Appendix H. Section VII.
Potential Effects of Climate Change on Future Water Supplies and Demands

Methods

The general procedures used in this section are similar to those described in the USBR 2011 West-Wide Climate Risk Assessments. Future temperature and precipitation projections were obtained from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive site maintained by the U.S. Bureau of Reclamation at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/. The root climate data sources for this archive are the World Climate Research Program Coupled Model Intercomparison Project 3 (WCRP CMIP3) phase 3 multi-model climate projections (Meehl et al., 2007). The CMIP3 dataset consists of results from coupled atmosphere and ocean general circulation models, which simulate global climate responses to future greenhouse gas (primarily carbon dioxide) emissions. A range of modeled scenarios are available, based on how potential green-house gas emission rates and atmospheric concentrations might vary with global technological and economic developments during the 21st Century. In total, 112 climate projections, based on projections by 16 different CMIP3 models, were downloaded and used for this analysis. The CMIP3 and CMIP5 Climate and Hydrology Projections archive site contains global-scale, climate projections, statistically down-scaled to a 12-kilometer (km) square grid (1/8° latitude by 1/8° longitude), which were used because raw CMIP3 dataset and climate models projections are too coarse for basin-scale water resources planning.

Hydrology projections also were downloaded from the same Reclamation Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive website, for the same 112 CMIP3 projections. The projections were developed using the University of Washington Variable Infiltration Capacity (VIC) hydrology model (Liang et al. 1994; Liang et al. 1996; Nijssen et al. 1997) to translate climate data to streamflow runoff; the VIC model also produces evapotranspiration and snow water equivalent output data. Input data to the VIC model is spatially downscaled precipitation, temperature, and wind speed data. Output includes runoff (both surface and subsurface runoff), evapotranspiration, and snow water equivalents over a grid corresponding to the watershed selected. The model solves the water balance for each grid cell, and then the gridded runoff is linked and hydraulically routed to a watershed outflow point.

The 112 downscaled CMIP3 temperature, precipitation, and hydrologic projections were obtained from the USBR website for the 1950-2099 period. Because the period for this State Water Plan cycle is 20 years, discussions here will focus on comparing model results that are representative of the recent past (1950-1999) to those for a look-ahead period centered on the year 2035 (years 2010-2059).

Temperature

Figure 1 graphs simulated Yellowstone River Basin mean-annual temperature-. The solid line represents the median change, while the shaded band represents the variability for the 112 climate projections. The consensus message for all of these projections is that temperature in the Yellowstone River Basin will continue a warming trend into the future, although the rate of warming projected varies among the models and scenarios. Estimated average-annual temperature increase for the 2010-2059 period, over those for 1950-1999 period, range from 1.2° to 4.9° Fahrenheit, with the median increase being 2.9°.

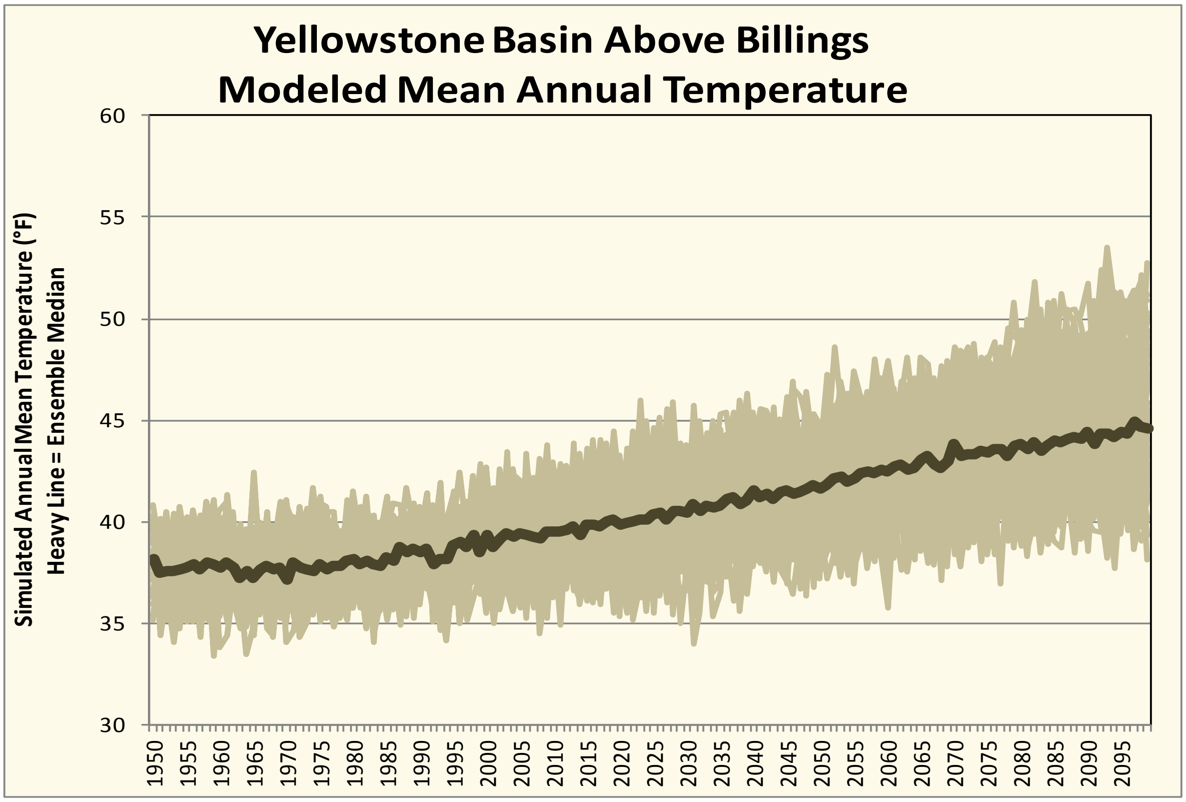

Figure 1. Mean annual temperature simulations based on downscaled projections from 112 GCM models.

<u>Precipitation</u>

The projections for precipitation are more variable, with scenario trends varying from slightly wetter to slightly drier, with most depicting a small wetting trend, but possibly increased variability over time (Figure 2). For the Yellowstone River Basin, the maximum projected change for the 2010-3059 period relative to the 1950-1999 period was an increase of 5 inches (20 percent) and the minimum was for a decrease of 1.2 inches (-5 percent), with a median projected increase of 1.1 inches (2.4 percent).

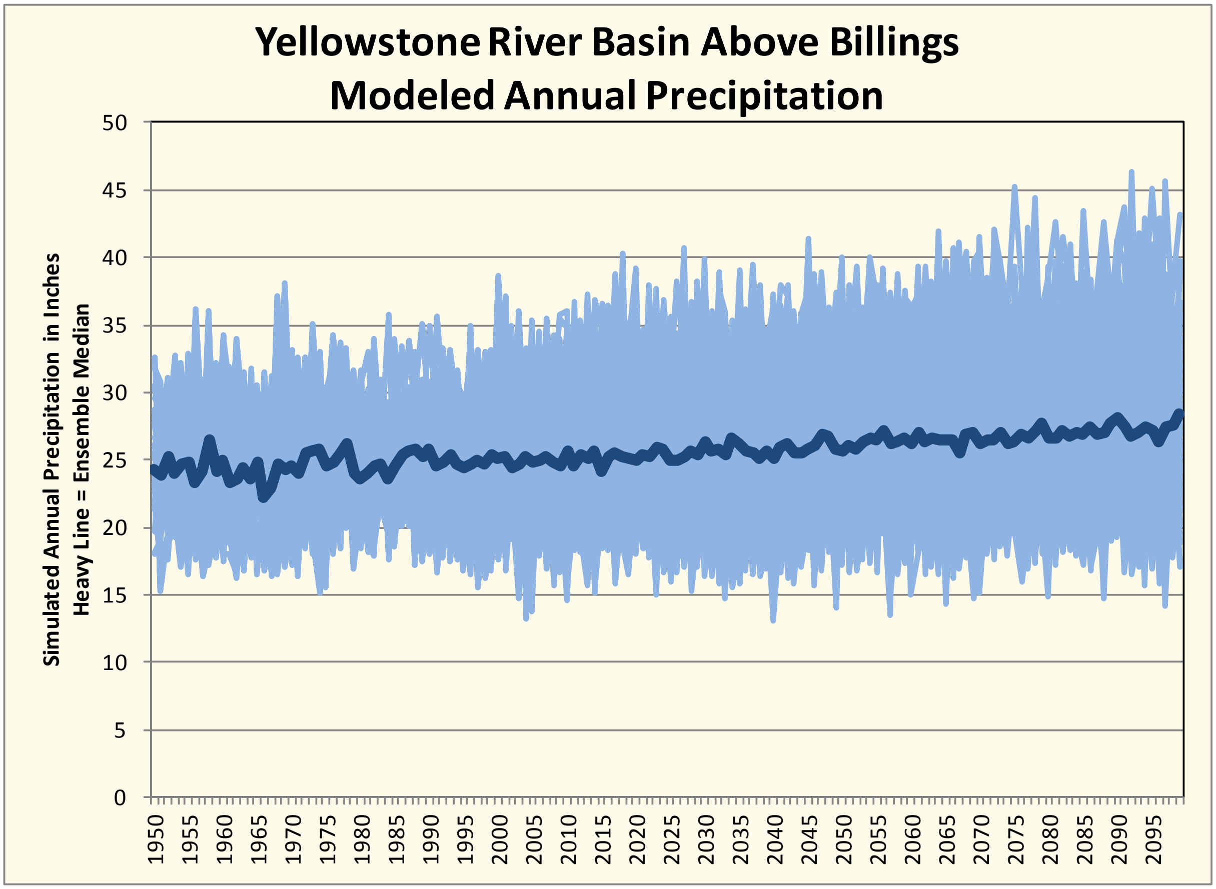

Figure 2. Annual precipitation simulations, for the Yellowstone Basin above Billings, based on downscaled projections from 112 GCM models.

<u>Evapotranspiration</u>

As described in the Streamflow section of this report, only about 18 percent (about 3.5 inches/per unit area) of the precipitation that falls on the Yellowstone River Basin ultimately leaves as streamflow. Most precipitation will infiltrate into the soil profile and most of this will be consumed by plants or evaporated from the surface of the soil through the process of evapotranspiration. Evapotranspiration is projected to increase under most scenarios as temperatures warm and the growing season increases, although some of the modeled scenarios show an evapotranspiration decrease due to projected drier conditions. Figure 3 depicts modeled evapotranspiration by natural vegetation in the Yellowstone Basin for the 1950-2099 period. Evapotranspiration is projected to increase under most modeled scenarios for the 2010-1959 period compared to the 1950-1999 period. The maximum modeled increase was 1.3 inches (10 percent), the maximum decrease 0.3 inches (-2.5 percent), and the median increase was 0.5 inches (3.9 percent).

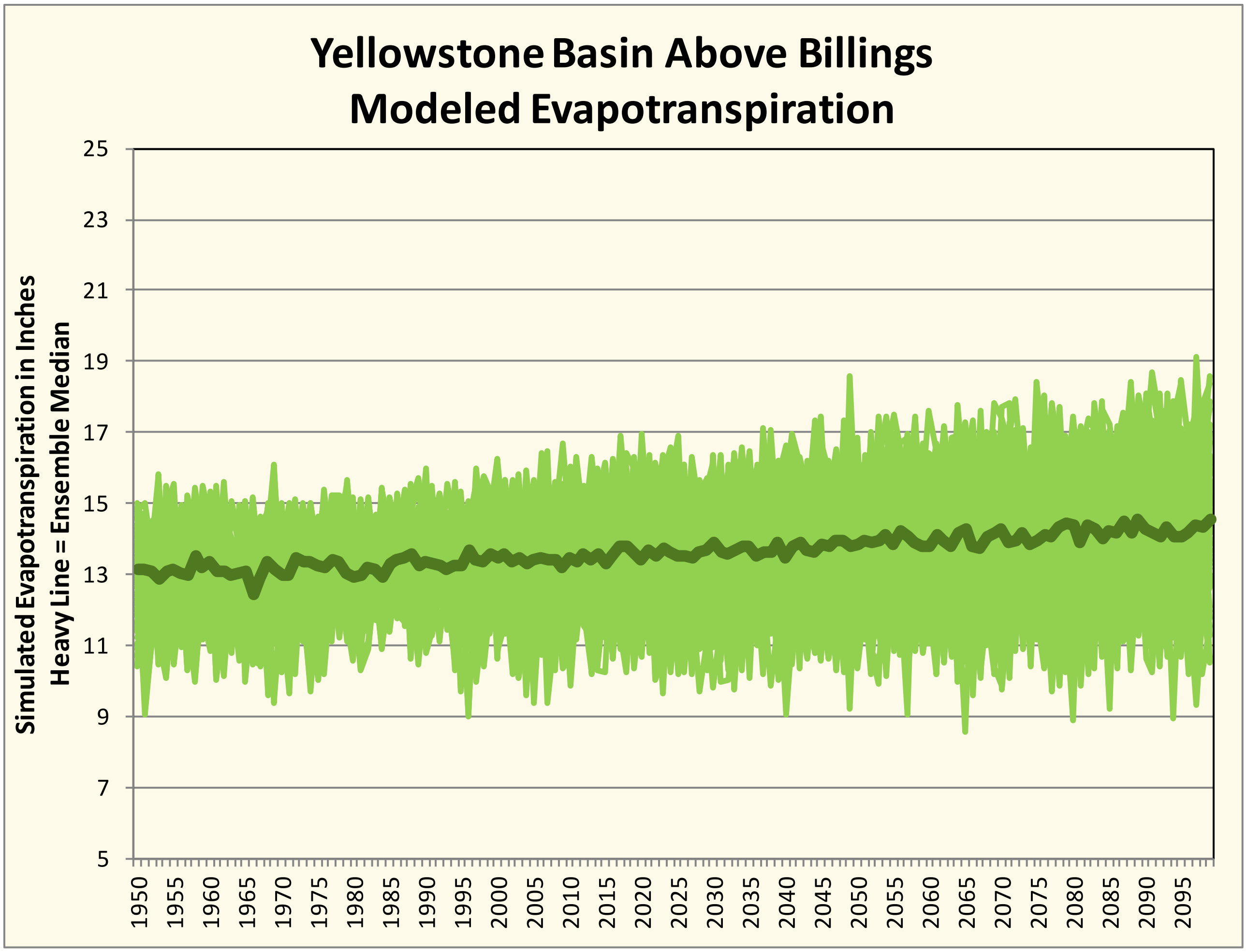

Figure 3. Annual evapotranspiration by vegetation, for the Yellowstone Basin , based on VIC model results and downscaled projections from 112 GCM models.

Runoff (Annual Volume)

The total amount of runoff produced in the Yellowstone River Basin depends on the amount of precipitation received, how much is consumed by evapotranspiration and evaporation, and how much is stored as groundwater. Figure 4 depicts the modeled annual runoff volumes for the Yellowstone River Basin near Billings. For this graph, unique colors have been assigned to each of the 112 model simulation trace lines, with the dark line depicting the ensemble median. Although most scenarios project modest increases in precipitation for the Yellowstone River Basin, the projected ET increases appear to offset these. Annual runoff volume is projected to be similar under most modeled scenarios for the 2010-2059 period compared to the 1950-1999 period, with a few scenarios projecting substantial increases and a few others projecting substantial decreases.

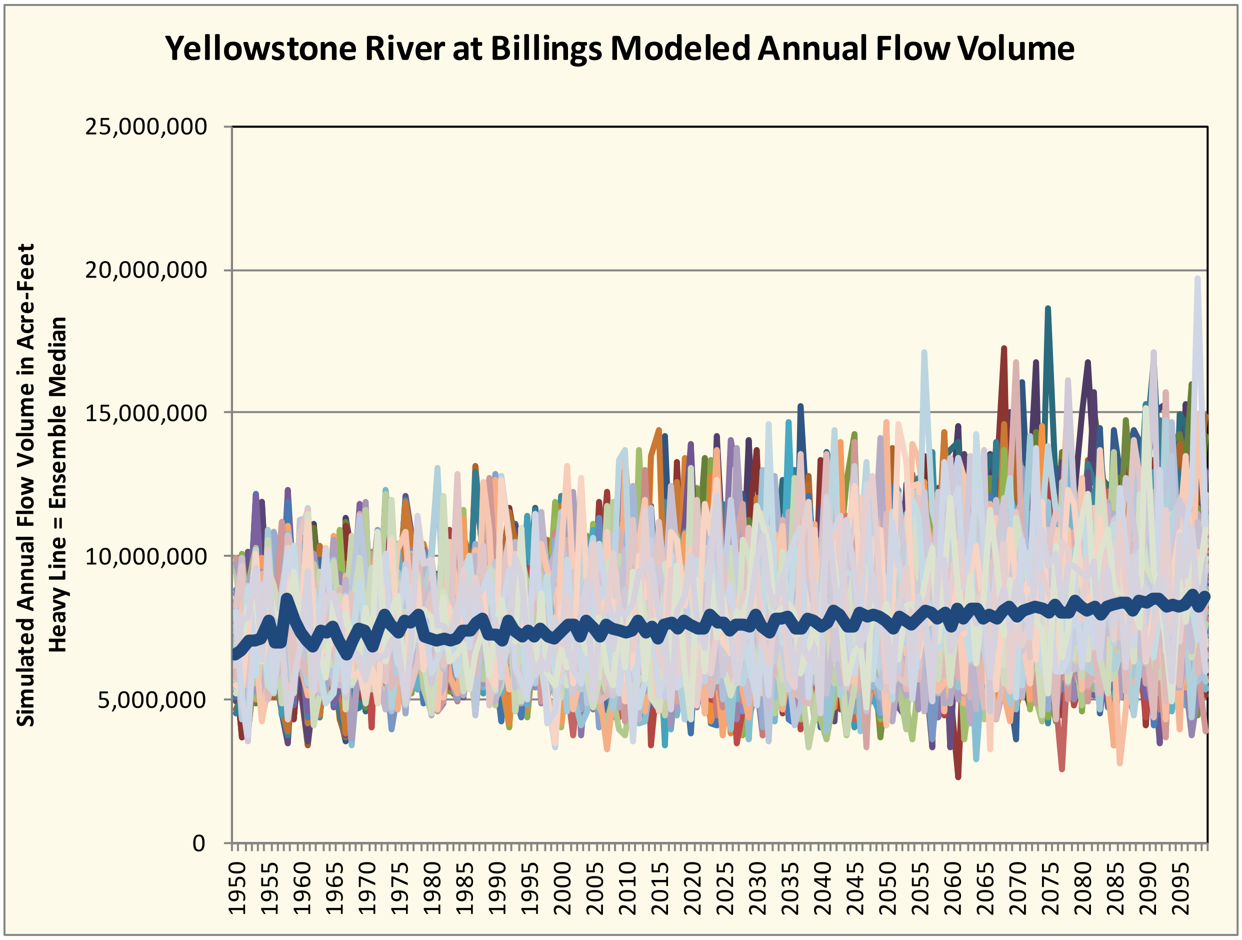

Figure 4. Simulated annual natural flow volumes for the Yellowstone River at Billings based on VIC model results and downscaled projections from 112 GCM models.

Snow

Warmer temperatures will affect accumulation of snow in the mountains during the cooler months and availability of melting snow to sustain runoff during spring and summer. The hydrology of the Yellowstone River Basin is snow-melt dominated and warming temperatures will lead to proportionally more rain and less snow. Snow water equivalent (SWE) on April 1 is a measure for assessing snowpack and subsequent spring–summer runoff conditions in the snowmelt dominated basins. SWE is a variable computed and used by the VIC hydrology model for each grid cell. Figure 5 depicts modeled April 1 snowmelt conditions for the Yellowstone Basin headwaters area (upstream of Billings) for the 112 simulations. This gridded SWE on April 1st was averaged over all the grid cells in the headwaters area to calculate the basin-wide April 1st SWE in each of the simulation years from 1950–2099. April 1st SWE shows a decreasing trend, although about 20 percent of the modeled scenarios show a trend of increasing April 1 SWE for the years 2010-2059 relative to the 1950-1999 base. The highest decrease for the 2010-2059 period relative to the 1950-1999 base was 1.4 inches SWE (32.4 percent decrease) while the largest increase was 1.0 inches (24.4 percent) and the median SWE decrease was 0.4 inches (8.9

percent). Under most modeled scenarios, increased precipitation overall, mostly in the form of rain, might somewhat offset the snow decreases.

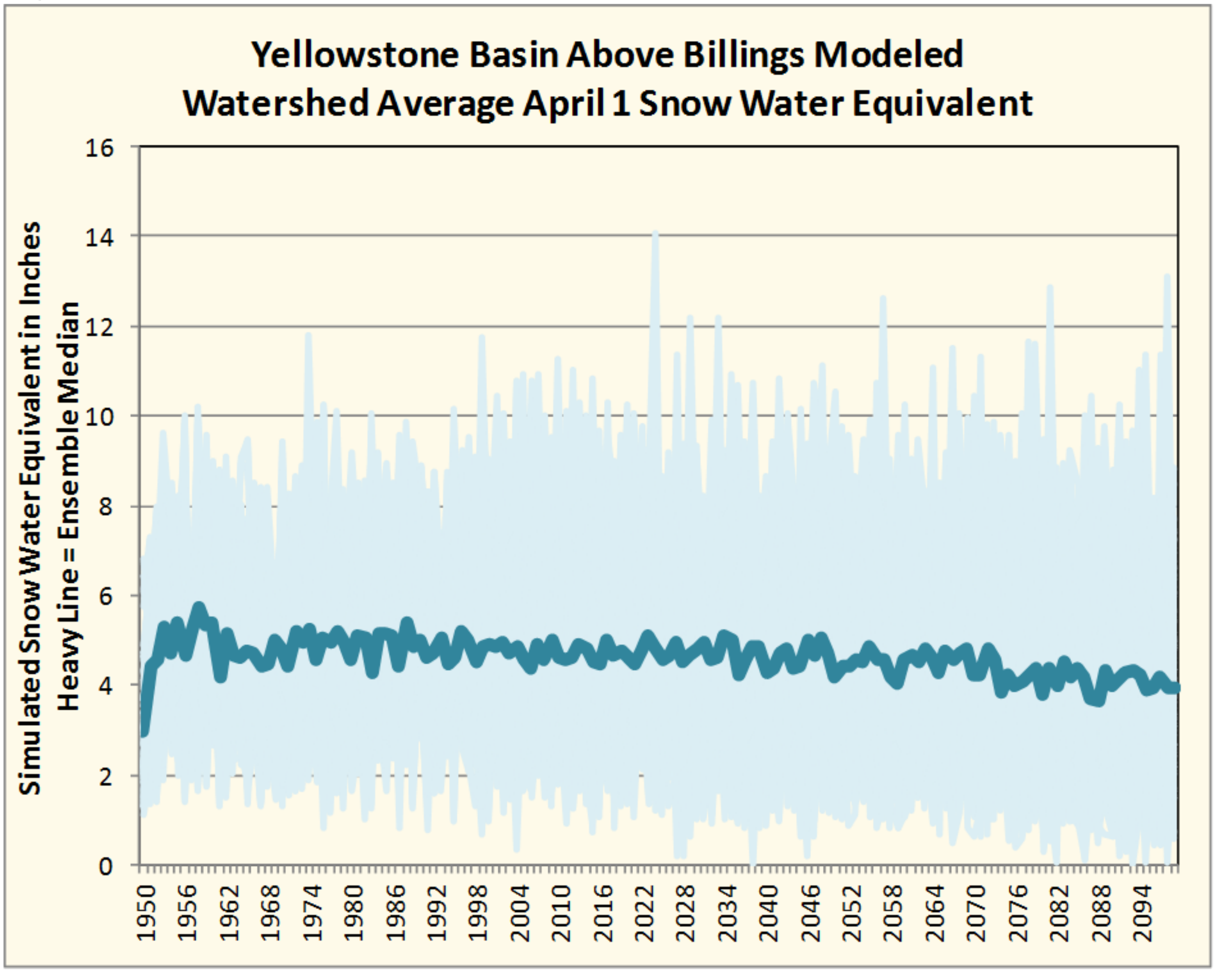

Figure 5. Modeled April 1 snow water equivalents for the Missouri River headwaters area based on VIC model results and downscaled projections from 112 GCM models.