Sec. 27. Section 473.7, Code 2009, is amended to read as follows:

473.7 DUTIES OF THE OFFICE

12. Conduct a study on activities related to energy production and use which contribute to global climate change in conjunction with institutions under the control of the state board of regents. The study shall take the form of a climate change impacts review, to include the following:

a. Performance of an initial review of available climate change impacts studies relevant to this state.
b. Preparation of a summary of available data on recent changes in relevant climate conditions.
c. Identification of climate change impacts issues which require further research and an estimate of their cost.
d. Identification of important public policy issues relevant to climate change impacts.

In the course of the review, the institutions shall meet at least twice with the Iowa climate change advisory council established in section 455B.851. The office shall submit a report, based upon input from the institutions, containing its findings and recommendations to the governor and general assembly by January 1, 2011.

4 November 2009

Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections

Eugene S. Takle
Climate Science Initiative
Iowa State University
Ames, IA 50011
gstakle@iastate.edu
515-294-9871

Introduction

Climate in Iowa is changing in ways, at rates, and for reasons that require analysis for future planning and risk management. A recent headline in *Science* declared "Stationarity is Dead…" (Milly et al., 2009). The article summarizes scientific consensus that decadal natural variability together with anthropogenically induced climate change have rendered inoperable the assumption of climate stationarity in relation to water management. That is, the past 30, 50, or even 100 years of climate data are no longer the sole source of the best available information for future planning relating to use of water resources. While observations are the cornerstone of climate science, models must now be used to synthesize observations and consulted for evidence that future climate scenarios might significantly depart from past experience.

The authors argue that stationarity cannot be revived and that recent developments have led the science-using community to the opinion that the time has come to move beyond the wait-and-see approach. Patterns of observed changes in annual streamflow trends across the globe are unlikely to have arisen from human land-use changes alone. However, after accounting for these changes, remaining trends in hydrological factors are consistent with modeled response to climate forcing – providing substantial evidence that anthropogenically induced climate change is a contributing factor.

Iowa's economy is highly dependent on water for its rain-fed agriculture. Timing and amounts of precipitation are critical to agricultural production. But there are many other climate factors that influence the economy and well being of Iowa citizens and communities. This paper provides a very brief overview of climate factors and possible changes that are of interest for Iowa. Appendix 1 provides a (likely incomplete) list of factors for consideration when assessing impacts of climate change for Iowa.

Observed and Projected Changes for Iowa

The following paragraphs provide examples of recent trends and variability of a few climate factors in Iowa and projections of their future changes. These trends and projections are based on analyses of Iowa's past climate, global modeling studies reported by the Intergovernmental Panel on Climate Change (IPCC 2007), the report of the US Climate Change Science Program (Backlund et al., 2008), our own peer-reviewed climate change research results from Iowa State University (see citations), and personal interactions with colleagues in the climate science community.

Precipitation

Precipitation in Iowa has trended gradually upward for the last 100 years, although year-to-year variability is high (Fig. 1). Eastern Iowa has a higher upward trend than the statewide average (Fig. 2). A notable trend, however, is that there has been a change in "seasonality": most of the increase has come in the first half of the year, leading to wetter springs and drier autumns. Trends toward more precipitation and changed seasonality, as well as higher increases in eastern Iowa, are projected to continue (IPCC, 2007). This has high impact on agriculture due to the possibility of more water-logging of soils and delayed planting in spring but improved crop dry-down conditions in fall. The central US also has been experiencing more variability of summer precipitation (CCSP, 2008), with more intense rain events and hence more episodes of higher runoff. Records for Iowa also show a higher tendency for more intense rain events (Fig. 3). Although we have not looked at this specifically for Iowa, some regions, such as Europe that also experience more intense rain events, are finding longer periods between rain events, thereby leading to increased probability of drought. A very strong trend in Iowa and the Midwest is an increase in absolute humidity as measured by dew-point temperature (Fig. 4). This also has agricultural and horticultural implications of higher probability of disease and pathogens such as fungus and toxins. There is growing evidence that summer storm systems may be stronger, although trends in extreme events such as tornadoes are difficult to quantify. Higher winter temperatures bring higher probability of rain and lower probability of snow, which may lead to more winter soil moisture recharge.

Temperature

A robust result of analysis of temperature records is that Iowa now has longer frost-free periods than in the past (Fig. 5), with a statewide average of about 5 more frost-free days than in 1950. I prefer not to use the term "growing season" because changes in temperature and precipitation may even shorten the growing season for some plants despite a longer frost-free period. Winter temperatures have increased more than summer temperatures. Fig. 6 reveals the downward trend in heating degree days, widely used as a measure of cold-season demand for space heating. Iowa now experiences fewer extreme cold temperatures in winter as evidenced by Figs 7 and 8. I caution, however, that the extreme cold data for Des Moines might be influence by the urban heat-island effect not accounted for in these plots. More occurrences of temperatures hovering near 32^{o} F in transition seasons will likely increase the number of freeze-thaw cycles. It also is likely that temperature variability may increase in a future climate.

A trend in summer temperatures that seems counter to global and continental trends likely related to anthropogenic climate change is that Iowa (and the central US) has fewer extreme high temperatures in summer than in the past (see Figs. 9 and 10). Our research has suggested more soil moisture is a mechanism for this anomaly (Pan et al., 2004). Another possibility is that recent temperature increases over higher terrain in the western US is producing a tendency toward more high pressure to the west of Iowa and a consequent increase in flow from the north during the warm season (Pan el al., 2009b), but there may be other explanations (Kunkel et al., 2006). This trend has been highly favorable to corn production in Iowa, and likely has been a contributing factor to the current upward trends in corn yields of 3 bushels per acre per year, compared to 2 bushels per acre per year before 1995 (K. R. Lamkey, private communication). Results of global climate models (IPCC 2007) do not project this pause in the warming to persist, although our regional model simulations for the mid 21st century (Pan et al., 2004) suggest the central use will warm but not nearly as much as other regions of the US. More extensive modeling we currently have in progress likely will shed more light on this important feature of Iowa's summertime climate.

Wind speed

Surface wind speeds (at the standard measurement height of 10 m) have been reported to be declining over the last 30 years (Pryor et al., 2009), and future projections suggest this trend will continue (Segal et al., 2001). Reduced surface wind speeds have negative impact on agriculture (less ventilation of crops during intense heat, longer dew periods at night, etc.) and human health (more intense heat waves, build-up of urban air pollutants, etc.). This trend in surface winds does not necessarily mean that wind speeds at heights of wind turbine generators (80-100 m) will be declining, since factors such as land use have lesser impact at 80 m than at 10 m. Interannual variability of wind speed at turbine heights is of much more importance to the wind power industry than is long-term trend.

Solar radiation, cloud cover

Surface solar radiation in the Mississippi River Basin has been declining due to increased cloud cover for the period 1948-2004 (Qian et al., 2007). These authors use a model to estimate hydrological properties not routinely measured, and they find that evapotranspiration also has been declining. Simulations of a future climate based on increased greenhouse gas concentrations (Pan et al., 2004) shows that the decline in surface solar radiation is likely to continue.

Streamflow

Levels of streamflow are amplified by changes in precipitation, leaving areas having relatively modest topographic variation prone to flooding, as has been demonstrated in the last 20 years in Iowa. Our studies of streamflow (Jha et al., 2004) under climate change show that 21% increase in precipitation in a future scenario (2040s) climate leads to a 50% increase in streamflow in the Upper Mississippi River Basin. Fig. 11 (adapted from data presented in Jha et al. [2004]) shows this relationship between precipitation and streamflow.

Soil moisture, tile drainage

Soil moisture has not been widely measured over long periods of time to assess trends. Variations in soils, slope, and subsurface geological conditions are complicating factors that also influence soil moisture variability. Iowa soils generally are deep with good water-holding capacity, so soil moisture is related to total seasonal precipitation and is less sensitive to exact timing of precipitation than would, say, sandy soils or shallow soils. The IPCC (2007) report suggests that, based on global model simulations, the model consensus is that there will be a weak decline in soil moisture in Iowa over the 21st century. Interannual variation likely will be a more significant factor than long-term trends, however.

The precipitation intensity increase observed in the Midwest in the 20th century is projected to continue in the future. Over vast areas of Iowa having poor natural soil drainage, flow in agricultural drainage tile responds disproportionately to rainfall. Our simulations of tile drainage by two regional climate models for a mid-century climate scenario (Singh et al., 2009) showed that increases in precipitation of 24% and 32% (and accompanying warming) leads to drainage tile flow increases of 35% and 80%, respectively, together with a seasonality shift toward more spring precipitation and flow. The proportionately higher increase in drainage tile flow (compared to increase in precipitation) is consistent with the higher increase in streamflow previously mentioned.

Tropospheric ozone

Ozone in the lowest five miles of the atmosphere (troposphere) is produced by both natural and anthropogenic (mainly high-temperature burning) causes. Being distinctly different in concentration from stratospheric ozone (which is produced naturally and destroyed by human emissions of long-lived chlorine containing compounds), tropospheric ozone has negative impact on agriculture and human health. General increases in temperature and population growth suggest future increases in tropospheric ozone are likely. Agricultural crops, particularly soybeans, as well as horticultural crops, are negatively impacted by tropospheric ozone.

Carbon dioxide

Carbon dioxide has increased by over 30% since the beginning of the industrial revolution and 22% since 1960. Enhanced atmospheric carbon dioxide enhances crop growth, particularly in C3 plants such as soybeans. Continued increase of atmospheric carbon dioxide will continue to favor C3 plants over C4 plants (such as corn) and will provide some plants in natural ecosystems a favorable advantage over their competitors. Most plants considered weeds for agriculture are C3 plants, unfortunately. Recent research indicates that some of the beneficial effects of increased carbon dioxide are offset by negative effects of enhanced tropospheric ozone (McKee, 1994).

Soil carbon

While not normally considered a climate factor, carbon content of soil has high agricultural impact due to its water-holding capacity and general contribution to soil quality. It also is a candidate for carbon sequestration in efforts to mitigate climate change. Iowa soils have lost about half of their pre-European-settlement carbon levels due to agricultural tillage. While reduced tillage is stemming this trend, climate change in the form of temperature increases and increased soil moisture likely will accelerate soil microbial activity that leads to breakdown of soil plant matter into carbon dioxide. Our studies (Pan et al., 2009a) show that higher carbon uptake by crops in future climates lead to higher plant respiration as well as higher amounts of grain. Since grain is harvested and not returned to the soil and other plant parts do not add extra carbon to the soil, there is a reduction in soil carbon in future climates.

Plant growth

Phenological stages are shortened in higher temperature and higher humidity environments, which might make plants more vulnerable to extreme climate conditions during critical periods such as pollination. Weeds (many being C3 plants) grow more rapidly under elevated atmospheric carbon dioxide. Weeds are observed to be migrating northward and are becoming less sensitive to herbicides (Backlund et al., 2008). Plants generally have increased water used efficiency and are more drought tolerant under higher atmospheric carbon dioxide levels. Some plants have had unusually strong response to climate change. Studies of poison ivy, for example, has shown a doubled growth rate and a more powerful form of urushiol, the oil that causes the allergic reaction and rash (Doheny, 2007).

Risk factors

Tables 1 and 2 give the distribution of insured crop losses for Iowa due to weather and economic factors for corn and soybeans, respectively (Milliman 2009). It is clear that for both crops the dominant factor leading to insured losses is precipitation extremes – droughts or excess precipitation. Crop breeding advances by major seed corn companies have improved drought tolerance for corn. However, negative consequences of heavy precipitation and water-logged soils in the form of delayed planting, increased soil compaction, and reduced flow of oxygen to the root zone are not good candidates for improvements in crop breeding.

Engineering Standards: What is “Normal Climate”?

The design process for major infrastructure, including roads, bridges, and buildings, requires information about ambient weather conditions to be experienced by the structure. Likewise, advance planning for water management and power generation and distribution requires future climate information on scales of weeks to decades. The conventional practice in the engineering community is to use the time-honored method developed by the World Meteorological Organization (WMO) and the National Oceanic and Atmospheric Administration (NOAA). This method uses the most recent three completed decades as the definition of “normal climate”. Currently the observed weather conditions at a location from 1971-2000 are averaged to produce the location’s “normal climate”. Use of such data for estimating natural gas send-out by utility firms, for example, leads to serious over-estimates of consumer demand in a location such as Iowa where winters are becoming much more mild. Alternative methods are needed to better represent continuing climate trends, while concurrently allowing for high levels of interannual variability.

In a peer-reviewed paper in the *Journal of Applied Meteorology and Climatology*, NOAA authors lead off their abstract with:

> *WMO-recommended 30-yr normals are no longer generally useful for the design, planning, and decisionmaking purposes for which they were intended. They not only have little relevance to the future climate, but are often unrepresentative of the current climate. The reason for this is rapid global climate change over the last 30 yr that is likely to continue into the future.* (Livezey et al., 2007).

There currently is no widely accepted replacement for the WMO standard for projecting future climate at arbitrary locations across the US.

Similarly, the building industry uses a "typical meteorological year" or TMY, which consists of hourly values of meteorological variables for each day of the year that can be used for designing heating and cooling systems and ambient conditions for determining typical heat and moisture flow through buildings. The TMY currently used (TMY3) (NREL, 2009) is computed from a composite of hourly values of meteorological conditions for the period 1991-2005 for 1020 locations across the US. However, this does not provide information about future scenario ambient climate conditions or inter-annual variability likely to be experienced by buildings, roads, and bridges over the next 40-60 years.

Asphalt and concrete highways are subject to cracking and rutting that are temperature and precipitation dependent. The "Pavement Performance Model" (Breakah et al., 2009) provides guidance for design but requires future scenario climate information.

Future Scenarios Climates for Iowa at County Scale

Research in progress is producing scenarios of future climates at approximately the county scale (50-km grid boxes) over nearly all of North America under the North American Regional Climate Change Assessment Program (NARCCAP: http://www.narccap.ucar.edu/). This program uses four AR4 (IPCC 2007) global climate models of contemporary and future climates to provide input to six regional climate models for assessing climate change between the end of the 20th C and the period 2040-2070 for the A2 SRES emissions scenario. Regional model output will be available at 3-hourly intervals to create meteorological fields to evaluate impacts of climate change on agriculture, water resources, human health, ecosystems and other applications. The archive will be complete by early 2010. The Regional Climate Modeling Laboratory at Iowa State University is centrally involved in developing regional climate scenarios for this project.

References:

Backlund, P. and Co-Authors, 2008: The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. US Global Climate Change Research Program Synthesis and Assessment Product 4.3. US EPA, Washington, DC. 362 pp. [Available online at http://www.gcrio.org/orders/product_info.php?products_id=212].

Breakah, T. M., R. C. Williams, D Herzmann, and E. S. Takle, 2009: The effects of utilizing accurate climatic conditions for mechanistic-empirical pavement design, a case study. Accepted *Bulletin American Society of Civil Engineers.*

CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

Doheny, K., 2007: Climate change brings super poison ivy. WebMD [Available online at http://www.webmd.com/skin-problems-and-treatments/features/climate-change-brings-super-poison-ivy].

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jha, M., Z. Pan, E. S. Takle, R. Gu, 2004: Impact of climate change on stream flow in the Upper Mississippi River Basin: A regional climate model perspective. *J. Geophys. Res.* **109**, D09105, doi:10.1029/2003JD003686.

Kunkel, K.E., X.-Z. Liang, J. Zhu, and Y. Lin, 2006: Can CGCMs simulate the Twentieth Century “warming hole” in the central United States. *J. Climate* **19**, 4137-153.

Livezey, R. E., K. Y. Vinnikov, M. M. Timofeyeva, R. Tinker, and H. M. van den Dool, 2007: Estimation and extrapolation of climate normals and climatic trends. *J. Appl. Meteor. and Clim*. **46**, 1759–1776.

McKee, D. J., 1994: Tropospheric Ozone: Human Health and Agricultural Impacts. Lewis Publishers., Boca Raton, FL. 333 pp.

Milliman, Inc., 2009. Based on 1995-2006 data from the Risk Management Agency Website (http://www.rma.usda.gov/data/cause.html)

Milly, P. C. D., Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer, 2009: Stationarity Is dead: Whither water management? *Science* **319**, 573-574.

NREL, 2009: National Renewable Energy Laboratory National Solar Radiation Database. [Available online at http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/]

Qian, T., A. Dai, and K. E. Trenberth, 2007: Hydroclimatic trends in the Mississippi River Basin from 1948 to 2004. *J. Climate* **20**, 4599-4614.

Pan, Z., D. Andrade, J. Wimberley, N. McKinney, M. Segal, and E. S. Takle, 2009a: Changes and uncertainty factors in soil carbon in the agricultural U. S. Midwest under climate change. Submitted to *Ecological Modeling.*

Pan, Z., M. Segal, X.-Z. Li, and B. Zib, 2009b: Global climate change impact on the Midwestern U.S - a summer cooling trend. IN S Pryor, ed., *Regional Climate Variability, Predictability, and Change in Midwestern USA*. Indiana University Press, 312pp.

Pan, Z., R. W. Arritt, E. S. Takle, W. J. Gutowski, Jr., C. J. Anderson, and M. Segal, 2004: Altered hydrologic feedback in a warming climate introduces a "warming hole". *Geophys. Res. Lett***. 31***,* L17109, doi:10.1029/2004GL020528*.*

Pan, Z., M. Segal, R. W. Arritt, and E. S. Takle, 2004: On the potential change in solar radiation over the U.S. due to increases of atmospheric greenhouse gases. *Int. J. Renewable Energy* **29**, 1923-1928.

Pryor, S. C., R. J. Barthelmie, D. T. Young, E. S. Takle, R. W. Arritt, D. Flory, W. J. Gutowski Jr., A. Nunes, and J. Roads (2009), Wind speed trends over the contiguous United States, *J. Geophys. Res*. **114**, D14105, doi:10.1029/2008JD011416.

Segal, M., Z. Pan, R. W. Arritt, and E. S. Takle, 2001: On the potential change in wind power over the U.S. due to increases of atmospheric greenhouse gases. *Int. J. Renewable Energy* **24**, 235-243.

Singh, Ranvir, Matthew J. Helmers, Amy Kaleita, and Eugene S. Takle, 2009: Potential impact of climate change on subsurface drainage in Iowa's subsurface drained landscapes. *Journal of Irrigation and Drainage Engineering*, July/August 2009, 459-466. DOI**:** 10.1061/ ASCE IR.1943-4774.0000009

Table 1. Insured crop loss for corn in Iowa (Milliman, 2009)

Factor	**Percent**
Cold Winter	0.9
Decline in Price	6.6
Drought	35.5
Excess Moist/Precip/Rain	38.4
Flood	2.6
Freeze	0.1
Hail	7.2
Heat	1.2
Hot Wind	0.0
Mycotoxin (Aflatoxin)	1.0
Plant Disease	0.3
Winds/Excess Wind	5.0
Other	1.1
Total	100.0

Table 2. Insured crop loss for soybeans in Iowa (Milliman, 2009)

Factor	**Percent**
Cold Winter	0.6
Decline in Price	4.8
Drought	56.8
Excess Moist/Precip/Rain	20.2
Flood	1.4
Freeze	0.1
Hail	13.0
Heat	0.9
Hot Wind	0.0
Mycotoxin (Aflatoxin)	0.0
Plant Disease	1.1
Winds/Excess Wind	0.2
Other	1.1
Total	100.0

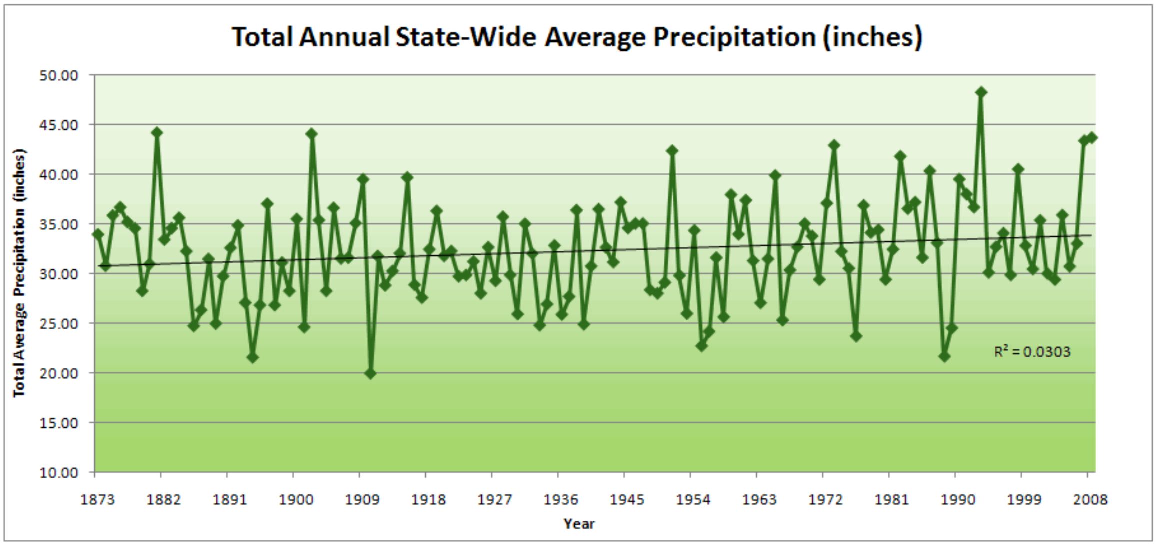


Figure 1. State-wide data

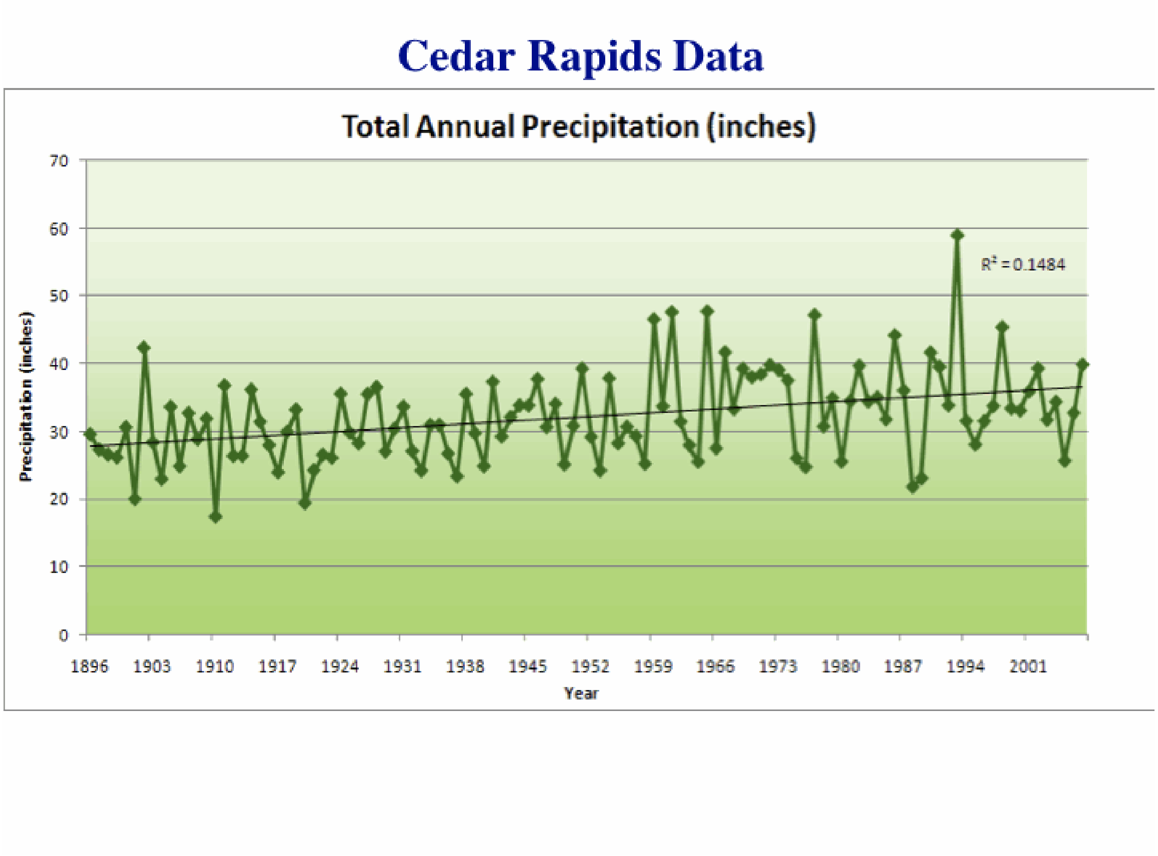


Figure 2. Cedar Rapids data

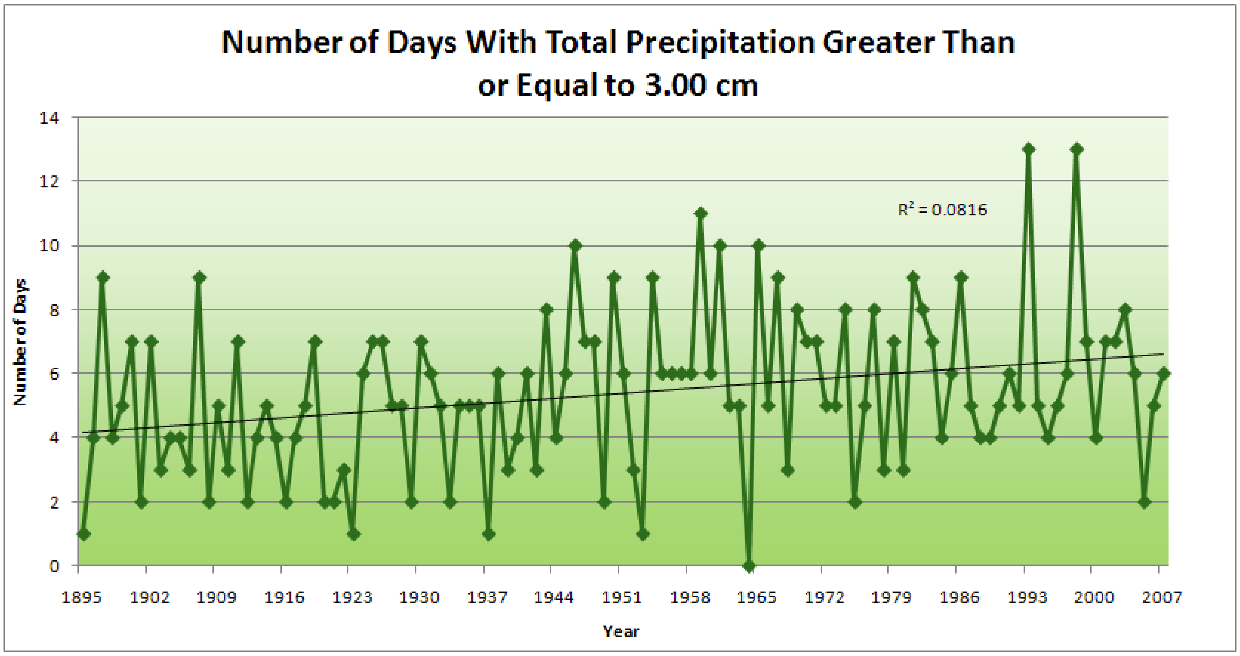
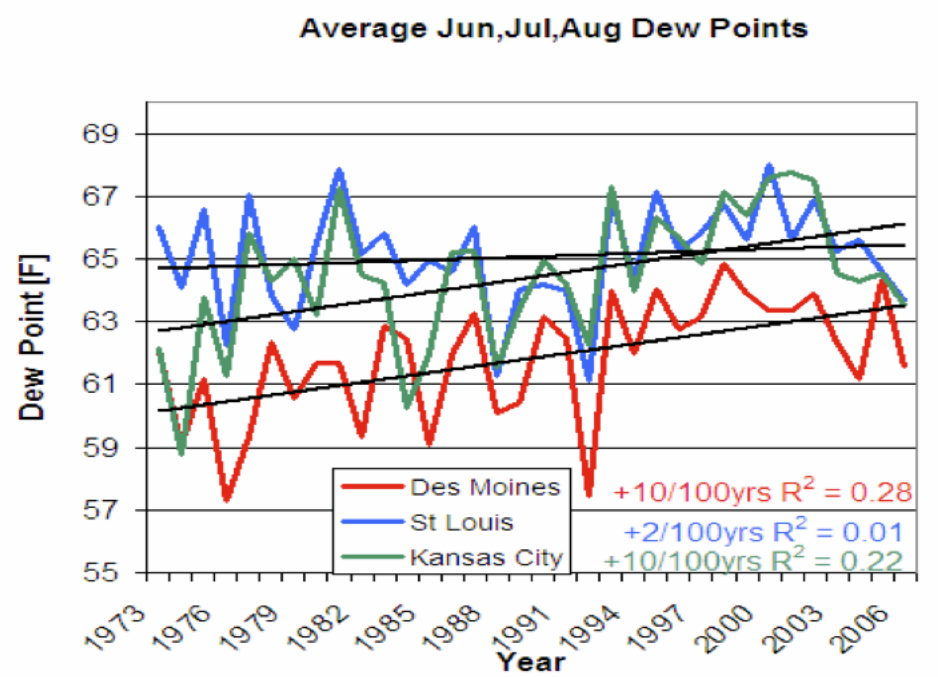


Figure 3. Cedar Rapids data



D. Herzmann, Iowa Environmental Mesonet

Figure 4

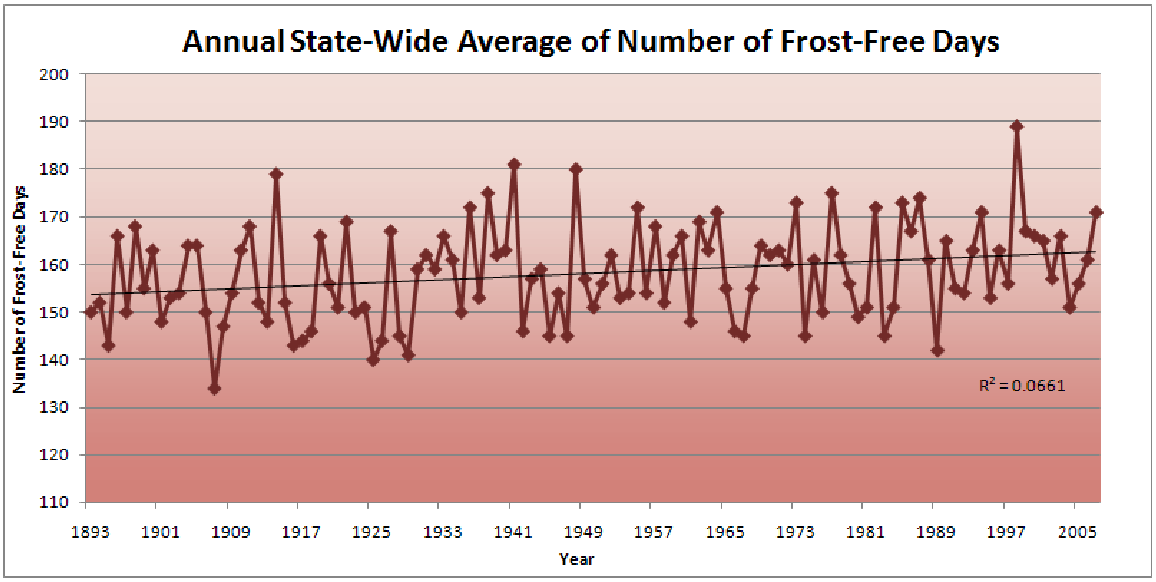


Figure 5. State-wide data

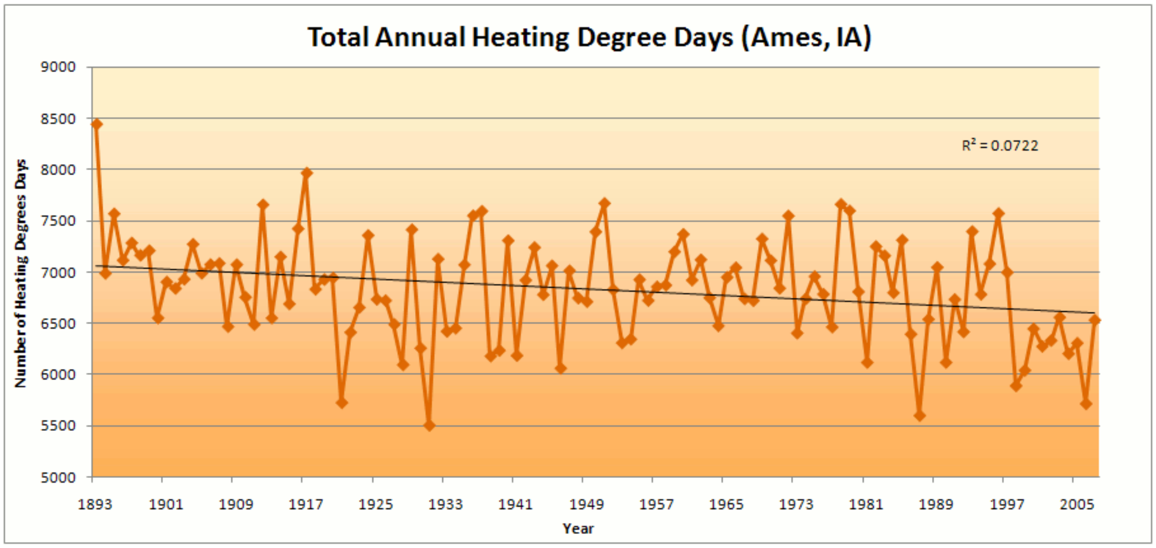


Figure 6. Ames data

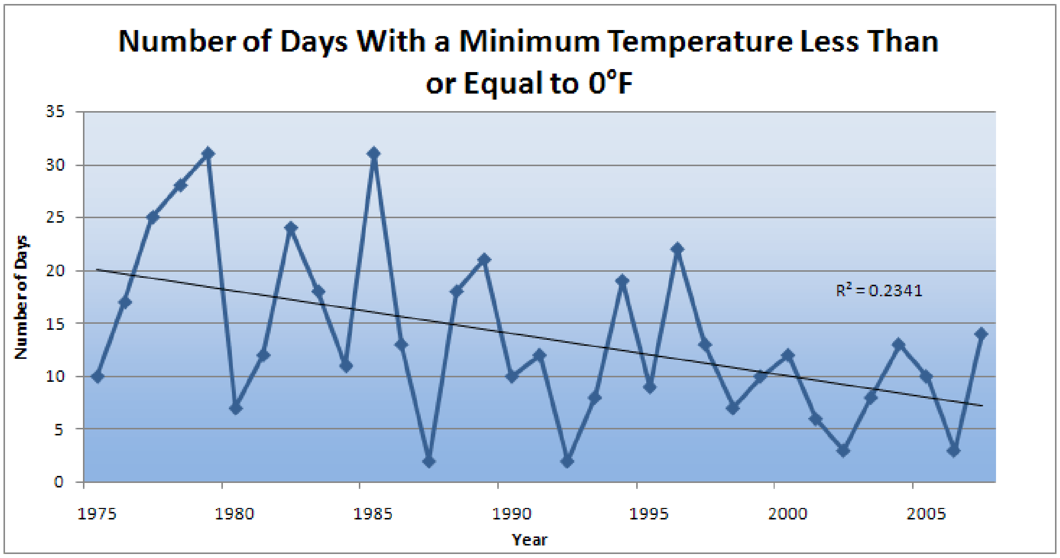


Figure 7. Des Moines Airport data. Caution: these data might be influence by urban heat island effects due to growth to the north and west of the airport.

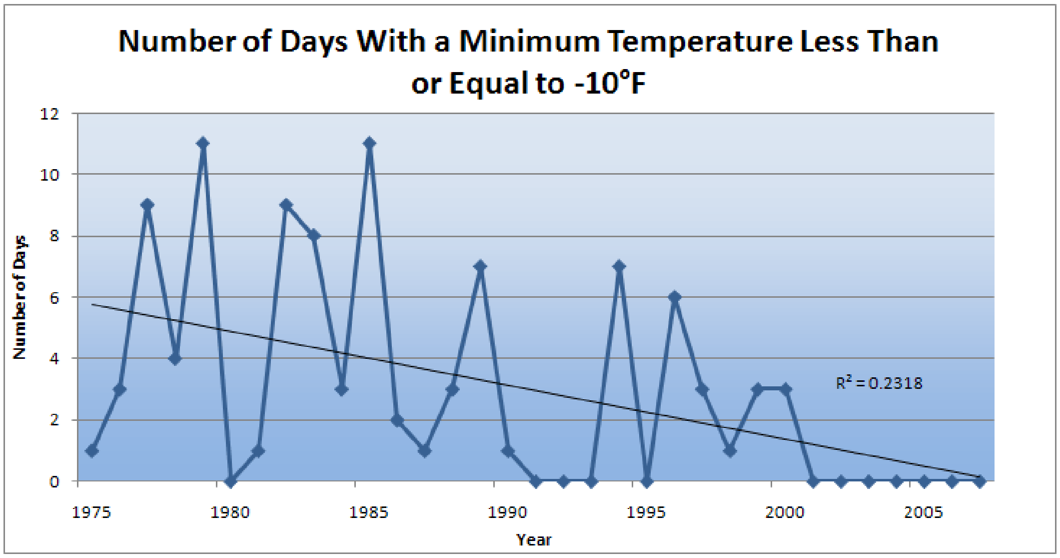


Figure 8. Des Moines Airport data. Caution: these data might be influence by urban heat island effects due to growth to the north and west of the airport.

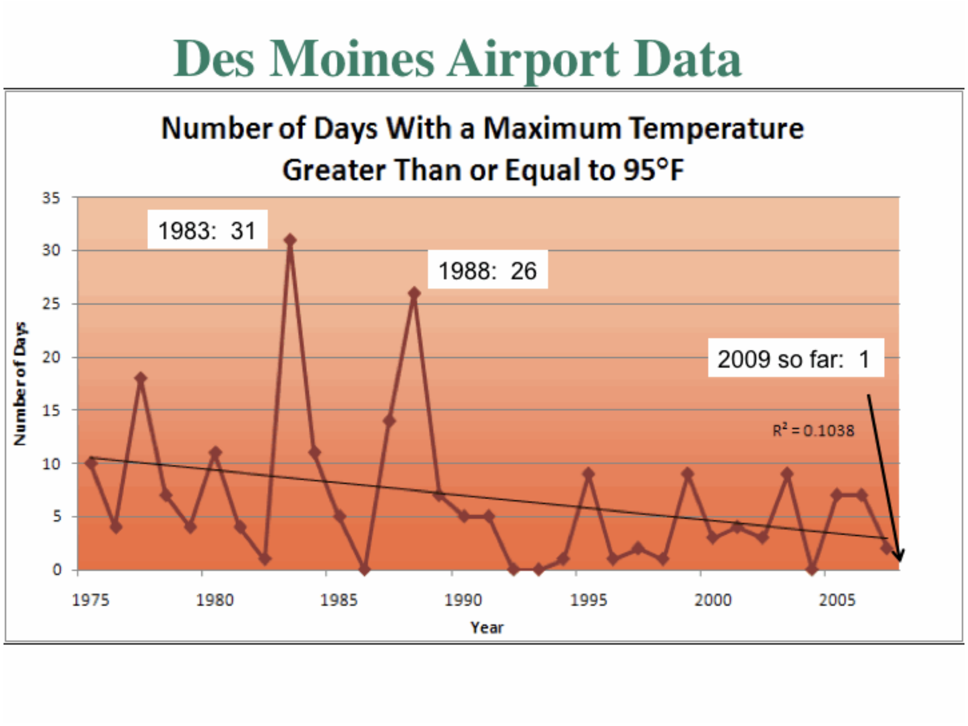


Figure 9. Des Moines data

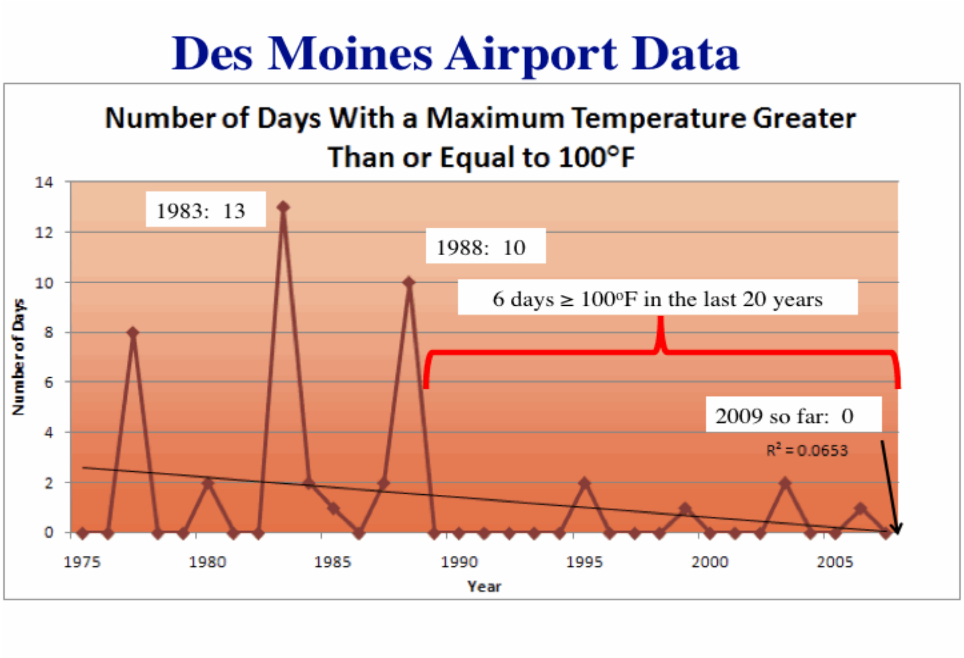


Figure 10. Des Moines data

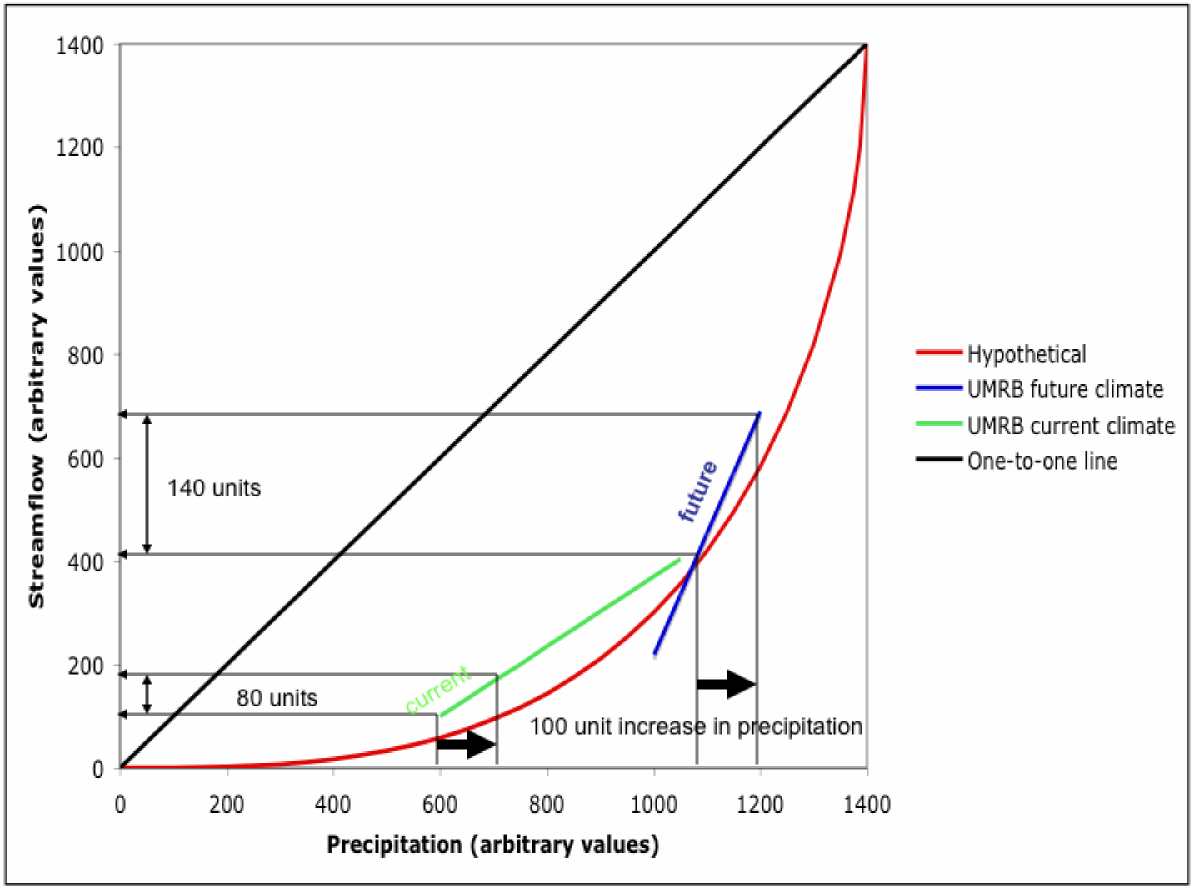


Figure 11. Adapted from data from the Upper Mississippi River Basin given in Jha et al. (2004).

APPENDIX 1.

Potential Iowa Vulnerabilities to Climate Change and Climate Variation

- Agriculture
  - Droughts and floods
  - Soil erosion
  - Accelerated weed growth
  - Soil carbon gain or loss
  - Commodity crops
    - Frost-free days
    - Last spring frost, first fall frost
    - Intensive heat during pollination
    - Pests and pathogens
    - Fungus, molds, toxins
    - Soils compaction
    - Water logging of soils
    - Fall crop dry-down
    - Harvest conditions
    - Hail
  - Energy crops
  - Specialty crops
  - Animal agriculture
    - Milk and egg production
    - Breeding success
    - Weight gains in meat animals
    - Animal health (heat, freezing precipitation)
    - Disease
  - Agricultural soil drainage
  - Pests and pathogens
    - More favorable conditions due to higher humidity and more leaf wetness
    - More overwintering due to more mild winter temperatures
  - Impact of wind farms on crops

- Water
  - Lakes and streams
    - Water quantity
    - Water quality
    - Recreation impacts
    - Aquatic ecosystems
  - Streamflow, major rivers
    - Transportation disruption
    - Flooding
      - Increased installation of drainage tile changes peak flow

        - Ecosystem resilience
    - Reservoirs
        - Managing water levels
            - More extreme precipitation events
            - Increased installation of drainage tile changes inflow rates
        - Siltation
    - Rural and urban water supplies
        - Quantity
        - Quality

Human Health
- Heat waves
- Disease vectors
- Hazard mitigation (health effects of floods)
- Molds
    - more groundwater and wet basements
    - higher ambient dew point temperatures

Ecosystems
- Functioning
- Invasive species
- Ecosystem services

Energy Production and consumption
- Wind power resource availability
- Solar power resource availability
- Biomass
- Energy demand

Infrastructure
- Roads, bridges
- Building codes

Communities
- Planning (flood plain, energy conservation)
- Water systems