Homeland Security

NATIONAL PROTECTION AND PROGRAMS DIRECTORATE

OFFICE OF CYBER AND INFRASTRUCTURE ANALYSIS

INFRASTRUCTURE RISK ASSESSMENT

POTENTIAL IMPACTS OF CLIMATE CHANGE ON INFRASTRUCTURE IN THE PLATTE RIVER BASIN

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INTRODUCTION

The Department of Homeland Security's Office of Cyber and Infrastructure and Analysis (DHS/OCIA)[1] manages the advanced modeling, simulation, and analysis capabilities of the National Infrastructure Simulation and Analysis Center (NISAC) in support of the DHS critical infrastructure security and resilience mission.

Climatic fluctuations, such as drought or floods, have always presented challenges to the management of water utilities. In response to these challenges, many utilities conduct safe yield studies that evaluate the long-term sustainability of their freshwater resources. Many of these efforts are based on time series analyses of long-term hydrologic data such as precipitation and stream gauge data. Climate change may change hydrologic conditions to such an extent that the existing precipitation and gauge data is no longer representative of the functioning of the hydrologic system, thereby diminishing the value of these data for long-term response planning.

Climate change has the potential to impact operations of many of the nation's water supply systems. Projections suggest increasing temperatures and associated evapotranspiration, altered precipitation patterns, and more intense and frequent storms or drought.[2] Of particular interest is a study on the effect of climate change on the frequency and intensity of droughts over the next century, assessed by applying Standardized Precipitation Indices and the Palmer Drought Severity Index to the full suite of 22 International Panel on Climate Change (IPCC) Global Climate Models (GCMs) for three emissions scenarios.[3] The IPCC GCM scenario results indicate an increase in the number of drought months across most of the Continental United States, with some of the most significant changes occurring in regions already experiencing limited water availability (Figure 1) and rapid demand growth due to increased population and agricultural water use.

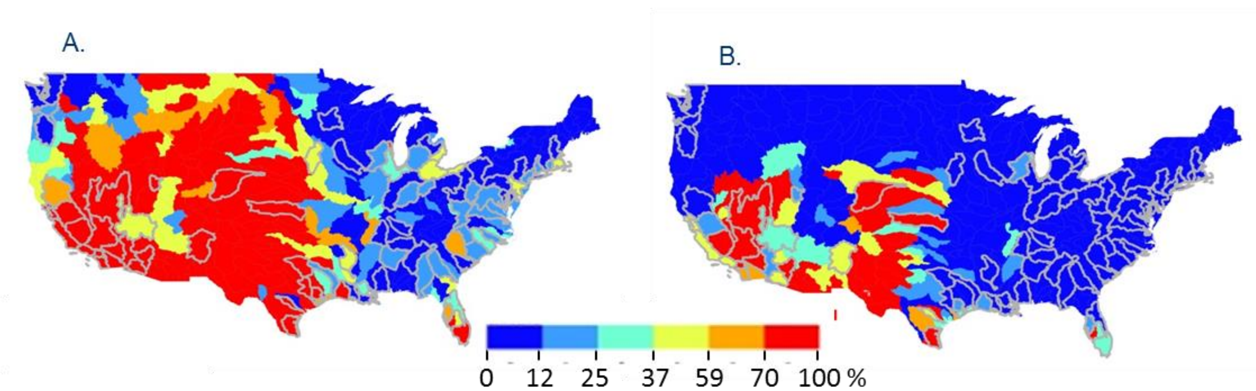

FIGURE 1—WATER AVAILABILITY IN THE UNITED STATES: A. SURFACE WATER; B. GROUNDWATER (ESTIMATED ANNUAL DEMAND AS A PERCENT OF ESTIMATED ANNUAL BASE FLOW).[4]

A few studies from 2010-2012 considered how such changes in climate might affect water supply. One such study by Roy, et al. considered impacts across the conterminous United States at the county level.[5] That analysis involved developing a water supply sustainability risk index that takes into account attributes such as degree of development of renewable water supply, susceptibility to drought, growth in water withdrawal, increased need for storage, and groundwater use. The analysis found that 70 percent of U.S. counties could face climate-related risks for two or more of the water supply attributes by 2050; more than 400 of those counties had four or more attributes at risk. The majority of Platte River counties in Colorado and Nebraska face climate-related risks for three or more attributes. These at-risk counties match well with the limited water availability basins shown in Figure 1.

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[1] In February 2014, NPPD created the Office of Cyber and Infrastructure Analysis by integrating analytic resources from across NPPD including the Homeland Infrastructure Threat and Risk Analysis Center (HITRAC) and the National Infrastructure Simulation and Analysis Center (NISAC).
[2] U.S. Global Change Research Program, "Third National Climate Assessment," http://www.globalchange.gov/what-we-do/assessment/draft-report-information, accessed April 2013.
[3] Strzepek, K., G. Yohe, J. Neumann, and B. Boehlert. "Characterizing changes in drought risk for the United States from climate change," Environmental Research Letters 5(044012)(2010): p. 9.
[4] Source: Sandia National Laboratories.
[5] Roy, S.B., L. Chen, E.H. Girvetz, E.P. Maurer, W.B. Mills, and T.M. Grieb, 2012. Projecting water withdrawal and supply for future decades in the U.S. under climate change scenarios. Environmental Science and Technology, 2012, 46, pp. 2545-2556.

Regional studies of climate change impacts have been performed, including a 2012 Bureau of Reclamation study of the Colorado River basin.[6] The 2012 study defined current and future water supply and demand imbalances in both the Colorado River basin and the adjacent areas of other states that will receive Colorado River water through 2060. Further, the study was intended to develop and analyze adaptation and mitigation strategies to resolve those imbalances. Comparing the median of water supply projections with the median of the water demand projections in the study area, the long-term projected imbalance for Colorado River water supply is about 3.2 million Acre-Feet per year by 2060.

PROBLEM STATEMENT

OCIA's analysis of the Platte River basin evaluates how climate impacts water supplies and other critical infrastructures and identifies potential adaptations to reduce the risks.

To study the effects of climate on water supply in the Platte River basin, it is necessary first to quantify the projected changes in average annual temperatures and precipitation. Composite IPCC model results show an increase of 4 to 8 degrees Fahrenheit (Figure 2) for the Platte River basin based on low and high carbon dioxide (CO2) emission scenarios. The results are derived from comparison of historical averages (1971-1999) to IPCC projected averages (2070-2099). The most pronounced precipitation change in the study region occurs in the high emission case (Figure 3); results indicate greater precipitation in winter and spring and lower precipitation in summer. The low emission scenario results indicate a slight increase in winter precipitation with little change for the other seasons. IPCC model results indicate greater variability in precipitation in the next 20 to 30 years. A detailed study of water supply indicates that the Platte River basin will have an even greater supply shortage by 2060 than current projections due to less precipitation, greater temperatures, and higher evapotranspiration rates. This study also evaluates mitigation options, finding that brackish groundwater desalinization is the most cost-effective option to offset the approximately 670,000 Acre-Feet per year projected shortfall.

Climate data for Colorado show a consistent upward trend in the 10-year average annual mean temperature since 1970. The highest recorded annual average temperature occurred in the mid-1930s and was between 3 and 4 degrees Fahrenheit above the 1950-1999 average.[7] No trends are evident in the precipitation data over the period of 1977-2006, due in part to the variability from year-to-year.[8]

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[6] U.S. Bureau of Reclamation, "Colorado River Basin Water Supply and Demand Study, December 2012," http://www.usbr.gov/WaterSMART/bsp/docs/finalreport/LowerRioGrande/LowerRioGrandeBasinStudy.pdf, accessed December 18, 2013, http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html, accessed April 2013.

[7] Ray, A.J., J.J. Barsugli, K.B. Averyt, K. Wolther, M. Hoerling, N. Doesken, B. Udall, and R. Webb, "Climate Change in Colorado," Colorado Water Conservation Board (2008).

[8] Ibid.

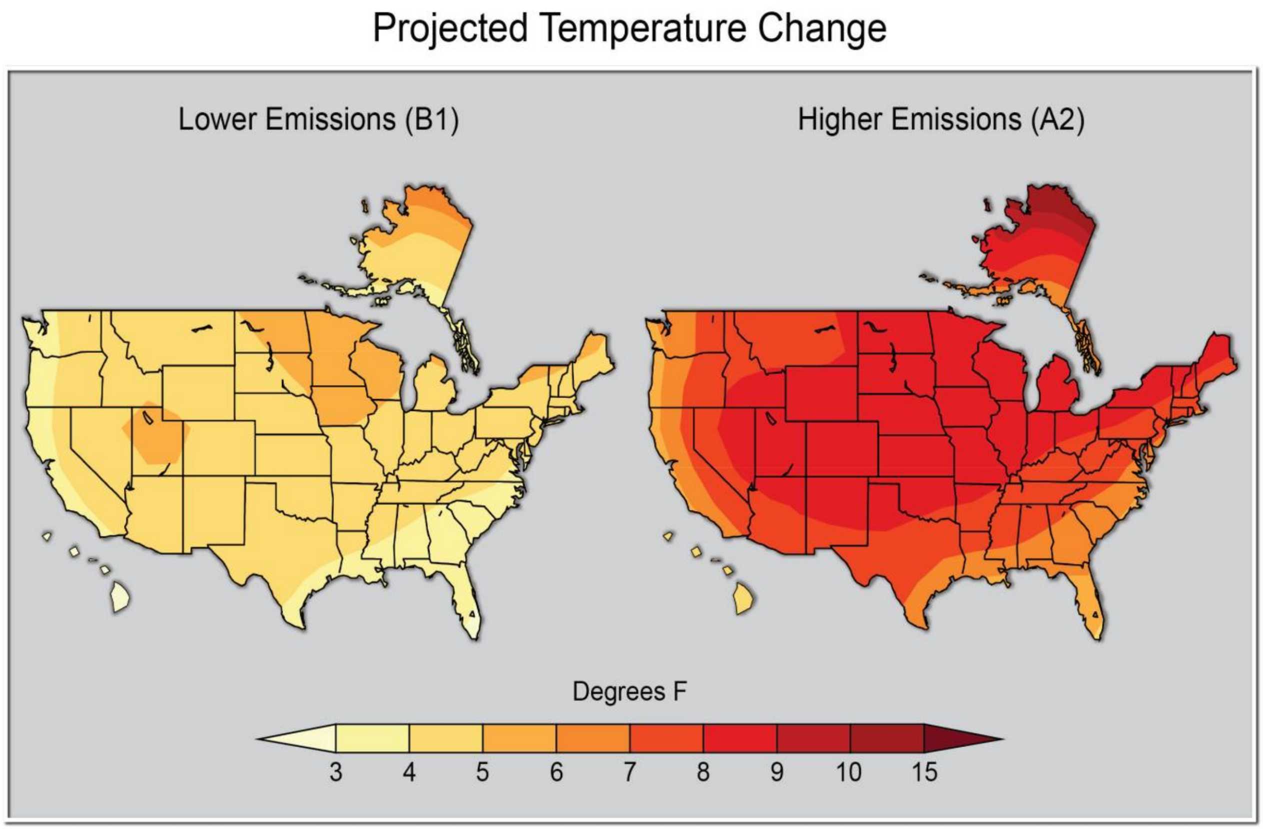

FIGURE 2—PROJECTED CHANGE IN AVERAGE SURFACE AIR TEMPERATURE (2070-2099) RELATIVE TO RECENT AVERAGES (1971-1999): THE LOWER EMISSIONS SCENARIO (B1) ASSUMES SUBSTANTIAL REDUCTIONS IN HEAT-TRAPPING GASES DUE TO LOWER EMISSIONS; THE HIGHER EMISSIONS SCENARIO (A2) ASSUMES CONTINUED INCREASES IN GLOBAL EMISSIONS.[9]

[9] Source: National Climate Assessment and Development Advisory Committee (NCADAC), 2013, 2013 National Climate Assessment (Draft for Public Comment v. 11 Jan 2013), http://ncadac.globalchange.gov, accessed January 15, 2014.

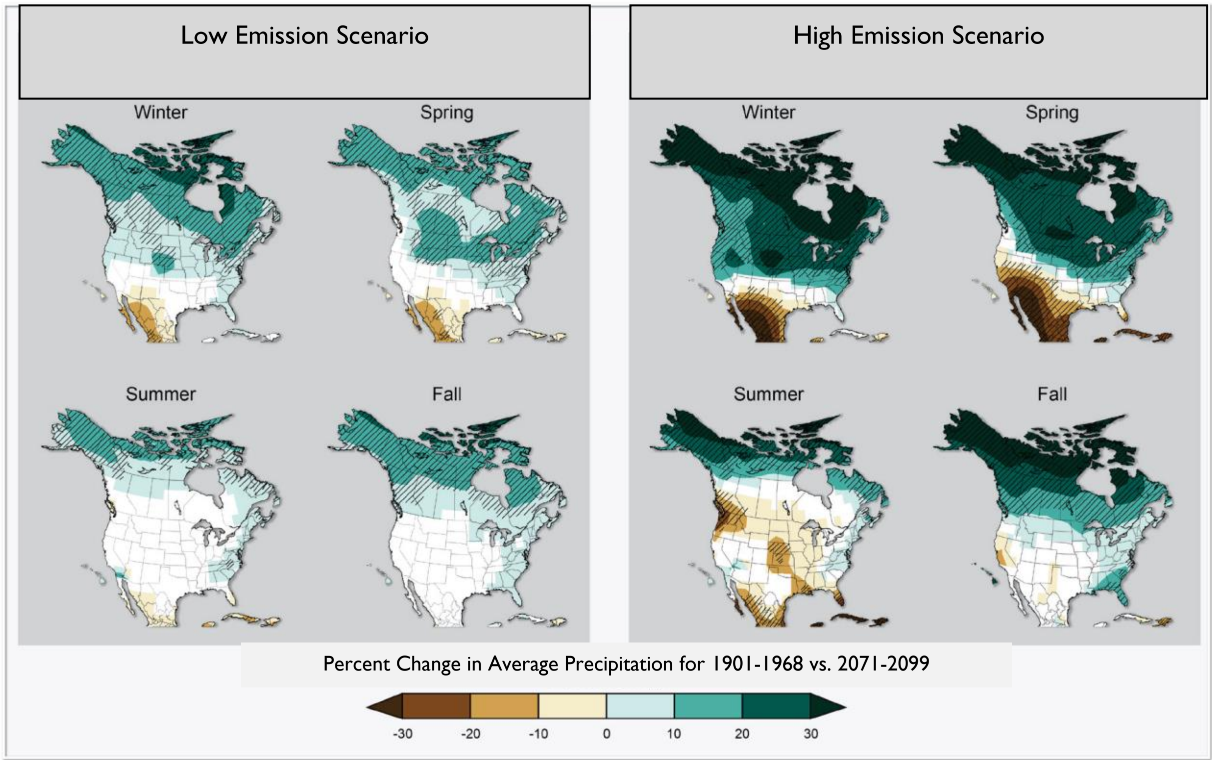

FIGURE 3—COUPLED MODEL INTERCOMPARISION PROJECT PHASE 2 (CMIP5) MODELS PROJECTED PERCENT CHANGE IN AVERAGE PRECIPITATION FOR AVERAGE FOR 1901-1968 VS. 2071-2099[10]

PROJECT METHODOLOGY

The first step of this analysis is a literature review identifying regional hydrologic data, hydrologic studies, water conditions, state water management plans, water allocations, regional climate studies, climate projections, and potential climate-related water supply issues. The results of the literature review are provided as an annotated bibliography in Appendix A.

Two climate change scenarios—extended drought and frequent large-magnitude flooding—are used to identify potential population, infrastructure, and economic impacts, as well as possible regional risk-mitigation strategies.

OCIA used existing studies (discussed above) and current information to provide a basin-wide, qualitative analysis of the potential impacts due to changes in flooding and extended drought. OCIA analyzes scenario impacts to water supply (major water supply processes shown in green in Figure 4), other infrastructure assets, and the regional economy. Water supply disruption impacts were evaluated across multiple sectors including infrastructure, residential, commercial, industrial, agricultural, and environmental water use. Spatial data analysis identifies infrastructure assets in the scenario risk zones.

Standard economic accounting methods are not sufficient for analyzing drought impacts on the regional economy. An alternative methodology, which has general applicability for estimating economic impacts of long-term stresses, is developed as part of this analysis. Further economic analysis issues are identified for flooding impacts, and improvements to the current analytic approach are discussed.

[10] Source: National Climate Assessment and Development Advisory Committee (NCADAC), 2013, 2013 National Climate Assessment (Draft for Public Comment v. 11 Jan 2013), http://ncadac.globalchange.gov, accessed January 15, 2014. (Note that a more recent historical comparison consistent with other scenarios will be provided in the final NCA report.)

The final step in this analysis is to identify examples of potential risk mitigation strategies and their implications. The risk mitigation strategies focus on water management options for sustaining and growing economic activities in the event of more frequent drought and flooding.

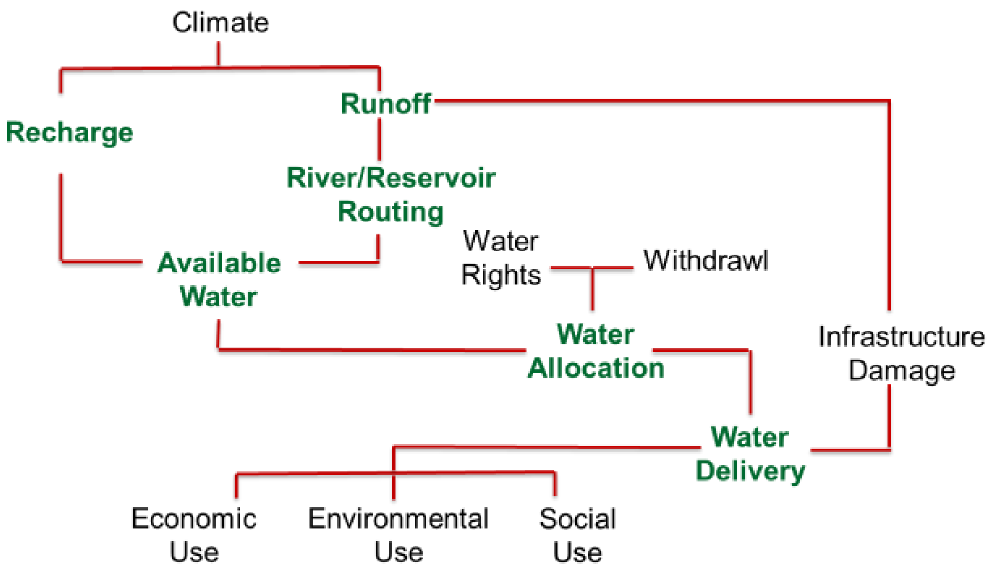

FIGURE 4—WATER SUPPLY PROCESSES[11]

PLATTE RIVER BASIN OVERVIEW

The Platte River Basin is located in northeastern Colorado, southeastern Wyoming, and central Nebraska (see Figure 5) and includes the areas located in Hydrologic Unit Code (HUC) 1018 (North Platte), 1019 (South Platte), and 1020 (Platte). The headwaters of the North and South Platte Rivers are located in the Rocky Mountains with the Platte River terminating where it feeds into the Missouri River in the plains of Nebraska.

[11] Source: Sandia National Laboratories.

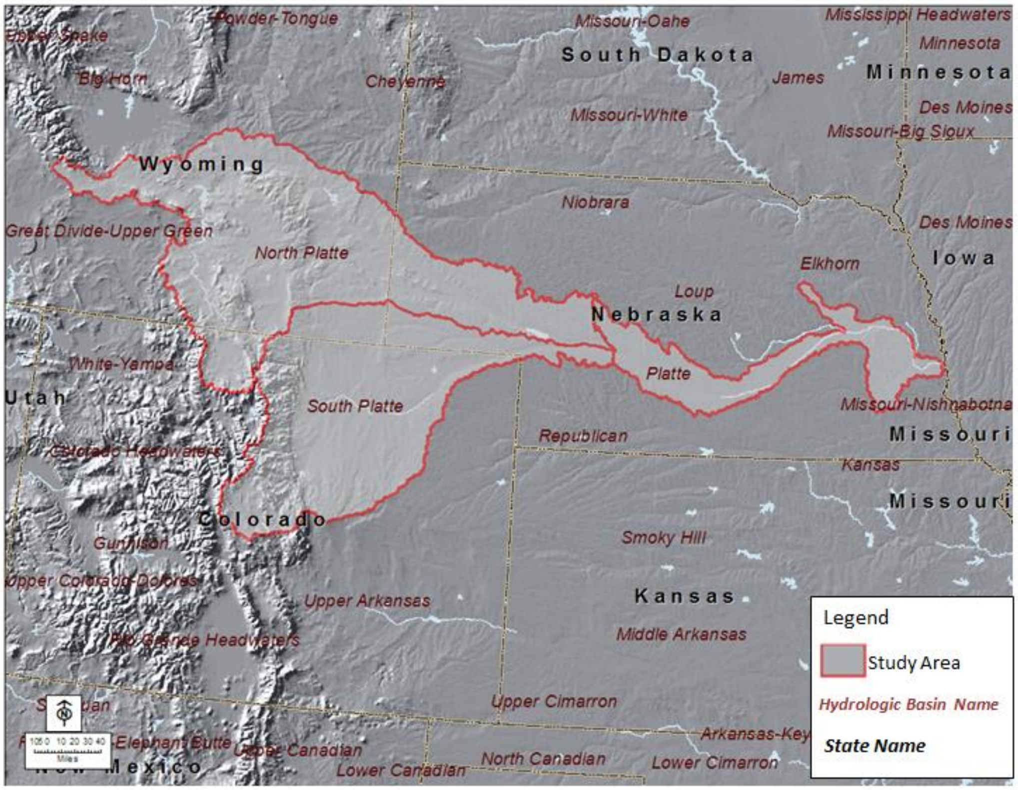

FIGURE 5—PLATTE RIVER BASIN IN WYOMING, COLORADO, AND NEBRASKA[12]

The study area does not include all the hydrologically connected regions (e.g., the Loup and Elkhorn basins are not included in the study area). Denver, Colorado is the most populous city in the study area. Agriculture, the main water consumer, is present throughout the basin, but is predominantly in Nebraska and three counties in Colorado (Figure 6). In areas where surface water rights are already fully appropriated, such as the Platte basin in Nebraska, it will be necessary to transfer those rights to support new or different uses of surface water.[13] Surface water use by type and State is summarized in Table 1. Irrigation is the primary water use in the basin, representing more than 80 percent of the annual total. Municipal and domestic use is approximately 15 percent, and industrial use is around 5 percent of the total surface water use in the Platte River basin. Roughly 71,000 Acre-Feet per year of water is consumed by thermoelectric generation associated with 8500 megawatt (MW) of capacity. An additional 657 MW of capacity is fueled by hydropower generation on Platte Basin streams. Groundwater is used throughout the basin, particularly for domestic and industrial supplies in Nebraska, where surface water is fully allocated.

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[12] Source: Sandia National Laboratories based on US Geological Survey Hydrologic Unit Code 4 (HUC 4 Regions) data.
[13] Nebraska Department of Natural Resources, "2013 Annual Evaluation of Availability of Hydrologically Connected Water Supplies: Determination of Fully Appropriated," www.nlcs1.nlc.state.ne.us/epubs/N1500/A005-2013.pdf, accessed January 15, 2014.

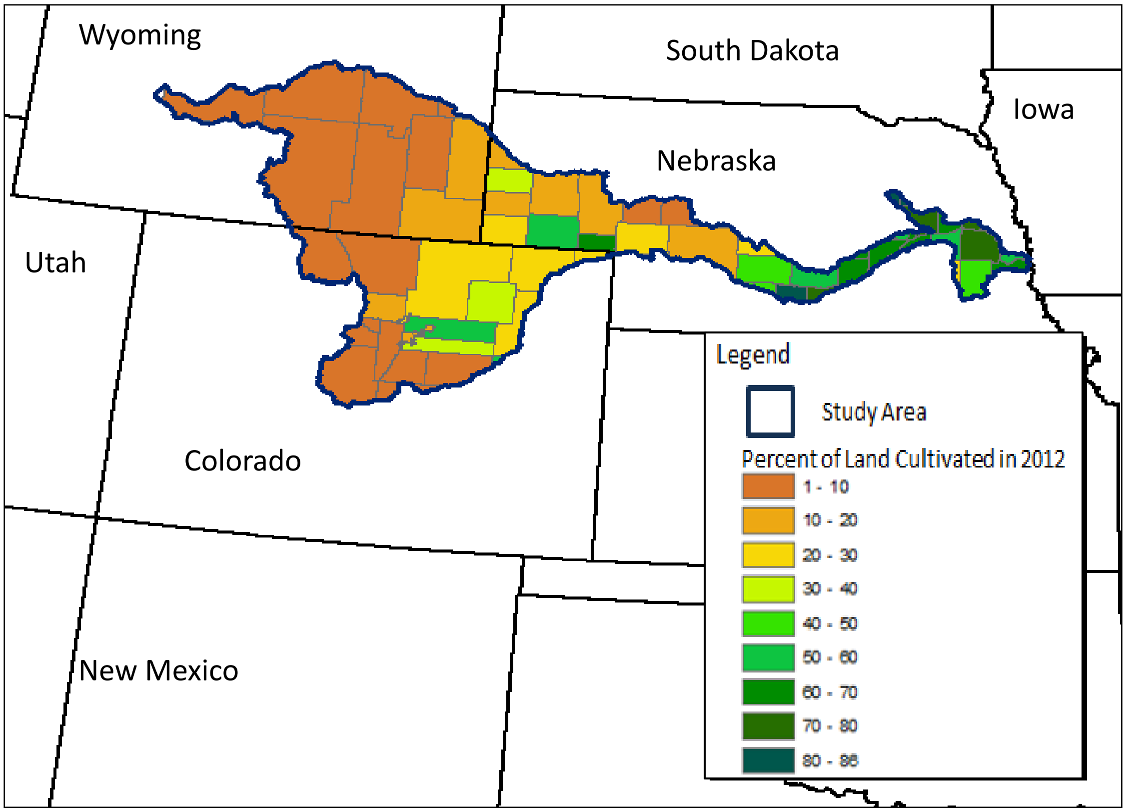

FIGURE 6—CULTIVATED LAND (PERCENT BY COUNTY) IN THE PLATTE RIVER BASIN[14]

TABLE 1—ESTIMATED AVERAGE ANNUAL SURFACE WATER USED IN THE PLATTE RIVER BASIN IN 2000[15,16,17]

Average Consumptive Water Use (Acre-Feet per year)				
Use	State			Total
	Colorado	Wyoming	Nebraska**	
Irrigation	2,942,400	549,807	727,023	4,219,230
Municipal and Domestic	772,900	2,1840	784	795,524
Industrial	*	131,344	62,374	193,718
Total	3,715,300	702,991	790,181	5,208,472

* Colorado combines Municipal & Industrial use.
** County data used to approximate basin level.

STATE WATER PLANS

Water resources are managed at the State level and water shortages create trans-jurisdictional boundary issues that are resolved in the courts. State water plans evaluate water allocations, project future demands, and provide summary data on water use and water issues. The plans, tailored to State needs, vary in content and the type of

[14] Source: Sandia National Laboratories based on data from USDA, "2007 Census of Agriculture," http://www.agcensus.usda.gov/Publications/2007/Full_Report, accessed January 15, 2014.
[15] USGS, 2001. Fresh surface-water use for Nebraska, by county, for year 2000, http://ne.water.usgs.gov/wudatasw.html, accessed December 29, 2013.
[16] Colorado Water Conservation Board, 2004. Statewide Water Supply Initiative, http://cwcbweblink.state.co.us/weblink/0/doc/144066/Electronic.aspx?searchid=2c16c041-d0b2-4ec5-ac42-8b95aa0c04e3, accessed January 15, 2014.
[17] Wyoming Water Development Commission, 2006. Platte River Basin Plan, http://waterplan.state.wy.us/plan/platte/platte-plan.html, accessed January 15, 2014.

information provided. Colorado's plan includes basin-level assessment of the impact of climate change and population growth on future demands and details regarding water permits spread across several reports.[18] Wyoming has a detailed plan for the Platte River basin that provides information on surface and groundwater permits for major water users, recreational uses, water quality by sub-basin, condition-dependent reservoir operation plans to maintain sufficient water for environmental use, and assessment of future water development potential at the sub-basin level.[19] Nebraska's annual water supply report focuses on water allocation issues and constraints and the State hazard mitigation plan includes drought and flood risk mitigation actions.[20,21]

REGIONAL CLIMATE STUDIES

Several studies used IPCC climate change projections to estimate changes to streamflow, aquifer recharge, water quality, and impacts to water deliveries. No single study has investigated the entire basin; rather each study addresses individual sub-basins and a specific aspect of the climate change picture.

The South Platte basin has received the most attention, undoubtedly because of its relationship to the Denver metropolitan area. The U.S. Environmental Protection Agency (EPA) studied the South Platte as part of an investigation of 20 large U.S. watersheds to characterize the sensitivity of streamflow, nutrient (nitrogen and phosphorus) loading, and sediment loading to a range of plausible mid-21st century climate change and urban development scenarios.[22] The EPA conducted watershed simulations using the Soil Water Assessment Tool and Hydrologic Simulation Program models. Scenarios of future climate change were developed based on statistically and dynamically downscaled climate model simulations representative of the period between 2041 and 2070.

Across the six different model and scenario pairs considered, results suggest:

- A 10 percent decrease in streamflow volume;
- A slight increase in precipitation intensity;
- A 5 percent reduction in the 7-day low flow;
- A 29 percent increase in the 100-year peak flow;
- A 13-day shift in the hydrograph toward earlier season runoff; and
- An accompanying slight improvement in total dissolved solids (TDS), phosphorous loading, and nitrogen loading.

In a similarly structured 2007 study, "Response of streamflow to weather variability under climate change in the Colorado Rockies," flows of the South Platte were projected to decrease by up to 34 percent relative to current by the year 2090.[23] A climate-driven water resource systems model of the southwestern United States was used to explore the implications of growth, extended drought, and climate warming on the allocation of water among competing uses.[24] One of the basins studied was the South Platte. The Water Evaluation and Planning model platform was used to project climate impact to 2050. Rather than climate simulations, future projections were constructed by a re-sequencing of historic data from 1948 to 2010 that result in much of the Southwest in persistent drought throughout the simulation with periods of severe drought. The re-sequenced climate series

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18 There are multiple documents related to Colorado water planning (for example Mayer, P. and S. Wytinck 2007. Colorado Drought and Water Supply Update 2007; Colorado Water Conservation Board: Ray, A., J. Barsugli, K. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall, and R. Webb, 2008, Climate Change in Colorado, CU-NOAA Western Water Assessment for the Colorado Water Conservation Board); Colorado Water Conservation Board, 2007, Colorado's Water Supply Future Statewide Water Supply Initiative—Phase 2).

19 Wyoming Water Development Commission, Platte River Basin Plan Final Report, http://waterplan.state.wy.us/plan/platte/platte-plan.html, accessed January 15, 2014.

20 Nebraska Department of Natural Resources, 2013 Annual Evaluation of Availability of Hydrologically Connected Water Supplies: Determination of Fully Appropriated. Nebraska Department of Natural Resources, www.nlcs1.nlc.state.ne.us/epubs/N1500/A005-2013.pdf, accessed January 15, 2014.

21 Nebraska Emergency Management Agency, State of Nebraska Hazard Mitigation Plan, http://www.nema.ne.gov/pdf/hazmitplan.pdf, accessed October 27, 2014.

22 U.S. EPA (Environmental Protection Agency), Watershed modeling to assess the sensitivity of streamflow, nutrient, and sediment loads to potential climate change and urban development in 20 U.S. watersheds, National Center for Environmental Assessment, Washington, D.C.: EPA/600/R-12/058F. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=256912, accessed January 15, 2014.

23 Boosik, K., and J. A. Ramirez. "Response of streamflow to weather variability under climate change in the Colorado Rockies," Journal of Hydrologic Engineering 12(1)(2007): pp. 63-72.

24 Yates, D., J. Meldrum, and K. Averyt. "The influence of future electricity mix alternatives on southwestern US water resources," Environmental Research Letters, (2013): p. 8.

represents a dry epoch relative to the historical record based on tree-ring data. Results suggest an approximately 4 degrees Fahrenheit increase in temperature coupled with a 15 percent reduction in streamflow. Reductions were mapped to potential deliveries to municipal, thermoelectric, and agricultural uses. Projected impacts were to municipal outdoor water use due to mandated lawn-watering restrictions, with the remaining impacts likely to be borne by irrigated agriculture. With this assumption, several periods are identified during which deliveries were reduced by roughly 17 percent of the historical average under non-drought conditions.

While the South Platte basin has been well studied, the only identified North Platte basin study, from 2011, used the variable infiltration capacity (VIC) hydrologic model.[25] The assessment used multiple models and multiple scenarios from the World Climate Research Programme's database. The simulated streamflows suggest the possibility of increased annual streamflow for this region through 2100: a 5.8 percent increase in annual streamflow (ensemble average of simulated streamflow projections). In the simulations, the wet months (November-April) become wetter and the summer months (June-August) become drier.

No studies were identified that focus on the Nebraska reach of the Platte basin. Groundwater becomes the primary water source in the eastern Platte basin. The principle aquifer is the High Plains or Ogallala aquifer. Significant groundwater withdrawals began in 1950 along the Platte River in Colorado and Nebraska.[26] Withdrawals in the western portion of the Platte basin are noted to be causing significant declines in groundwater levels. Given the importance of this aquifer, the potential impact of climate change on recharge rate out to 2050 was investigated.[27] The Crosbie et al. study used 16 global climate models and three global warming scenarios. Groundwater recharge was modeled using the Soil-Vegetation-Atmosphere-Transfer model for a variety of soil and vegetation types representative of the High Plains. The median projection under a 2050 climate indicates increased recharge in the Northern High Plains of 8 percent. While this is an encouraging result, recharge accounts for only about 15 percent of current pumping; thus structural changes in irrigation practices will be required to achieve sustainable agricultural production in western reaches of the aquifer.[28]

REGIONAL WATER SUPPLY AND DEMAND DATA

The Platte River is characterized by significant gradients in terms of headwater to prairie and from west to east. Precipitation exceeds 30 inches per year in the headwaters of Colorado and Wyoming, which quickly decreases to less than 15 inches per year in the lowland prairies. Continuing east, precipitation once again increases to approximately 30 inches per year. Streamflow increases from west to east as drainage area increases (Table 2). Two principal aquifers are associated with the Platte River; the Denver basin in Colorado and the High Plains aquifer that dominates the central and eastern portion of the Platte River. The character of water use also transitions from west to east, with extensive municipal use in the South Platte associated with Denver that transitions to irrigated agriculture throughout the remainder of the river basin.

TABLE 2—ANNUAL STREAM FLOW FOR THE PLATTE RIVER

River Reach	Average Annual Discharge (cfs*)
North Platte	829.57
South Platte	412.12
Middle Platte	1772.98
Lower Platte	6977.17
*Cubic feet per second.	

25 Acharya, A., P.C. Piechota, and G. Tootle, "Quantitative assessment of climate change impacts on the hydrology of the North Platte River watershed, Wyoming," Journal of Hydrologic Engineering, 17(10) (2011):pp. 1071-1083.
26 USGCRP, Regional Climate Impacts: Great Plains, 2009 National Climate Assessment.
27 Crosbie, R. S., B. R. Scanlon, F. S. Mpelasoka, R. C. Reedy, J. B. Gates, and L. Zhang, "Potential climate change effects on groundwater recharge in the High Plains Aquifer," Water Resources Research, 49(7) (2013): p 3936-3951.
28 Steward, D.R., P.J. Bruss, X. Yang, S.A. Staggenborg, S.M. Welch, and M.D. Apley, Tapping unsustainable groundwater stores for agricultural production in the High Plains Aquifer of Kansas, projections to 2110, Proceedings of the National Academy of Sciences. September 10, 2013; 110(37).

There are 15 inter-basin transfers of water into the South Platte basin. The three largest inter-basin transfers, each greater than 50,000 Acre-Feet per year, are from Adams, Moffat, and Roberts, to the Big Thompson River, Boulder Creek, and Bear Creek, respectively. These account for about 95 percent of the inter-basin transfers (383,000 Acre-Feet per year); they are largely designed to serve the rapidly growing Denver metropolitan area. While there are almost 1,000 reservoirs in the South Platte, total storage is limited, thus providing little opportunity for year-to-year carry over.

Figure 7, shows a map of the Platte River along with its key electric power infrastructure assets including hydroelectric and coal-fired generators that are dependent on water resources.

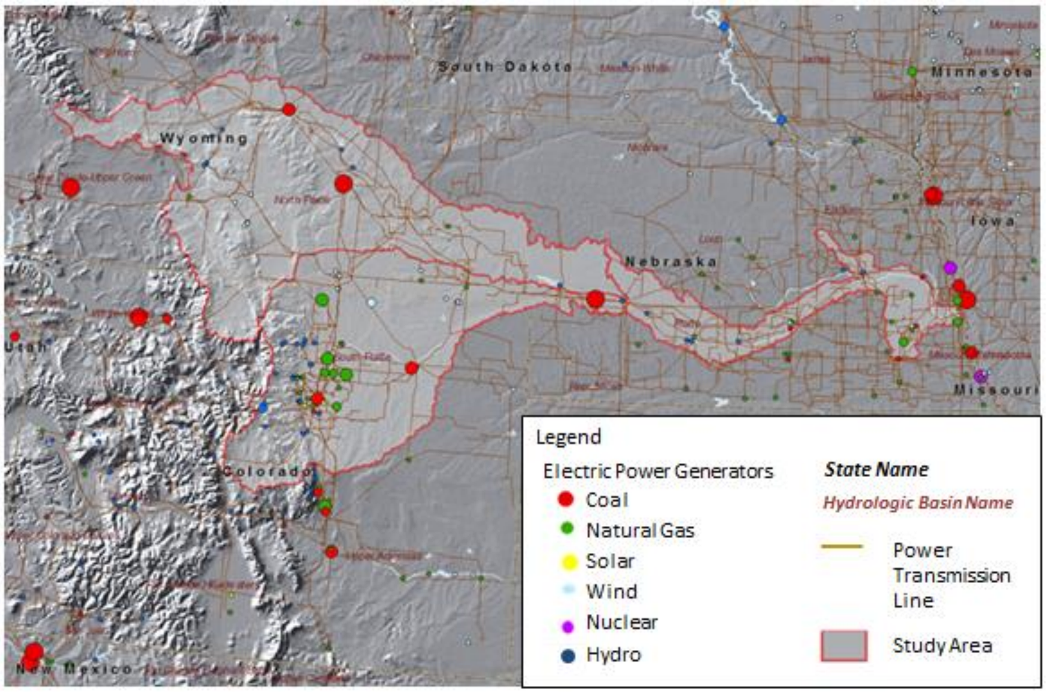

FIGURE 7—MAP OF THE PLATTE RIVER STUDY AREA SHOWING POWER GENERATORS AND TRANSMISSION LINES (GENERATOR DOT SIZE IS PROPORTIONAL TO INSTALLED CAPACITY)[29]

SCENARIO ANALYSES

Climate change will alter precipitation and temperature patterns, making prediction of water supply conditions more difficult and uncertain. Uncertainty affects planning and risk quantification; however, these changes can cause three types of issues for water supply: too much water, too little water, and changes in water quality (due to flooding, drought, and changes in water use). For this study, the potential impacts of increased climate variability in the next 30 years on infrastructure assets are evaluated using two general scenarios. The first scenario assumes the 500-year flood becomes the 100-year flood. The second scenario assumes multi-year droughts become more common. The drought of 2012 and extreme flooding event in 2013 in Boulder, Colorado, provide an example for future increased climate variability, illustrating how greater variability in precipitation could cause year-to-year or multi-year changes, from severe drought to extreme flooding and back again. Climate change threats are multi-hazard with uncertain magnitude and frequency.

INCREASED FREQUENCY OF FLOODING

The Federal Emergency Management Agency's (FEMA's) floodplain mapping in the region is incomplete as can be seen in the discontinuous nature of the 100-year floodplain in Figure 8. In the areas where the mapping is

[29] Source: Sandia National Laboratories based on HSIP Gold 2012 data.

complete, the 500-year floodplain is very similar in extent to the 100-year floodplain; however, there are some significant differences in a few urban areas within the region. Large areas of residential, commercial, and industrial land lie within the 500-year floodplain in northwest Denver, Colorado (Figure 9); Commerce City, Colorado (Figure 10); North Platte, Nebraska (Figure 11); Central City, Nebraska (Figure 12); Lexington, Nebraska (Figure 13); and Freemont, Nebraska (Figure 14).

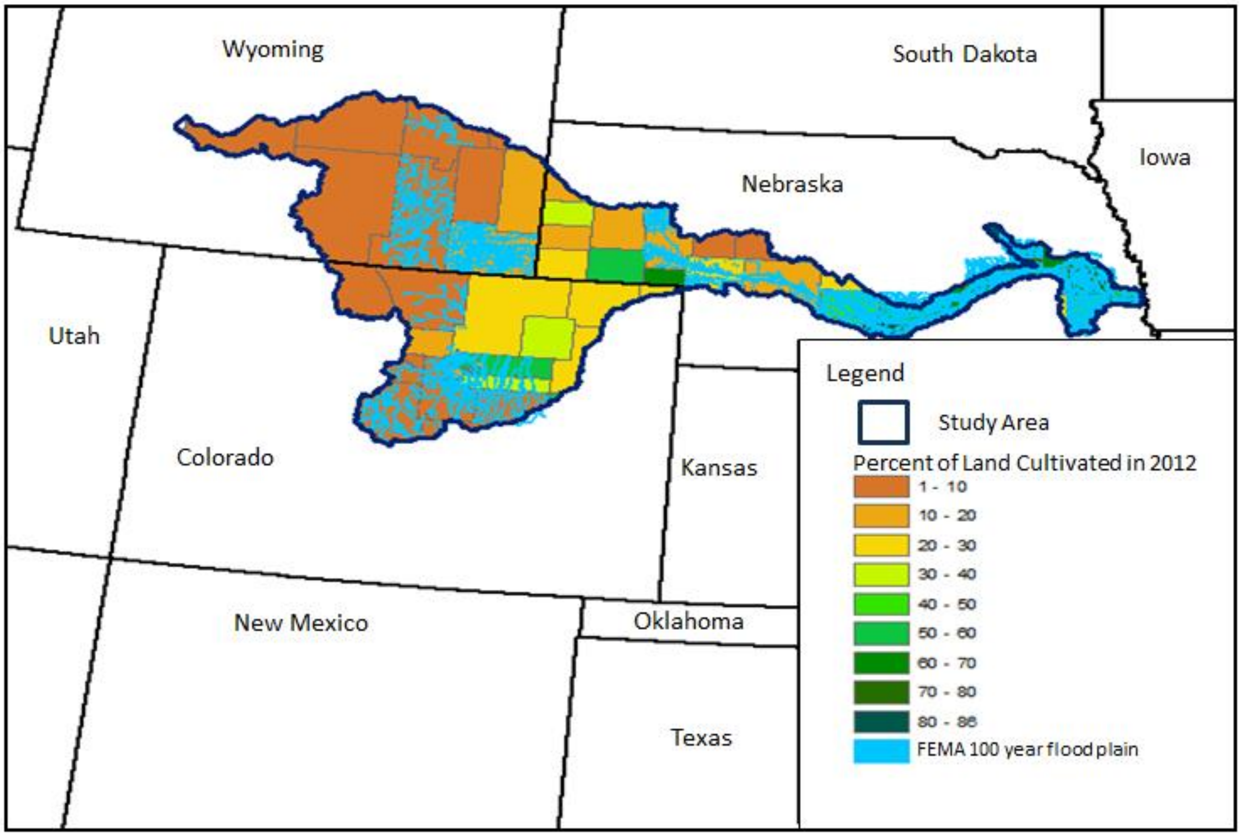

FIGURE 8—FEMA 100-YEAR FLOODPLAIN MAP SUPERIMPOSED ON MAP SHOWING PERCENT OF CULTIVATED LAND BY COUNTY IN THE PLATTE RIVER BASIN STUDY AREA[30]

[30] Source: Sandia National Laboratories based on data from USDA, "2007 Census of Agriculture," http://www.agcensus.usda.gov/Publications/2007/Full_Report, accessed January 15, 2014.

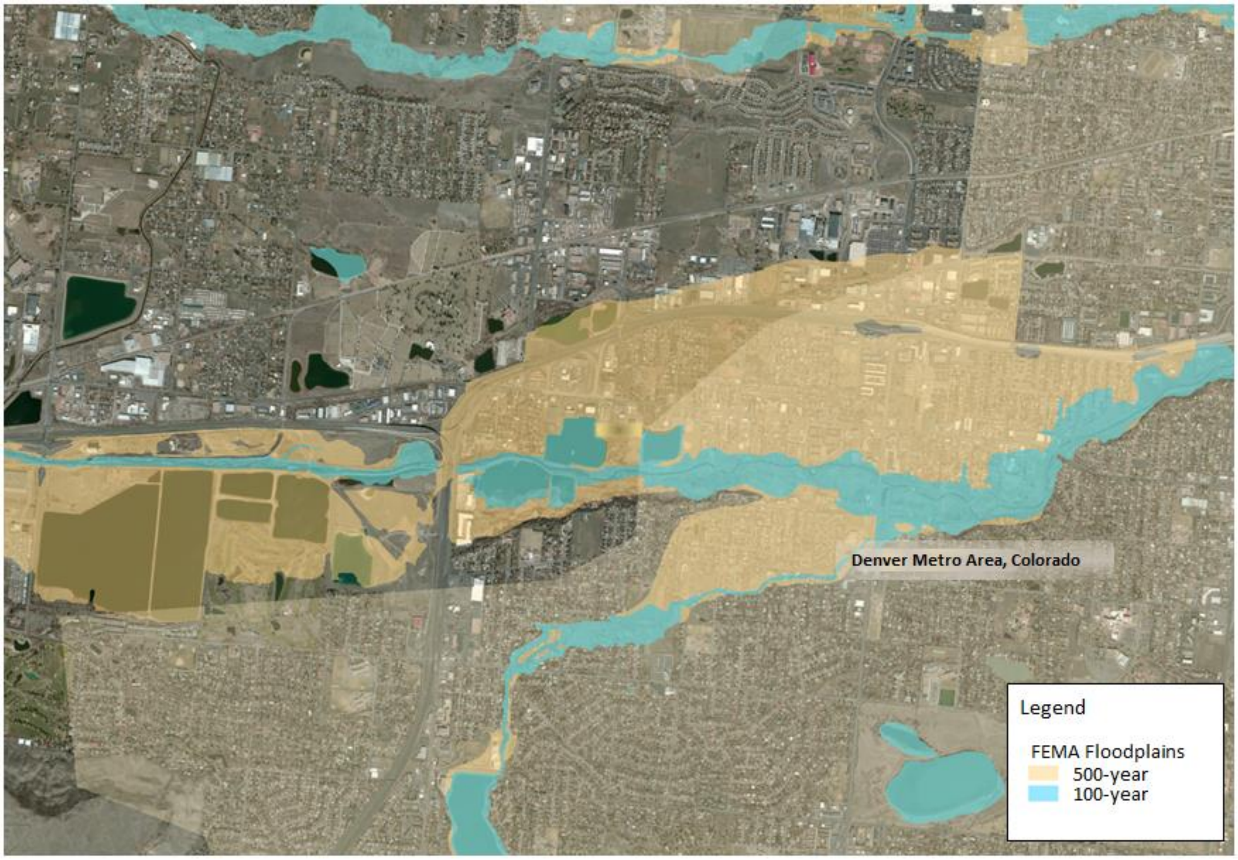

FIGURE 9—FEMA 500-YEAR AND 100-YEAR FLOODPLAIN IN AREAS IN NORTHWEST DENVER, COLORADO[31]

[31] Source: Sandia National Laboratories based on FEMA floodplain data.

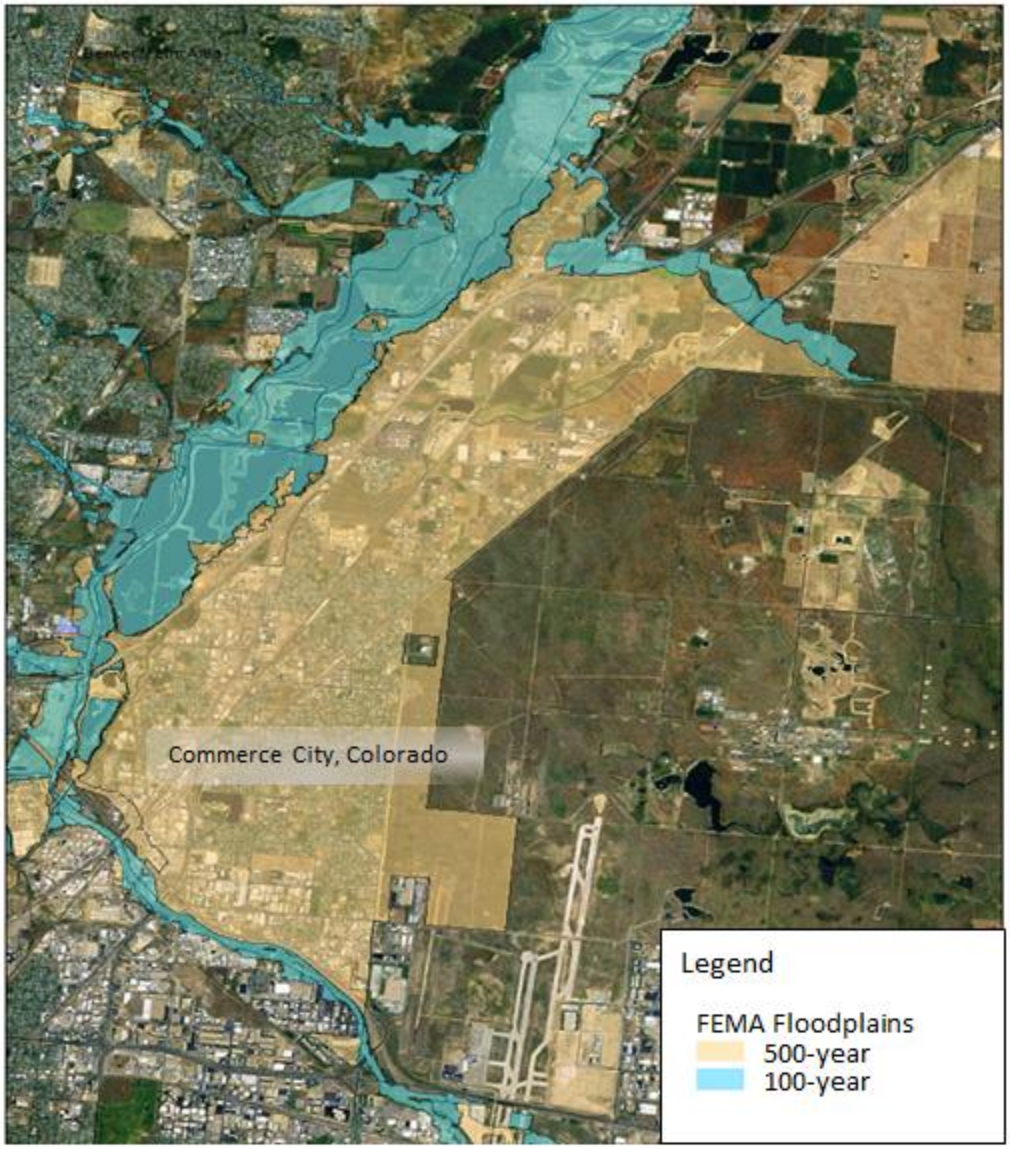

FIGURE 10—COMMERCE CITY, COLORADO, 100-YEAR AND 500-YEAR FLOODPLAINS[32]

[32] Source: Sandia National Laboratories based on FEMA floodplain data.

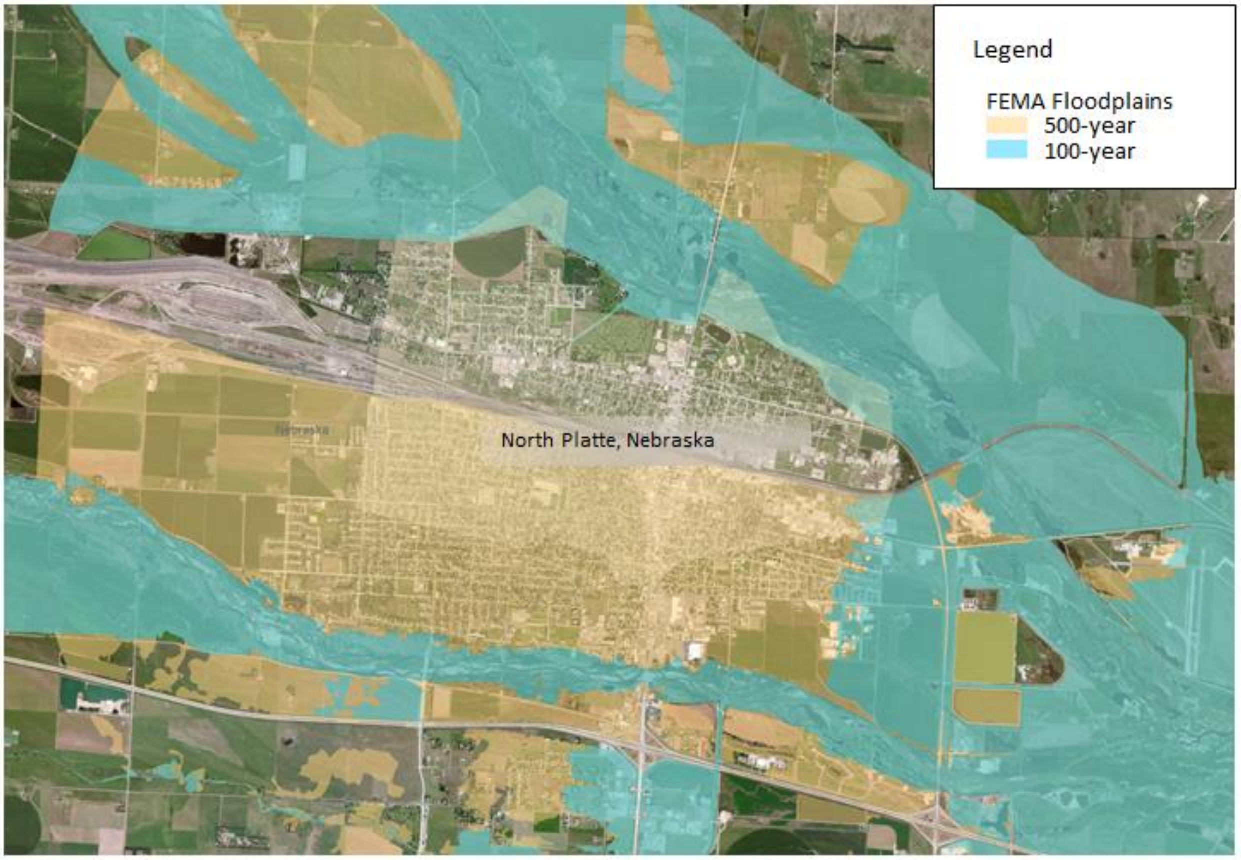

FIGURE 11—NORTH PLATTE, NEBRASKA, 100-YEAR AND 500-YEAR FLOODPLAINS[33]

[33] Source: Sandia National Laboratories based on FEMA floodplain data.

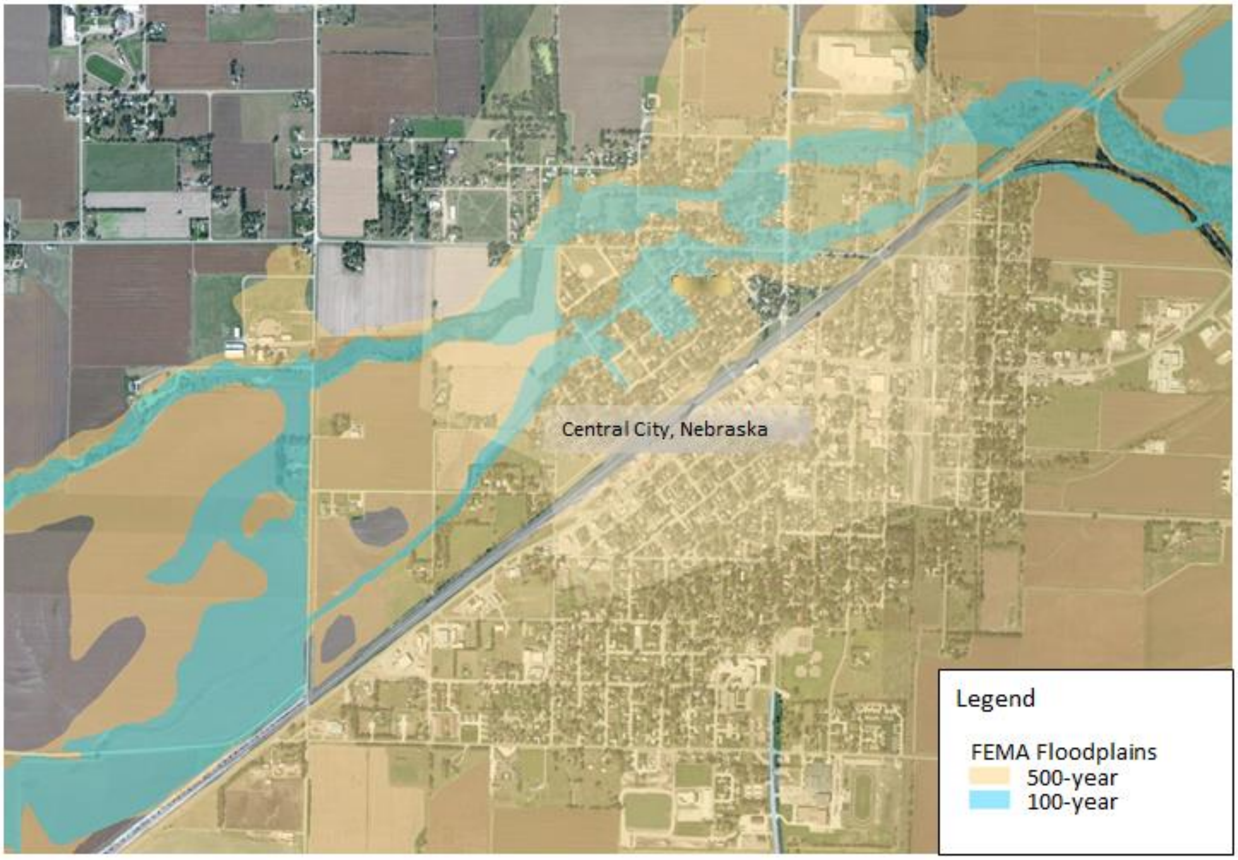

FIGURE 12—CENTRAL CITY, NEBRASKA, 100-YEAR AND 500-YEAR FLOODPLAINS[34]

[34] Source: Sandia National Laboratories based on FEMA floodplain data.

FIGURE 13—LEXINGTON, NEBRASKA, 100-YEAR AND 500-YEAR FLOODPLAINS[35]

[35] Source: Sandia National Laboratories based on FEMA floodplain data.

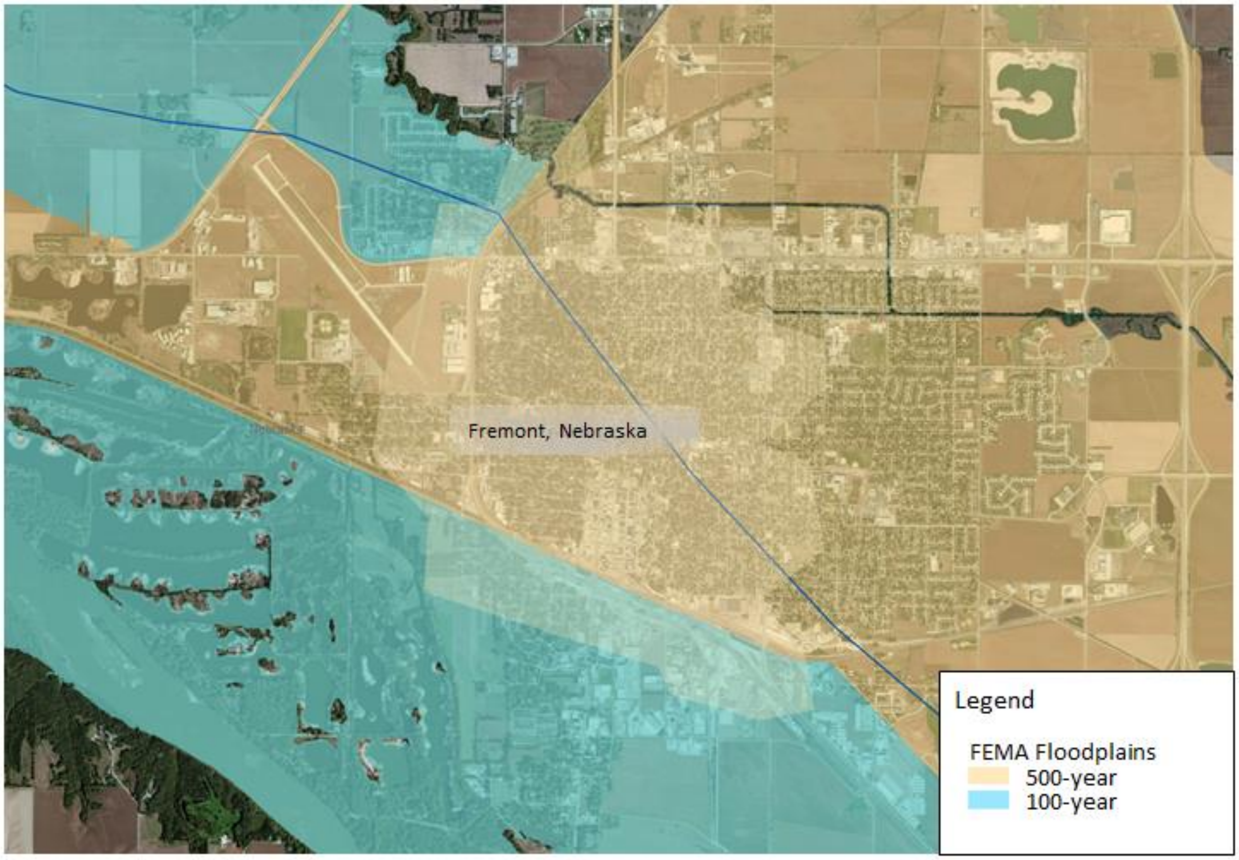

FIGURE 14—FREMONT, NEBRASKA, 100-YEAR AND 500-YEAR FLOODPLAINS[36]

[36] Source: Sandia National Laboratories based on FEMA floodplain data.

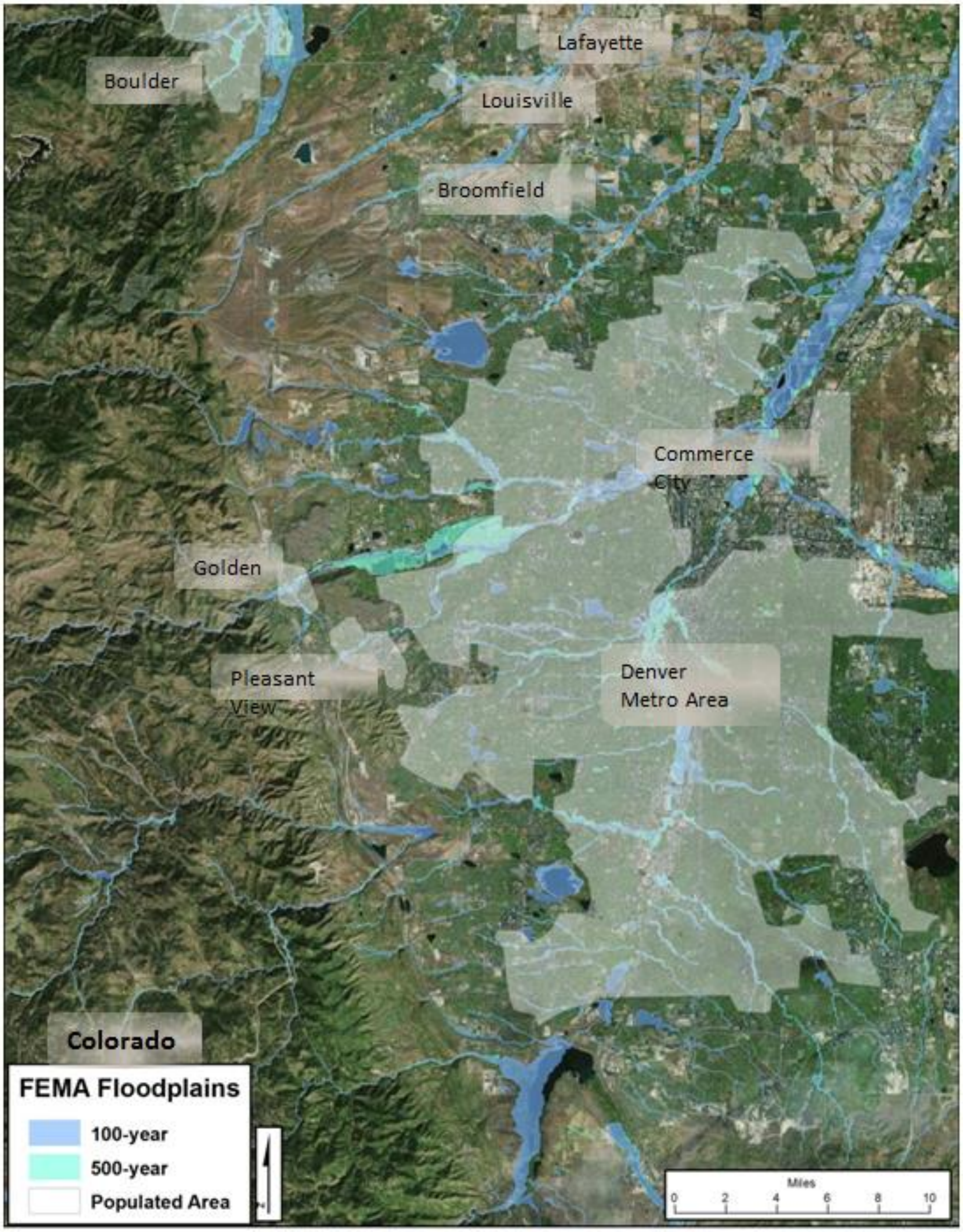

FIGURE 15—EXTENT OF FLOODPLAIN AREAS ALONG THE FRONT RANGE NEAR DENVER, COLORADO[37]

The extent of the floodplain is controlled by the steep topography in the western portion of the basin, spreading out as the topography changes (Figure 15) and again when the North and South Platte Rivers merge in Nebraska. Topography also influences the speed of flow, and therefore the force of floodwaters and the damage they cause to infrastructure and other sector assets.

[37] Source: Sandia National Laboratories based on FEMA floodplain data.

INFRASTRUCTURE IMPACTS

Assets in the 500-year floodplain, but not the 100-year floodplain, are the ones at increased risk in the flooding scenario. Figure 16 provides a satellite view of Commerce City in the 500-year floodplain, which includes fuel storage tanks at the Suncor Energy, Inc. (USA); the Commerce City East Refinery (southwest corner of the map); rail lines (diagonal lines southwest to northeast); large, possibly industrial or commercial buildings; and homes.

FIGURE 16—ENLARGED AREA OF THE COMMERCE CITY, COLORADO, 500-YEAR FLOODPLAIN SHOWING INFRASTRUCTURE ASSETS, POSSIBLE INDUSTRIAL AND COMMERCIAL BUILDINGS, AND RESIDENTIAL AREAS[38]

This is not a complete assessment of at-risk infrastructure assets within the floodplains due to flooding. Rail lines, roads, bridges, and water assets that are likely to be disrupted and possibly damaged were not included in the spatial analysis because they are located within the 100-year floodplain and damage estimates are beyond the scope of this analysis. Moving water treatment plants out of the flood zone to protect them would be costly, considering land purchases and construction costs. Bridges for rail and roads are functionally required to cross water bodies

[38] Source: Sandia National Laboratories based on FEMA floodplain data.

and thus cannot be moved out of the flood zone. Detailed lists of the assets summarized in Table 3 are provided in Appendix B: Infrastructure Assets in Floodplain Areas.

TABLE 3—SUMMARY STATISTICS FOR INFRASTRUCTURE ASSETS IN THE 100-YEAR FLOODPLAIN AND ADDITIONAL ASSETS IN THE 500-YEAR FLOODPLAIN

Asset Type	Assets in 100-year Floodplain	Additional Assets in 500-year Floodplain
Chemical Plants	3	9
Electric Power Plants	15	3
Electric Power Substations	49	20
Petroleum Refineries	0	2
Petroleum Terminals	0	3
Public Health - Hospitals	1	3
Public Health - Nursing Homes and Assisted Living Facilities	8	36
Telecom - Wire Centers	18	7

QUALITATIVE ASSESSMENT OF IMPACTS BY ASSET TYPE

CHEMICAL PLANTS

No supply chain impacts are anticipated from the potential disruption of the chemical facilities in the 100-year and 500-year flood scenarios. There are many producers of ethanol, aluminum sulfate, plant-based oils, sodium bisulfite, and sulfur across the United States; in the flood scenario, production disruption for all but industrial gasses could be offset by national production capacity. The industrial gas market is local or regional due to the high cost of transporting a large number of gas cylinders a long distance. Temporary shortages or price increases for some industrial gases are possible, but no significant impacts to supply chains are expected.

ELECTRIC POWER PLANTS

The Dave Johnston coal-fired Power Plant, located in Glenrock, Wyoming, has an operating capacity of 816.7 MW, and is the largest capacity power generation station located within the mapped Platte River floodplain areas. Located in the 100-year floodplain, the Dave Johnston Plant is at risk for damage due to flooding. Half the power plants at risk from flooding have less than 50 MW of generating capacity and are very unlikely to create regional power supply issues if shut down or damaged. Substation flooding can cause localized power outages, reducing the demand (due to lack of connectivity) and altering the consequences of power generation loss. Flood simulation would provide a better estimate of the potential simultaneous asset damage and associated outage areas.

HOSPITALS, NURSING HOMES, AND ASSISTED LIVING FACILITIES

While hospitals have backup generation to offset power outages that might result from flooding, generators located in the basements of buildings can be vulnerable to flooding. Hospitals and nursing homes are likely to be evacuated prior to flooding, but only if there is sufficient warning and the projected flood magnitudes warrant the risk of moving patients.

Each facility will have to consider multiple factors, including:

- The effort and time required to move patients,
- The number of patients and their conditions,
- Proximity of the backup healthcare facilities,
- Staffing, resources of the backup facilities, and
- The availability of specialized transport.

Evacuation alternatives may depend on the extent of flooding, as more than one location may be evacuating patients. There are more hospitals and nursing homes in the 500-year floodplain than in the 100-year floodplain.

PETROLEUM FACILITIES

Suncor Energy Refinery and Tank Farm, Commerce City (Denver area), Colorado: This refinery complex has a capacity of 93,000 barrels per day, and supplies Denver and the surrounding area with about one-third of the fuel consumed. Although the refinery structure itself is not in the 500-year floodplain, some of the surrounding tank farms are in the 500-year floodplain (Figure 17). In the event of a flood, it is likely that the refinery would execute a planned shutdown as a precaution against damage and expense from an unplanned shutdown. Time to shut down and re-start would be about 2 weeks. Additional imports of fuel into the area, use of fuels in storage tanks, and consumer conservation of fuels will offset the disruption of plant production caused by temporary plant closure.

Holly Frontier Refinery, Cheyenne, Wyoming: The footprint of this refinery and its associated storage tanks are almost entirely outside the 500-year floodplain (Figure 18). No disruption of operations would be expected.

Union Pacific Railroad and Fuel Storage Tank in North Platte, Nebraska: Figure 19 shows two storage tanks for diesel fuel at a large railroad switching yard. A section of the tracks is in the 500-year floodplain. The tanks are not within the mapped floodplain, and they are protected by berms that would prevent minor flooding damage. Flooding of the rail yard could shut down or temporarily reduce the capacity of a major rail transportation yard until the flood waters recede and damage repaired. Operation of the rail yard could likely resume soon after the flood receded.

Rocky Mountain Pipeline Terminal in DuPont (Denver area), Colorado: This is a terminal with storage tanks and truck racks delivering fuel from Cheyenne, Wyoming to the Denver area. This terminal delivers less than 28,000 barrels per day of fuel. Flooding would be expected to shut down the transfer of fuel to tanker trucks, but would likely not affect flow on the associated pipeline.

FIGURE 17—SUNCOR REFINERIES IN CENTRAL CITY, COLORADO, WITH FUEL STORAGE TANKS (CIRCLED) LOCATED WITHIN THE FEMA 500-YEAR FLOODPLAIN[39]

[39] Source: Sandia National Laboratories based on FEMA floodplain data.

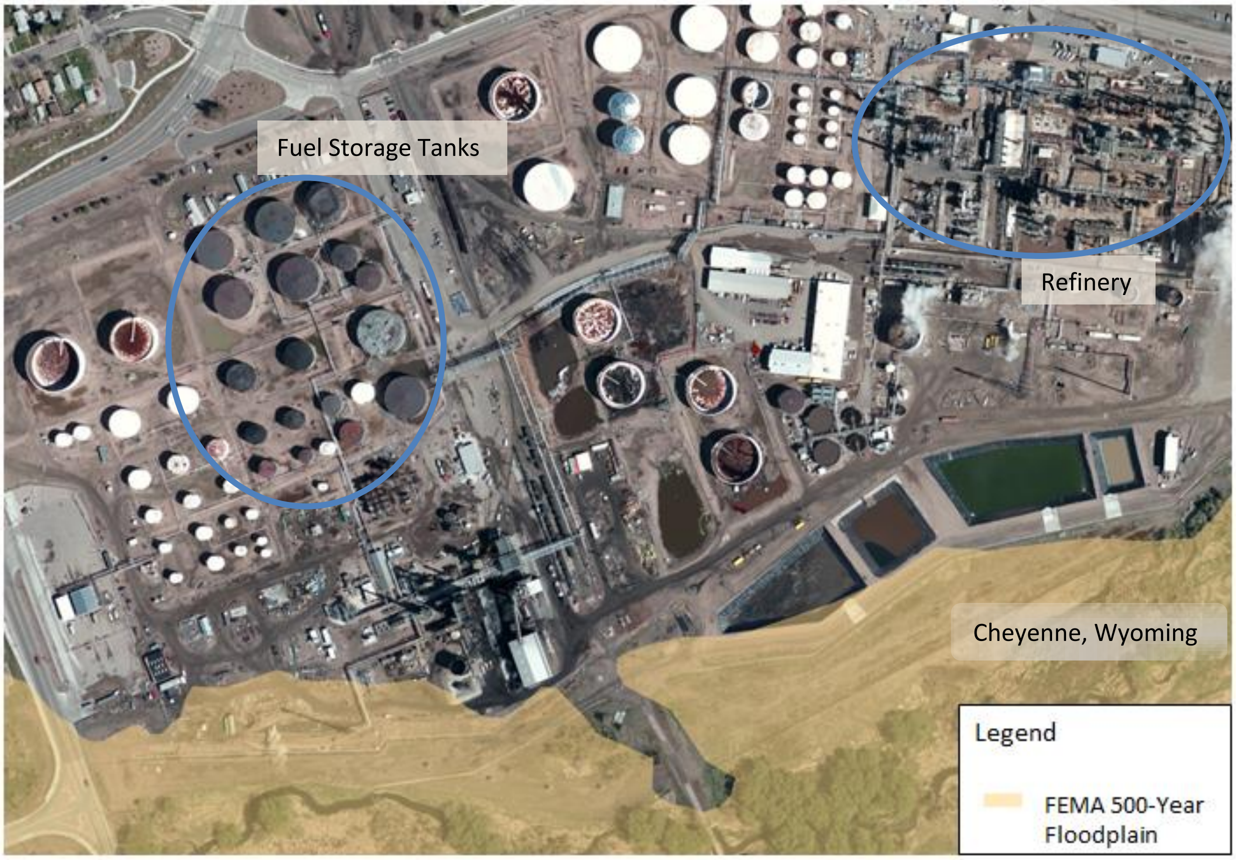

FIGURE 18—HOLLY REFINERY IN CHEYENNE, WYOMING, LOCATED NEAR THE FEMA 500-YEAR FLOODPLAIN[40]

[40] Source: Sandia National Laboratories based on FEMA floodplain data.

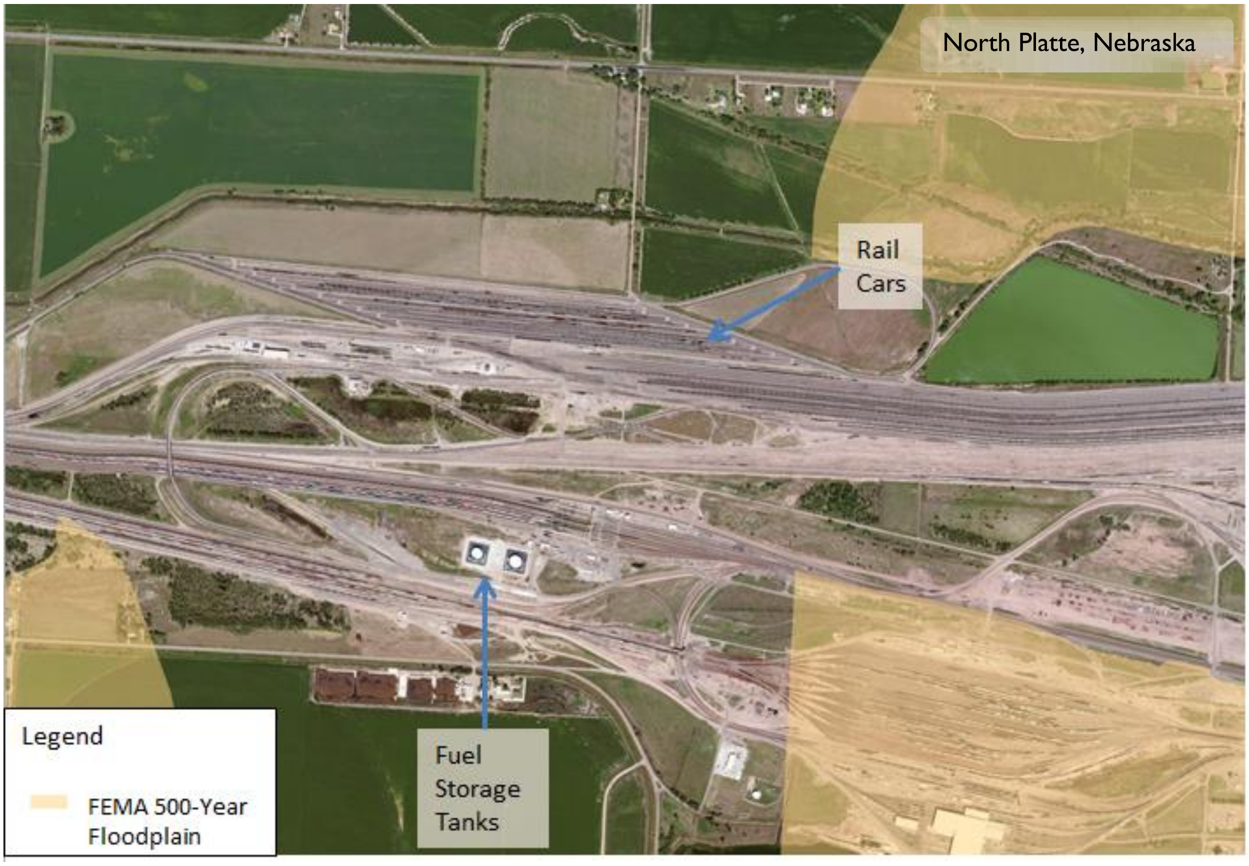

FIGURE 19—RAIL TRANSPORTATION HUB IN NORTH PLATTE, NEBRASKA, AND FEMA 500-YEAR FLOODPLAIN[41]

COMMUNICATIONS

Flooding presents significant risk to communications assets. Electronic equipment would require replacement if it came into prolonged contact with water. Individual telephone poles and end-subscriber cable typically would be replaced within a few days. Several weeks may be required to replace a communications switch due to the complexity of the equipment, installation, and testing procedures. Most communications wire centers are designed with equipment raised above the floor to prevent damage during minor flooding, but when flooding depths are greater than three feet, equipment could be destroyed, necessitating replacement. Even in wire centers with equipment on upper floors, service problems could result from inaccessibility and flood damage to generators and backup battery systems.

The wire centers in the floodplain provide landline and, in some cases, cellular switching service for customers in the affected area. The 18 wire centers in the 100-year floodplain have approximately 79,000 households in their service territory, and the additional seven wire centers in the 500-year floodplain have 66,000 households in their service territory. Any of the households that rely on land line service for voice and Internet service will experience a disruption if the wire center is not functioning.

POPULATION AND ECONOMIC IMPACTS

The data concerning regions at risk for increased frequency and magnitude of flooding due to climate change are used to analyze the types of potential economic impacts (a qualitative assessment). It is assumed that flooding will cause damage to substation assets, cause local power outages, and affect other infrastructure and businesses in the outage areas. As prescribed by this scenario, assets in the 500-year flood zone are at increased risk.

[41] Source: Sandia National Laboratories based on FEMA floodplain data.

Flooding creates the potential for accidental deaths, which are often the driving factor in economic impact analysis. Several metrics for assessing economic impacts of acute disruptive events are readily available: changes to income, business disruptions, property values, and the value of statistical life. For some types of acute disruptions, a simple calculation involving the number of anticipated casualties and the dollar amount of property damage may be enough to provide roughly the magnitude of the economic consequences of an acute disruption event. However, regional economic activity can also be impacted by the influence of climate uncertainties on business decisions and business interdependencies with infrastructures.

BUSINESS DISRUPTIONS

Business disruptions occur when firms and industries in an affected region cannot operate business-as-usual during an acute disruption event. Local and regional businesses rely on local and regional infrastructure to provide their business services. A sample of infrastructure-provided services includes potable water, electricity, passable roads, and communications.

A change in regional gross domestic product (GDP) is equivalent to the region's value added production. Firms in a given geographical region make a direct, accountable contribution to the economic output of that region; thus, summing up the product of those firms is typically the means of measuring regional GDP. One measure of a firm's contribution is the amount of sales it had over a specified period, usually a year, but this measure typically includes significant double counting. A better measure of the true regional product is the value added to the inputs (value added). The summation of the value added of all firms in the region of interest provides a better measure of regional GDP. In this case, the region is the area affected by damage and infrastructure service disruption.

It is difficult to address the role of individual businesses, a single company's network of facilities, or a regional complex of plants in the greater U.S. economy. The goal of the economic analysis methodology is to estimate the sum of all GDP impacts across the local, state, and national economy resulting from a disruption in production within selected industries and geographical regions.

Regional economic impacts are calculated taking into account such pertinent factors as:

- The area directly affected, based on the damage and flood zones;
- The duration of the disruption, based on empirical models of electric power restoration and restoration of other infrastructure services, plus the time required for flood waters to recede; and
- The magnitude of the impact, often based on the degree of disruption. Low, Medium, and High Impact cases can be submitted to scale disruption scenarios and restoration times.

The Regional Economic Accounting tool (REAcct), developed by NISAC to rapidly provide order-of-magnitude estimates of the potential economic severity of a disaster, provides a means for estimating the economic impacts of flooding events. At a national level, the U.S. Bureau of Economic Analysis (BEA) provides more detail on inter-industry relationships than is available at smaller geographic levels that would be impacted by single flood events.

LIMITATIONS OF AVAILABLE DATA

REAcct currently uses county employment data by industry to calculate GDP losses per county and per industry. Use of these data is an issue for geographic areas that only include portions of a county or counties (as is the case for flooding). The accuracy of the GDP would be greatly improved if data of business locations within the county and the number of employees at each location were available. Dun and Bradstreet sell data that include this information for a sub-set of self-reporting businesses and other sources might be available.

Determining the locations of businesses that are highly dependent upon the water infrastructure, face significant supply chain risks, or are considered lifeline industries is required to analyze the economic impact of floods. The economic impacts of drought depend on how water is allocated, the relative economic productivity of the water users and associated businesses, the costs associated with obtaining water rights, treating waste water streams for reuse and capital investments in water efficiency improvements, and the ability of businesses to adapt and compete in the market place.

FLOOD RISK MITIGATION OPTIONS

There are several options for reducing risks to infrastructure, population, and the economy. Each option will have costs and benefits, and a combination of options may be required to reach local and regional risk-reduction goals. In general, risk can be reduced by eliminating threats, reducing the likelihood of threats or consequences, or reducing the consequences. Increasing resilience is another option; resilience implies an acceptance of some or all of the risks and taking actions to reduce recovery time, effort, and costs.

Standard flood risk reduction measures include building standards that prevent development in certain floodplains (e.g., the 100-year floodplain) and installing flood control features to limit the extent of those floodplains. In this case, climate change is projected to increase the frequency of variability in flooding events. It is possible that the existing 500-year floodplain would become the 100-year floodplain and assets would need to move out of that zone or the zone would have to be modified through engineering to maintain acceptable levels of risk.

Flood control features, would protect all sectors, while moving infrastructure assets would protect local system function and reduce the dependence on flood control systems for risk mitigation. A combination of these actions may be the most cost effective mitigation.

INFRASTRUCTURE RISK MITIGATION FOR INCREASED FLOOD FREQUENCY AND MAGNITUDE

A more detailed assessment of the floodplain extent and uncertainty in urban areas where the 500-year floodplain is much more extensive than the 100-year floodplain is warranted prior to taking or recommending specific actions. To prevent disruption of lifeline services and reduce economic impacts, States and public utility boards could require infrastructure owners and operators to move assets out of the 500-year floodplain or install enhanced flood protection features sufficient to protect against the 500-year flood for isolated at-risk assets. State or Federal agencies could reduce asset risks due to flooding by constructing and maintaining enhanced flood protection measures for populated areas like the northwest Denver metropolitan area, Commerce City, Central City, North Platte, Lexington, and Freemont. All of these measures would incur a cost.

Flood control features, would protect all sectors, while moving infrastructure assets would protect local system function and reduce the dependence on flood control systems for risk mitigation. A combination of the two could be effective. A more detailed risk analysis for each location is needed to determine the most cost effective mitigation.

PROLONGED DROUGHT

Surface water is fully appropriated in portions of the hydrologic basin and there has already been litigation to force Colorado and Wyoming to maintain flows that meet or exceed legally mandated minimums. Drought of any size will cause water supply issues for those with the most junior water rights. The most senior rights belong to traditional agricultural landowners. This means utilities in urban areas are forced to institute watering restrictions to reduce water withdrawals. Local and county municipalities may implement fines against urban and suburban users in order to curb water usage. Dryland farming and self-supplied residential, commercial, and industrial surface-water users are likely to be impacted first.

With prolonged, severe drought, as experienced in Texas in 2011 through 2012, emergency measures may be taken to prioritize water allocations to urban areas and suspend historic water rights held by agricultural businesses.[42,43] Temperatures and low-flow conditions can limit cooling water discharges to protect the environment.[44]

INFRASTRUCTURE IMPACTS

Unirrigated dryland farms are the first infrastructure operations that will be impacted by drought. Within the Platte River Basin, the majority of farms are in Nebraska. Figure 20 shows the percent of harvested land that is irrigated by county in the Platte River Basin region. Dryland farming dominates in 12 counties across the basin (seven counties in Colorado and five in Nebraska, where less than 30 percent of the harvested acres were irrigated in 2007).

Dryland farming is always at risk to climate fluctuations. Irrigated agricultural businesses may not be as prepared for water-supply disruptions. This difference in preparedness is reflected in survey results from a Colorado study showing that dryland farmers were more likely to continue to operate in the face of extended drought conditions than were the ones who irrigated.[45] Dryland farmers indicated there was only a 3 percent (on average) probability that they would quit farming in 2012 if conditions returned to normal and a 22 percent probability if drought continued the next year. In contrast, the irrigating farmers and ranchers indicated a 13-15 percent probability of quitting even if conditions returned to normal and a 22-36 percent probability of quitting if the drought continued. Irrigated livestock operations were the most likely to quit operations and reported lower-to-normal calving rates and higher costs per pound gained, which impacts profit margins and results in reductions in the size of herds.

42 Economic Research Service, "U.S. Drought 2012: Farm and Food Impacts, U.S. Department of Agriculture," http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx, accessed April 2013.
43 Fannin, B. 2012. Agri Life TODAY, Updated 2011 Texas agriculture losses total $7.62 billion, Agri Life TODAY, http://today.agrilife.org/2012/03/21/updated-2011-texas-agricultural-drought-losses-total-7-62-billion/, accessed April 2013.
44 Fowler, T., "More power plant woes likely if Texas drought drags into winter," Fuelfix.com, http://fuelfix.com/blog/2011/08/24/more-power-plant-woes-likely-if-texas-drought-drags-into-winter/, accessed April 2013.
45 Nelson, R., J. Pritchett and C. Goemans, "Survey Summary: Farm and Ranch Managers' Responses to the 2011 Drought," Colorado Drought Survey.

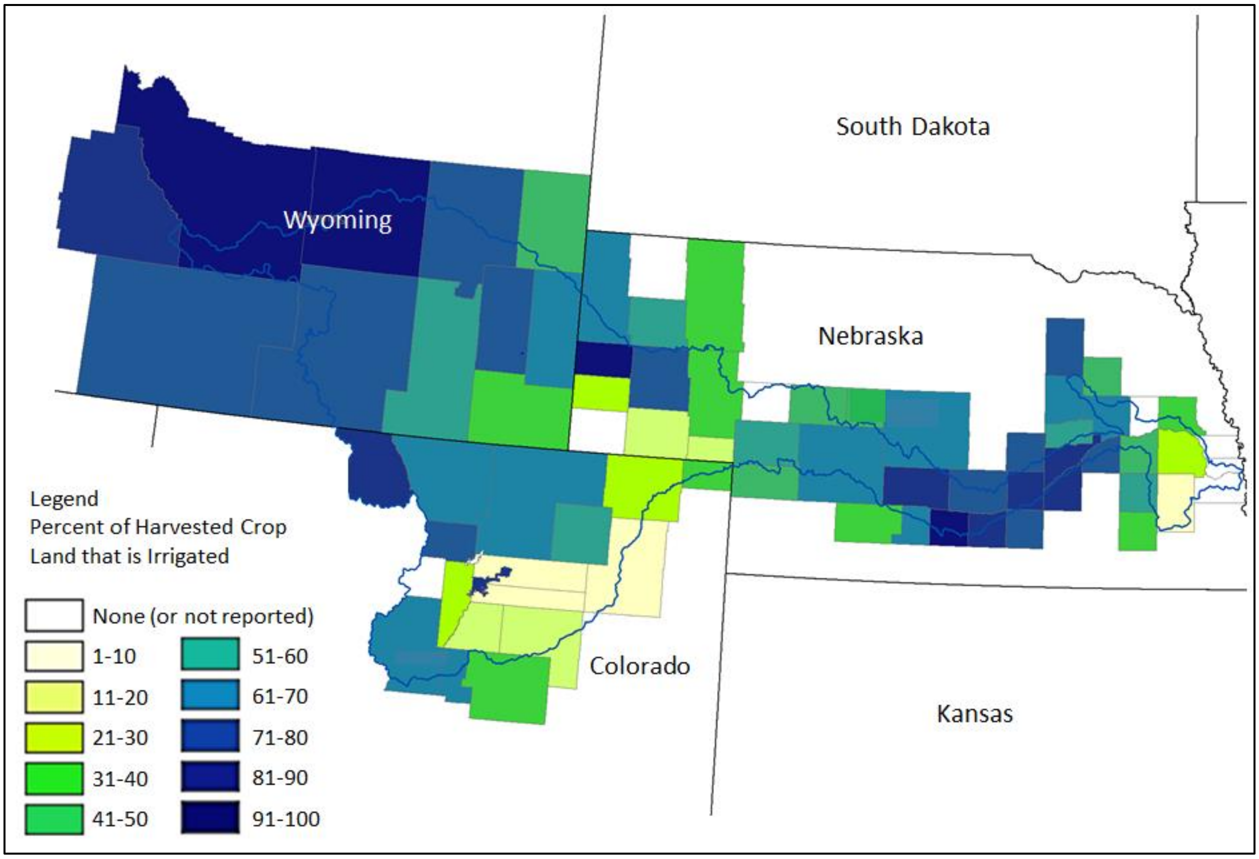

FIGURE 20—PERCENT OF HARVESTED LAND THAT IS IRRIGATED[46]

The regional impacts of farming losses due to drought depend on the intensity of farming, temperature stresses, and irrigation intensity. The survey of Colorado farmers also elicited the impact of the 2011 drought on the productivity impacts as a function of the harvested percent of land that was planted and percent yield relative to a typical year. Of the Colorado crops, the greatest reported impacts were to dryland sorghum (24 percent of a normal year) with other dryland crops yielding 40 percent (corn) and 46 percent (wheat) of a normal year. Irrigated barley and wheat yields were about 80 percent of a normal year, while potato crops were not impacted in 2011.

Although the percent of harvested acres that are irrigated in the mountainous areas of Wyoming and Colorado and in Denver are high (greater than 80 percent), there are relatively few harvested acres in those counties. Figure 21 shows the irrigation intensity by county, which is the percent of the total land area in the county that is irrigated, harvested land. The high-intensity irrigated farming is in Nebraska at the end of the Platte water supply chain and in an area with limited groundwater resources, yet groundwater is a significant water source for irrigation in eastern Nebraska (Figure 22).

[46] Source: Sandia National Laboratories, based on data from USDA, "2007 Census of Agriculture," http://www.agcensus.usda.gov/Publications/2007/Full_Report, accessed January 15, 2014.

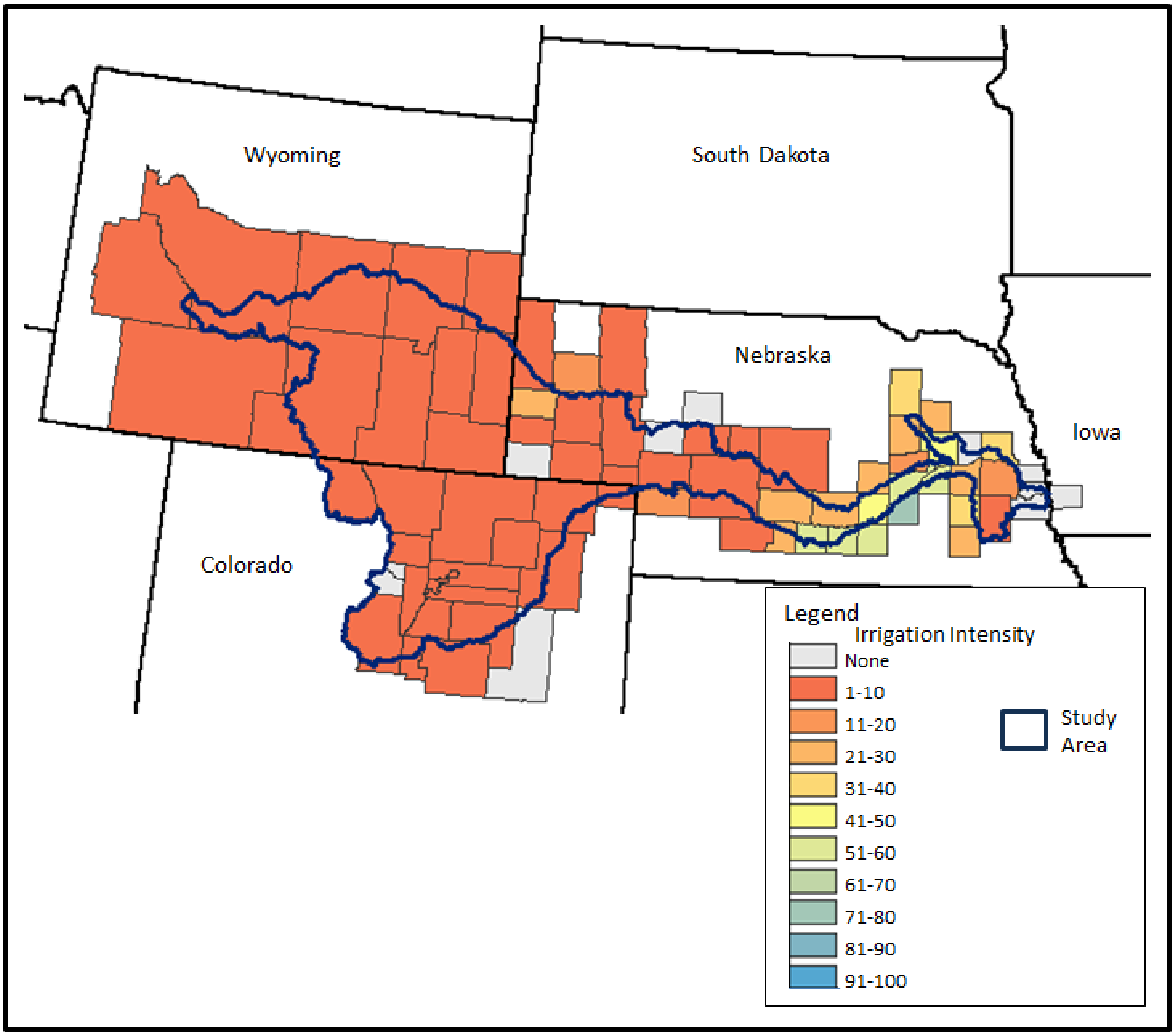

FIGURE 21—IRRIGATION INTENSITY BY COUNTY.[47]

Dryland farming intensity is greatest in three counties in eastern Colorado (Adams, Arapahoe, and Washington), which had total sales of approximately $312 million in 2007. If drought drives the dryland farmers out of business in these three counties, the land may be used for other purposes such as residential or commercial property development. Since Adams and Arapahoe counties are adjacent to Denver, alternative land use is likely.

[47] Source: Sandia National Laboratories based on data from USDA, "2007 Census of Agriculture," http://www.agcensus.usda.gov/Publications/2007/Full_Report, accessed January 15, 2014.

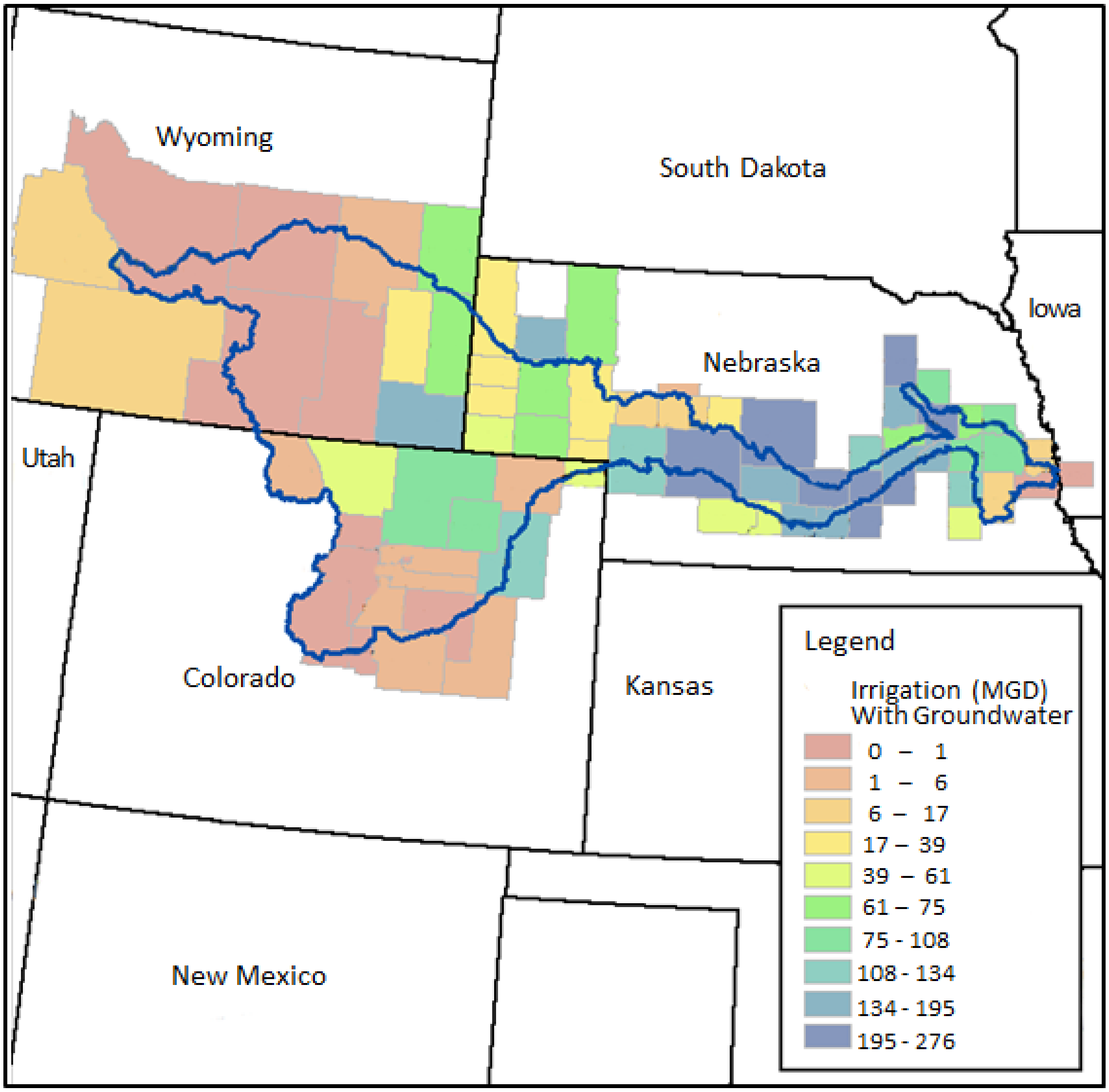

FIGURE 22—IRRIGATION WITH FRESH GROUNDWATER IN 2005 (MILLIONS OF GALLONS PER DAY)[48]

The threat of climate change on irrigated agriculture is particularly important, considering that the Platte River basin also sustains one of the world's major agricultural economies. Eastern Nebraska is the western edge of the U.S. Corn Belt, the most productive agro-ecosystem on the planet. This region produces more than 40 percent of the world's corn and soybean supplies. The irrigated corn that accounts for 14 percent of total corn production is produced almost entirely in the Great Plains with water drawn from the Platte River, its tributaries, and the High Plains aquifer. Nebraska also is the nation's second-largest producer of corn ethanol, which increases the demand for both corn and water.[49]

ECONOMIC IMPACTS OF DROUGHT

Water restrictions for urban areas are the next phase of drought impacts after the impacts to dryland farming. The major urban areas include the Denver metropolitan area (population 1.2 million), Lincoln (population 198,000),

[48] Source: Sandia National Laboratories, based on data from USDA, "2007 Census of Agriculture," http://www.agcensus.usda.gov/Publications/2007/Full_Report, accessed January 15, 2014.
[49] University of Nebraska–Lincoln Office of Research, "Sustainability in a Time of Climate Change: Developing an Intensive Research Framework for the Platte River Basin and the High Plains, Lincoln, NE."

Fort Collins (population 93,000), Greely (population 75,000), Cheyenne (population 50,000), and Casper (population 50,000). Water restrictions will affect landscaping purchases and influence property values, but these impacts are not major regional economic issues. Drought is a chronic disruption that will result in competition for scarce water resources by all economic sectors. This competition among sectors will affect economic productive capacity in the short term; and, if the water scarcity persists, will result in decreased potential for long-term regional growth.

The identification of central industry sectors, sectors that are dependent on water, the equilibrium displacement mathematical program (EDMP), and input-output (IO) analysis are useful for estimating a regionally comprehensive economic impact. Outstanding questions remain about what a region can do to avoid negative economic impacts from drought if most central industry sectors are vulnerable to water resources scarcity. The dependence of a regional economy on water is evaluated through a hydro-sorting process developed for this analysis. Water resources are defined as any body of water that contains either fresh or saline water and originates from surface or groundwater sources. In economic terms water is a capital stock. Fresh water is the primary source when water is needed for production. Water is a renewable resource stock with a natural recharge rate. Over-utilization of water can deplete and eventually exhaust this resource stock.

Water resources as factors of production are discussed by Gatto and Lanzafame, who use neoclassical growth models to analyze potential restrictions in economic growth due to a socially optimal constraint on water use.[50] A basic neoclassical model of the Solow-Swan model can be used to demonstrate destruction or constrained use of capital stock.[51,52] If water as a capital stock cannot be recovered, repaired, or reconstructed, the regional economy in question is less resilient to drought.[53] The Vugrin, et al. definition of system resilience is:

> *…given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is the ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels….*[54]

If the regional economy in question has high concentrations of industry sectors reliant on water and water is unavailable to maintain system performance, the regional economy would be vulnerable to drought and less resilient.

Three metrics of economic resilience can include:

- Impact on system productivity.
- Time to system recovery—does not apply to chronic disruptions.
- Cost—price changes due to water scarcity.

Maintaining regional economic growth requires resilience in the face of all disruptions and stresses. For drought and chronic water supply shortages, the first step in the economic resilience assessment is to evaluate the consumptive use of water by economically central and non-central industry sectors to identify how vulnerable the regional economic activity is to water resource limitations. This provides the information needed to identify potential structural changes in the regional economy and allow evaluation of the sustainability of strategies that try to maintain the status quo through water pricing and incentives for efficient water use.

This economic analysis framework provides a path for quantifying the change in economic activity by quantifying the upstream and downstream linkages of a chronic disruptive event, such as prolonged severe drought. The linkage assessment examines how water scarcity and factors of production will force regional economic

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50 Gatto, E., and M. Lanzafame, "Water Resource as a Factor of Production: Water Use and Economic Growth," European Regional Science Association Conference.
51 Solow, "A Contribution to the Theory of Economic Growth," Quarterly Journal of Economics 70(1)(1956): pp. 65–94.
52 Swan, "Economic Growth and Capital Accumulation," Economic Record 32(2)(1956): pp. 334–361.
53 Rose, A., Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions. Environmental Hazards, (2007): pp. 383-398.
54 Vugrin, Eric D., Drake E. Warren, Mark A. Ehlen, and R. Chris Camphouse, "A framework for assessing the resilience of infrastructure and economic systems," Sustainable and Resilient Critical Infrastructure Systems, Berlin, Germany: Springer Berlin-Heidelberg, 2010: pp. 77-116.

adaptations to preserve growth. A separate NISAC report will provide a detailed description of, and justification for, using an EDMP-IO based analysis to quantify chronic, regional water shortage impacts on economic activities.

DROUGHT RISK MITIGATION OPTIONS

Agriculture, the largest water user, holds priority of water rights. This priority is the fundamental issue that must be addressed to offset water shortage risks to the other economic sectors. Use-it-or-lose-it rules incentivize water use to maintain ownership of valuable water rights. Alternative systems, such as a bank for leasing water rights (an expansion of the water bank concept employed by Nebraska), might provide financial incentives sufficient to create more dynamic, adaptive water use.[55] Whether this water bank option would create a more resilient regional economy, however, must be analyzed. Further, it will be critical to evaluate how this mitigation impacts food and grain production.

CONCLUSION

Climate change is projected to increase the threat of both flooding and drought within the Platte River Basin. There are several options for reducing risks to infrastructure, population, and the economy due to these climate threats. Each option will have costs and benefits; a combination of options may be required to reach local and regional risk-reduction goals.

Two populated areas in Colorado, northwest Denver metropolitan area and Commerce City, and four populated areas of Nebraska, Central City, North Platte, Lexington, and Freemont, have assets that are at greater risk of flooding due to climate change than other locations within the study area. Enhanced flood-control features would protect all sectors. The alternative is to move assets away from the 100- and 500-year floodplain. This is an expensive process and thus only likely to occur in isolated cases and perhaps only following damage due to flooding. A more detailed assessment of the floodplain extent, particularly in urban areas where the 500-year floodplain is much more extensive than the 100-year floodplain, is warranted prior to taking or recommending a sweeping set of costly mitigation actions.

One of the most difficult climate impacts to mitigate is long-term severe-to-profound drought, because it requires changes to how water is allocated in a system with a long historical precedent for water rights allocation. Water shortages and re-allocation of water have the potential for far-reaching, unintended consequences.

Multiyear drought can cause surface-water supply shortages across the basin and further depletion of water stored in the High Plains aquifer. Agriculture is the largest water user, but holds priority in water rights. This is the fundamental issue to be addressed in order to offset water shortage risks to the other economic sectors. Use-it-or-lose-it rules incentivize water use simply to maintain ownership of valuable water rights.

Alternative systems, such as a bank for water rights through which rights could be leased, might provide a financial incentive sufficient to create more dynamic, adaptive water use. More efficient processes and crop changes could reduce water needs. Additional analysis would be required to determine whether these options would create a regional economy that is more resilient to drought and more likely to support economic growth. Additional analysis is also required to evaluate the risks of incentivizing unreliable food and grain production, which would drive global food prices higher and create instabilities at the global scale.

The analytical framework used in this study provides a method for quantifying changes in economic activity due to water interdependencies. The framework also illuminates water scarcity impacts on a growing regional economy.

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55 Central Platte Natural Resources District. "Water Banking Program," http://www.cpnrd.org/Water_Bank.html, accessed October 27, 2014.

APPENDIX A: LITERATURE REVIEW – ANNOTATED REFERENCES

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United States Geological Survey, National Water Information System (NWIS), http://waterdata.usgs.gov, accessed November 12, 2013.

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Yates, D., J. Meldrum, and K. Averyt, "The influence of future electricity mix alternatives on southwestern US water resources," Environmental Research Letters, 8, doi:10.1088/1748-9326/8/4/045005.

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Steward, D.R., P.J. Bruss, X. Yang, X., S.A. Staggenborg, S.M. Welch, and M.D. Apley, "Tapping unsustainable groundwater stores for agricultural production in the High Plains aquifer of Kansas, projections to 2110," Proceedings of the National Academy of Sciences, September 10, 2013,110(37).

U.S. Department of Energy, "US Energy Sector Vulnerabilities to Climate Change and Extreme Weather," DOE/PI-0013.

The historical example provided for the Platte basin is for the case of a prolonged drought in 2006 that impacted hydropower generation by ~50 percent for a series of plants along the North Platte. This is an issue that DOE has to be concerned about. However, these reductions in capacity were more of an economic issue than a power delivery issue. Hydropower is a minor component of the regional power generation capacity and that power outages are of concern due to flooding damage to substations &/or power lines. This study also shows how hydrologic fracturing plays within the basin, which is an issue for active hydraulic fracturing during extreme prolonged drought (as illustrated by the Texas 2011-12 drought issues).

DOE focuses on the adaptations they are currently funding (increasing water use efficiency in hydraulic fracturing, flood walls in storm surge areas, more efficient cooling towers for specific power plants (for a plant in GA and one in NM), increasing renewable energy sources and consumer energy efficiency upgrades.

COLORADO

Mayer, P. and S. Wytinck, "Colorado Drought and Water Supply Update 2007." Colorado Water Conservation Board, (2007): p. 151.

This focuses on who has conservation plans, the funding for conservation efforts and types of conservation efforts by utility.

Nelson, R., J. Pritchett, and C. Goemans, "Survey Summary: Farm and Ranch Managers' Responses to the 2011 Drought," Colorado Drought Survey, (2012): p. 22.

This survey does not include any participants from the Platte basin, but discusses the adaptive behavior of individual survey respondents.

Ray, A., J. Barsugli, K. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall, and R. Webb, "Climate Change in Colorado," CU-NOAA Western Water Assessment for the Colorado Water Conservation Board.

Chapter 5 compares observed temperature and precipitation (1950-1999) to the IPCC projections for specific locations (Grand Junction, Steamboat Springs, and La Junta) and hydrologic changes for the Colorado River. General changes predicted with warming through 2050 include less winter precipitation (less snow pack), earlier peak flows (springtime peak is earlier by several weeks), and greater variability in precipitation events.

Gunter, A., C. Goemans, J. Pritchett, and D. Thilmany, "The Economic Impact of the 2011 Drought on Southern Colorado: A combined input-output and EDMP analysis," Colorado State University.

The Rio Grande and Arkansas River basins direct economic impacts of drought on agriculture (yields and harvested acres) and secondary economic impacts on the communities in these two basins. Greater impacts in Arkansas valley, where 37 percent of acreage is dry land vs. only 10 percent dry land acreage in the Rio Grande valley. Shortages drive prices higher and offset some of the losses.

Colorado Water Conservation Board, "Statewide Water Supply Initiative," (2004) p. 538.

A basin by basin water resource: geography, climate, topography, land use, and geology; state and federal water institutions and non-government interest groups; economic role of water (urban; agricultural, including mining; and recreation); legal framework; projected water demands; water supply availability; mitigation issues.

Dennehy, K., D. Litke, C. Tate and J. Heiny, "South Platte River Basin – Colorado, Nebraska and Wyoming," Water Resources Bulletin 29(4)(1993).

This describes the physical system, geology, and 1990 water use and hydrologic summary data (stream flow, recurrence intervals for high and low flow conditions, aquifers, water quality).

Strange, E., K. Fausch, and A. Covich, "Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin," Environmental Management 24(1)(1999): pp. 39–54.

This describes environmental water use and impacts due to drought/low flow.

Morea, S., N. Rowan, M. McCluskey, and B. Fernandez, "Memo on Basin Municipal and Industrial (M&I) Gap Analysis, CDM letter to Eric Heacox, Colorado Water Conservation Board," June 22, 2011.

Details a supplemental analysis to the State Water Supply Initiative 2010 gap analysis. Describes methods, projections of demand to 2050, and assumptions. Provides a low, medium, and high yield (and a low, medium, and high gap) estimate. Lists "identified projects and processes" (IPP) for closing the water supply gaps.

Colorado Water Conservation Board, 2007. Colorado's Water Supply Future Statewide Water Supply Initiative - Phase 2.

Delineation and prioritization of water uses based on legal rights, economic impacts, and environmental impacts. Evaluation of alternative transfer methods (interruptible supply agreements, long-term rotational fallowing, water banks, efficiency measures (for agriculture), end use purchase with leaseback under defined conditions). Tables of projected savings from conservation alternatives; potential changes in irrigated acres due to water rights transfers, urbanization, and other reasons; population projections; agriculture demands (2000);and projected M&I gaps (2030).

U.S. EPA (Environmental Protection Agency), 2013. Watershed modeling to assess the sensitivity of streamflow, nutrient, and sediment loads to potential climate change and urban development in 20 U.S. watersheds. National Center for Environmental Assessment, Washington, DC; EPA/600/R-12/058F. Available from the National Technical Information Service, Alexandria, VA, and online at http://www.epa.gov/ncea, accessed January 15, 2014.

Boosik, K., and J.A. and Ramirez, "Response of streamflow to weather variability under climate change in the Colorado Rockies," Journal of Hydrologic Engineering, 12(1)(2007): pp. 63-72.

U.S. Bureau of Reclamation, "Colorado River Basin Water Supply and Demand Study," http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html, accessed April 2013.

WYOMING

Acharya, A., P.C. Piechota, and G. Tootle, "Quantitative assessment of climate change impacts on the hydrology of the North Platte River watershed," Wyoming, Journal of Hydrologic Engineering, 17(10), DOI: 10.1061/(ASCE)HE.1943-5584.0000543.

Wyoming Water Development Commission, "Platte River Basin Plan."

Water supply (surface and groundwater), water use (agricultural, municipal, industrial, and recreational), storage (and number of users by reservoir), groundwater availability, and development potential (by aquifer and sub-basin).

NEBRASKA

Nebraska Department of Natural Resources, "2013 Annual Evaluation of Availability of Hydrologically Connected Water Supplies: Determination of Fully Appropriated."

Platte River Basin is in the Missouri Tributary Basins assessment. It includes surface and groundwater assessments, corn crop irrigation requirements, and wells by type (irrigation, aquaculture, commercial/industrial, public water supply, domestic, and livestock) and basin. Livestock is the highest rate of water consumption. (The lower Platte basin was not evaluated in this study.) Due to full appropriation determination, no new water rights are being issued, working to retire water uses.

Nebraska Department of Natural Resources, "Annual Report and Plan of Work for the Nebraska State Water Planning and Review Process."

This includes overviews of the studies, programs, and projects in the Platte and Lower Platte River basins. Platte river recovery implementation programs, watershed management action initiative, water use modeling, and lower Platte groundwater model study. There are links to some study websites.

Nebraska Emergency Management Agency, State of Nebraska Hazard Mitigation Plan (http://www.nema.ne.gov/pdf/hazmitplan.pdf, accessed October 27, 2014.)

Nebraska's hazard mitigation plan includes a history of the state's planning for climate hazards. The Climate Assessment and Response Committee (CARC) began developing a drought plan in 1998. The State Drought Mitigation Plan has been maintained by the CARC since it was first published in 1999. CARC also tracks drought conditions in the state. There is a

Water Availability and Outlook Committee (WAOC) and a Risk Assessment Committee (RAC). There is a Statewide Effective Digital Floodplain mapping project and local mitigation projects (for example flood buyout projects to move people and assets "out of hazard-prone areas" and critical facility flood proofing) that are part of the flood risk mitigations implemented and documented in this plan.

Central Platte Natural Resources District. Water Banking Program, http://www.cpnrd.org/Water_Bank.html accessed October 27, 2014.

The NRD water banking program is described. Started in 2007, the NRD purchases water rights and allows banking of rights to attain and maintain compliance with the Platte River Recover Implementation Program and Legislative Bill 962.

APPENDIX B: INFRASTRUCTURE ASSETS IN FLOODPLAIN AREAS

CHEMICAL PLANTS

Platte	Company	City	Chemicals
100-yr flood	American Air Liquide Holdings, Inc.	Denver, CO	Oxygen Argon, liquid Argon Oxygen, liquid Air separation plants Nitrogen Acetylene (non-chemical use) Nitrogen, liquid
100-yr flood	Archer Daniels Midland Company	Columbus, NE	Ethanol
100-yr flood	Matheson Trigas	Waverly, NE	Nitrogen, liquid Oxygen, liquid Argon Nitrogen Argon, liquid Oxygen Air separation plants
500-yr flood	Archer Daniels Midland Company	Lincoln, NE	Cottonseed oil Peanut oil Soybean oil Corn oil Hydrogen Palm oil Lecithin or derivatives
500-yr flood	General Chemical Corporation	Denver, CO	Alum, commercial
			Aluminum sulfate
500-yr flood	Zeeland Farm Services	North Platte, NE	Ethanol
500-yr flood	Sterling Ethanol, LLC	Sterling, CO	Ethanol
500-yr flood	Suncor Energy (U.S.A.), Inc.	Commerce City, CO	Sodium bisulfite Sulfur (elemental) Hydrogen Sodium hydrogen sulfite Sodium acid sulfite
500-yr flood	Green Plains Renewable Energy, Inc.	Central City, NE	Ethanol
500-yr flood	Yuma Ethanol, LLC	Sterling, CO	Ethanol

ELECTRIC POWER PLANTS

Platte	Name	Plant Operator	City	Operating Capacity (MW)
100-yr flood	Arapahoe	Public Service Co. of Colorado	Englewood, CO	158.0
100-yr flood	Cabin Creek	Public Service Co. of Colorado	Silver Plume, CO	300.0
100-yr flood	Dave Johnston	PacifiCorp	Glenrock, WY	816.7
100-yr flood	Fall River 1	Estes Park Light and Power Dept.	Estes Park, CO	0.0
100-yr flood	Kearney	Nebraska Public Power District	Kearney, NE	1.5
100-yr flood	Kingsley	Central Nebraska Public Power and Irrigation District	Keystone, NE	50.0
100-yr flood	Trigen Colorado	Colorado Energy Nations Co. LLP	Golden, CO	35.4
100-yr flood	Zuni	Public Service Co. of Colorado	Denver, CO	115.2
100-yr flood	Monroe	Nebraska Public Power District	Monroe, NE	8.4
100-yr flood	Papillion Creek Wastewater	Omaha (City of)	La Platte, NE	1.5
100-yr flood	Wahoo	Wahoo (City of)	Wahoo, NE	14.2
100-yr flood	Arapahoe Combustion Turbine Project	Southwest Generation Operating Co., LLC	Englewood, CO	193.9
100-yr flood	Harold Kramer	Nebraska Public Power District	Bellevue, NE	0.0
100-yr flood	SunE SR1 Broomfield8	SunE SR1 Broomfield8 LLC	Northglenn, CO	0.0
100-yr flood	Lincoln	Archer Daniels Midland Co.	Lincoln, NE	7.9
500-yr flood	Metro Wastewater Reclamation	Colorado Golden Energy Corp.	Commerce City, CO	15.0
500-yr flood	Fremont 1	Fremont Dept. of Public Utilities	Fremont, NE	0.0
500-yr flood	Lon Wright	Fremont Dept. of Public Utilities	Fremont, NE	170.0

ELECTRIC POWER SUBSTATIONS

Platte	Name	City	Maximum Voltage
500-yr flood	Derby	Commerce City, CO	115
100-yr flood	Mapleton	Commerce City, CO	115
500-yr flood	Metro Wastewater Reclamation	Commerce City, CO	0
100-yr flood	Denver Terminal	Denver, CO	230
500-yr flood	Platte	Denver, CO	230
100-yr flood	Thornton	Derby, CO	230
100-yr flood	Broomfield	Eastlake, CO	35
100-yr flood	Arapahoe	Englewood, CO	230
100-yr flood	Fall River (Larimer County)	Estes Park, CO	0

Platte	Name	City	Maximum Voltage
100-yr flood	Timberline	Fort Collins, CO	230
500-yr flood	Buckley	Foxfield, CO	115
500-yr flood	Orchard	Foxfield, CO	230
100-yr flood	Trigen Colorado	Golden, CO	0
100-yr flood	Cotter Mine	Leyden, CO	35
100-yr flood	Tap	Littleton, CO	115
100-yr flood	Quebec St. North Tap	Sullivan, CO	230
100-yr flood	Unknown	Archer, NE	35
500-yr flood	Sub 991	Arlington, NE	69
100-yr flood	Harold Kramer	Bellevue, NE	0
100-yr flood	Paddock	Central City, NE	35
100-yr flood	Unknown	Clarks, NE	35
100-yr flood	Cozad	Cozad, NE	115
100-yr flood	Tap	Darr, NE	NA
500-yr flood	991 Tap	Fremont, NE	69
500-yr flood	Fremont 1	Fremont, NE	0
500-yr flood	Lon Wright (Fremont 2)	Fremont, NE	69
500-yr flood	Sub 976	Fremont, NE	69
500-yr flood	Tap	Fremont, NE	NA
500-yr flood	Unknown	Fremont, NE	NA
100-yr flood	Tap	Fullerton, NE	35
100-yr flood	Unknown	Genoa, NE	35
100-yr flood	Gothenburg	Gothenburg, NE	115
500-yr flood	Sub F	Grand Island, NE	115
100-yr flood	Sub 992	Inglewood, NE	69
100-yr flood	Kearney	Kearney, NE	0
100-yr flood	Kearney	Kearney, NE	115
100-yr flood	Tap	Kearney, NE	115
100-yr flood	Kingsley	Keystone, NE	0
100-yr flood	Papillion Creek Wastewater	La Platte, NE	0
500-yr flood	Sub 904	La Platte, NE	69
500-yr flood	Unknown	Lexington, NE	35
100-yr flood	Westminster	Lexington, NE	115
100-yr flood	20th and Pioneers	Lincoln, NE	115
100-yr flood	29th and Leighton	Lincoln, NE	115
500-yr flood	3rd and Van Dorn	Lincoln, NE	115
100-yr flood	40th and Gertie	Lincoln, NE	115
100-yr flood	Lowell	Lowell, NE	115
100-yr flood	Unknown	Maxwell, NE	35
100-yr flood	Monroe	Monroe, NE	0

Platte	Name	City	Maximum Voltage
100-yr flood	North Bend	North Bend, NE	115
500-yr flood	Unknown	North Platte, NE	35
100-yr flood	Unknown	Oshkosh, NE	35
100-yr flood	Ravenna	Ravenna, NE	69
100-yr flood	Raymond	Raymond, NE	35
500-yr flood	Columbus East	Richland, NE	345
100-yr flood	Shelton	Shelton, NE	69
100-yr flood	Silver Creek	Silver Creek, NE	115
100-yr flood	979 Tap	Springfield, NE	69
100-yr flood	Tap	Touhy, NE	35
100-yr flood	Sub 984	Valley, NE	69
100-yr flood	Valley No 902	Valley, NE	69
100-yr flood	Wahoo	Wahoo, NE	0
100-yr flood	84th and Fletcher	Waverly, NE	115
500-yr flood	17th and Holdredge	West Lincoln, NE	115
100-yr flood	2nd and N	West Lincoln, NE	115
500-yr flood	8th and N	West Lincoln, NE	115
100-yr flood	SW 27th and F	West Lincoln, NE	115
100-yr flood	Happy Jack	Cheyenne, WY	115
100-yr flood	Dave Johnston	Glenrock, WY	230

PETROLEUM REFINERIES

Platte	Name	Owner	City	Capacity (barrels per day)	U.S. Rank
500-yr flood	Commerce City East	Suncor Energy (USA) Inc.	Denver, CO	36000	109
500-yr flood	Cheyenne	Holly Frontier Corp.	Cheyenne, WY	47000	104

CRUDE OIL PUMPING STATION

Platte	Name	Owner	Description	State
100-yr flood	Horse Creek	Mobil	Petroleum pumping station	WY

PETROLEUM TERMINALS, STORAGE FACILITIES, AND TANK FARMS

Platte	Owner	City
500-yr flood	Union Pacific	North Platte, NE
500-yr flood	Rocky Mountain Pipeline System LLC	DuPont, CO
500-yr flood	Suncor Energy USA	Commerce City, CO

HOSPITALS

Platte	Bed Count	Name	City
100-yr flood	12	Nebraska State Penitentiary Hospital And Clinic	Lincoln, NE
500-yr flood	116	Great Plains Regional Medical Center	North Platte, NE
500-yr flood	90	Fremont Area Medical Center	Fremont, NE
500-yr flood	20	Litzenberg Memorial County Hospital	Central City, NE

NURSING HOMES AND ASSISTED LIVING RESIDENCES

Platte	Facility Type	Beds	Name	City
100-yr flood	Assisted Living Residence	10	Wellington Assisted Living	Wellington, CO
100-yr flood	Assisted Living Residence	8	Golden Elders-Littleton	Littleton, CO
100-yr flood	Assisted Living Facility	42	Primrose Retirement of Grand Island	Grand Island, NE
100-yr flood	Assisted Living Facility	64	Orchard Gardens	Valley, NE
100-yr flood	Nursing Home	53	Birchwood Manor of North Bend	North Bend, NE
100-yr flood	Nursing Home	329	Grand Island Veterans Home	Grand Island, NE
100-yr flood	Assisted Living Facility	48	Grand Island Veterans Home	Grand Island, NE
100-yr flood	Nursing Home	66	Golden LivingCenter - Valhaven	Valley, NE
500-yr flood	Nursing Home	95	Woodridge Park Nursing And Rehabilitation Center	Commerce City, CO
500-yr flood	Nursing Care Facility	60	Douglas Care Center LLC	Douglas, WY
500-yr flood	Assisted Living Residence	10	Ashley Manor at Parfet	Wheat Ridge, CO
500-yr flood	Nursing Home	105	Woodridge Terrace Nursing and Rehabilitation	Commerce City, CO
500-yr flood	Assisted Living Residence	16	Veranda's Assisted Living at Wheat Ridge II	Wheat Ridge, CO
500-yr flood	Assisted Living Residence	16	Veranda's Assisted Living at Wheat Ridge I	Wheat Ridge, CO
500-yr flood	Nursing Home	24	The Suites at Holly Creek Health Center	Centennial, CO
500-yr flood	Assisted Living Residence	46	Suites at Holly Creek Assisted Living	Centennial, CO
500-yr flood	Assisted Living Residence	10	Mesa House	Commerce City, CO
500-yr flood	Assisted Living Facility	69	Premier Estates	North Platte, NE
500-yr flood	Assisted Living Facility	90	Hotel Pawnee	North Platte
500-yr flood	Assisted Living Facility	57	Linden Estates	North Platte
500-yr flood	Nursing Home	125	Linden Court	North Platte
500-yr flood	Nursing Home	71	Premier Estates Senior Living Community	North Platte, NE
500-yr flood	Nursing Home	64	Central City Care Center	Central City, NE
500-yr flood	Assisted Living Facility	50	Cottonwood Estates	Central City, NE

Platte	Facility Type	Beds	Name	City
500-yr flood	Assisted Living Facility	18	Live Inc.	Central City, NE
500-yr flood	Assisted Living Facility	43	Merrick Manor Assisted Living	Central City, NE
500-yr flood	Nursing Home	66	Plum Creek Care Center	Lexington, NE
500-yr flood	Nursing Home	131	The Ambassador Lincoln	Lincoln, NE
500-yr flood	Nursing Home	39	Nye Pointe	Fremont, NE
500-yr flood	Nursing Home	147	Arbor Manor Living Center	Fremont, NE
500-yr flood	Assisted Living Facility	47	Pathfinder House	Fremont, NE
500-yr flood	Assisted Living Facility	14	Edgewood Vista Fremont	Fremont, NE
500-yr flood	Assisted Living Facility	50	Nye Courte Retirement Community	Fremont, NE
500-yr flood	Nursing Home	100	Nye Legacy	Fremont, NE
500-yr flood	Assisted Living Facility	100	Shalimar Gardens Assisted Living	Fremont, NE
500-yr flood	Nursing Home	81	Pearl Street Health and Rehabilitation Center	Englewood, CO
500-yr flood	Assisted Living Facility	50	Liberty House	North Platte, NE
500-yr flood	Nursing Home	68	Centennial Park Retirement Village	North Platte, NE
500-yr flood	Assisted Living Facility	57	Centennial Park Retirement Village	North Platte, NE
500-yr flood	Assisted Living Facility	8	Life Essentials Assisted Living	Central City, NE
500-yr flood	Assisted Living Facility	29	Wel-Life at Plum Creek	Lexington, NE
500-yr flood	Assisted Living Facility	20	Central Assisted Living	Central City, NE
500-yr flood	Nursing Home	120	Sable Care and Rehabilitation Center	Aurora, CO
500-yr flood	Nursing Home	63	Good Samaritan Society - Wood River	Wood River, NE

TELECOM WIRE CENTERS

Platte	Wire Center Code	Wire Line Capacity	Number of ILEC Exchanges	Wireless Capacity	City
100-yr flood	ARCHNEXC	10000	1	0	Archer, NE
100-yr flood	ASLDNEXL	10000	1	0	Ashland, NE
100-yr flood	CLRKNEXS	20000	1	10000	Clarks, NE
100-yr flood	BRFDCOMA	152000	21	0	Broomfield, CO
100-yr flood	DNPHNEXM	10000	1	0	Doniphan, NE
100-yr flood	GLDNCOMA	105000	15	0	Golden, CO
100-yr flood	HRSHNEXS	10000	1	0	Hershey, NE
100-yr flood	RYMNNEXL	9000	2	0	Raymond, NE
100-yr flood	STLDNEXH	8000	3	0	Sutherland, NE
100-yr flood	WSTNNEXM	10000	1	0	Weston, NE
100-yr flood	YUTNNEXL	9000	1	0	Yutan, NE
100-yr flood	DNTNNEXL	7000	4	0	Denton, NE

Platte	Wire Center Code	Wire Line Capacity	Number of ILEC Exchanges	Wireless Capacity	City
100-yr flood	EVRGCOMA	31000	4	0	Evergreen, CO
100-yr flood	ITHCNEXL	9000	1	0	Ithaca, NE
100-yr flood	NBNDNEXC	10000	1	0	North Bend, NE
100-yr flood	MXWLNEXS	10000	1	0	Maxwell, NE
100-yr flood	PXTNNEXS	10000	1	0	Paxton, NE
100-yr flood	WVRLNEXL	8000	3	0	Waverly, NE
500-yr flood	DNVRCONE	69000	11	0	Commerce City, CO
500-yr flood	FRMTNENW	28000	5	0	Fremont, NE
500-yr flood	NPLTNENW	39000	4	10000	North Platte, NE
500-yr flood	CNCYNENW	9000	2	0	Central City, NE
500-yr flood	LXTNNENW	10000	1	0	Lexington, NE
500-yr flood	VLLYNENW	6000	3	0	Valley, NE
500-yr flood	SPFDNENW	3000	2	0	Springfield, NE

ACRONYMS

BEA	U.S. Bureau of Economic Analysis
CO2	Carbon Dioxide
CMIP5	Coupled Model Intercomparison Project Phase 5
DHS	U.S. Department of Homeland Security
DSL	Land line and Internet Access that Use Local Telephone Network Wires
EDMP	The Equilibrium Displacement Mathematical Program
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GCM	Global Climate Model
GDP	Gross Domestic Product
GIS	Geographic Information System
HUC	Hydrologic Unit Code
I-O	Input-Output
IPCC	International Panel on Climate Change
MW	Megawatt
NAICS	North American Industry Classification System
NCA	National Climate Assessment
NCADAC	National Climate Assessment and Development Advisory Committee
NISAC	National Infrastructure Simulation and Analysis Center
OCIA	Office of Cyber Infrastructure and Analysis
REAcct	Regional Economic Accounting Tool
RIMSII	The Regional Industrial Multiplier System
TDS	Total Dissolved Solids
VIC	Variable Infiltration Capacity
VSL	Value of statistical life

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