U.S. DEPARTMENT OF ENERGY

Effects of Climate Change on Federal Hydropower

Report to Congress
August 2013

United States Department of Energy
Washington, DC 20585

Message from the Assistant Secretary for Energy Efficiency and Renewable Energy

The Department of Energy is responding to Section 9505 of the Secure Water Act of 2009 (Omnibus Public Lands Act, Pub. L. No 111-11, Subtitle F), which requested the Department to submit a report to Congress on the observed and projected impacts of global climate change on federal hydropower generation. In response, the Department conducted a new, nationwide study of these impacts using climate modeling as well as hydrological and hydropower generation data. As required, the assessment was done in consultation with the United States Geological Survey, the National Oceanic and Atmospheric Administration, and the appropriate state water resource agencies.

This report summarizes the findings of the study as well as proposed operational responses to the predicted impacts from each Federal Power Marketing Administration.

Pursuant to statutory requirements, this report is being provided to the following Members of Congress:

- **The Honorable Ron Wyden**
  Chairman, Senate Committee on Energy and Natural Resources

- **The Honorable Lisa Murkowski**
  Ranking Member, Senate Committee on Energy and Natural Resources

- **The Honorable Fred Upton**
  Chairman, House Committee on Energy and Commerce

- **The Honorable Henry Waxman**
  Ranking Member, House Committee on Energy and Commerce

If you have any further questions, please contact me or Mr. Brad Crowell, Acting Assistant Secretary for the Office of Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely yours,

Dr. David T. Danielson

Executive Summary

As directed by Congress in Section 9505 of the SECURE Water Act of 2009 (Public Law 111-11), the U.S. Department of Energy (DOE), in consultation with the federal Power Marketing Administrations (PMAs) and other federal agencies, has prepared a comprehensive assessment examining the potential effects of climate change on water available for hydropower generation at federal facilities and on the marketing of that power. The results from the "9505 Assessment" are summarized here in this Report to Congress. The 9505 Assessment, the details of which are available separately,[1] included: 1) a historical analysis of the sensitivity of federal hydropower operations to climate variables, 2) a climate modeling analysis that projected climate conditions and impacts to hydropower into the future, and 3) a literature review of other related climate studies for comparison to the 9505 modeling results. The assessment used consistent methods across all PMA regions, to enable nationwide policy analysis.

Federal hydropower is an important part of the national renewable energy portfolio, because it accounts for approximately half of the U.S.'s installed conventional hydropower capacity. The 9505 Assessment quantified, for the first time at a national level, how federal power responds to water availability. Computer simulation models were used to make projections of regional climate conditions for 30 years into the future in each PMA region. Output variables included annual and seasonal estimates of air temperature, precipitation, runoff, frequency of occurrence of wet and dry water years, and an index of drought severity. Results show how changes in climate could affect both the timing and total amounts of runoff, though the patterns of possible changes are both spatially and temporally complex. Future changes to precipitation and runoff could potentially impact hydropower generation, water quality and supply, critical species habitat, and other important water uses that indirectly affect hydropower generation. At a national level, the median decrease in annual generation at federal projects is projected to be less than 2 billion kWh (2% of total), with a relatively high climate-model uncertainty.[1] While these estimates are similar to the recently observed variability of generation from federal hydropower and may appear to be manageable, extreme water years (both wet and dry) will pose significantly greater challenges to water managers, especially in water systems that have more limited reservoir storage and operational flexibility.

The 9505 Assessment gives federal hydropower administrators the opportunity to plan their operational or contracting responses to these changes. Recommendations from the PMA administrators on how they can respond to the effects of climate change are included as part of this Report to Congress. The future assessments that are required every five years under Section 9505 can be improved by incorporating improved climate models and data that will become available soon, closer examination of extreme events and longer-term change in more detail, and addressing the interactions among hydropower and other water uses.

EFFECTS OF CLIMATE CHANGE ON FEDERAL HYDROPOWER

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I. Legislative Language

This report responds to legislative language set forth in Section 9505 of The SECURE Water Act of 2009 (Omnibus Public Lands Act, Pub. L. No. 111-11, Subtitle F), wherein it is stated:

"(a) Duty of Secretary of Energy- The Secretary of Energy, in consultation with the Administrator of each Federal Power Marketing Administration, shall assess each effect of, and risk resulting from, global climate change with respect to water supplies that are required for the generation of hydroelectric power at each Federal water project that is applicable to a Federal Power Marketing Administration.

(b) Access to Appropriate Data-

(1) IN GENERAL- In carrying out each assessment under subsection (a), the Secretary of Energy shall consult with the United States Geological Survey, the National Oceanic and Atmospheric Administration, the program, and each appropriate State water resource agency, to ensure that the Secretary of Energy has access to the best available scientific information with respect to presently observed impacts and projected future impacts of global climate change on water supplies that are used to produce hydroelectric power.

(2) ACCESS TO DATA FOR CERTAIN ASSESSMENTS- In carrying out each assessment under subsection (a), with respect to the Bonneville Power Administration and the Western Area Power Administration, the Secretary of Energy shall consult with the Commissioner to access data and other information that--

(A) is collected by the Commissioner; and

(B) the Secretary of Energy determines to be necessary for the conduct of the assessment.

(c) Report- Not later than 2 years after the date of enactment of this Act, and every 5 years thereafter, the Secretary of Energy shall submit to the appropriate committees of Congress a report that describes--

(1) each effect of, and risk resulting from, global climate change with respect to--

(A) water supplies used for hydroelectric power generation; and

(B) power supplies marketed by each Federal Power Marketing Administration, pursuant to--

(i) long-term power contracts;

(ii) contingent capacity contracts; and

(iii) short-term sales; and

(2) each recommendation of the Administrator of each Federal Power Marketing Administration relating to any change in any operation or contracting practice of each Federal Power Marketing Administration to address each effect and risk described in paragraph (1), including the use of purchased power to meet long-term commitments of each Federal Power Marketing Administration.."

II. Methodology

The required report, *Assessment of the Effects of Climate Change on Federal Hydropower,*[1] was prepared by DOE's Office of Energy Efficiency and Renewable Energy, which engaged Oak Ridge National Laboratory (ORNL) to prepare an assessment of climate change effects on federal hydropower (herein referred to as the "9505 Assessment").

The 9505 Assessment provides a consistent and quantitative analysis of potential climate change effects across all four of the Power Marketing Administration (PMA) regions, enabling inter-regional comparisons at a national level. The four PMAs considered are: Bonneville Power Administration (BPA or Bonneville), Southeastern Power Administration (SEPA or Southeastern), Southwestern Power Administration (SWPA or Southwestern), and Western Area Power Administration (WAPA or Western). A new, integrated database was assembled to describe hydrology and hydropower at a regional scale for each of the PMA regions, and those data were used to describe the baselines for current climate and annual generation patterns. Future climate was simulated with a series of global and regional models (CCSM3,[2] RegCM3,[3] and VIC[4] described below), and model outputs were adjusted to be consistent with observed data for the recent past. This modeling framework enabled current climate conditions to be projected into near-term (2010-2024) and mid-term (2025-2039) periods and effects on hydropower generation at federal projects to be estimated. The full 9505 Assessment report contains more details and discussion and is accessible at ORNL's website.[5]

Scope and regionalization

The federal hydropower that is marketed through PMAs is generated from 132 power plants that are owned and operated by the U.S. Army Corps of Engineers (USACE), the Bureau of Reclamation (Reclamation) or the International Boundary Water Commission (IBWC)[6] (Figure 1). The scope of the 9505 Assessment was limited to these federal hydropower projects. Hydropower projects owned by the Tennessee Valley Authority (TVA) were not considered in the 9505 Assessment because TVA is not a PMA nor is the power produced at TVA's projects marketed by a PMA. Each of the four PMAs constituted a separate assessment region, and hydropower projects were grouped into specific assessment areas based on river basin hydrology and power systems (see Appendix for the definition of regions and assessment areas, plus more detailed maps of these areas).

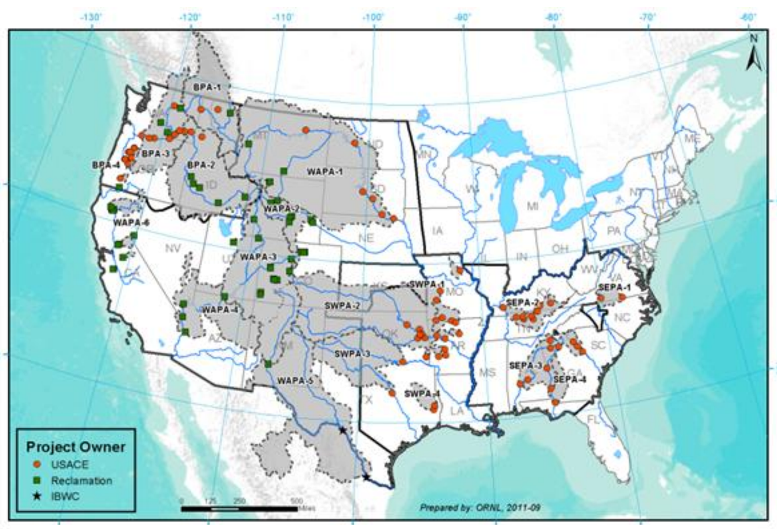

Figure 1. Regions and hydropower projects evaluated in the 9505 Assessment (see Appendix for details).

Integrated database

The 9505 Assessment required access to data from a wide range of sources (Table 1). The description of the federal hydropower infrastructure came from products of another DOE-funded project, the National Hydropower Asset Assessment Project (NHAAP), which is designed to build better understanding of hydropower in the U.S.[7] The core of NHAAP is a newly-created Water Power Geographic Information System (GIS) database that contains hydropower-related data from the following agencies: the U.S. Energy Information Administration (EIA), the Federal Energy Regulatory Commission (FERC), USACE, Reclamation, U.S. Geological Service (USGS), and TVA. It includes data on power generation, plant capacity, turbine types and ages, dam characteristics, historic streamflow records, stream segments, and meteorological observations. The resulting database contains a great deal of information needed to undertake this assessment of federal hydropower.

The primary variable used to evaluate water availability for hydropower is runoff, as defined by the USGS.[8] Unlike observations from stream gauges that report streamflow discharge at specific river locations, runoff represents the streamflow availability aggregated over a watershed area or river basin. Runoff is generally estimated by dividing the observed discharge

Table 1. Contents of the integrated database used in the 9505 Assessment.

Data Types	*Data Sources*
Hydropower Project Characteristics	• National Hydropower Asset Assessment Project (NHAAP)[9] • Form 860 Database, EIA • National Inventory of Dams (NID),USACE • Hydropower Asset Management Partnership (HydroAMP), Reclamation/Hydro-Québec/USACE/Bonneville
Hydropower Generation	• Form 906, 920, and 923 Database, EIA • Reclamation • USACE • PMAs
Observed Runoff and Streamflow	• WaterWatch Program, USGS[10] • HYDAT Database, Environment Canada
Observed Temperature and Precipitation	• Inside U.S., PRISM Research Group, Oregon State University[11] • Outside U.S., University of Delaware Air Temperature & Precipitation[12]
Watershed Boundary	• Watershed Boundary Dataset (WBD), National Resources Conservation Service (NRCS) • National Hydrography Dataset (NHD), USGS/EPA
Topography	• Global 30 Arc Second Elevation Data (GTOPO30), USGS
Land Cover	• Moderate Resolution Imaging Spectroradiometer (MODIS), NASA
General Circulation Model (GCM)	• Community Climate System Model version 3 (CCSM3)[13]
Regional Climate Model (RCM)	• Abdus Salam International Center for Theoretical Physics Regional Climate Model version 3 (RegCM3)[14]
Hydrologic Model	• Variability Infiltration Capacity (VIC) model[15]
Projected Monthly Temperature and Precipitation	• CMIP3 Bias Corrected and Spatially Downscaled (BCSD) dataset,[16] as used in the Secure Water Act Section 9503 assessment[17]

of a river by its corresponding drainage area, and it is measured in units comparable to precipitation (volume per unit area, or depth, per unit time). Therefore, runoff can be compared to precipitation to understand how much effective rainfall has eventually become streamflow. The USGS WaterWatch Computed Runoff is available in terms of monthly time series, from 1901 to the present, for each subbasin (8-digit hydrologic unit) defined in the National Resources Conservation Service's Watershed Boundary Dataset.

For watershed areas inside the U.S., the existing air temperature and precipitation characteristics were defined by data from the PRISM Climate Group at Oregon State University,[18] which is widely recognized as an extremely high-quality source for spatial data of this kind. The PRISM acronym stands for Parameter-elevation Regressions on Independent Slopes Model, indicating that data values are calculated with a weighted climate-elevation regression to compute the areal average of meteorological observations from gauge networks. The monthly PRISM output is grid-based and available at 4-km by 4-km spatial resolution from 1895 to the present for the conterminous U.S. For areas outside the U.S., data from the University of Delaware was used.[19]

Climate modeling

The climate simulation modeling used in the 9505 Assessment involved a series of three models (Figure 2). The second step of regional downscaling included an important process called bias correction, which adjusted model output to be consistent with recent climate conditions. In the case of the 9505 Assessment, the bias adjustment period was 1960-1999. One set of models and one emission scenario were applied consistently across all regions.

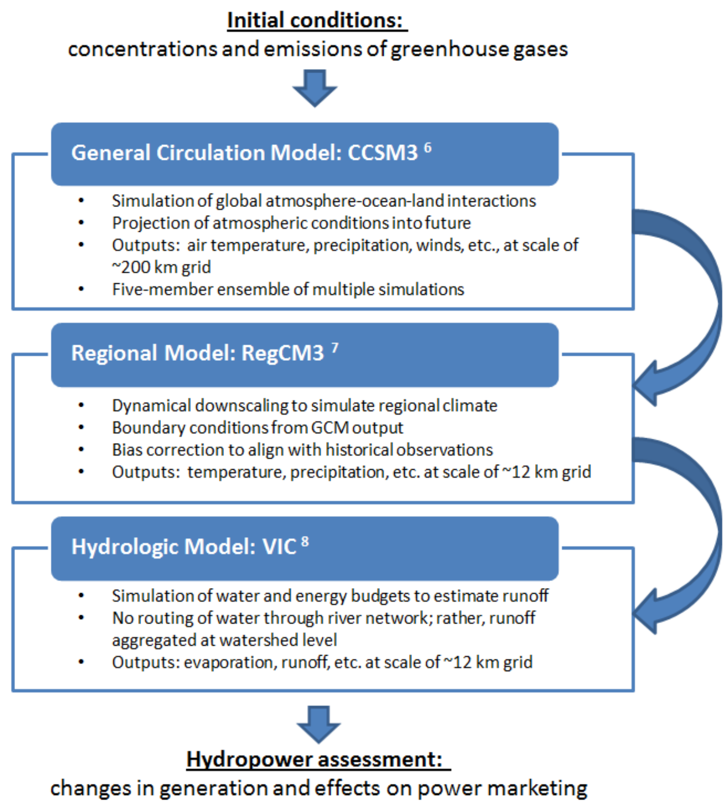

Figure 2. Simulation models applied to project future climate conditions.

The General Circulation Model (GCM) used in the 9505 Assessment was the Community Climate System Model version 3 (CCSM3),[20] a global climate model sponsored by the National Science Foundation and DOE.[21] GCMs of this type produce estimates of future climate conditions over long periods of time by simulating large-scale mass and energy exchange mechanisms across the globe, by solving three-dimensional governing equations for the atmosphere, ocean, and land surface. GCM outputs were not interpreted as absolute or deterministic predictions of future conditions on specific dates. Rather, the GCM was run multiple times with slightly different initial conditions. The probability distributions of the outputs were analyzed over seasons and annual periods. The ensemble of GCM outputs for the 9505 Assessment consisted of five simulation runs, driven by one scenario of greenhouse gas emissions.[22] The emission scenario used to drive the GCM model was the A1B scenario, which contained moderately high emissions that are most comparable to recent observations.[23,24]

The regional downscaling model used was the Regional Climate Model version 3 (RegCM3), developed at the International Centre for Theoretical Physics.[25] A regional climate model (RCM) is conceptually similar to a GCM but focuses on specific regions rather than the entire globe. By adjusting the RCM parameters to reach a good agreement between GCM and RCM outputs on the spatial boundary, the RCM was used to reproduce all GCM variables at a much finer resolution. A simulation ensemble of five members was used to represent model uncertainty and variability. A well-documented bias correction technique was then utilized to re-scale the RCM-downscaled temperature and precipitation to the observed ones from PRISM.[26] The bias correction technique improved the performance of the subsequent hydrologic simulation and preserved the projected climate change trends.

The hydrologic model applied in the 9505 Assessment was the widely-used Variability Infiltration Capacity (VIC) model that originated at the University of Washington.[27] With downscaled daily precipitation, maximum/minimum temperature, and wind speed as inputs, VIC computed potential evapotranspiration.[28] The water and energy balance was solved with multiple vegetation types and soil layers, which allowed for the variability of land surface features to be represented at a subgrid level. For each individual grid cell, VIC estimated the water budget of daily evaporation, snow pack, moisture storage, faster-response surface runoff, and slower-response baseflow. Routing of runoff through river networks to specific dam locations was not used in the 9505 assessment; rather, the runoff variable used was the sum of all grid cell within a watershed over the annual or seasonal period examined. The VIC model was also used in the Section 9503 assessment that was conducted by Reclamation under the SECURE Water Act.[29]

Interagency consultation and review

The accuracy and applicability of the 9505 Assessment benefited greatly from extensive consultations with other federal agencies, as directed by Congress in the SECURE Water Act, and from a thorough technical review that was consistent with the Office of Management and Budget's policies on information quality. The DOE team that conducted the 9505 Assessment worked closely with technical staff from the PMAs, Reclamation, and USACE to ensure consistency of methods and data. A review draft of the 9505 Assessment was prepared in July 2011 and subjected to a comprehensive peer review, which included USGS and NOAA scientists; results of that review are summarized in the final 9505 Assessment report.[30]

III. Findings

The major findings of the 9505 Assessment are summarized here; complete details are contained in the final 9505 Assessment report.[31]

Federal hydropower systems

There are more than 95 gigawatts (GW) of hydropower projects operating in the U.S. today, including conventional and pumped-storage hydropower. Of this installed capacity, approximately 77 GW are conventional hydropower. In 2009, the hydropower industry (federal and non-federal) generated more than 270 billion kilowatt-hours (kWh) of electricity, accounting for 65% of total renewable electricity generation.[32] Approximately half of the installed capacity of conventional hydropower in the U.S. is located at federal facilities. There are significantly more non-federal projects than federal projects, but the average federal project is much larger in size.

The USACE owns and operates 75 hydropower plants with a total capacity of 21.5 GW in 16 states, from Washington to Georgia (Figure 1). USACE hydropower plants are almost all integrated into multipurpose water projects which function to provide diverse water uses, including flood control, navigation, water supply, water quality protection, and ecosystem restoration. In addition to USACE's federally owned hydropower plants, there are another 90 non-federal hydropower plants located at USACE dams that have an additional 2.3 GW of capacity[33,34]—these are not considered in the 9505 Assessment because the power from those projects is not marketed by PMAs. Non-federal power plants at federal dams are regulated by FERC.

Reclamation owns and operates 58 federal hydropower plants that generate power for either Bonneville or Western, with a total capacity of 15.1 GW in 11 western states (Figure 1).[35] Reclamation's mission is to manage, develop, and protect water and related resources in an environmentally and economically sound manner. Reclamation reservoirs are operated for multiple purposes, including municipal and industrial water supplies, hydropower, irrigation water for agriculture, water quality improvement, flood control, river navigation, river regulation and control, fish and wildlife enhancement, outdoor recreation, and water-related research. The primary use of the power from Reclamation projects is for delivering water to meet the other, nonpower authorized purposes of the projects. Power in excess of that used in water delivery is sold to preferred customers through PMAs.

IBWC owns and operates two small hydropower projects on the Rio Grande River, with a total installed capacity of 100 megawatts.

Although federal hydropower projects are owned and operated by USACE and Reclamation, electricity produced at federal hydropower projects is marketed and distributed by the PMAs, which are part of DOE.[36] The federal power marketing program began in the early 1900s, when

Table 2. Comparison of Federal hydropower among the power marketing regions.

Region	*Hydropower plants*	*Installed capacity (GW)*	*Number of wholesale customers*	*Average Annual Generation (billion kWh)*	*Percent of regional electricity sales*	*Average Annual Revenue (million)*
Bonneville	31	20.5	276	77.3	35	$2,306
Western	55	10.2	682	29.7	4	$973
Southwestern	24	2.2	102	5.8	1.4	$164
Southeastern	22	4.1	489	7.8	1.0	$242
TOTAL	**132**	**37.0**	**1,549**	**120.6**	**n/a**	**$3,685**

excess hydropower produced at federal projects was sold to repay the government's investment in the projects, with interest. PMAs market power from federal projects at the lowest possible rates to preference customers, consistent with sound business principles, so as to encourage the most widespread use of federal assets. If excess power is available beyond the needs of preference customers, the PMAs may sell surpluses to non-preference entities. There are a number of important differences among the PMAs that account for both operational differences and differences in the effects and risks of climate change (Table 2). The most important differences are: originating legislation and statutory authorities, especially with respect to financing; relative size of their contribution to the total regional electricity market; role in electricity transmission; and number and size of power systems. Each of the four PMAs is a distinct and self-contained entity within DOE, much like a wholly owned subsidiary of a corporation.

Bonneville is the largest of the PMAs in terms of total hydroelectric capacity and annual generation, with more than 20 GW of installed capacity managed as the Federal Columbia River Power System (FCRPS), one integrated power system. Federal power sales from the FCRPS accounts for approximately 35% of total electricity demand in Bonneville's region. Currently, Bonneville is the only PMA that has the authority to directly finance the operations and maintenance (O&M) costs at federal projects and to develop or acquire new power resources to support customer load growth. Western is the largest PMA in terms of total area (Figure 1), but its hydropower projects are dispersed into ten different power systems and federal power sales only account for 4% of regional electricity demand in its 15-state service territory. At some projects (e.g., the Boulder Canyon Project), Western has similar financing authority to Bonneville, but not at all of its hydropower projects.[37] Western does not have the authority to acquire new power resources to meet load growth in the future. Southwestern and Southeastern power sales account for approximately 1% each of regional electricity demand.

Water availability and hydropower

Hydropower generation at federal facilities varies from year to year for a number of reasons, including variations in weather and runoff, changing condition of hydropower equipment, competing water demands from non-power uses, and environmental requirements, such as for the protection of species listed under the Endangered Species Act. The data assembled for the 9505 Assessment showed how sensitive federal hydropower projects are to available water, as represented by runoff. With exceptions of the Rio Grande and lower Apalachicola rivers, the annual generation in assessment areas was highly correlated with observed runoff values (observed data from USGS). In 16 of the 18 assessment areas, runoff variability explained from 66% to 98% of the variation in annual generation. In four of the areas in Western's region, generation was more related to multi-year runoff than single-year runoff—this was due to the presence of very large surface water reservoirs that carry over water from one year to another. These empirical relationships between generation and runoff were key tools in the 9505 Assessment because they enabled projected changes in future runoff to be translated into projected changes in annual generation.

The observed climate conditions over the past 40 years were described to provide a baseline against which to compare projections of future climate. In many locations, current climate conditions are already changing.[38,39] Baseline trends are discussed in the full 9505 Assessment report.[40]

Future climate and effects on generation

The 9505 Assessment estimated potential changes to the following climate variables for 30 years into the future: air temperature, precipitation, annual and seasonal runoff, frequency of different water year types ("dry" defined as the lower 20 percentile, "normal" as the middle 60 percentile, and "wet" as the upper 20 percentile), and intensity of low-flow periods relative to current conditions. The following summary statements are the results of the 9505 Assessment in the river basins that provide water for federal hydropower projects.

Significant increases in temperature were projected in all regions and time periods, in the range of +2 to +4 Fahrenheit (F) degrees between now and 2039, relative to current conditions. In all regions, projected temperature change is greater for the mid-term period (2025–2039) than for the near-term (2010–2024). Much more variable trends were projected for precipitation and runoff, both spatially and temporally. Examples of the projected spatial variability in runoff, the primary measure of water availability, are shown in Figure 3. When the full, 80-year period from 1960 to 2039 is considered, the only statistically significant changes in seasonal runoff are summer decreases in the BPA and WAPA regions, and spring increases in two northern WAPA regions.[41] The full 9505 Assessment contains complete quantitative estimates of these future climate variables for the near-term and mid-term periods.[42]

In the Bonneville region, annual precipitation was projected to be comparable to the recent historical record in all of the assessment areas, but seasonal patterns were estimated to change. Summer precipitation was projected to decrease while spring and fall precipitation was projected to increase everywhere except in the Cascade area. In the Cascade area, summer precipitation was projected to decrease, while only fall precipitation increases. Winter precipitation is not projected to change significantly in any of the Bonneville areas, indicating that most of the precipitation changes will be changes in timing of rainfall rather than in annual totals: generally drier summers and wetter spring and fall seasons.

Projected changes in runoff in the Bonneville region are different from precipitation because of the influence of increasing air temperatures on the timing of snowmelt and the amount of evaporation. The largest change projected for this region was for summer runoff, which was projected to decrease 20% or more in all areas. Reductions in summer runoff were projected to be greater in the mid-term than in the near-term. The frequency of dry water years was projected to increase from 2 dry years per decade to 3 per decade in all areas. The intensity of low-flow periods could increase (i.e., less available water in periods of drought) by as much as 30% to 40% in the summer when they do occur, compared to current conditions.

The projected changes in runoff in the Bonneville region translate into potential changes of annual hydropower generation from the FCRPS (Figure 4). In the near-term period (2010-2024), the mean change in annual generation for Bonneville was projected to be an increase of 1.3 billion kWh, less than 2% relative to the historic mean generation from 1989-2008. In the mid-term period (2025-2039), the mean change in annual generation for Bonneville was projected to be an increase of 2.6 billion kWh, 3.3% relative to the mean observed generation (Figure 4). The range of change in annual generation among five ensemble members is between +4 to -5 billion kWh in the near-term period, relative to current conditions – more explanation of this is in the full 9505 Assessment Report.[43] The variability of annual hydropower generation experienced at the federal projects in Bonneville's region over the past two decades was similar in magnitude to these projections of climate-related change.

In the Western region, annual precipitation was projected to be generally comparable to baseline conditions, except in the upper Missouri and Rio Grande areas. In the upper Missouri River area annual and summer precipitation were projected to increase. In the Rio Grande area drier conditions were projected to occur in the summer, fall and winter seasons. Lower seasonal precipitation was projected throughout the Colorado River in fall and winter, as well as in the lower Colorado in the summer. In the Central Valley of California, precipitation was projected to decrease in the summer and increase in the fall.

Except for the upper Missouri River area, runoff throughout the Western region was projected to decrease to a greater extent than precipitation. In the upper Missouri River, runoff was projected to increase in all seasons. In almost all other Western areas, summer and fall runoff were projected to be lower than current conditions. The Rio Grande River was projected to have lower runoff in all seasons, especially the winter, and changes there were greater in the later time period (Figure 3). The northern Central Valley of California was projected to have less runoff in the spring and summer seasons, more runoff in the fall season, but relatively no change in annual or winter runoff.

In the Western region, mean annual hydropower generation was projected to increase for both near-term and mid-term periods, based on the 9505 results (Figure 4). This trend is due to projected increases in runoff mostly in the upper Missouri River, a finding that is generally consistent with other studies conducted for the SECURE Water Act.[44] The Western region also

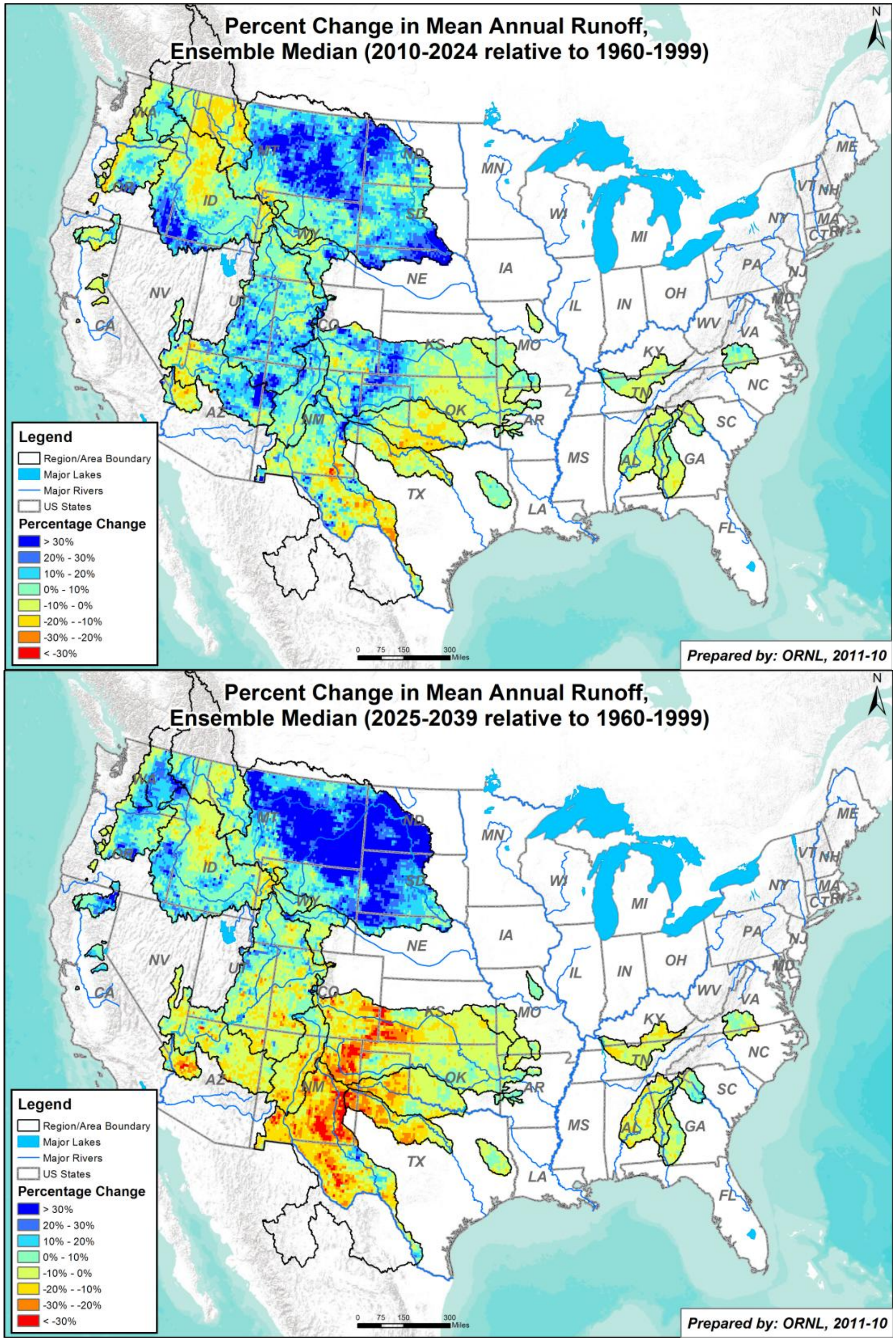

Figure 3. Examples of the spatial patterns of projected changes in future annual runoff.[45]

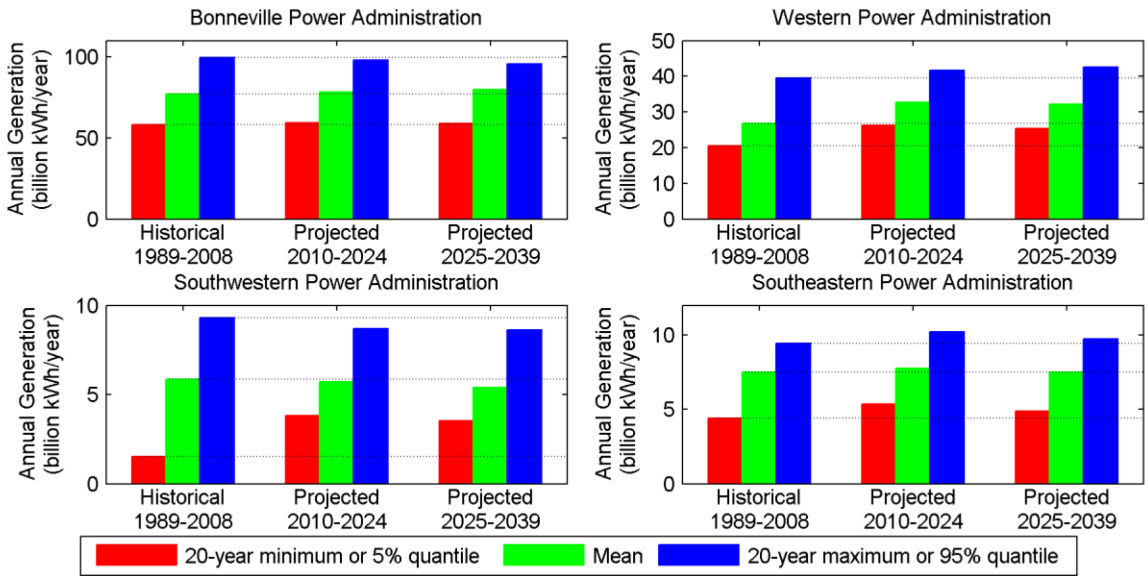

Figure 4. Historical and projected annual generation for near-term (2010–2024) and mid-term (2025–2039) periods for each PMA region (historical values are the lowest and highest years in the 20-year record, while projected values are the comparable 5% and 95% qualities over all ensemble members for a 15-year period).

has relatively large reservoir storage capabilities. These reservoirs can compensate for periods of low water to some degree and mitigate changes in annual hydroelectric generation.

However, the projected increase in generation may not be fully realized if the short-term rate of runoff exceeds the hydraulic capacity of reservoir systems, or if changes in reservoir operations to accommodate competing water uses reduce storage volumes available for power. Increasing challenges with flood operations are likely to occur in the northern parts of both Bonneville's and Western's regions.[46] Examination of these site-specific issues was beyond the scope and capabilities of this first 9505 assessment. In other parts of Western's region, projected total changes in generation were smaller and more variable than in the Missouri River. Mean projected changes in annual generation for the whole Western region were an increase of 6 billion kWh (22%) in the near-term and 5.5 billion kWh (20%) in the mid-term, relative to the historical baseline of 1989-2008 (Figure 4).

In the Southwestern region, as with other regions, runoff was projected to change more than precipitation, due to higher air temperatures that will lead to more evapotranspiration and a lower ratio of runoff to precipitation. All areas of the Southwestern region were projected to experience drier summer seasons. Precipitation in the spring, fall and winter seasons was projected to be generally similar to current conditions.

The 9505 projections for future runoff in the Southwestern region indicated the strongest changes in summer runoff. Spring runoff is historically the greatest in the Southwestern region, and projections show the potential for spring runoff to increase, especially in the area of the

Arkansas River. However, total annual runoff is relatively unaffected, because shifts in seasonal runoff tend to balance each other. The Texas coastal area projections differ from the rest of the region, as total, summer, and fall runoff do not show as much of the decreasing trends as other areas. Projected drying patterns in the Southwestern region show the frequency of dry water years could increase by one or two events per decade, compared to two per decade now, and the low-flow periods could be 10% to 30% more intense (i.e., drier) than they have been in the last two decades.

The mean 9505 projections for hydropower generation in the Southwestern region indicated a 0.1 billion kWh (1.8%) reduction in the near term and 0.5 billion kWh (7.7%) reduction in the mid-term period, relative to the historic observation from 1989-2008 (Figure 4). The range of change among the five ensemble members is relatively large so there is the potential for year-to-year uncertainty in hydropower operations.[47] Over the most recent 20 years, Southwestern's total annual generation has varied from a high of 9.32 billion kWh in 1993 to a low of 1.54 billion kWh in 2006, representing a range of -75% to +55% of the median generation during that time period. Although it is projected that there will be more frequent dry water years in the future in this region (i.e., one or two more dry years per decade by the mid-term period, depending on the subregion), the range of year-to-year annual system generation should be similar to what Southwestern has encountered in recent years.

The projected climate change patterns in the Southeastern region were different from the more western PMA regions, as might be expected. Increases in air temperature in the Southeastern region were projected to be in the same 2 to 4 degree range as the other regions except that the winter season was not expected to be significantly different than current conditions. Precipitation changes were also expected to be less different from current conditions, with a few important exceptions. Summer and fall precipitation were projected to increase in the Roanoke River in Virginia, while winter precipitation was projected to decrease. Annual and summer precipitation was projected to decrease in the Cumberland River of Kentucky and Tennessee, and annual precipitation was projected to decrease in the lower Apalachicola River of southern Georgia.

Changes in runoff in the Southeastern region were projected to be somewhat more intense than the changes in precipitation, similar to the Southwestern region. The Roanoke River could experience significantly higher runoff in the summer and fall seasons. The Cumberland River could have significantly lower runoff in all seasons except in summer. Total annual runoff in the Alabama and Savannah River systems was not projected to change much, but runoff in the spring and winter seasons could be lower while summer runoff could be higher. In the lower Apalachicola River, both annual and winter runoff was projected to decrease. There is predicted to be one or two more dry years per decade throughout the Southeastern region, compared to current conditions, and when low-flow periods do occur, they may be 10% to 30% more intense than now.

The mean projected change in annual federal hydropower generation for the Southeastern region is a 0.27 billion kWh (3.6%) increase in the near-term period and nearly no change in the mid-term period, relative to the historic observation from 1989-2008 (Figure 4). However, as in other regions, the range between high and low ensemble members is relatively large, indicating the likelihood of extreme water years and generation outputs. In the past 20 years, total annual generation from projects in this region has ranged between a maximum of 9.44 billion kWh in 1993 to a minimum of 4.29 billion kWh in 2008. Although the projected change in generation may add to this historic variability, and more dry water years are projected for the future, the range of annual generation in the Southeastern region is projected to be similar to the recent past.

Limits to the 9505 Assessment

The modeling approach developed for the 9505 Assessment proved defensible and efficient with respect to estimating potential future changes in annual runoff and hydropower generation. A new, integrated database was assembled to describe hydrology and hydropower at a regional scale for all four PMA regions, and those data were used to develop regression models of average annual generation as a function of runoff. Future climate was simulated with a series of global and regional models, and model outputs were adjusted to be consistent with observed data for the recent past. This modeling framework enabled current climate conditions to be projected into near-term (2010–2024) and mid-term (2025–2039) periods and to be estimated as to how changes in water availability would affect hydropower generation at federal projects. The 9505 Assessment results therefore fulfill the Congressional direction.

However, the assessment approach developed in this first 9505 report did not address some of the more detailed aspects of climate and hydropower, especially at shorter time intervals (e.g., monthly changes and extreme events) or dependent on local conditions (e.g., thermal habitat for fish). The assessment models also could not resolve project-specific conditions at each federal project without significantly more time and effort. The lack of consistent monthly hydrology and generation data was a major factor in limiting this first assessment. The site-specific complexities of surface water reservoir operations are another factor limiting assessment capabilities. In order to represent monthly or shorter hydrology in river basins where many multiple-use reservoirs are located, such as is the case in almost all federal hydropower systems, a much more detailed water-balance modeling approach would be needed. Such details were beyond the scope of this first 9505 Assessment.

The 9505 Assessment did not attempt to project climate change impacts to hydropower beyond 30 years into the future, because there are too many other non-climate issues that will interact with climate effects and that are dependent on policy decisions of several types. With only one emission scenario modeled, the first assessment also did not quantify uncertainty related to future emissions. Three of these non-climate factors are: 1) the type and efficiency of hydropower equipment as it is replaced and upgraded over time, 2) the reallocation of water storage in federal reservoirs to non-power uses, and 3) changing water management practices to meet new environmental requirements. Each of these factors has the potential to have greater impacts on federal power generation than climate change, at least at specific projects or river basins. Climate change will interact with these additional factors in both synergistic and antagonistic ways which cannot be quantified with existing assessment methods.

The range of projection estimates for hydropower over the next 30 years are generally similar to the recently observed year-to-year variability of generation from federal hydropower, and therefore may appear to be manageable over that time frame. However, extreme water years, both wet and dry, will pose significantly greater challenges to water managers. More importantly, longer-term changes in hydrology from both climatic shifts and competing, non-power water uses will definitely have additional impacts on federal hydropower—these longer-term, more complex, and site-specific impacts were not addressed in this first 9505 Assessment.

Preparing for Future Hydropower Assessments

Section 9505 of Secure Water Act instructed DOE to submit a first Report to Congress on climate effects to federal hydropower, then to repeat these assessments every five years through 2023. There are a number of ways that the assessment approach presented here can be improved for subsequent assessments:

- **Establish an ongoing monitoring, data collection, storage and analysis effort for hydropower plant operations and generation, with at least monthly resolution at all federal facilities.** Do this in cooperation with the PMAs and federal hydropower owners to produce a consistent database for tracking trends against baseline conditions. The integrated database contents would include water, power, climate, and financial information (e.g., monthly electricity prices at the NERC subregion level). Data on both energy supply and demand would be needed as well.

- **Develop a more detailed modeling approach to link project operations and climate variables to generation patterns and water resource management decisions at federal hydropower projects.** The regression approach used in this first 9505 Assessment (runoff versus generation) performed reasonably well, but it was limited in its ability to resolve seasonal and monthly changes. A new modeling approach that incorporates water storage, water surface elevation (i.e., head), and competing water uses throughout upstream watersheds would provide better understanding of future conditions and mitigation options. The VIC model that was used to estimate future runoff can be improved, especially in dry watersheds, or it could be replaced with more advanced hydrologic models. Improved methods for using more GCM simulations could be investigated, especially since new versions of climate models will be available soon as part of the next round of IPCC reports. The improved modeling capabilities would also enable more in-depth impact assessment of hydro-meteorological extremes on hydropower generation, especially for reservoir operation during the flood periods and competing water usage during the drought periods.

- **Integrate climate change assessment with other water resources planning activities, so that the full spectrum of factors affecting water availability and use can be considered together.** Climate change effects will not occur independent of other stressors on water availability, so interactions must be addressed as directly as possible. Cumulative impact assessment, including climate change effects, could be a goal to better inform hydropower planning and resource management policies. Ultimately, federal, including TVA, and non-federal hydropower could also be addressed together, given they operate with the same water resources and send their electricity into the same power grids. Other factors that could be considered in more integrated assessment include:
    - the water-use intensiveness of competing water uses and how those affect the overall availability of water supplies;
    - tradeoffs between hydropower and other sources of energy in a region as they affect GHG emissions and water resource impacts; and
    - benefits and costs of long-term investments in replacement and rehabilitation of the aging hydropower infrastructure.
- **Explore interactions among the power systems within each PMA and also between the PMAs and the larger electric reliability regions or markets in which they operate.** The PMA's specialization in hydropower makes them more vulnerable than other electric power marketers to the generation risk associated to climate change. Even though PMAs can pass purchased power expenditures through to their firm power customers, there is a threshold beyond which those customers might find better rates from alternative suppliers. The number of alternative suppliers and the correlation between their generation mix and that of the PMAs affect the probability of reaching that threshold.
- **Establish a regular interaction of hydropower interests and the community of scientists working to improve the models of future climates, so that the key variables affecting hydropower are incorporated into climate models.** This could be done via the DOE Office of Energy Efficiency and Renewable Energy and PMA participation on interagency coordination bodies, such as the Federal Climate Change and Water Working Group (CCAWWG) and the Interagency Climate Change Adaption Task Force. Hydropower industry and other stakeholders should be directly consulted in ongoing studies of climate change, so that products from such research are responsive to end-user needs.

IV. Recommendations from the Administrators

As called for in the SECURE Water legislation, the PMA Administrators have provided the following recommendations regarding potential changes in operation or contracting practices that may be needed in response to the effects of climate change. The following recommendations were based on the 9505 Assessment,[48] as well as other available information, such as the Secure Water Act 9503 study[49] and work in the Columbia River Basin by the River Management Joint Operating Committee (RMJOC).[50,51]

Bonneville Power Administration

The 9505 Assessment generally reinforces Bonneville's growing understanding of the potential impacts of climate change on the Northwest hydropower system. Although the 9505 methods and specific results differ somewhat from other recent studies, the general trends expressed in the 9505 Assessment are consistent with others. Existing research indicates that climate change will likely lead to warmer temperatures, declining snow pack, earlier winter-spring runoff, and reduced summer streamflows in Bonneville's region. The 9505 Assessment adds to the pool of information that will enable Bonneville to integrate climate change scenarios into the operations planning and modeling tools that inform their decision-making.

Operating through the RMJOC, Bonneville, Reclamation, and USACE, along with other regional parties, are conducting a long-term planning study of climate change impacts on the Northwest.[52] The RMJOC climate change study has an emphasis on flood control and hydropower generation impacts affecting the FCRPS. The RMJOC study uses the results from more GCMs and emission scenarios than did the 9505 Assessment, and other analysis methods are different. Due to these differences, the 9505 Assessment estimated larger reductions in future runoff than the RMJOC study.

The primary risks to Bonneville operations and contract practices that were identified in the 9505 Assessment are:

- Slight change in annual generation in the near-term and mid-term projection.
- Changes in seasonal generation, with decreases in the summer period.
- Increased risk to Cascade Basin projects' ability to maintain summer water quality and minimum flow objectives.
- Expectation that energy demand and use will increase as a result of higher air temperatures.
- Long-term increase in streamflow volatility resulting in reduced surplus sales, changes in seasonal pricing, and eventual increase in rates for customers.

Bonneville does not recommend any immediate changes to its operation or contracting practices in response to potential climate change effects. Bonneville will continue to study climate change projections and potential impacts, and has established a process to responsibly integrate climate change implications into their day-to-day operations when needed. An internal Climate Change Risk Management Team was created to identify any data gaps and research needs and to integrate the latest scientific information into the planning and decision-making process. For example, Bonneville will be integrating data from the RMJOC climate change study into its ongoing long-term planning efforts. Through continuous learning and adaptive management, Bonneville is striving to be responsibly informed on any decision to make changes in operations or contracting practices in the future.

For dam operations, the kind of weather and streamflow variability projected for the near-term to mid-term that has been produced from both the 9505 Assessment and other climate change studies is still within the variability seen in the 70-year historic water-year record. While changes may eventually be warranted before empirical data shows consistent data outside the historical record, current empirical weather events are still manageable for the near term under existing operational norms. As more research and results begin to solidify the trends, Bonneville's power operations and USACE's flood control operations may be reexamined to determine appropriate responses for optimal performance. The Intergovernmental Panel on Climate Change provides all its climate change data sets on line for public use. From this information, Bonneville and others can conduct new studies to update the current understanding of climate change in the Northwest and to further refine understanding through downscaled scenarios. These modeling and scenario activities will help Bonneville to:

- Optimize integration of flood control, hydropower generation, and fish and wildlife operations in the face of changing conditions.
- Adapt operational flexibility to manage more extreme events and changes in the timing of streamflows through storage and release.
- Consider investment in hydropower equipment upgrades.

The primary risks of climate change to Bonneville's contracting practices relate to electricity rates for customers. For power sales to requirements customers and associated contracts, over the next five years, the risks are minimal. In December 2008, Bonneville and its requirements customers signed long-term power contracts with delivery to begin in 2011. These contracts are take-or-pay contracts for prescribed amounts of power. These contracts anticipated potential on-going changes to the amount and timing of power from the FCRPS, whether these changes are due to climate change, fish and wildlife measures, or any other reason. Under the contracts, the amount customers pay for power may be affected by changes in the output capability of the FCRPS. Whether customer rates might be affected by stream flow changes as a result of climate change over time is a question that deserves some attention.

Bulk power trading is a function of the inventory estimates of available power from the FCRPS. Until such time as inventory changes measurably, contracting practices will continue to monitor the situation, but practices will not be altered. Scenario analyses will be conducted to examine different types of trading strategies. Long-term power contracts either already incorporate changing system conditions or may be examined in the future if implicated by scenario analysis. Short term sales may be examined in the future given inventory changes and if implicated by scenario analyses.

Looking forward, Bonneville is well positioned to further understand and adapt to any changes to the FCRPS that might emerge. Internal structures are being set up to enable a responsible and responsive approach to climate change. Through existing and evolving internal structures, Bonneville will be undertaking the following activities:

- Review research.
- Continually monitor new climate change research of the Northwest.
- Identify research gaps that may be important to the hydropower system.
- Assist efforts to fill pertinent research gaps.
- Apply the latest understanding and research to operational and resource planning in the form of additional scenarios and sensitivity analysis.
- Understand the hydro system vulnerabilities to climate change impacts.
- Consider potential responses to vulnerabilities.
- Consider stakeholder outreach on climate change issues.
- Determine when data and understanding warrant changes to Bonneville's operations or practices.
- Coordinate with other Federal agencies in communicating results and import of climate change studies.

Preparing thoroughly now with the best possible scientific data and policy analysis should put Bonneville in a good position to respond effectively and in a timely manner to the physical impacts of climate change as they emerge. Bonneville does acknowledge that due to the nature of climate change and our understanding thereof, some surprises may occur, so an integrated system of continual learning and adaptive management is the best way to prepare for an uncertain future.

Western Area Power Administration

Recommendations for Western's adaptations to mitigate potential climate change impacts to hydroelectric generation are generally limited to maintaining and improving the present capabilities of adapting to existing climate variability. Western currently has substantial capabilities for dealing with climate uncertainty and variability, including:

- large capacity for water storage in both surface reservoirs and natural ice and snow fields,
- good methods for forecasting hydrologic and operational conditions weeks and months into the future,
- use of contract terms allowing for adjustments in commitments of energy delivery, and
- the ability to make power purchases during drought periods and sell hydroelectric generation surplus during wet hydrologic conditions.

Western supplies only a portion of its customer's wholesale power requirements and is not obligated to meet any of its customers full load or load growth through hydropower resources (Western provides full load service to a small class of Sierra Nevada Region customers using non-federal generation). In all of Western's subareas, the Administrator's primary recommendation is to continue to maintain the ability for Western to change energy and capacity allocations within current and future contractual arrangements. Maintaining this type of flexibility now and in the future allows Western to adjust contractual commitments based on observed changes to generation over time, giving Western the most flexibility to meet power customers' needs.

In the Colorado River Basin, Western recommends that it continue to work with its customers and Reclamation in managing the operation of Hoover and Glen Canyon dams, and making equipment upgrades to the Lower Basin dams to successfully cope with the impacts from future climate changes in order to preserve their power production capabilities.

Western also recommends that work should proceed with ongoing efforts to improve the quality of hydroelectric modeling software for use by Western and Reclamation, and to improve the quality of runoff forecasting by the responsible state and federal agencies.

Southwestern Power Administration

Unlike river systems in other regions that contain large surface water reservoirs with the ability to store water over multiple years, Southwestern's river systems do not have large water storage capacity. The Southwestern region also lacks mountains with ice and snowpack that provide natural water storage. Southwestern's projects therefore must rely directly on rainfall for hydropower generation. While the 9505 Assessment does reveal the potential for impacts from climate change, particularly in the mid-term period, it also suggests that the long-term change due to climate variation should be within the natural variability that Southwestern already encounters. Nevertheless, Southwestern must remain alert to any factors that could impact inflows, storage, or project operation and, subsequently, hydropower generation capability in the Southwestern region. Of particular concern from the 9505 Assessment is the potential increased frequency of drought conditions, compounded by higher temperatures that would likely result in higher energy demand during the summer, which is the peak energy demand season in the Southwestern region.

The wide variation in rainfall, runoff, and generation historically experienced in Southwestern's region has resulted in the development of a marketing plan for Federal hydropower that already contains flexibility, contingencies, and the ability to purchase energy when necessary to firm the hydropower resources. Purchases are blended with the available Federal hydroelectric power and energy to make a more beneficial and reliable product while assuring the repayment of the Federal investment, with interest. Southwestern uses a number of factors and computer models to determine when to purchase replacement power: a non-hydro guide curve (developed using period-of-record system simulations) in combination with inflow trends, storage remaining, long-term weather forecasts, the Palmer Drought Severity Index, season of the year, price of power, impacts on competing users, and anticipated electrical loads. Current funding mechanisms for the purchase of replacement power include: use of power receipts authority; alternative financing arrangements with customers; and a Continuing Fund (for emergency power expenses in periods of below-average hydropower generation). In the event climate conditions deteriorate to the level of a severe drought, Southwestern should have sufficient funding mechanisms for purchasing replacement power, provided Southwestern is able to access the Continuing Fund. Additionally, Southwestern's replacement power purchase capabilities are dependent upon the availability of energy and transmission in the region.

In addition to Southwestern's ability to purchase power, Southwestern has a contract remedy in its Uncontrollable Forces provision, which relates to "failure of water supply," such as the result of a severe, long-term drought. If circumstances prevail such that it becomes imminently unlikely that Southwestern can meet contractual power obligations due to a severe water shortage, the Uncontrollable Forces provision can be used. The prospect of the Uncontrolled Forces provision was effective during the 2005–2006 drought in the Southwestern region in that it led to the voluntary customer deferment of peaking energy for the summer of 2006 and the contract year ending in 2007. The agreement allowed for the deferred volume of energy to be received back to the customers over the following three years. This action reduced the Federal government's energy obligation throughout the drought.

All of the Southwestern region hydropower projects are multi-purpose projects, and the various competing uses affect the operation and available storage of each project, including flood control, water supply, navigation, fish and wildlife, both in-lake and downstream recreation, and tourism. Southwestern actively participates in numerous water resource committees and work groups; participates, reviews, and comments on studies; and continuously communicates with USACE and stakeholders concerning the balance of power and non-power uses, and the availability of water at each project and for the region as a whole. Southwestern is continually aware of, and proactively responsive to, competing use demands on project storage and climate and hydrologic conditions that impact inflows in the Southwestern region.

Southwestern will continue to review and monitor the concerns that were identified in the 9505 Assessment and incorporate those along with the various other concerns that impact Southwestern's hydropower production capability.

Southeastern Power Administration

Like Western and Southwestern, Southeastern is not a full-requirements power supplier and makes up only a small percentage of its customers' electric power resource requirements. Under the current marketing strategy and marketing policies, Southeastern has maintained effective operations through increasingly severe droughts. The hydrologic variability described in the 9505 Assessment did not exceed the variances already incorporated into Southeastern's market strategy. Southeastern participates in hydrologic studies, modeling groups, and other stakeholder activities concerning the operation of the Federal projects. The USACE and Southeastern routinely communicate and adjust project operations to optimize water use and power production.

All of the capacity and energy produced at USACE projects marketed by Southeastern is allocated to customers through long-term contractual arrangements. Southeastern does not currently have any provisions for short-term sales. Southeastern's long-term contracts specify the amount of capacity and energy available to each customer. Each contract also has provisions to disperse power in excess of the contractual obligation and for mechanisms of replacement if project operations cannot support the minimum requirements.

Purchase Power and Pumped Power are two of the mechanisms that Southeastern currently uses to provide energy when hydrologic conditions are insufficient to meet contractual requirements. Southeastern and USACE routinely communicate hydrologic forecasts. These forecasts provide information to Southeastern concerning expected inflow and the potential shortfalls in generations. Southeastern can then make a preemptive decision to purchase replacement power and conserve project storage for a time when replacement power would be more expensive or seasonal operations restrict the deliverability of replacement power.

Southeastern utilizes customer funding agreements, when possible, to provide for replacement and refurbishment of failed or damaged generating equipment that would otherwise remain out of service while awaiting congressional appropriations. Customer funding expedites the rehabilitation of existing generating equipment, which increases power production and enhances equipment reliability. Utilization of this funding maximizes the availability of renewable generation resources.

Southeastern believes these processes have already been implemented in such a way as to respond to the expected climate changes presented in this report. Southeastern will continue to monitor the issues set forth in this study, and will seek to participate in any process that is beneficial to hydropower and aids in Southeastern's ability to meet contractual obligations.

It is therefore recommended that Southeastern continue its current strategy of operational reviews and rate studies, which are viable responses to the expected climate changes presented in this report.

V. Conclusion

The 9505 Assessment described in this report is the first comprehensive assessment of climate change impacts that specifically focuses on the entire federal hydropower portfolio in the U.S. (excluding TVA). The methods were designed to provide an objective, quantitative evaluation of the effects and risks to federal hydropower that could be applied consistently across all four of the PMA regions. The climate projections from the 9505 Assessment were compared to other published studies and found to be generally consistent with them.[53] The 9505 Assessment results add to a growing body of evidence on climate impacts, indicating the likelihood of change at federal hydropower projects.

While challenges to federal hydropower that are associated with climate change appear to be manageable on a national scale over the next few decades, challenges within specific regions and seasons may be more difficult to manage, and those challenges will likely increase in the second half of the 21st century – those longer-term impacts were beyond the scope of this first 9505 Assessment. Natural climate variability and anthropogenic climate change are not the only factors that affect water availability for federal hydropower. Other important factors currently influencing federal hydropower are: 1) the potential for changes in reservoir operations to meet new, non-power uses; and 2) the aging of federal hydropower assets, which is leading to lower reliability and more outages. Future 9505 Assessments should address the interactions among climate and non-climate influences on water resources and the potential for shorter-term (i.e., seasonal) changes in reservoir operations to mitigate impacts.

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[45] Table 7-1 of the 9505 Assessment report (Sale et al., 2011) shows the number of ensemble members that have statistically significant increases or decreases in air temperature, precipitation, or runoff on annual and seasonal periods, for each of the 18 subregions considered.

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[50] Reservoir Management Joint Operating Committee. 2010. Climate and Hydrology Datasets for use in the RMJOC Agencies' Longer-Term Planning Studies: Part I - Future Climate and Hydrology Datasets. Available at: http://www.usbr.gov/pn/programs/climatechange/reports/.

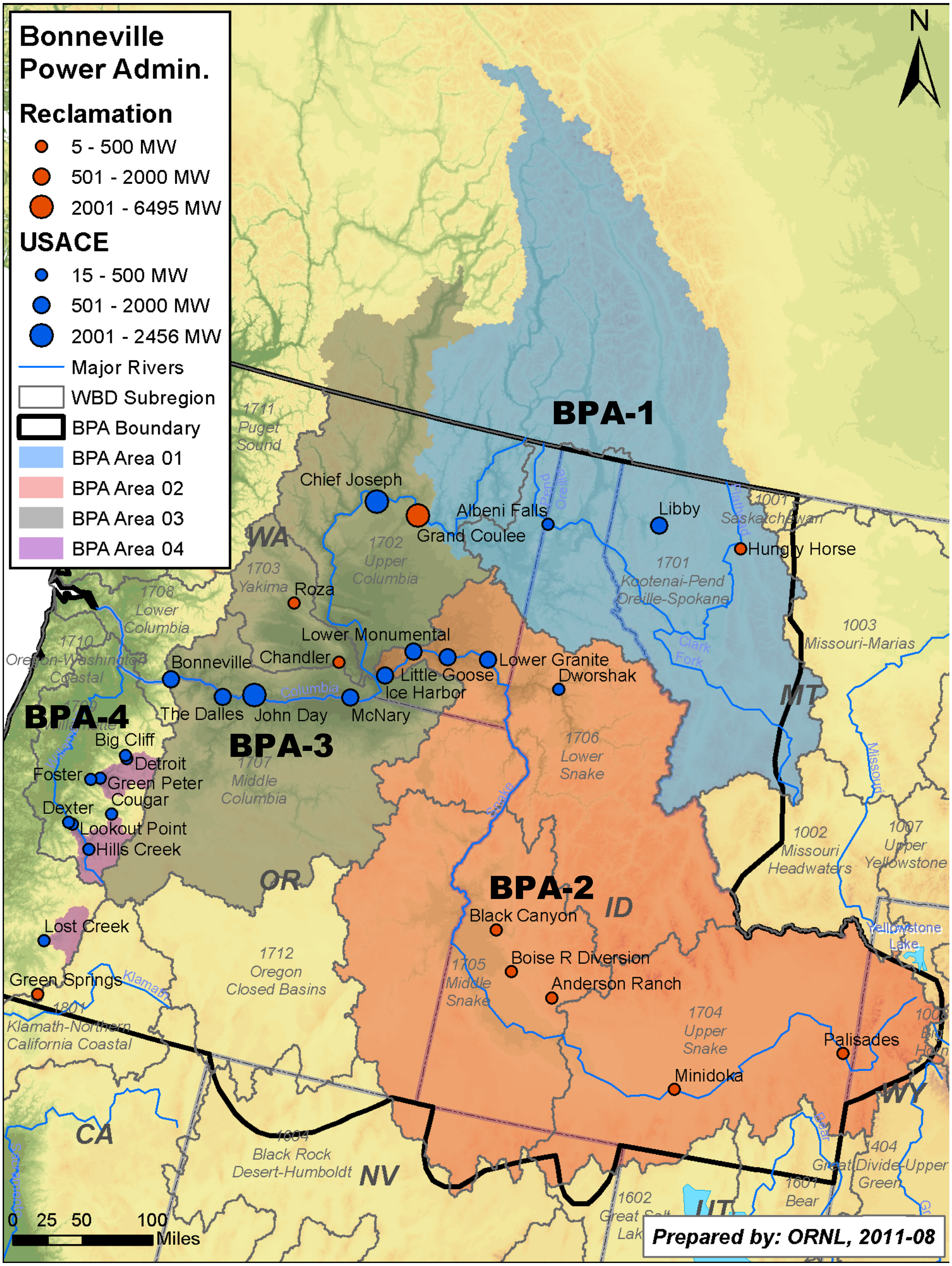
[51] Ibid.

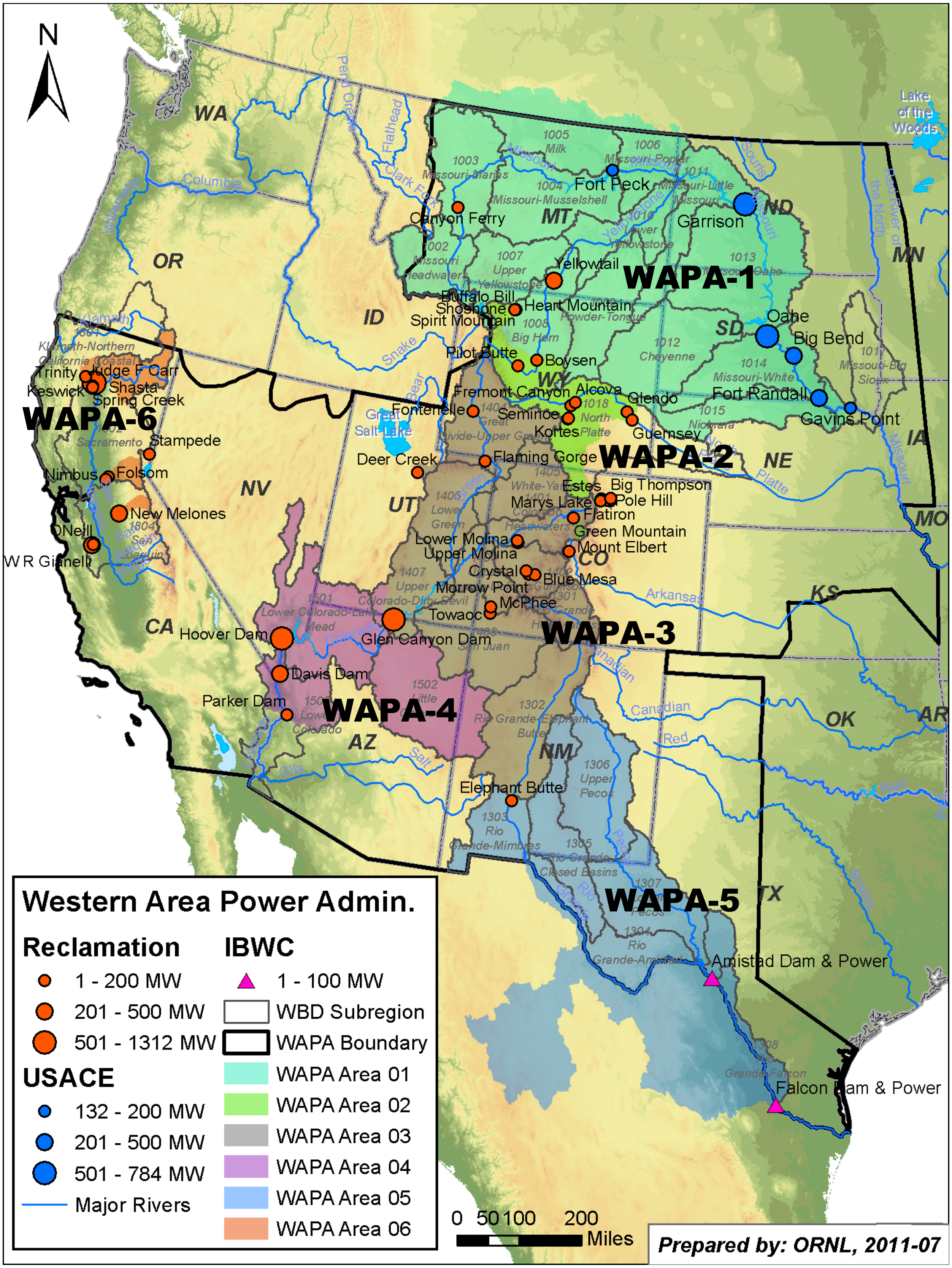
[52] Table 7-1 of the 9505 Assessment report (Sale et al., 2011) shows the number of ensemble members that have statistically significant increases or decreases in air temperature, precipitation, or runoff on annual and seasonal periods, for each of the 18 subregions considered.

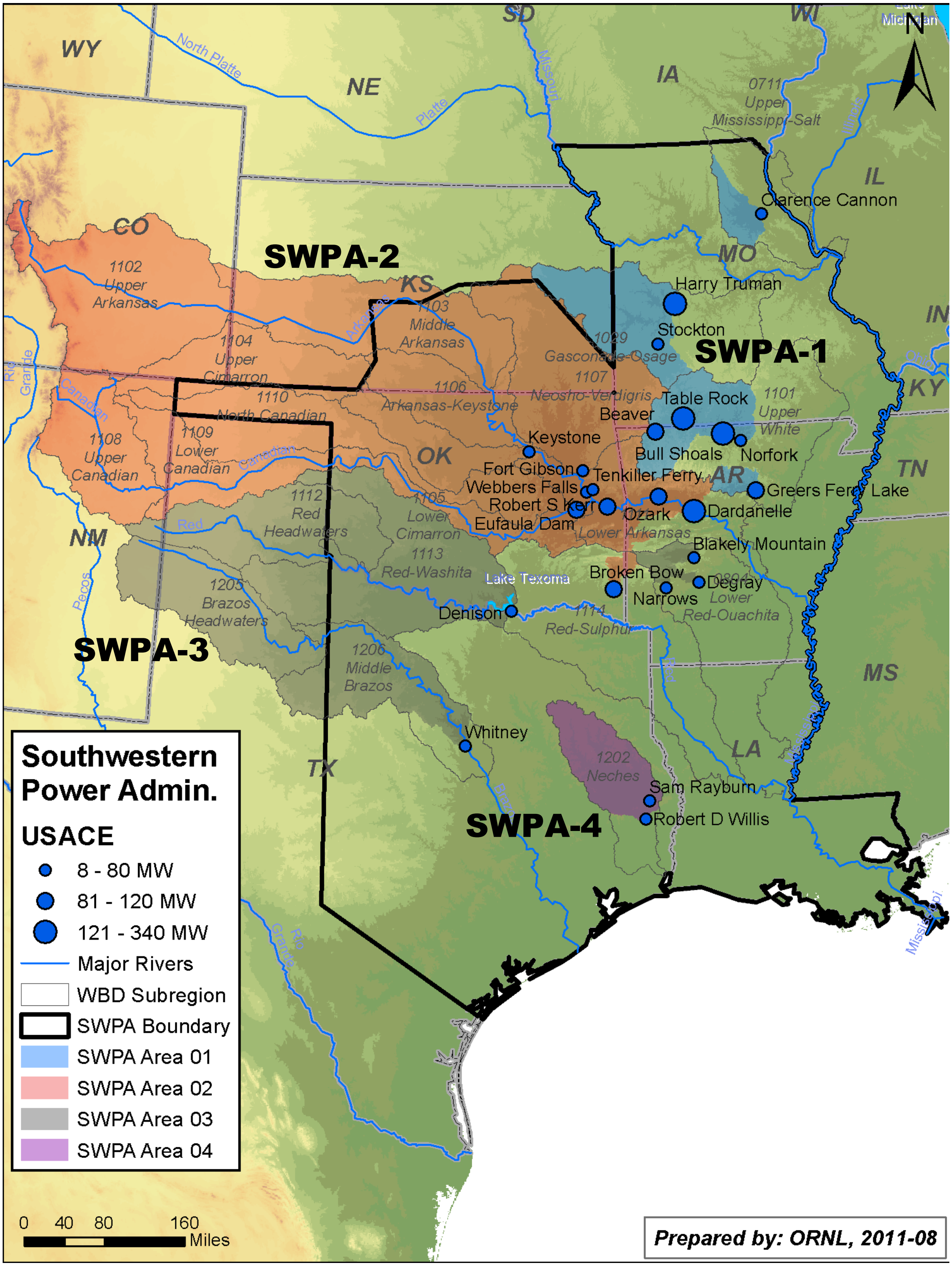
[53] Sale, Kao, Ashfaq, et al. 2011. Assessments of the Effects of Climate Change on Federal Hydropower.

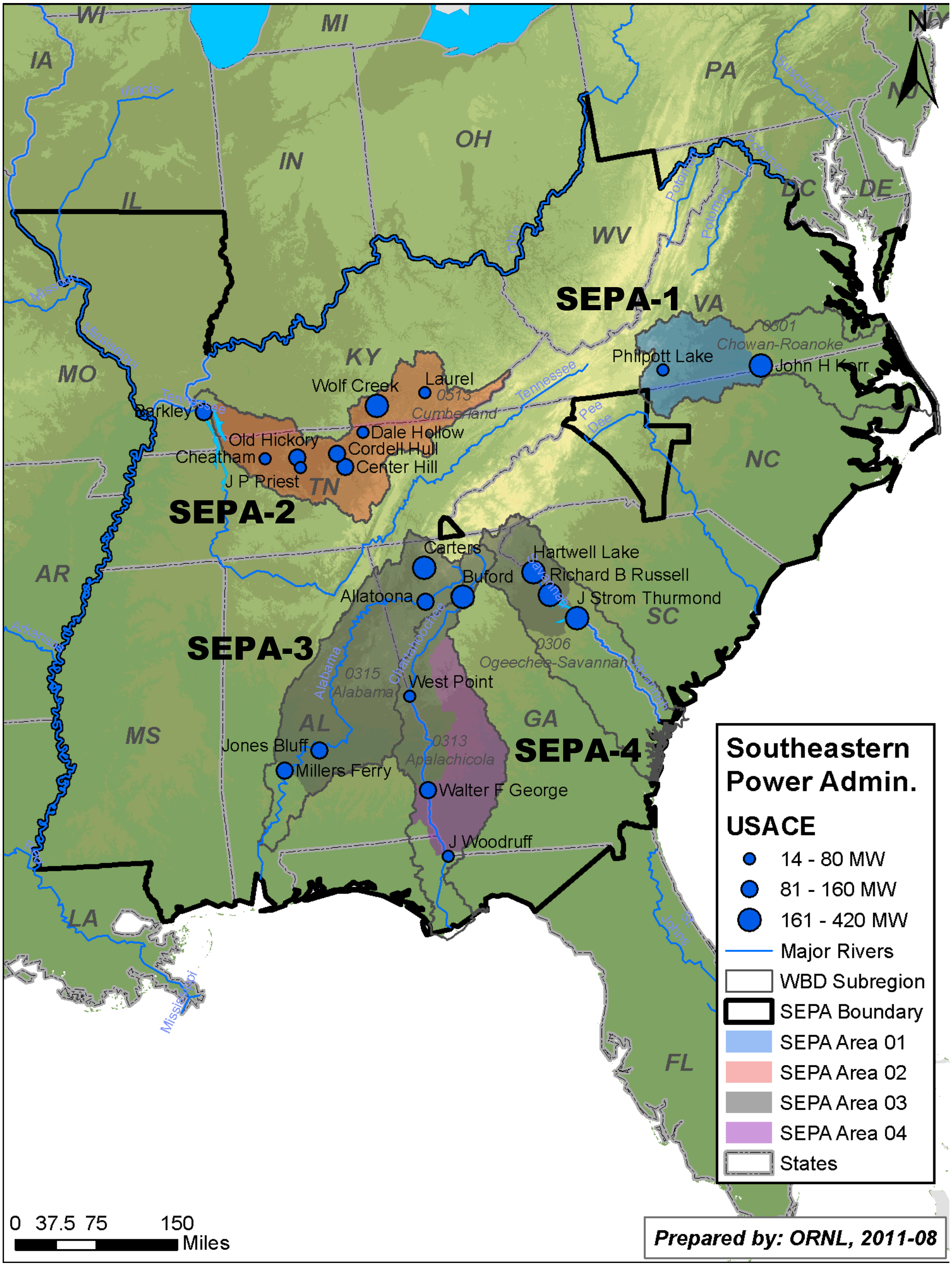
APPENDIX. Regions and assessment areas

Assessment areas	*Rivers and federal dams*	*Federal power systems*
Bonneville region		
BPA-1	the Upper Columbia River upstream and including Grand Coulee Dam	Federal Columbia River Power System
BPA-2	the Snake River upstream of its confluence with the Columbia River	Federal Columbia River Power System
BPA-3	the lower and mid-Columbia River, from Bonneville Dam upstream to the tailwater of Grand Coulee	Federal Columbia River Power System
BPA-4	the Cascade Mountain projects in southeastern Oregon	Federal Columbia River Power System
Western region		
WAPA-1	the upper Missouri River and tributaries upstream of the USACE Gavins Point project	Pick-Sloan Missouri River Basin Program
WAPA-2	smaller watersheds in the upper parts of the North Platte, South Platte, Bighorn, upper Arkansas, and upper Colorado Rivers	Loveland Area Projects
WAPA-3	the upper Colorado and upper Rio Grande river basins	Salt Lake City Area Integrated Projects and Provo River Project
WAPA-4	the lower Colorado River Basin, including Reclamation's Hoover, Davis, and Parker dams	Boulder Canyon, Central Arizona and Parker-Davis Projects
WAPA-5	the lower Rio Grande River, including two small projects operated by the International Boundary and Water Commission	Amistad-Falcon Project
WAPA-6	the Central Valley of California (Trinity, Sacramento, American, Stanislaus, and San Joaquin river systems) and Truckee and lower Carson River systems	Central Valley and Washoe Projects
Southwestern region		
SWPA-1	Ozark Plateau rivers in Missouri and northern Arkansas (Osage, upper White, and Salt River Basins)	Financially Integrated Projects in the Interconnected System
SWPA-2	the Arkansas River Basin in Oklahoma and Arkansas, plus the Broken Bow project in the Red River Basin, included for interconnected system reasons	Financially Integrated Projects in the Interconnected System
SWPA-3	the Red and Brazos River Basins in Oklahoma and Texas, plus parts of the Ouachita River Basin in Arkansas and Oklahoma	Financially Integrated Projects
SWPA-4	the Neches River Basin in southeastern Texas	Isolated Projects
Southeastern region		
SEPA-1	the Roanoke River Basin in Virginia and North Carolina	Kerr-Philpot System
SEPA-2	the Cumberland River Basin in Kentucky and Tennessee	Cumberland System
SEPA-3	the combination of the Savannah, upper Apalachicola, and Alabama River Basins in South Carolina, Georgia, and Alabama	Georgia-Alabama-South Carolina System
SEPA-4	the lower Apalachicola and Flint River Basins in Georgia and Florida	Jim Woodruff System


Bonneville Power Admin.
Reclamation
5 - 500 MW
501 - 2000 MW
2001 - 6495 MW
USACE
15 - 500 MW
501 - 2000 MW
2001 - 2456 MW
Major Rivers
WBD Subregion
BPA Boundary
BPA Area 01
BPA Area 02
BPA Area 03
BPA Area 04
N
BPA-1
BPA-2
BPA-3
BPA-4
WA
OR
ID
MT
CA
NV
WY
1711 Puget Sound
1702 Upper Columbia
1703 Yakima
1708 Lower Columbia
1710 Oregon-Washington Coastal
1701 Kootenai-Pend Oreille-Spokane
1001 Saskatchewan
1003 Missouri-Marias
1706 Lower Snake
1707 Middle Columbia
1002 Missouri Headwaters
1007 Upper Yellowstone
1712 Oregon Closed Basins
1705 Middle Snake
1704 Upper Snake
1801 Klamath-Northern California Coastal
1604 Black Rock Desert-Humboldt
1602 Great Salt Lake
1601 Bear
1404 Great Divide-Upper Green
Yellowstone Lake
Chief Joseph
Grand Coulee
Albeni Falls
Libby
Hungry Horse
Roza
Lower Monumental
Chandler
Lower Granite
Little Goose
Ice Harbor
Dworshak
Bonneville
The Dalles
John Day
McNary
Big Cliff
Detroit
Foster
Green Peter
Cougar
Dexter
Lookout Point
Hills Creek
Lost Creek
Green Springs
Black Canyon
Boise R Diversion
Anderson Ranch
Palisades
Minidoka
Columbia
Snake
Clark Fork
Missouri
Klamath
0 25 50 100 Miles
Prepared by: ORNL, 2011-08


Western Area Power Admin.
Reclamation
1 - 200 MW
201 - 500 MW
501 - 1312 MW
USACE
132 - 200 MW
201 - 500 MW
501 - 784 MW
Major Rivers
IBWC
1 - 100 MW
WBD Subregion
WAPA Boundary
WAPA Area 01
WAPA Area 02
WAPA Area 03
WAPA Area 04
WAPA Area 05
WAPA Area 06
WAPA-1
WAPA-2
WAPA-3
WAPA-4
WAPA-5
WAPA-6
0 50 100 200 Miles
Prepared by: ORNL, 2011-07


SWPA-1
SWPA-2
SWPA-3
SWPA-4
Southwestern Power Admin.
USACE
8 - 80 MW
81 - 120 MW
121 - 340 MW
Major Rivers
WBD Subregion
SWPA Boundary
SWPA Area 01
SWPA Area 02
SWPA Area 03
SWPA Area 04
0 40 80 160 Miles
Prepared by: ORNL, 2011-08
Clarence Cannon
Harry Truman
Stockton
Table Rock
Beaver
Bull Shoals
Norfork
Keystone
Fort Gibson
Tenkiller Ferry
Webbers Falls
Robert S Kerr
Eufaula Dam
Ozark
Dardanelle
Greers Ferry Lake
Blakely Mountain
Broken Bow
Degray
Narrows
Denison
Lake Texoma
Whitney
Sam Rayburn
Robert D Willis
1102 Upper Arkansas
1103 Middle Arkansas
1104 Upper Cimarron
1105 Lower Cimarron
1106 Arkansas-Keystone
1107 Neosho-Verdigris
1108 Upper Canadian
1109 Lower Canadian
1110 North Canadian
1112 Red Headwaters
1113 Red-Washita
1114 Red-Sulphur
1101 Upper White
1029 Gasconade-Osage
0711 Upper Mississippi-Salt
1205 Brazos Headwaters
1206 Middle Brazos
1202 Neches
Lower Arkansas
Lower Red-Ouachita
WY
NE
SD
IA
WI
IL
IN
KY
TN
MO
KS
CO
OK
AR
NM
TX
LA
MS
N


SEPA-1
SEPA-2
SEPA-3
SEPA-4
Philpott Lake
John H Kerr
0301
Chowan-Roanoke
Wolf Creek
Laurel
0513
Cumberland
Barkley
Dale Hollow
Old Hickory
Cordell Hull
Cheatham
Center Hill
J P Priest
Carters
Hartwell Lake
Buford
Richard B Russell
Allatoona
J Strom Thurmond
0306
Ogeechee-Savannah
0315
Alabama
West Point
Jones Bluff
Millers Ferry
0313
Apalachicola
Walter F George
J Woodruff
WI
MI
IA
PA
NJ
NY
OH
IN
IL
DC
DE
WV
VA
KY
MO
TN
NC
AR
SC
GA
AL
MS
LA
FL
Southeastern
Power Admin.
USACE
14 - 80 MW
81 - 160 MW
161 - 420 MW
Major Rivers
WBD Subregion
SEPA Boundary
SEPA Area 01
SEPA Area 02
SEPA Area 03
SEPA Area 04
States
0 37.5 75 150
Miles
Prepared by: ORNL, 2011-08