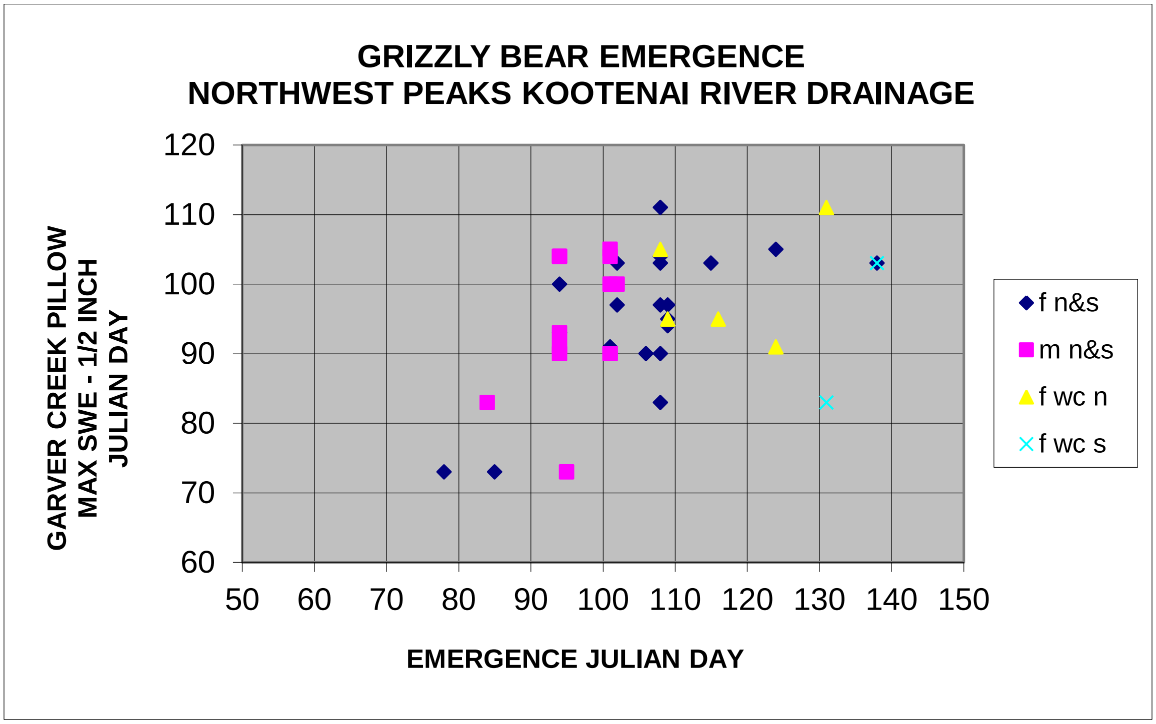


Figure 23. Grizzly Bears emerge from their dens about a week after Garver Creek SNOTEL loses ½ inch SWE in early melt years and up to about two weeks later in years with a late melt. Males emerge earlier than females and females with cubs.

Fires can have a significant effect on the hydrology of a drainage. The majority of watersheds in Montana have a Lodgepole forest. Figures 24 and 25 show how presence or removal of forest can affect the snowpack. Changes in runoff need to be adjusted for fire effects before relating all changes to climate change. After a fire, insect or disease mortality or logging, runoff increases due to reduced interception of snow and rainfall in the forest canopy. As trees re-grow, runoff gradually declines under the same precipitation and temperature regime due to increased interception and sublimation. See Figure 11 for slope of decreased runoff due to the re-growth of trees.

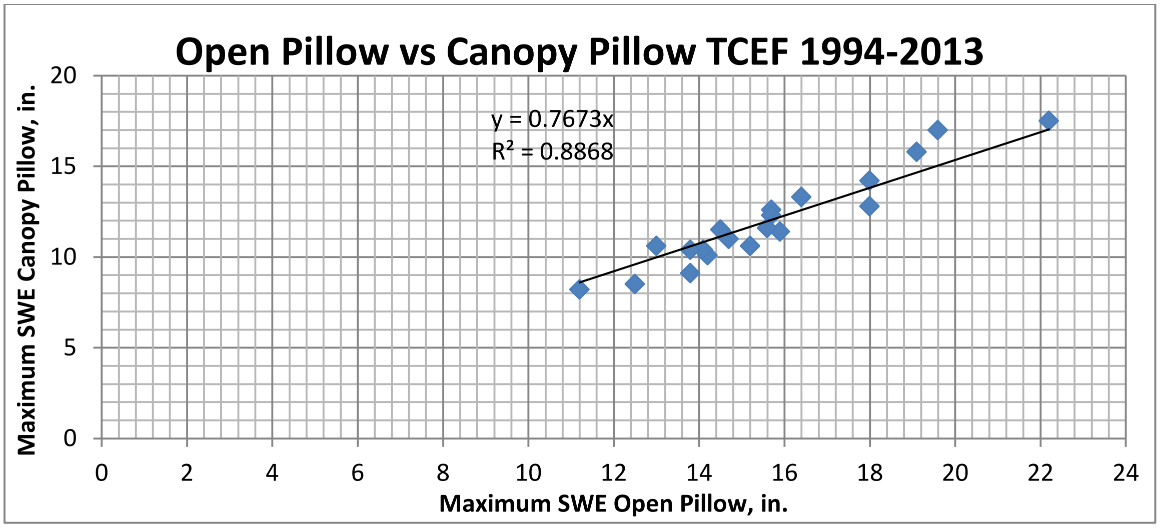


Figure 24. Maximum SWE under a Lodgepole canopy is about 77 percent of the maximum SWE in a nearby opening at Onion Park SNOTEL site on the Tenderfoot Creek Experimental Forest in Central Montana.

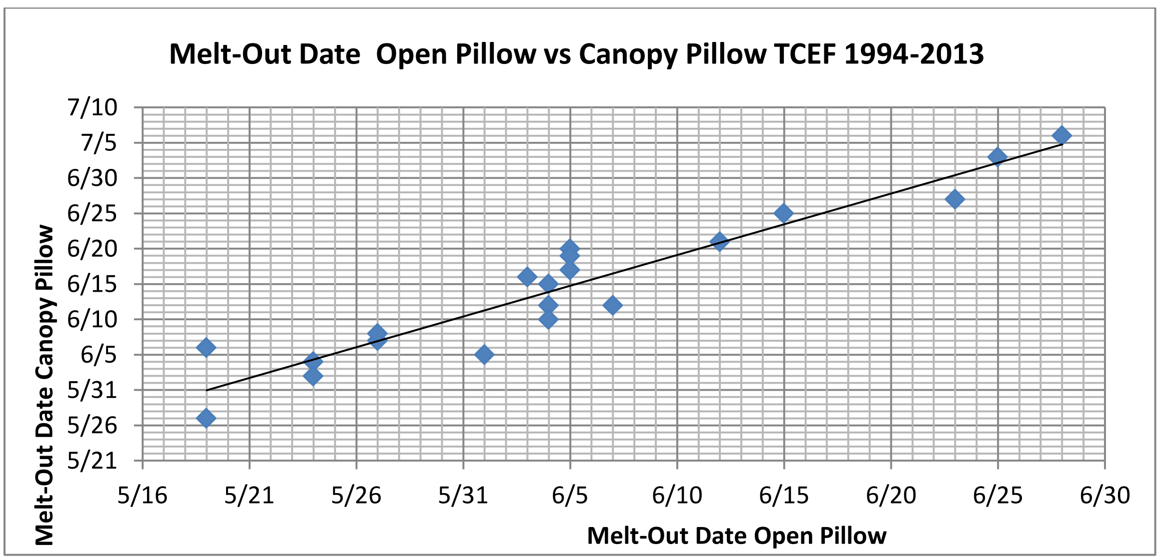


Figure 25. Melt-Out date under a Lodgepole Pine canopy is about 7 to 10 days after snow has melted from a nearby opening at Onion Park SNOTEL site on the Tenderfoot Creek Experimental Forest in Central Montana. Melt rates under the forest canopy are about 40% of that in adjacent openings.

When modeling runoff from mountain watersheds, the effect of the forest canopy needs to be considered. Many watersheds in Montana are 70 to 80 percent forested. When using SNOTEL data as input to models, effects of forest canopy need to be applied to the SNOTEL data in order to have the model provide acceptable results. In Lodgepole Pine stands, the relationships shown in Figures 24 and

25 needs to be incorporated. In addition, response of rain falling on the forest canopy also need to be considered.

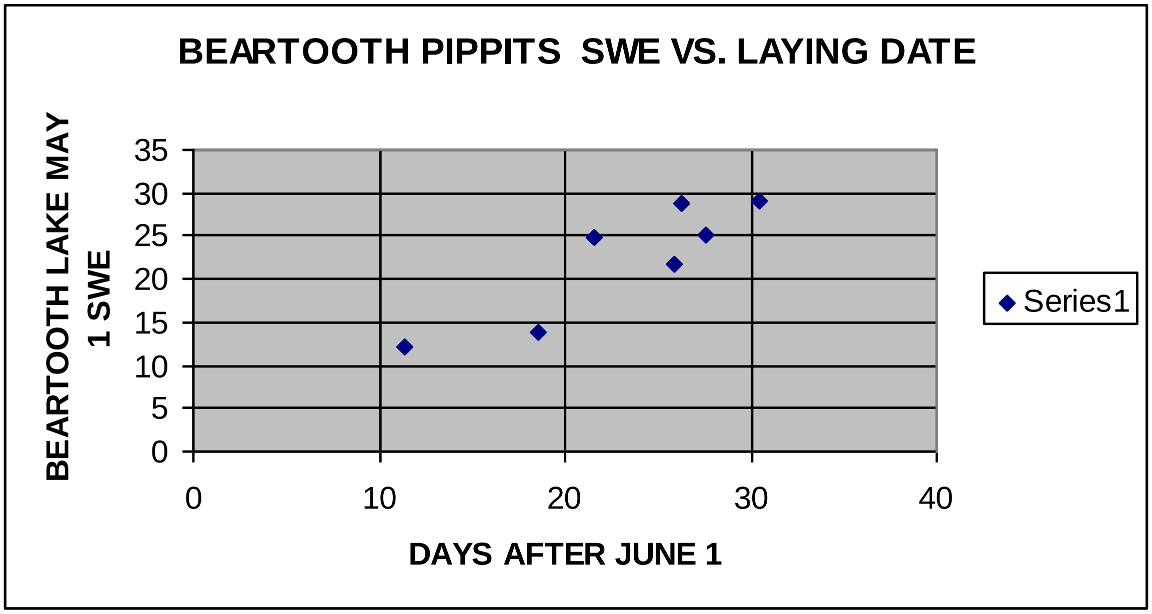


Figure 26. American Pippits on the Beartooth Plateau nested later on years with heavier May 1 snowpack. Snow covering the nesting areas was the most probable cause of the birds waiting until the snow melted to establish their nests and suggests they can change their nesting time to coincide with current conditions. The snow cover is also related to the availability of insects and seeds needed for food.

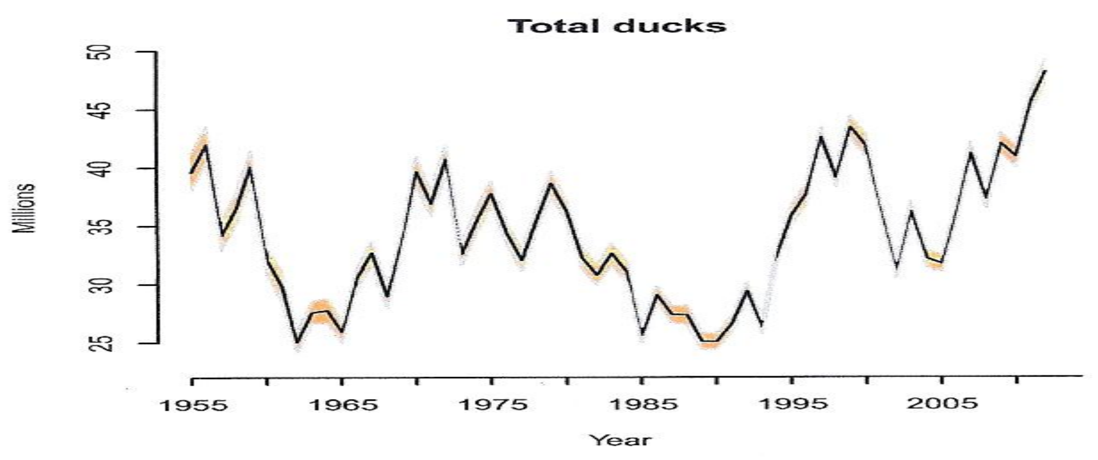
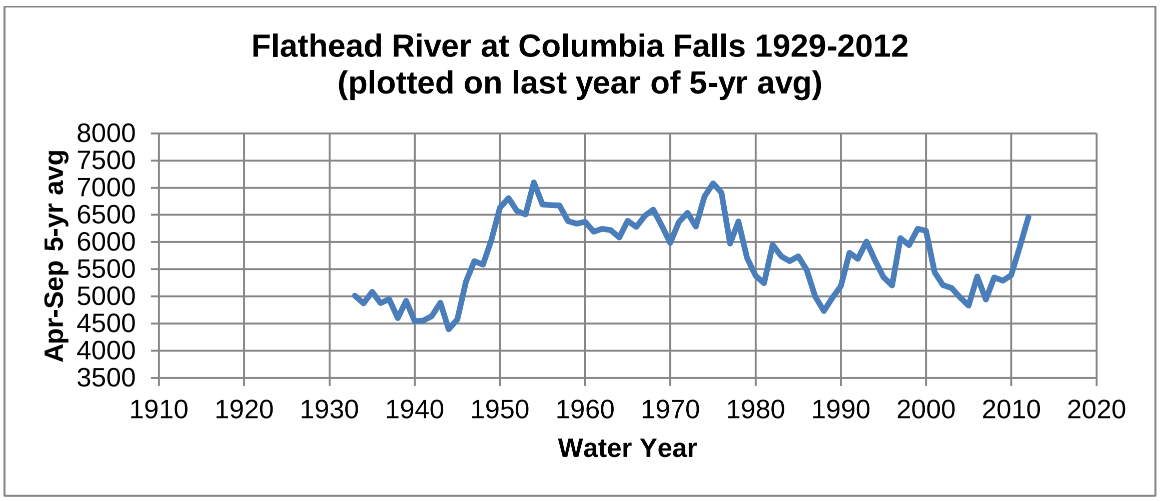


Figure 27. Total number of ducks counted in the US Pacific Flyway varies from year to year based on adult population carried over from previous year, nesting success, and duckling survival which are all related to weather and runoff conditions. In some areas hunting and predators may influence survival. The fact that trends are upward or downward for short periods does not represent the longer overall trend.

Temperatures and precipitation in Montana are largely determined by the location of the Jet Stream. A Jet out of the west carries moisture and moderate temperatures. Areas to the north of the Jet Stream generally carry dry and cold air out of Canada. Areas to the south of the Jet Stream generally carry dry and warm air out of the southwest. Storms coming into Montana from the east that originate in the Gulf of Mexico carry large amounts of moisture and deposit large amounts of precipitation where the mountains cause the storms to rise or when the storm must go up and over a cold front. Weather across the northern part of the state may be different than across the southern part. Generally precipitation across the areas from west to east is similar while precipitation from north to south is more variable due to the location of the Jet Stream. How CO_2 concentration affects the path of the Jet Stream has not been determined. Figure 28 shows how the pattern of west-east runoff in the Kootenai and Flathead Rivers are similar. The similarity of another west-east pattern of the Madison and Gallatin Rivers is shown in Figure 29. Figure 30 shows how northern streams are different from southern streams.



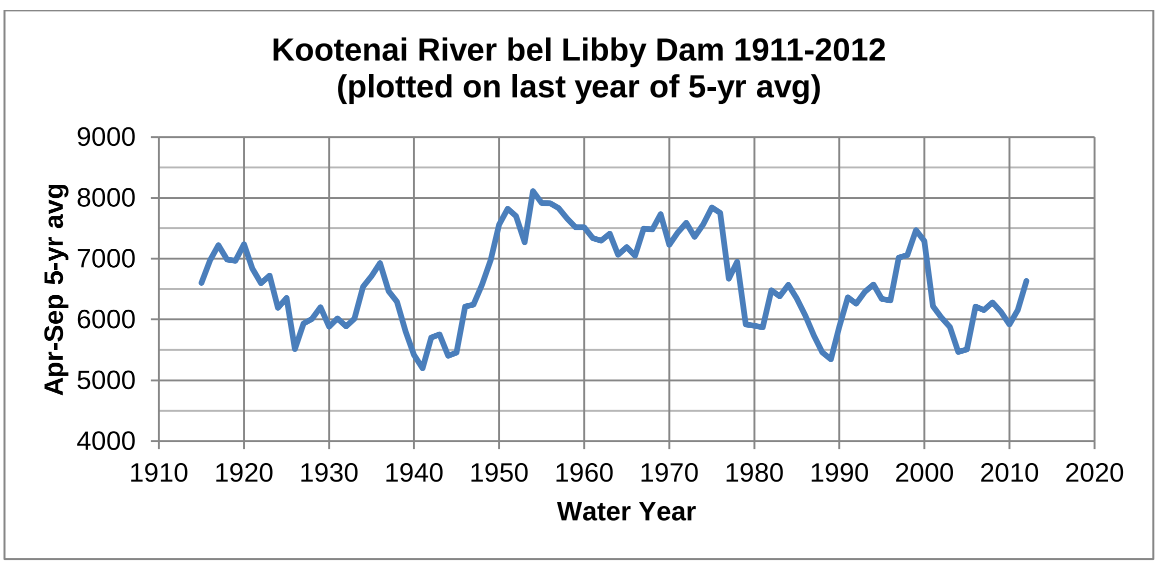
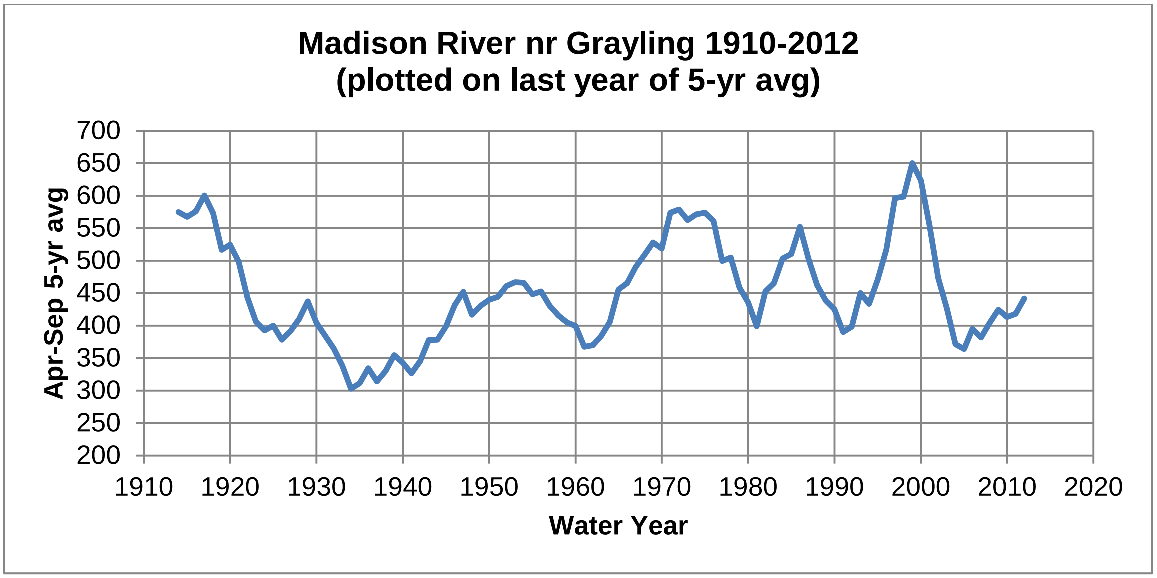


Figure 28. West-east streams in the northern part of Montana show similar runoff patterns.



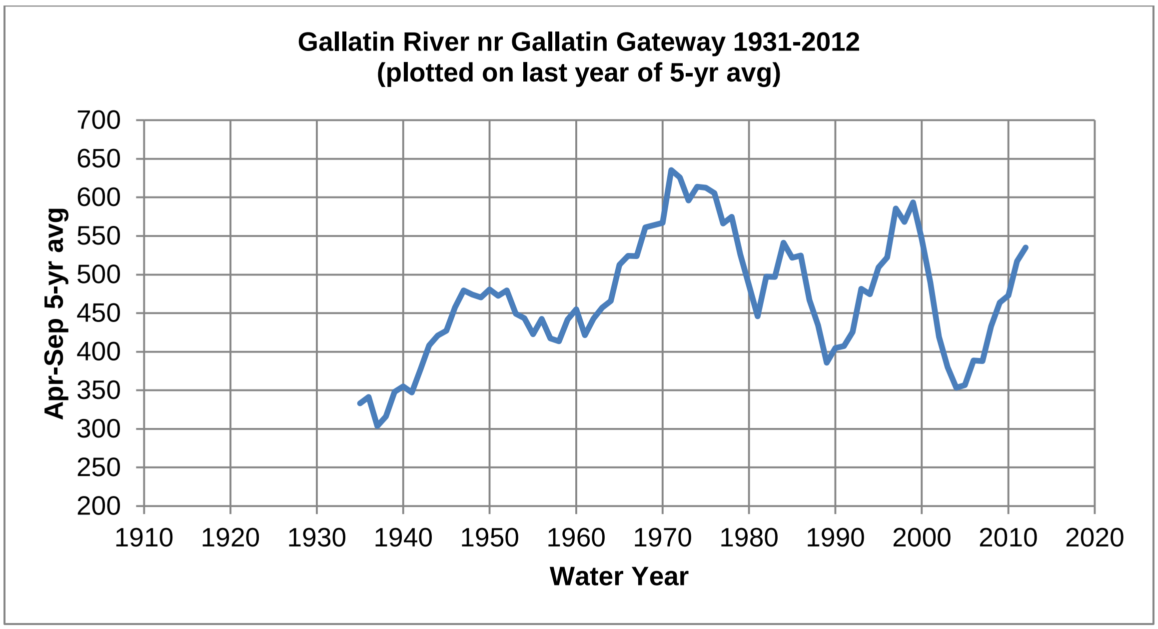
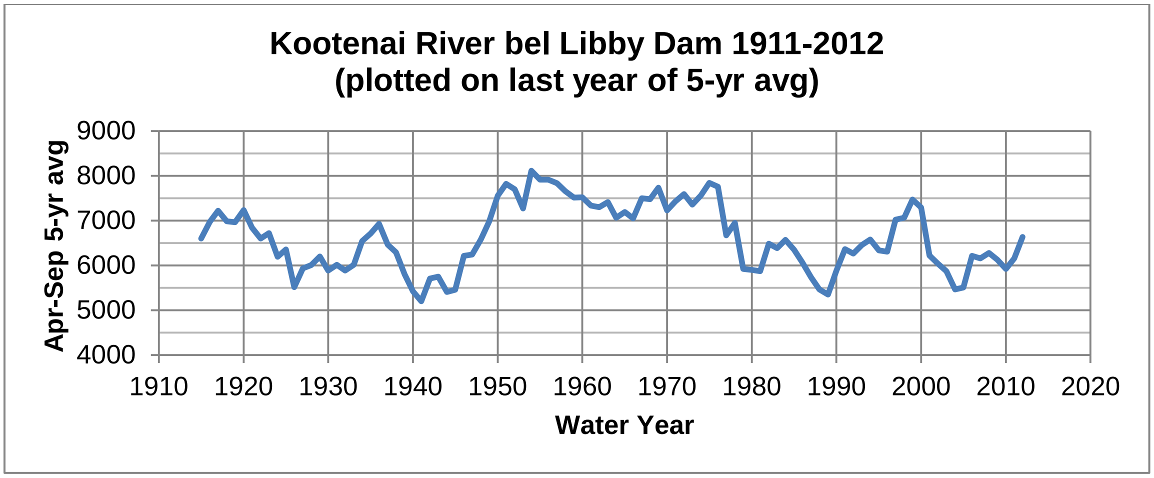
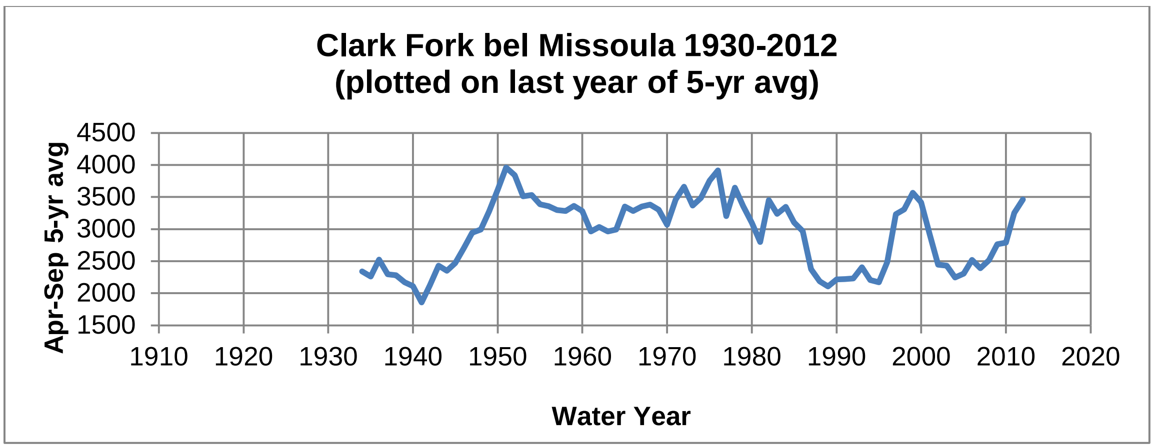


Figure 29. West-east streams in southern part of Montana show similar runoff patterns.





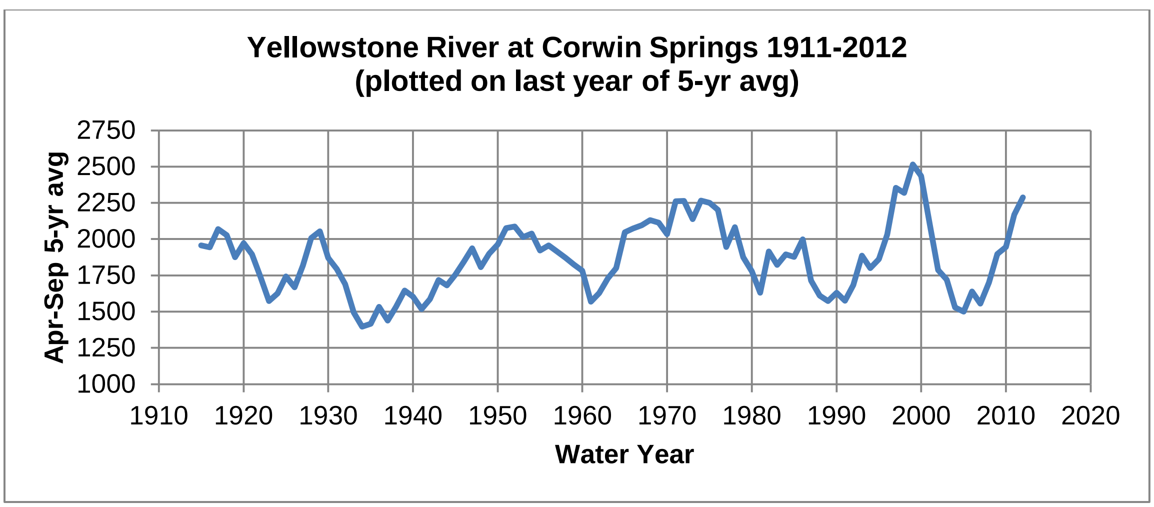


Figure 30. When streams in northwest Montana that have some of their source in Canada are compared to those in west central Montana and with those in the southwest part with some of their source in Wyoming, differences and similarities indicate different patterns of moisture being distributed by the Jet Stream as it shifts from north to south or south to north. Movement of the Jet Stream does not seem to have any relationship to CO_2 concentration.

If weather and resultant streamflow continue to be more variable, it may be economically feasible to construct more storage reservoirs, particularly if people continue to build in the floodplain and population continues to increase. Reservoirs may be designed to store and release annual runoff

Figure 31. Inflow and outflow hydrograph for 2012 water-year for Gibson Reservoir in west-central Montana which is primarily used to supplement irrigation water on Sun River drainage.

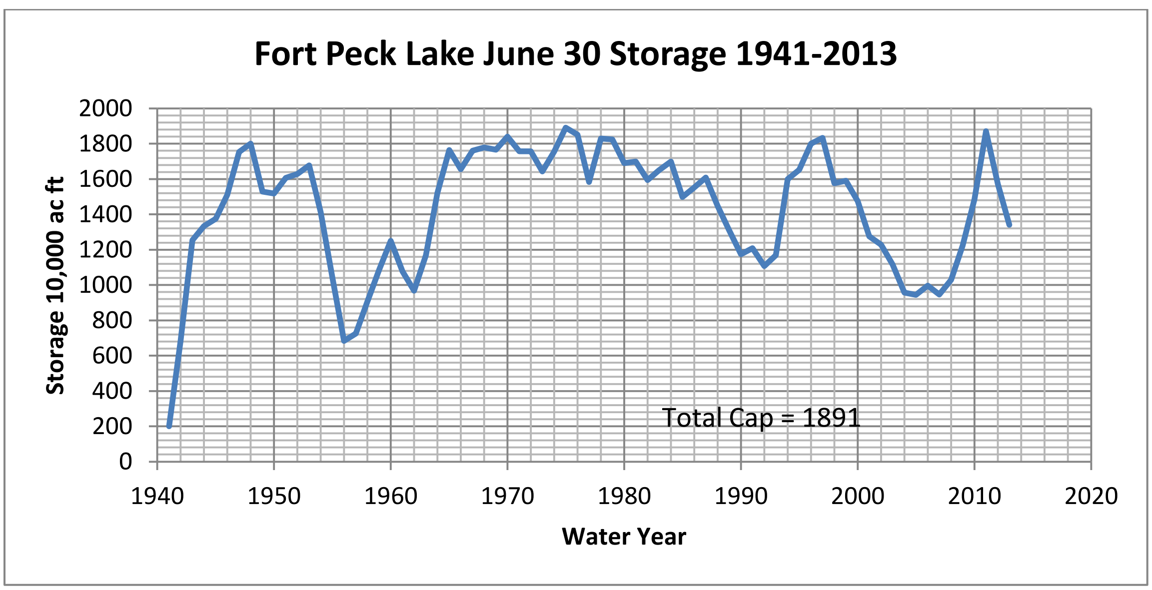


Figure 32. Annual storage on June 30 in Fort Peck Lake which is a multipurpose reservoir in northeast Montana. In the past 73 years, there were four periods of major filling and four periods when there were major releases. Some people who use short records in their analysis for trying to make the case for climate change have a tendency to select those periods that show the best fit to their philosophy.

such as Gibson Reservoir on Sun River (Figure 31) in west central Montana or those that have multi-purpose uses such as Fort Peck Lake in northeastern Montana (Figure 32). Irrigation reservoirs do not generally have storage dedicated directly to flood storage. However, some incidental flood reduction is possible. Water is stored when it is in excess during spring runoff and then released for irrigation or other uses during lower summer flows. Larger reservoirs have storage that can be released over 10 to 15 years and have multi-purpose uses such as flood control, hydro-electric power generation, recreation, downstream flows for fisheries, recreation, barge traffic and other uses.

Our plant and animal diversity is the result of changing climatic conditions. Different plants respond to cool-wet springs, others to warm-wet springs, etc, so that over time, different species are able to produce seed to perpetuate that species. With a constant climate, there would be limited species richness.

Some plants take more than one year to produce seed. Huckleberries start in the fall and then produce berries next fall assuming weather events are favorable. Whitebark Pine trees must have a long enough growing season to start cones in the fall and then have favorable weather through the next two summers in order to produce pine cone nuts. If the growing season is too short in year one, there will be no cones in year three.

During severe winters, some animals will abort their fetus to make it easier for the adult to live and reproduce again. Multiple birth species will have twins or triplets when wintering conditions are not severe and many will survive to adults if spring and summer forage is adequate.

Plants and animals that have learned how to adapt are here today, those that have not are gone. It is interesting that we can determine the carrying capacity of the land for elk or deer or many other species but cannot determine what it is for humans.

Plants and animals respond to phenological or hydrologic time. Humans generally respond to calendar time. In Montana, most climatic or hydrologic events have occurred over a 7 to 8 week time span over the past century. Movement of a week or two over shorter time periods is well within the normal range of variability. For example, the salmon flies do not always emerge at Varney Bridge on the average date of June 25th (Figure 21). Emergence a week or two either earlier or later is well within the historic variability. Fish spawning periods are established by water temperatures and not photoperiods. Spring spawning by Rainbow and Cutthroat Trout and Grayling is established by snowpack and melt. Melting snow water has a temperature of 32 ^{0}F as it leaves the snowpack and this suppresses the stream temperature as long as there is melting snow. When the snow is gone, air temperatures can raise stream temperatures. When the stream temperature reaches different thresholds, it in turn triggers fish spawning and emergence of aquatic insects. In the fall as stream temperatures drop, fall spawning by Brown Trout and Whitefish is triggered.

Monitoring any changes that are occurring in the climate system requires an adequate daily network of 130-140 SNOTEL stations in higher elevations, 400-500 Climatological stations in valley areas, and an active stream gaging program of about 250-300 stations in Montana. Funding to keep these stations operating should not be subject to political ideology or used as political pawns.

Some studies suggest tree rings indicate that snow packs have been decreasing for the past 2000 years. Some tree growth takes place while there is still snow on the ground. Data from the higher elevation stations in the GYA suggest that less than 20 percent of the growing season for trees is related to moisture from snowmelt. Soils are always at field capacity when the snow melts to zero each spring. As the tree ages, canopy growth reduces the amount of moisture entering the soil under the tree canopy, nutrients are being reduced as the tree ages, and tree rings are narrower under same moisture/temperature conditions as the tree girth increases. The fact that tree rings become narrower as the tree ages does not indicate less snowpack but is more representative of spring and summer precipitation and temperatures and increased girth as the tree ages. In most mountainous areas, over 80 percent of the growing season occurs after the snow has melted.

Just because some variables seem to correlate well does not always indicate a good cause and effect relationship. For example, if CO_2 levels are plotted against the highest Dow Jones Industrial Average (DJIA) for each year since 1901, the R^2 value of the correlation is 0.94 (Figure 33). Normally, this would indicate a high degree of correlation. Using the same philosophy that some scientists have used in climate change studies, a drop in the DJIA should cause the CO_2 levels to fall. Likewise, if the Dow continues to increase, it should be expected that the CO_2 levels would also increase. Many other variables also have a high degree of correlation with CO_2 but they are not specifically related to or are the cause of the increasing CO_2 levels. These include over 100 years of US Senator's salary (1888 to present), gasoline prices and many other non-related indexes.

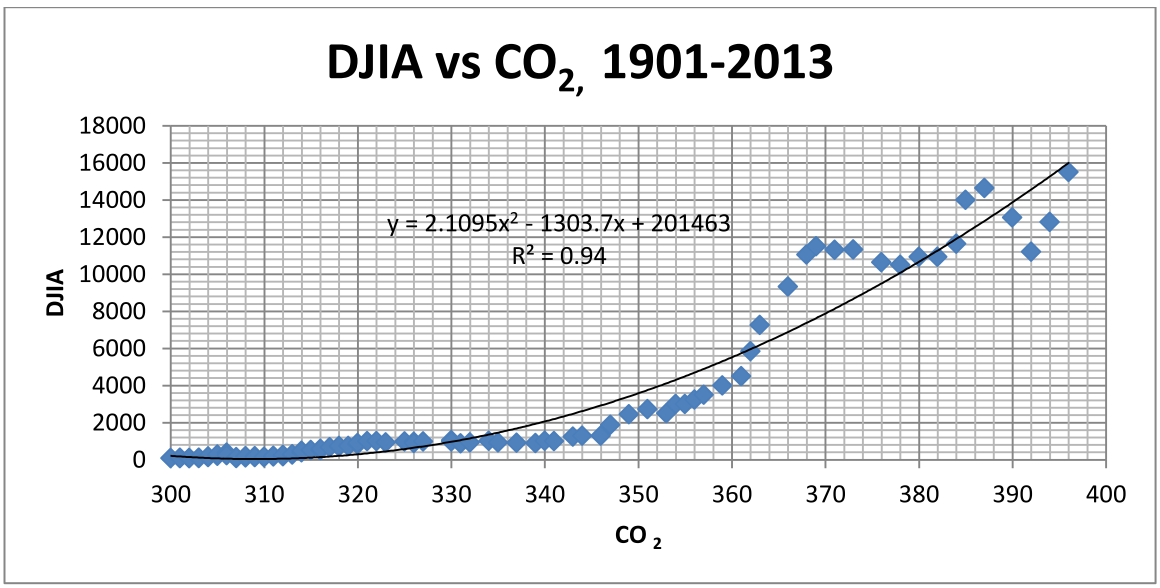


Figure 33. Statistical relationships between some variables such as Dow Jones Industrial Average indicate a very high degree of correlation but they may not be good predictors of the future conditions as the two parameters may have little physical relationship to each other.

Author's experience: The author has been involved with the snow survey and water supply forecasting program in Montana and northern Wyoming since 1954. He has served as Civil Engineer, Hydrologist and Snow Survey Supervisor in Montana and Data Collection Office Supervisor for Montana and Northern Wyoming. Since retirement from the Soil Conservation Service, he has been a consultant specializing in mountain hydrology and climatology.