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Guidance for the California LCC and other wetland habitat conservation programs in the Pacific Flyway

Progress Update
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Data Summary

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
WESTERN ECOLOGICAL RESEARCH CENTER

Understanding impacts of climate change on ecology and habitats of waterfowl, shorebirds, and other waterbirds: Guidance for the California LCC and other wetland habitat conservation programs in the Pacific Flyway

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Summary: This update describes the progress made and summarizes the data produced as a result of analysis conducted during the first 6 months of the multi-year project to understand impacts of climate change on habitats and ecology of waterfowl and other waterbirds in the Central Valley. The project is progressing as planned and has attracted new partnerships due to demonstrated progress and the high level of interest in this topic. Progress made during the first 6 months of this on-going project met project deliverables goals which included establishing the project website (http://www.werc.usgs.gov/Project.aspx?ProjectID=204) and modeling of one Central Valley basin (i.e., Butte Basin). For the Butte Basin we have:

1) downscaled climate model predictions of temperature and precipitation patterns, applied them to models to simulate potential evapotranspiration and climatic water deficits (CWD) and to estimate runoff and water supplies for 5 climates (recent historical and 4 projected climates [2 CO_2 emission scenarios x 2 global climate models])

2) adapted the Water Evaluation and Planning model for the Central Valley Planning Area (WEAP-CV) used by the State of California to better estimate water supplies for wetlands and agricultural habitats of importance to waterfowl and other waterbirds in the Butte Basin

3) applied the Adapted WEAP-CV model to investigate water supply amounts and timing for each habitat under current water management policy for each climate and projected urbanization scenario

4) estimated area of key waterbird habitats supported by water supplies available under 31 scenarios representing: a) existing habitat and average water-year conditions, b) CVJV-goal habitat and average water-year conditions, or c) CVJV-goal habitat and dry water-year conditions,

5) applied the TRUEMET model to evaluate adequacy of food supplies resulting from selected scenarios representing a range of conditions to support wintering waterfowl at CVJV-goal population levels.

Preliminary results indicate that additional impact of projected climate on waterfowl food habitats in Butte Basin was relatively small compared to projected urbanization and water-year wetness for the scenarios we evaluated. The greatest reduction in food habitat area resulted from loss of rice habitat. However, all scenarios we evaluated so far assume present-day water supply prioritization as listed in our adapted WEAP-CV model; loss of top demand priority for public wetlands or lowering priority of private wetlands or agriculture would result in additional impacts. In addition, we evaluated only 2 scenarios representing extended drought conditions; evaluation of additional drought scenarios is required to fully evaluate impacts on food habitats.

Assuming continued project funding support, our future work will include a) an evaluation of our work to-date to ensure accuracy, improve efficiency, and refine focus of our future modeling efforts on the most realistic and informative scenarios, b) continuing with additional modeling into other Central Valley regions guided by the evaluation of our work to-date, c) continued and expanded translation of changes in water supplies and habitats supported by those water supplies into impacts on ecology of waterfowl, shorebirds, and other waterbirds; and d) continuing to update the CA-LCC and Central Valley Joint Venture (CVJV) on project progress and help adapt results into conservation planning.

Acknowledgments: We thank the numerous individuals and organizations that helped make this study possible and the first 6 months a success. Operational funding was provided by the California LCC with in-kind salaries and/or computing equipment and logistical support provided by all project partners including USGS-WERC, USGS-California Water Science Center, Ducks Unlimited Inc., and PRBO Conservation Science. Ben Gustafson and Bill Perry (USGS-WERC) provided GIS support. Dr. David Purkey (Stockholm Environment Institute [SEI]), and Dr. John Eadie (UC-Davis) provided consultation.

BACKGROUND

Waterbird habitats in the Central Valley of California that are critical to waterfowl and other wetland birds are dependent on snow pack and other precipitation for water supplies. Hydrology of most waterbird habitats in the Central Valley, which include wetlands, flooded rice fields, and other flooded agricultural lands, have been greatly modified. Natural overflow flooding from snow-melt and rain has mostly been replaced by managed flooding with controlled diversions and pumped water delivery from ditches, rivers, sloughs, and wells. Thus, the amount of water stored in reservoirs is crucial to determining the amount of waterbird habitat in the Central Valley. During years with average or above-average reservoir levels, water is available to allow summer irrigations and normal fall flooding and winter maintenance of managed habitats; winter rains provide additional winter habitat. Dry-to-extreme drought conditions can restrict summer irrigations, reducing wetland production of seeds, and reduce or delay fall and winter flooding. Dry winters also produce little or no lowland or bypass flooding.

Food availability is a key factor limiting waterfowl during migration and winter (Miller 1986, Conroy et al. 1989, Reinecke et al. 1989), and habitat conditions during the non- breeding period may influence reproductive success (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Raveling and Heitmeyer 1989). Like most JVs, the CVJV uses a food energy (i.e., bioenergetics) modeling approach to establish habitat objectives for waterfowl and other waterbirds (CVJV 2006). First, waterbird population objectives, based upon historic bird use patterns and plan population goals (e.g., North American Waterfowl Management Plan) are set. Next, using daily energy requirement for individuals of each species, the amount of required energy to sustain for those goal “use-days” are determined. Finally, using data on food density produced by each type of waterbird habitat (e.g., wetland and flooded agriculture), the model compares population food energy needs to food energy supplied by the mix of available habitats. Timing and amounts of necessary water supplies can then be estimated based on required area of habitats.

Global climate models indicate substantial changes in temperature and timing and amounts of precipitation in watersheds of the Central Valley, translating into temporal and spatial variations in many of the driving forces that define the availability and productivity of habitats. Waterbird habitats in the Central Valley that are critical to waterfowl and other birds are dependent on precipitation and snow pack for water supplies. Changes in timing, amounts, and distribution of precipitation can have major impacts on waterbirds and their habitats. For instance, lack of adequate water supplies in the Central Valley could reduce productivity of wetland habitats and area of wetlands and post-harvest flooded crop fields, changing waterbird distribution in the valley (Fleskes et al. 2005, Ackerman et al. 2006). Increases in climatic water deficits (CWD) that impact vegetation and associated fauna and insects surrounding wetlands may reduce the ecosystem diversity and impact wetland habitats. Thus, climate change could alter when and where critical resources are available and needed for migratory birds.

PROJECT GOALS

The goals of this project are to develop landscape change scenarios based upon water availability and precipitation and temperature patterns projected from downscaled models and investigate impacts of these changes on habitats and ecology of waterfowl, shorebirds, and other waterbirds in the Central Valley. Specific project goals are to:

- Develop scenarios of Central Valley landscape change based upon changes in water availability, local precipitation, temperature patterns, potential evapotranspiration, and climatic water deficits predicted from downscaled global climate models for the next century.

- Use bioenergetics modeling and ecological relationships of waterfowl, shorebirds, and other waterbirds and their habitats to investigate scenario impacts on key bird metrics (i.e., abundance, distribution, body condition, and survival) under different management scenarios in the Central Valley.
- Identify timing and locations of critical waterfowl, shorebird, and other waterbird resources that are most at risk due to climate change in the Central Valley.
- Develop adaptive management strategies to account for climate change in waterbird habitat conservation planning in the Central Valley.

ACCOMPLISHMENTS

The project is progressing as planned and has attracted new partnerships due to demonstrated progress and the high level of interest in this topic. Progress made during the first 6 months of this on-going project met project deliverables goals which included establishing the project website (http://www.werc.usgs.gov/Project.aspx?ProjectID=204) and modeling of one Central Valley basin (e.g., Butte Basin). For the Butte Basin we have: ***a)*** downscaled climate model projections of temperature and precipitation patterns and modeled potential evapotranspiration and climatic water deficits and estimated runoff and water supplies for 5 climates (recent historical and 4 projected climates [2 CO_2 emission scenarios x 2 climate global climate models]), ***b)*** adapted the Water Evaluation and Planning System model for the Central Valley Planning Area (WEAP-CV) used by the State of California to better estimate water supplies for wetlands and agricultural habitats of importance to waterfowl and other waterbirds in the Butte Basin, ***c)*** applied the Adapted WEAP-CV model to investigate water supply amounts and timing for each habitat under each climate, projected urbanization, and current water management policy, ***d)*** estimated area of key waterbird habitats supported by water supplies available under 31 scenarios (Table 1) representing i) existing habitat and average water-year conditions, ii) CVJV-goal habitat and average water-year conditions, or iii) CVJV-goal habitat and dry water-year conditions, and ***e)*** estimated impacts of selected scenarios representing a range of conditions on wintering waterfowl food supplies.

CLIMATE DOWNSCALING

The downscaling of global climate projections employed a rigorous approach to reducing uncertainty in the process and was applied to fine-scale (270-m spatial scale) hydrologic models.

CO_2 Projections: To assess the impacts of climate change, many global socio-economic scenarios are being developed by the Intergovernmental Panel on Climate Change (IPCC) to provide estimates of possible magnitudes of greenhouse gas emissions that are responsible for much of the climate change. The choice of greenhouse gas emissions scenarios which focused on A2 (medium-high) and B1 (low) emissions, was based upon implementation decisions made earlier by IPCC4 (Nakic'enovic' et al. 2000):

> *The B1 scenario assumes that global CO_2 emissions peak at approximately 10 gigatons per year (Gt/year) in mid-twenty-first century before dropping below current levels by 2100. This yields a doubling of CO_2 concentrations relative to its pre-industrial level by the end of the century, followed by a leveling of the concentrations.*
>
> *Under the A2 scenario, CO_2 emissions continue to climb throughout the century, reaching almost 30 Gt/year. By the end of the twenty-first century, CO_2 concentrations reach more than triple their pre-industrial levels.*

Climate Models: The scenarios of CO_2 projections are used as boundary conditions for global circulation models (GCMs) that provide us with insight into how human behavior in the future may influence changes in climate. These GCMs have a coarse spatial resolution with a grid-cell size on the order of 2.5° × 2.5° (approximately 275 × 275 km2) that is far too coarse for landscape or basin-scale models that investigate hydrologic or ecologic implications of climate change. These simulations of climate change need to be downscaled for ecological scale modeling to a resolution on the order of 1000's or 100's of meters or less. Because the observed western US climate has exhibited considerable natural variability at seasonal to inter-decadal time scales, the historical simulations by the climate models were required to contain variability that resembles that from observations at these short period climatic time scales. Finally, the selection of models was designed to include models with differing levels of sensitivity to greenhouse gas forcing.

On the basis of these criteria, two global climate models (GCMs) were identified, the Parallel Climate Model (PCM; with simulations from NCAR and DOE groups; see Washington et al. 2000; Meehl et al. 2003) and the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 model (Stouffer et al. 2006; Delworth et al. 2006). By linear regressions with the current weather or climate pattern as the dependent variable and selected historical patterns as independent variables, high quality analogues can be constructed that should tend to describe the evolution of weather or climate into the future (Hidalgo et al. 2008, van den Dool 2003).

These four climate change projections (i.e., PCM-B1, GFDL-B1, PCM-A2, GFDL-A2) were selected for the State of California to produce a realistic simulation of aspects of California's recent historical climate – particularly the distribution of monthly temperatures and the strong seasonal cycle of precipitation that exists in the region and throughout the western states (Cayan et al. 2007).

WATER EVALUATION AND PLANNING MODEL-CENTRAL VALLEY PLANNING AREA (WEAP-CV)

We used the Water Evaluation and Planning system (WEAP) Software developed by Stockholm Environment Institute (SEI) to model water supplies for waterfowl food habitats in the Central Valley. We obtained the WEAP Central Valley Planning Area model (WEAP-CV) from the State of California and SEI, and adapted it as needed. The WEAP-CV model has undergone peer review, its use has been published, and it is currently being used by the State of California for water supply management and planning in the Central Valley (e.g., Joyce et al. 2010 and Yates et al. 2009). WEAP-CV contains the major components of water supply and delivery systems, and water demands within "Planning Areas" (used by the California Department of Water Resources) within the Central Valley. Components include the State and Central Valley Water Projects, groundwater, major surface streams, and estimated demands for water by agricultural and urban users. WEAP-CV additionally includes physical (e.g., reservoir capacity), operational (e.g., reservoir storage zones), and regulatory constraints (e.g., various stream flow requirements and priority of water use among users) on water use. The model evaluates three population growth scenarios — "Current Trends", "Strategic Growth", and "Expansive Growth" — representing various population growth and urban land use trajectories (Joyce et al. 2010).

ADAPTING WEAP-CV

We adapted the WEAP-CV model (hereafter "WEAP-CV Adapted Model") to better specify factors of particular interest for our evaluation of changes in waterfowl habitats. This included adapting the Current Trends population growth scenario of the WEAP-CV model to include water demands (including area of wetland and agricultural food habitats), surface water supplies, and climatic water deficit (or net evapotranspiration) specific to the Butte Basin. The Current Trends scenario projected agricultural and urban water demands into the future based on recent land use and water demand trajectories. We used the WEAP-CV Adapted Model to compare effects of recent and projected climate on water supplies used for existing waterfowl, shorebird, and other waterbird food habitats in Butte Basin. We also examined effects of projected climate on water supplies needed for goal waterfowl food supplies in Butte Basin following planned wetland restoration as established by the Central Valley Joint Venture (CVJV) in the CVJV Plan (CVJV 2006).

While modifying water demands and surface supplies relating to the Butte Basin, we preserved most other WEAP-CV structural and data components for the WEAP-CV Adapted Model. Agricultural and wetland areas and classifications for Butte Basin specified in the WEAP-CV Adapted Model were based on the CVJV Plan, Central Valley Wetlands Water Supply Investigations CVPIA 3406 (d)(6)(A,B) report (CVPIA 2000) (hereafter, Water Report), and unpublished data (M. Petrie, personal communication, October 7, 2010). Similarly, urban development projections in the Butte Basin included in the WEAP-CV Adapted Model were based on information in the CVJV Plan. We disaggregated agricultural and wetland water demands within the Butte Basin from demands in overlapping Planning Areas already existing in WEAP-CV. We also specified for the Butte Basin region additional agricultural and wetland areas (and related water demands) that were identified as important food habitats for waterfowl.

In the WEAP modeling environment, a “Demand Site” or “Catchment” object can each be used to specify any particular type of water demand (e.g., agricultural or wetland irrigation). However, Catchment objects are used to mathematically simulate landscape processes including evapotranspiration, runoff to a surface stream, and infiltration to groundwater in addition to water demand, while Demand Site objects are used to solely simulate water demand. As an alternative to Catchment simulation of water supplies, WEAP also allows separate specification of runoff to “River” (surface streams) and infiltration to “Groundwater” (groundwater) objects. In WEAP-CV, many of the water demands and a majority of the surface water runoff and groundwater infiltration are simulated in Catchment objects representing regional areas. The data we used to model surface water supply and water demand in the Butte Basin were not easily integrated with Catchment objects in WEAP-CV.

Consequently, we replaced Catchment objects related to Butte Basin with Demand Site objects and used data from climate models in River objects (D. Purkey, personal communication, September 15, 2010) (Figs. 2-4). Recent historical (between 1989-90 and 2004-05 water-years) mean monthly water supply requirement for each Catchment object related to the basin was calculated using WEAP-CV and entered as data for the Demand Site objects. Using these calculations we further calculated data for Demand Site variables “Annual Water Use Rate” (= annual water supply requirement/irrigated Catchment area) and “Monthly Variation” in water demand (= percent of the Annual Water Use Rate used each month). Data for Catchment variable “Area” was included as data for Demand Site “Annual Activity Level”. These data were then used to define Demand Sites. We disaggregated agricultural and wetland water demands within the Butte Basin from demands in overlapping Planning Areas already existing in WEAP-CV. We distinguished between Annual Activity Levels of agricultural demands in the Butte Basin and Planning Areas by subtracting crop areas for the Butte Basin indicated in the CVJV Plan from the sum of overlying Planning Area Catchments PA507_East and PA507_West. The calculated difference in areas was used to specify Annual Activity Levels of crops in the 507 Planning Area outside of Butte Basin. We replaced two Catchments objects (“Gray_Lodge” and “Butte Sink”) that were used in WEAP-CV to represent wetlands for the Planning areas overlying Butte Basin with Demand Sites. We specified Annual Activity Level for agricultural and wetland Demand Sites representing the Butte Basin using information from the CVJV Plan, Water Report, and other information (M. Petrie, personal communication, October 7, 2010). We specified Annual Water Use Rates and water demand Monthly Variation for the disaggregated agricultural Demand Sites within and outside of Butte Basin based on mean of Catchments PA507_East and PA507_West Annual Water Use Rates and demand Monthly Variation. Because crop areas within each PA507 Catchment were uncertain of how much crop area from each Catchment was within Butte Basin, mean estimates could not weighted by Catchment area included in Butte Basin. We did not replace Catchments related to water supplies outside of the Butte Basin with Demand Sites.

In WEAP-CV, urban indoor water demands were specified using Demand Site objects. For all urban indoor Demand Sites included in WEAP-CV (Current Trends Scenario), we initially (before projecting future urban development) constrained Demand Site data to a year 2005 level in urban development reflecting relatively current levels of indoor water demand. Demand Site variables that we constrained to a 2005 level were Annual Activity Level and Annual Water Use Rate which represent the quantity of the demand sector (i.e., number of residential households and number of commercial and industrial production units), and annual rate of water use per unit of activity (AF per household or production unit), respectively. Physical and operational data used for reservoirs in the WEAP-CV were retained in the WEAP-CV Adapted Model. However, we recalculated net evaporation (calculated as potential evapotranspiration - precipitation in mm) for Whiskeytown (Clear Creek), Clair Engel (Trinity River), Shasta (Sacramento River), and Oroville (Feather River) reservoirs using historical climate data and future climate predictions for each mountain watershed.

Butte Basin-specific Changes: Water runoff from drainages supplying Butte Basin has been estimated based on downscaled climate model predictions of temperature and precipitation patterns, potential evapotranspiration, and climatic water deficits using the four climate change projections and recent historical climate (1971-2000). Thus, the resulting climate scenarios that we examined were:

a) 1971-2000 (Recent Historical Climate)
b) PCM-B1: low emissions-less sensitive to greenhouse gas emissions
c) GFDL-B1: low emissions- more sensitive to greenhouse gas emissions
d) PCM-A2: medium-high emissions- less sensitive to greenhouse gas emissions
e) GFDL-A2: medium-high emissions- more sensitive to greenhouse gas emissions

Time Projections: Modeling provided results for monthly historical (1971-2000) and future (2001-2099) surface runoff for multiple streams and climatic water deficit within basins. Modeling results for each of the four climate change projections was subsequently divided into "projection" periods 2001-2030 (30 years), 2031-2060 (30 years), and 2061-2099 (39 years).

Wetness Scenarios: We wished to compare impacts of average and dry year conditions on existing and goal waterfowl food supplies. Thus, our analysis evaluating impacts of average year conditions included model scenarios (variations in model assumptions) based on seven consecutive average water-years (water-year is the period October-September of the following year). For average year conditions, surface runoff and CWD results were used. CWD is defined as the amount of additional water that would have evaporated or transpired had it been present in the soils given the temperature forcing. This calculation is an effective estimate of drought stress on soils and plants and recent studies suggest it may serve as an effective control on vegetation cover types. These were applied for each of recent climate and the four climate change projections and were subsequently averaged for 1971-2000 (30 years), 2001-2030 (30 years), 2031-2060 (30 years), and 2061-2099 (39 years), and used in the WEAP-CV model. Scenarios with a time series of seven consecutive average water-years allowed appropriate comparison with dry year scenarios, which included a time series of one average year followed by six dry years. For dry year scenarios, we based a time series of six dry years on the approximate maximum number of consecutive years that drought has occurred in recent history (Gehrts 2002). For dry year conditions, the lowest quartile (i.e., 75% of runoff values higher) was used for surface runoff. However, similar to average water-year scenarios, average CWD was used because based on model results, potential evapotranspiration varied little with precipitation for recent and projected climates.

Human Population Growth: We additionally accounted for effects of the projected year-2040 level of urban growth on land and water use within the Butte Basin (CVJV 2006). Effects of urbanization on existing farmland are quantified for each basin in the CVJV Plan (CVJV 2006). Reduction in agricultural land and water use was estimated to be -9.3% for farmland in Butte Basin (specific estimates for total rice, total corn, winter-flooded rice, all other agriculture). An increase in urban land and water use was predicted with outdoor landscape use based on 9.3% growth in urban area divided proportionally between existing residential and commercial areas and indoor domestic use based on current projections included in the WEAP-CV model.

Habitat Water Demands: In the WEAP-CV Adapted Model, we specified multiple agricultural and wetland food habitats and additional surface supplies for the Butte Basin. We also defined regulatory and operational constraints — demand priorities, water supply preferences, and maximum flow amount of a potential supply that is allowed — for these food habitats as defined in WEAP-CV or Water Report (Table 2). Demand priority represents the priority of water allocation among all demand sectors (Table 3). Water supply preference represents the relative preferences of potential supplies used by a particular Demand Site (e.g., greater preference for water from Feather River than Sacramento River or groundwater). Maximum flow amount of a potential supply is represented as the maximum amount (%) of a Demand Site's water demand that can be supported by a particular water supply.

Wetland and Agricultural Habitats: We classified Butte Basin wetlands in as many groups as current information would allow, which should better aid future refinement and accuracy of the WEAP-CV Adapted Model as new information becomes available. The Water Report provided detailed information about wetland habitat types in the Butte Basin. Based on this information we were able to distinguish 12 wetland habitat types providing food for waterfowl (Table 4). Wetland classifications were based on ownership, regional differences in water supply sources, water supply reliability, irrigation schedule, and demand priority (public wetlands have a priority of "1" indicating first priority, while private wetlands have a priority of "3", equivalent to agriculture) (Tables 2 and 4). Wetlands in Upper Butte Basin relied on many of the same water supplies as did wetlands in the Butte Sink with the exception of the addition of Sacramento River surface water, however, reliance on irrigation return flow was more limited — and not specified in the model (Table 2). Privately-owned wetlands with "High" or "Moderate" water reliability classifications (Water Report), which are supported by contracts with water agencies or alternate water rights, were collectively considered to have highly reliable water supplies. Based on contracts and water rights, wetlands with relatively highly reliable water supplies ("high-reliability wetlands") used a variety of surface and ground water supplies (Table 2). Conversely, privately-owned wetlands with a "Low" reliability classification were primarily supported by irrigation return flows (Water Report); consequently, they were considered to have relatively less reliable supplies and were specified in the model as being solely dependent on return flows (Tables 2 and 4).

The remaining wetland area classified with "Unknown" water reliability was 17% and 4% of area within Upper Butte and Butte Sink regions, respectively. We classified the wetlands with unknown water reliability into high- and low-reliability wetlands for each region by assuming that the actual areas of wetlands with high- and low-reliability supply were proportional to areas of known reliability. For Upper Butte, we estimated that proportions of wetlands with high- and low-reliability supply were 96% and 4%, respectively. For Butte Sink, we estimated that proportions of wetlands with high- and low-reliability supply were 80% and 20%, respectively. Because little area (approximately 123 and 22 acres of seasonal and semipermanent wetlands, respectively) within the Upper Butte region was estimated to have low water reliability, and for ease of modeling, we specified that all wetland area in the Upper Butte region have highly reliable water supplies.

Public and privately-owned seasonal wetland areas were further divided into early- and late-flooded classes; early-flooded seasonal wetlands were flooded starting in August, whereas late-flooded wetlands were flooded starting in September (Table 5). Flooding of both types were assumed to be maintained through March and to receive irrigation in May after drawdown to allow food plant germination. Areas of permanent and semi-permanent wetlands were combined and the irrigation schedule for semi-permanent wetlands was adopted (Table 5) because only a small proportion of the combined area was permanent wetlands (Mark Petrie, personal communication, October 6, 2010). Areas of wetlands reported in the Water Report were less than more recent estimates (i.e., years 2003-04) of seasonal and semipermanent wetlands on private land provided in the CVJV Plan. Therefore, we applied the more recent CVJV Plan estimated areas of wetlands to the previously indicated classifications and respective area proportions calculated from information in the Water Report and provided by Mark Petrie (Table 4).

We quantified areas of agricultural land use including food habitats (i.e., winter-flooded rice; unplowed, winter-dry rice; and unplowed winter-dry corn [in Butte Basin no corn was flooded]) in the Butte Basin based on areas provided in the CVJV Plan. Agricultural crops in the Butte Basin were classified as “Total Rice”, “Total Corn”, and “Other Agriculture” (Table 6). Water demand of some of the agricultural area available as food habitat for waterfowl (i.e., unplowed, non-flooded post-harvest treatment of rice and corn fields) was accounted for by the previously indicated crop classifications; thus, no additional classifications were needed for these food habitats. In addition, we specified an additional Demand Site for water demands between October and March for winter-flooded rice (CVJV Plan) (Table 6). We considered all 12 wetland types (Table 4), winter-flooded rice, and unplowed winter-dry rice and corn to be important food habitats for waterfowl and to include in the WEAP-CV Adapted Model. For average- and dry-water year scenarios we calculated the area of each type of waterfowl habitat supported by water supplies in each of the months of August-September of year 6 and October-March in year 7.

Butte Creek and Return Flow Water Supplies: Because Butte Creek and irrigation return flows to surface waters have been identified as important water supplies for private wetlands in the Butte Basin (Water Report), we included them as additional water supplies in the WEAP-CV Adapted Model. We specified Butte Creek as a “River” object. Climate model results necessitated that we aggregate surface runoff from the North Fork of the Feather and the Pit Rivers farther downstream at Oroville and Shasta Reservoirs, respectively. As a consequence, the WEAP-CV Adapted Model does not include regulation of stream flows in Lake Almanor or Pit River storage. Surface runoff aggregation farther downstream also required that the water demands represented on these streams in WEAP-CV be relocated to the contiguous tributaries (Feather and Sacramento Rivers) upstream of Oroville and Shasta reservoirs.

We divided available irrigation return flow (low-reliability supply) indicated in the Water Report into separate supplies for privately-owned seasonal and semi-permanent wetlands, respectively, solely relying on low-reliability supply. We added two “Other Supply” objects — used to simulate a variety of water sources that do not have storage capacity — to represent these low-reliability supplies in the model. We calculated monthly return flow amounts (cfs) used in Other Supply objects, using annual supply amounts (acre feet; AF) indicated in the Water Report and monthly proportion of total annual return flow using WEAP-CV results. Monthly quantities of low-reliability supplies for wetlands are currently specified the same in all scenarios and may not accurately represent actual supplies available for low-reliability wetlands in scenarios accounting for projected urbanization. In calculating monthly return flow amounts, we first computed monthly return flow produced in each of two agricultural Catchments (PA507_West and PA507_East) within the 507 Planning Area. We computed monthly return flow for each Catchment as the product of WEAP-CV results "Irrigation Return Flow Fraction to SW" and "Supply Delivered" produced from the WEAP-CV. Estimated monthly return flows produced in each Catchment were summed to produce total monthly Catchment return flow. We divided total monthly Catchment return flow by the total annual (solely months that seasonal wetlands and semi-permanent wetlands, respectively, were irrigated) Catchment return flow to produce monthly proportion of total annual return flow. Because Low-reliability supply wetlands presumably receive enough natural runoff and return flow in the fall and winter of most years (Water Report), we divided the water year into fall-winter (October-March) and spring-summer (April-September) periods in calculating monthly water allocation. Correspondingly, we specified that return flow allocation support 100% of the water demand in each month between October and March.

After calculating the supply of return flow remaining for use during April-September, we divided the remaining supply among months between April-September based on "return flow availability" ranks that we assigned to months. A month assigned a rank of "1" was allocated as much of the available supply needed to support the respective wetland water demand in that month. Other months with higher ranks were subsequently allocated water according to order of rank. Months assigned equal ranks were allocated an equal amount of available water. We determined ranks based on monthly proportion of total return flow for April-September (standardized to sum to 1). For seasonal wetlands, the monthly return flow proportions were 0.27 (May), 0.56 (August), and 0.16 (September), and corresponding ranks were 2 (May), 1 (August), and 2 (September). For semi-permanent wetlands, monthly return flow proportions were 0.06 (April), 0.23 (May), 0.21 (June), and 0.50 (July) and corresponding ranks were 3 (April), 2 (May), 2 (June), and 1 (July). In addition to return flows used by wetlands relying exclusively on low-reliability supply, we calculated other return flows released from Demand Sites (formerly Catchment objects) to streams and providing additional supply downstream (e.g., for wetlands relying on high-reliability supply). We calculated these return flows as the product of mean "Irrigation Return Flow Fraction" and mean "Supply Delivered" (results produced from WEAP-CV).

Because Demand Sites in the WEAP-CV Adapted Model were in many cases aggregates of sites in WEAP-CV (primarily upper Sacramento River and upper Feather River watersheds), some return flow consequently was aggregated. As a result, the WEAP-CV Adapted Model allowed Demand Sites farthest upstream greater access to return flow, while available return flow was potentially reduced for sites farthest downstream relative to WEAP-CV. Because food habitats in the Butte Basin are generally downstream of other Demand Sites higher in the watersheds, return flow available for food habitats hypothetically may be slightly underestimated by the WEAP-CV Adapted Model. However, Demand Sites in the Butte Basin, which release most of the return flow available for food habitats in the Butte Basin were not aggregated with upstream Demand Sites allowing return flow calculated within the basin to be available for these habitats. Thus, except for certain return flow that was aggregated with the aggregate Demand Sites previously indicated, we specified the allocation of return flow to stream reaches consistent with WEAP-CV. More specifically, we specified return flows for a stream reach either above or below the Demand Site withdrawing from the stream and producing the return flow consistent with Catchment runoff in WEAP-CV. In the situation of specifying return flow above a Demand Site, a Demand Site was effectively allowed the reuse of return flow.

Sutter Bypass and Groundwater Supplies: Because Sutter Bypass receives natural and irrigation return flows not estimated by climate models, mean monthly runoff from low-elevation Catchments to Sutter Bypass was calculated using WEAP-CV and specified in the WEAP-CV Adapted Model. Similarly, we used WEAP-CV to calculate mean groundwater recharge between Catchment and Groundwater objects for Redding, Redbluff-Corning, Butte, and Sutter-Yuba Groundwater Basins. Groundwater recharge was represented by mean monthly infiltration from Catchments to groundwater basins (in million AF).

Operational and Regulatory Constraints: Demand priorities (Table 3), supply preferences, and maximum flow amount from a particular supply for all Catchments and Demand Sites identified in WEAP-CV, generally were retained in the WEAP-CV Adapted Model. However, we established priorities, preferences, and maximum flow amount from a particular supply for Demand Sites in the Butte Basin (Table 2) by using a combination of information from WEAP-CV, CVJV Plan, and Water Report. Although publicly-managed wetlands retained a WEAP-CV priority of "1", privately-managed wetlands were assigned a priority of "3" consistent with agriculture (Table 2). Because the same water rights and supply contracts that support farming generally support wetlands in the Butte Basin (Water Report), we assumed that water supply for crops and private wetlands would be similarly reliable. Due to differences in the spatial extents and respective water supplies considered in WEAP-CV and the other references, we assumed that some supplies used in the 507 Planning Area (Fig. 2) did not apply to Butte Basin Demand Sites. More specifically, Sutter-Yuba groundwater and Yuba River were not considered to be supplies for Butte Basin wetland and agricultural Demand Sites. For wetlands using groundwater, we constrained maximum amount of groundwater supply to 4% of the wetland supply requirement, which is consistent with the Water Report. We assumed that groundwater required for agricultural Demand Sites in the Butte Basin could provide up to 50% of the water supply, which is consistent with data for Planning Area 507 in WEAP-CV.

ADAPTING WEAP-CV FOR EXISTING FOOD HABITAT AND AVERAGE WATER-YEAR CONDITIONS

In addition to adaptations as described above to integrate WEAP-CV with surface water runoff, potential evapotranspiration, and climatic water deficit (CWD) data for Butte Basin produced from the downscaled climate models, we also adapted the model for specific conditions. Results from each of the four climate-CO_2 scenarios were subsequently averaged for 1971-2000 (30 years), 2001-2030 (30 years), 2031-2060 (30 years), and 2061-2099 (39 years). WEAP-CV Adapted Model scenarios relating to each of these time periods were subsequently produced using these results. We used runoff data produced from climate models to define River object monthly flow rates (WEAP variable "headflow" in cfs) in model scenarios.

Climate Outside Butte Basin: To simulate average water supply throughout the Central Valley in model scenarios, we also needed to adjust water supplies located outside of the Butte Basin accordingly. Water-year 1972-73 approximated recent historical average annual unimpaired runoff in the Central Valley (Gehrts 2000) and for watersheds draining into Butte Basin (downscaled climate model results). Thus, we specified in the model that Catchment climatic processes in watersheds outside of the Butte Basin reflect 1972-73 water-year conditions. Consequently, for watersheds outside of the basin, we used WEAP-CV Catchment climate and River data for water-year 1972-73 across all seven time steps in the series. Until climate model data also could be produced and applied to CVJV basins outside of the Butte Basin, 1972-73 water-year conditions were used for Catchments outside of Butte Basin in projected climate scenarios in addition to recent climate scenarios.

Adjusting Water Demand Using CWD and PET: To account for projected climate change effects on seasonal changes in water demand by plants and in evaporation, we adjusted water demand of agricultural and wetland Demand Sites by percent change in median CWD between recent and projected climates. The median CWD was used as the measure of central tendency because distribution of CWD values across years was highly skewed in several months consisting mainly of zeros and a few large values (Note: This approach likely underestimates future change in CWD and will be evaluated for future modeling.) We calculated proportional differences in CWD between historical and projected climate scenarios (CWD change) as the following (projected CWD − historical CWD)/historical CWD, for each of the three projected time periods (2001-30, 2031-60, and 2061-99). Proportional differences greater than one were constrained to positive one, so that demand could increase by a maximum of 100 percent, which is consistent with calculated minimum negative CWD change of negative one (maximum reduction in demand by 100 percent). Some CWD change values in November and March could not be accurately calculated because historic CWD was zero while projected CWD was > 0 (n= 7-9 [7-9% of all values] depending on the projected time period). In these situations CWD change was assumed to be zero, which seemed reasonable because CWD values (AF/Acre) projected by climate models was generally small and would have lead to a small change in supply requirement. We calculated CWD change for each of the CWD regions of Butte Basin (Fig. 5) represented in climate models. Wetland and crop areas within Butte Basin varied substantially among the CWD regions. Thus, we weighted CWD change for each CWD region-crop/wetland combination by the proportions of respective crop and wetland areas within each CWD region.

We delineated and calculated wetland and crop areas within each CWD region using GIS and map data. We used raster data (1998) provided by Ducks Unlimited, Inc. to calculate areas of rice, and seasonal and semi-permanent wetlands within each CWD region. We used vector data (1999-2004 depending on county) provided by California Department of Water Resources to calculate areas of corn and all other crops combined within each CWD region. Based on areas calculated, we computed the proportions of each crop and wetland area within each CWD region. Proportions of seasonal and semi-permanent wetland areas within CWD regions were similar, and the area of seasonal wetlands calculated using GIS was similar to area stated in CVJV Plan. Thus, we used the calculated proportions of seasonal wetland area within CWD regions, which were used to weight CWD change for both seasonal and semiperminent wetlands. CWD change weighted by wetland and crop areas within each CWD region and Butte Basin could then be applied to the historical water use rate of each agricultural and wetland Demand Site. We adjusted “Annual Water Use Rate” and “Monthly Variation” WEAP variables for respective agricultural and wetland Demand Sites using CWD change for each climate projection scenario. We essentially adjusted monthly water demand as follows: current monthly water demand + current monthly water demand * monthly CWD change. This allowed us to account for potential changes in supply requirement due to changes in climate effects on evapotranspiration of plants. We could not adjust outdoor land use water demand because information about how urban outdoor land use area varied among CWD regions was lacking.

We also calculated effect of projected climate on evaporation and corresponding change in water demand of winter-flooded rice fields. Net change in mean potential evapotranspiration (PET change) for winter-flooded rice was weighted and calculated similarly to CWD change based on the same regions, but mean PET change for each region was used instead. PET change was used instead of CWD change because winter-flooded rice fields are largely flooded surfaces (i.e., reservoirs) devoid of live vegetation. Monthly net change in potential evapotranspiration (PET change) for winter-flooded rice was a weighted average calculated similar to CWD, but because no Net PET values were zero no related numerical problems were encountered. However, calculated projected water demand for winter-flooded rice in March (GFDL-B1, GFDL-A2, and PCM-B1 scenarios) was < 0, and was constrained to a value of zero (i.e., no water required for winter flooded rice in March). Net PET change was calculated based on climate modeling results as ((projected net PET) – (recent climate net PET))/ absolute value (recent climate net PET), for which net PET = evapotranspiration – precipitation. We adjusted Annual Water Use Rate and Monthly Variation variables for winter-flooded rice using net PET change similarly to Demand Sites adjusted using CWD change (i.e., current monthly water demand + current monthly water demand * monthly Net PET change).

Human Population Growth: We projected to a year-2040 level of urban development, corresponding agricultural land area reduction, and urban indoor water use within and outside of the Butte Basin. To this stage of adapting WEAP-CV, we have not projected Urban outdoor and agricultural water demands outside of the Butte Basin to 2040 or 2099 levels. Projection of farmland reduction to a year-2040 level was previously conducted in the CVJV Plan and was applied to the 2030 and 2060 climate projection scenarios. Between 2000 and 2040 the human population is projected to increase by 237,000 people in the Butte Basin. With an increase in urban development, a concomitant reduction in area of irrigated agriculture and winter-flooded rice is projected to occur. In Butte Basin, the predicted relationship of 0.1008 acre loss of farmland per additional person correspondsto a reduction of 23,894 acres of irrigated Basin farmland (9.3% of total irrigated area of about 257,000 acres) by 2040 (CVJV Plan). The correspondent predicted estimates (proportional reduction) of total rice, corn, and all other crops combined were 12,851 acres, 467 acres, and 10,576 acres, respectively. Consistent with the CVJV Plan, we assumed that the projected reduction in area of winter-flooded rice (12,851acres) was in proportion with the loss of total rice. Corresponding areas of total rice, winter-flooded rice, total corn, and all other crops combined by 2040 were 125,335 acres, 90,241 acres, 4,552 acres, and 103,144 acres, respectively.

Calculated crop area reduction was used to also calculate increases in outdoor urban land and water use for both growth projection scenarios. The projected additional urbanized area was divided between the two urban uses in proportion to existing commercial (7.1% of total urban area) and residential (37.6 % of total urban area) development areas in the 507 Planning Area. The corresponding calculated areas of residential and commercial urban outdoor land use by 2040 were 12,667 (existing 3,708) and 2,398 (existing 701) acres, respectively. The remaining projected area of urban outdoor land use was divided among high, medium, and low residential housing areas, which were not irrigated. Urban indoor water demands outside of Butte Basin were projected by constraining “Annual Activity Level” and “Annual Water Use Rate” to a 2040 level similar to scenarios based on existing urban development specifying a 2005 level of indoor water demand.

We projected to a year-2099 level urban development, agricultural land area reduction, and urban indoor water demand within and outside of the Butte Basin similarly to 2040-level projections. However, because urban indoor demands are projected in WEAP-CV only to maximum year 2050, we based urban indoor demands outside of Butte Basin on the same year-2040 indoor demand projections as were projected for 2040 projection scenarios. We estimated agricultural land reduction in Butte Basin by year 2099 for the 2099 climate projection using the estimated annual population increase between 2000 and 2040 (5,925 people/year) and projecting the population size to year 2099 (approximately 587,000 additional people since 2000). We calculated the reduction in area of all irrigated farmland in the basin as the product of projected additional number of people and 0.1008 farmland acre loss per additional person (59,181 acres). We then calculated the fraction of farmland reduction relative to total existing farmland (“reduction fraction”), or 59,181 acres reduction/257,000 existing acres = 0.23. We calculated the reduction in area of rice (total and winter-flooded), corn, and all other agriculture in the basin as the product of the reduction fraction and estimated existing areas of the respective crops. The calculated crop area reduction of total rice, winter-flooded rice, total corn, and all other crops combined were 31,820 acres, 22,910 acres, 1,156 acres, and 26,205 acres respectively. Calculated reduction in crop areas was subtracted from the existing total crop areas to produce crop areas for period 2061-99 climate scenarios of the WEAP-CV Adapted Model. Corresponding areas of total rice, winter-flooded rice, total corn, and all other crops combined by 2099 were 106,366 acres, 76,584 acres, 3,863 acres, and 87,515 acres, respectively. Consistent with 2040 urban development projections, the projected additional urbanized area was divided between the two urban uses in proportion to existing commercial and residential development areas in the 507 Planning Area. The corresponding calculated areas of residential and commercial urban outdoor land use by 2099 were 25,938 and 4,905 acres, respectively. Consistent with 2040 urban development projections, the remaining projected area of urban outdoor land use was divided among high, medium, and low residential housing areas, which were not irrigated.

Additional effects of urbanization by 2040 and 2099 within the basin include increases and decreases in runoff/infiltration from the urban and agricultural landscapes, respectively. Thus, for scenarios with projected urbanization and based on this land use change, we projected monthly increases and decreases in surface runoff to the Feather River and the Sutter Bypass, respectively . Ideally we would have adjusted the amount of runoff and recharge (previously specified in the Current Trends scenario) to the respective stream reaches and groundwater basins based on initial model data and results. However, because we lacked sufficient information to determine how changes in land use would affect the distribution of groundwater recharge between Butte and Yuba-Sutter groundwater basins, we only projected the predicted changes in runoff to the predictions for surface supplies. Based on the Current Trends Scenario of WEAP-CV, we projected monthly increases and decreases in runoff to the Feather River and the Sutter Bypass, respectively, for both 2040 and 2099 projections. For 2040 projections, we calculated a monthly average increase in runoff of 0.8 cfs to Feather River and a monthly average decrease of 38 cfs to Sutter Bypass. For 2099 projections, we calculated a monthly average increase in runoff of 2.0 cfs to Feather River and a monthly average decrease of 95 cfs to Sutter Bypass. Adjustment calculations were as follows:

1) Projected additional runoff to Feather River from former Catchment PA507W_O = Average historical irrigation return flow + [1]Runoff rate per unit area * [2]Catchment urbanization.
2) Projected reduced runoff to Sutter Bypass from former Catchment PA507_East = Average historical runoff – [1]Runoff rate per unit area * [2]Catchment urbanization.

[1]Runoff rate per unit area (cfs/acre) = runoff rate/Catchment area of respective Catchment. Runoff rate was calculated using WEAP-CV.
[2]Catchment urbanization (acres) = added area of commercial and residential development to existing commercial and residential areas in Catchment PA507W_O. Catchment growth also represents the reduction of farmland area in former Catchment PA507_East.

Note: Adjusted runoff to Feather River is based solely on irrigation return flow to stream reach because runoff data provided by climate models account for all natural surface flow into the Basin as previously indicated. Because Sutter Bypass was modeled in WEAP-CV as a diversion (not stream flow), it receives contributions from various sources including natural and return flows contiguous with the Bypass not modeled in climate models. Thus, reductions in surface flow to the Bypass include reductions in natural flow and return flows corresponding with the loss of agricultural area from former Catchment PA507_East.

Based on the above, we estimated effect of urbanization and climate change on areas and water supply available versus need for waterfowl food habitats assuming average water-year conditions for the following 15 scenarios:

1) Recent climate (1971-2000 average);
2) Recent climate (1971-2000 average) + 2040 urban growth projection;
3) Recent climate (1971-2000 average) + 2099 urban growth projection;
4) PCM-B1, 2001-30 average projected climate + 2040 urban growth projection;
5) GFDL-B1, 2001-30 average projected climate + 2040 urban growth projection;
6) PCM-A2, 2001-30 average projected climate + 2040 urban growth projection;
7) GFDL-A2, 2001-30 average projected climate + 2040 urban growth projection;

8) PCM-B1, 2031-60 average projected climate + 2040 urban growth projection;
9) GFDL-B1, 2031-60 average projected climate + 2040 urban growth projection;
10) PCM-A2, 2031-60 average projected climate + 2040 urban growth projection;
11) GFDL-A2, 2031-60 average projected climate + 2040 urban growth projection;
12) PCM-B1, 2061-99 average projected climate + 2099 urban growth projection;
13) GFDL-B1, 2061-99 average projected climate + 2099 urban growth projection;
14) PCM-A2, 2061-99 average projected climate + 2099 urban growth projection; and
15) GFDL-A2, 2061-99 average projected climate + 2099 urban growth projection.

ADAPTING WEAP-CV FOR FOOD HABITAT AT CVJV GOAL LEVELS AND AVERAGE WATER-YEAR CONDITIONS

Scenarios were developed in the WEAP-CV Adapted Model to examine the ability of water supplies to support CVJV food habitat goal objectives (CVJV Plan), while accounting for projected climate and projected urban development at year 2040- and 2099-levels. "Goal waterfowl food" scenarios were specified using the same parameterization and data previously specified for the "Existing food habitat and average water-year condition" scenario described above. We used the same climate and projected urban development data but we adjusted areas of rice fields and the various types of wetlands consistent with CVJV waterfowl food supply goals.

The general objective of the CVJV is to increase the amount of available food by restoring substantial areas of wetland habitats, while accommodating a moderate reduction in area of winter-flooded and unplowed winter-dry rice (i.e., "waterfowl-friendly" rice; CVJV 2006). CVJV aims to restore an additional 17,000 acres (42%) of seasonal wetlands to increase the existing area of 23,340 acres to 40,340 acres. In the CVJV Plan, post-harvest rice was the sole food habitat considered in the agricultural enhancement objectives (i.e., corn was excluded). Because of projected urbanization and restoration of wetlands on existing rice land, agricultural enhancement objectives include a net reduction in waterfowl-friendly rice from an existing 128,513 acres to 104,000 acres by year 2040 (CVJV Plan). Consistent with the CVJV Plan, this reduction in waterfowl-friendly rice equates to a decline in winter-flooded rice from the existing 99,494 acres to the objective 62,000 acres. Conversely, it also equates to an increase in unplowed, winter-dry rice from the existing 29,019 acres to the objective 42,000 acres. In 2003-04, Butte Basin contained 4,119 acres of semipermanent-permanent wetlands with 425 acres still needing to be restored to achieve the CVJV goal of 4,544 restored semipermanent wetland acres (Mark Petrie, personal communication, October 7, 2010).

The CVJV considered land use changes through year 2040 in developing CVJV Plan goal objectives. We additionally considered urbanization effects on land use through 2099 in developing goal waterfowl food scenarios by projecting the 2000-2040 annual urbanization rate to 2099. In producing goal waterfowl food scenarios, we assumed that rice areas will decline consistent with "existing food" scenarios that include projected 2099 urban development. In calculating the 2099 projected rice area for goal waterfowl food scenarios, we subtracted the 17,000 acres of rice projected to be restored as wetlands from the area of rice (106,366 acres) in the "existing" waterfowl food (projecting urbanization to year 2099) scenarios. The resulting projected post-harvest rice area was 89,366 acres, which we divided into winter-flooded (51,144 acres); unplowed, winter-dry (34,646 acres); and plowed, winter-dry (3,576 acres) fields in the same proportions as rice field areas specified in CVJV Plan goal objectives. Thus, estimated rice food habitat (85,790 acres) was less than rice habitat (104,000 acres) needed to support goal waterfowl abundance. To compensate for the corresponding potential food energy deficit, we estimated the additional area of seasonal wetlands that would be needed to support goal waterfowl abundance in Butte Basin by 2099. We calculated the total food energy deficit (7,235,649,536 kcal) as the product of estimated metabolizable energy density (397,345 kcal/acre) for rice calculated from CVJV Plan Table 5-8, and estimated rice habitat deficit (18,210 acres). Finally, we calculated the additional area of seasonal wetlands (11,971 acres) required to support goal waterfowl abundance by dividing total food energy deficit by energy density of seasonal wetlands (604,409 kcal/acre) calculated using Table 5-8. In calculating energy density of wetlands, to be consistent with the CVJV Plan we solely considered energy provided from seeds of wetland plants, excluding invertebrates (invertebrates are used as food by only some species, during only some of the target months, and invertebrates only comprise 4.8 % of estimated available food).

Using the previous information relating to urban development and CVJV Plan goals, we included 2040 and 2099 projections of agricultural and wetland areas in goal waterfowl food scenarios. We additionally assumed that all restored wetlands were on private lands and that areas of goal wetland classes were restored in the same proportions as existing areas of early-/late-flooded and high-/low-reliability classes. We calculated the area of total rice specified in goal scenarios projecting land use to 2040 as the following: 138,186 existing acres planted −12,851 acres-reduction from urbanization projected to 2040 − 17,000 acres-reduction from wetland restoration = 108,335 acres. For goal scenarios projecting land use to 2040, we specified 108,335 acres of total rice and 62,000 acres of winter-flooded rice as specified in CVJV goal objectives. The corresponding specified area of additionally restored seasonal wetlands was 17,000 acres, divided among the wetland classes in the same proportions as existing areas of private wetlands. For goal scenarios projecting land use to 2099, we specified 89,366 acres of total rice and 51,144 acres of winter-flooded rice as previously calculated. Corresponding specified area of additionally restored seasonal wetlands was 11,971 acres, divided among the wetland classes in the same proportions as existing areas of private wetlands. We specified 4,544 acres of semi-permanent wetlands for goal scenarios projecting land use to 2040 and 2099 levels. We were uncertain about how conversion of rice fields to wetlands would change runoff to Sutter Bypass and did not further adjust runoff to Sutter Bypass. Based on WEAP-CV, we expected return flow to Feather River to change little and therefore did not adjust runoff.

Based on the above, we estimated the effect of urbanization and climate change on areas and water supplies available versus required for waterfowl food habitats needed to support CVJV goal winter waterfowl populations under average water-year conditions:

1) Recent climate (1971-2000 average) + 2040 urban growth projection + 2040 goal waterfowl food projection;
2) Recent climate (1971-2000 average) + 2099 urban growth projection + 2099 goal waterfowl food projection;
3) PCM-B1, 2001-30 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
4) GFDL-B1, 2001-30 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
5) PCM-A2, 2001-30 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
6) GFDL-A2, 2001-30 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
7) PCM-B1, 2031-60 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;

8) GFDL-B1, 2031-60 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
9) PCM-A2, 2031-60 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
10) GFDL-A2, 2031-60 average projected climate + 2040 urban growth projection + 2040 goal waterfowl food projection;
11) PCM-B1, 2061-99 average projected climate + 2099 urban growth projection + 2099 goal waterfowl food projection;
12) GFDL-B1, 2061-99 average projected climate + 2099 urban growth projection + 2099 goal waterfowl food projection;
13) PCM-A2, 2061-99 average projected climate + 2099 urban growth projection + 2099 goal waterfowl food projection; and
14) GFDL-A2, 2061-99 average projected climate + 2099 urban growth projection + 2099 goal waterfowl food projection.

ADAPTING WEAP-CV FOR FOOD HABITAT AT CVJV GOAL LEVELS AND DRY WATER-YEAR CONDITIONS

In addition to examining food habitats under average-water year conditions, we also analyzed drought effects on food habitats for two scenarios. For our initial analysis, we compared reductions in CVJV goal food habitats between recent and projected GFDL-A2 (projected to period 2031-60) climates based on consecutive years of drought and 2040-level of urban development. As previously indicated, drought scenarios were based on a time series beginning with the Current Accounts year (consistent with other scenarios), followed by six consecutive dry years. We specified scenarios of goal food habitat and dry water-year conditions based on the existing parameterization and data for scenarios of goal food habitat and average water-year conditions, including the same food habitat areas and projected urban development data.

Basin-specific Climate: Similar to average water-year scenarios, average CWD was used because based on model results, potential evapotranspiration varied little with precipitation for recent and projected climates (as noted earlier, this approach likely underestimates change in CWD and will be evaluated). However, we replaced mean flow values with the lower quartile value (i.e., median of the lowest 50% of data values) of monthly stream runoff for each of recent and GFDL-A2 climates. Similarly, mean groundwater recharge values were replaced with lower quartile recharge values for Redding, Butte, and Sutter-Yuba groundwater basins.

Climate Outside of Butte Basin: To simulate dry water-year conditions throughout the Central Valley in model scenarios, we also needed to adjust water supplies located outside of the Butte Basin accordingly. Water-year 1984-85 approximated recent historical lower quartile annual unimpaired runoff in the Central Valley (Gehrts 2000) and for watersheds draining into Butte Basin (from downscaled climate model results). Thus, we specified in the model that Catchment climatic processes in watersheds outside of the Butte Basin reflect 1984-85 water-year conditions. Consequently, for watersheds outside of the basin, we used WEAP-CV Catchment climate and River data for water-year 1984-85 across latter six time steps in the series. Until climate model data also could be produced and applied to CVJV basins outside of the Butte Basin, for dry year scenarios, 1984-85 water-year conditions were used for Catchments outside of Butte Basin in projected climate scenarios in addition to recent climate scenarios.

CALCULATING AREA OF EACH FOOD HABITAT SUPPORTED BY AVAILABLE WATER SUPPLIES

We used WEAP-CV Adapted Model "Coverage" results and area of each food habitat to calculate the area of each food habitat that was supported by available water supplies under each scenario. Coverage produced by the model represents the percent of the water supply requirement that is actually attained for a particular water demand (or Demand Site). Coverage of 100% represents complete attainment of the required supply for that habitat. We calculated area of each food habitat supported by water supplies as the product of Coverage/100 and food habitat area. We base this calculation on the premise that the proportion of the supply requirement attained is equivalent to the proportion of available food habitat area that could be supported. Because harvest of rice and corn crops was assumed to generally occur in September, corresponding post-harvest food supply in these fields was assumed to first become available in September. For some climate scenarios of future time periods, Coverage was less than 100% for total corn and rice during the planting or growing season (i.e., April-August) proceeding the time period of interest. Therefore, we adjusted the area for all months following months of limited water even if water supply was fully available in the following months (e.g., if water supplies are inadequate for the planting or growing season, then no crop is available for flooding). For example, Coverage for corn and rice was 95% in July and/or August for many climate projection scenarios and the resulting area of food habitat supported in September- March for these scenarios reflected the area calculated in August and July.

BIOENERGETICS MODELING WITH TRUEMET

We used the bioenergetic model TRUEMET (CVJV 2006) to evaluate habitat conditions under each of the above scenarios for wintering waterfowl. The model provides an estimate of population food energy demand and food energy supplies for specified time periods. Population energy demand is a function of period specific population objectives and the daily energy requirement of individual birds. Population energy supply is a function of the foraging habitats available and the biomass and nutritional quality of foods contained in these habitats. A comparison of energy supply vs. energy needs provides a measure of carrying capacity relative to bird population objectives.

The results produced by TRUEMET are a function of model structure and parameter inputs; thus, there are two types of error inherent in any modeling exercise, conceptual (theoretical assumptions used to build the model) and empirical (the availability, precision and accuracy of data used for model inputs). Model structure was determined by the set of rules that dictated how birds foraged. We assumed: 1) birds were ideal free foragers (Fretwell 1972) and were not prevented from accessing food resources due to interference competition; 2) birds switched to alternate foods when preferred foods were depleted below some foraging threshold; 3) the functional relationships that determined population energy demand and population food energy supplies were linear; and 4) that there was no cost associated with traveling between foraging patches. In some cases, empirical work has shown these assumptions to be false (e.g., Nolet et al. 2006) but in most cases these assumptions prove valid (Arzel et al. 2007, Goss-Custard et al. 2003). Additional studies of waterfowl foraging ecology would either improve model structure or confirm the validity of our daily ration approach.

Although the model can be used to evaluate the carrying capacity of existing landscapes, it can also be used to predict how changes in policy, land use, or habitat programs might impact priority bird species. There are six explicit inputs required for each model run:

1. Time periods being modeled.
2. Waterfowl population objectives.
3. Waterfowl daily energy requirements.
4. Amount of each habitat type available in each time period.
5. The biomass of food in each habitat type on day one.
6. The nutritional quality of each food type.

Time Periods Being Modeled: Within TRUEMET the user must first define the length of the non-breeding period. The non-breeding period can then be sub-divided into as many time segments as desired. For example, population energy demand vs. energy supply may be modeled on a daily, weekly, or monthly basis within the larger non-breeding period. The length of these time segments is usually determined by data restrictions. We modeled energy demand vs. supply on a bi-weekly basis for the period late-August to late-March which encompasses the wintering interval for most waterfowl species in the Central Valley.

Waterfowl Population Objectives: Waterfowl population objectives used in TRUEMET are specific to each time segment (e.g. the month of October). Ideally, these time specific population objectives are derived from the North American Waterfowl Management Plan (United States Fish and Wildlife Service and Canadian Wildlife Service 1986). We used CVJV-goal populations of waterfowl as defined in the CVJV Plan (CVJV 2006).

Waterfowl Daily Energy Requirements: Within TRUEMET the user may sub-divide waterfowl into separate foraging guilds that have access to specific foraging habitats. For example, population objectives for each dabbling duck species may be combined into a single "dabbling duck" guild. TRUEMET requires an estimate of the daily energy requirement of the average bird in each foraging guild. To estimate the daily energy requirement of this average bird a resting metabolic rate (RMR) is calculated using the following equation from Miller and Eadie (2006), where RMR is multiplied by a factor of three to account for energy costs of free living. We assumed body mass is equal to the average body mass of birds in a foraging guild as described in the CVJV plan (CVJV 2006):

$$\text{RMR (kJ/day)} = 433 * (\text{body mass in kg})^{0.785}$$

Habitat Availability and Biomass and Nutritional Quality of Foods: TRUEMET requires information on the availability of waterfowl habitat, the biomass of foods in those habitats, and the nutritional quality of those foods. Habitat availability is a function of habitat area (e.g. acres) and the ability of waterfowl to access foods produced in a habitat type. For example, managed wetlands may total 500 acres but these habitats may only become available after October 1 when they are intentionally flooded.

Food biomass estimates are obtained by local sampling or from published sources. However, waterfowl abandon feeding in habitats before all food is exhausted because at some point the costs of continuing to forage on a diminishing resource exceeds energy gained; this value is called the giving-up-density or foraging threshold (Nolet et al. 2006). For example, mallards feeding in dry fields in Texas reduced corn densities to 13 lbs / acre before abandoning fields (Baldassare and Bolen 1984). Consequently, we adjusted our biomass estimates by subtracting published estimates of giving-up-densities. For agricultural foods we subtracted 13 lbs / acre (Baldassare and Bolen 1984), for seed resources in wetland habitats we subtracted 30 lbs/acre (Naylor 2002). Although waterfowl carrying capacity is strongly dependent on food biomass, the energy or calories provided by these foods is also important. True metabolizable energy or TME provides a measure of the energy waterfowl are able to extract from foods.

PRELIMINARY RESULTS

(*The following results should be considered preliminary and are presented primarily to demonstrate the types of information produced by our modeling rather than as data on which to base management decisions. We will evaluate accuracy of and finalize these results during future work.)*

Preliminary results of the 31 scenarios that we evaluated (Table 1) representing: a) existing food habitat and average water-year conditions, b) CVJV-goal food habitat and average water-year conditions, and c) CVJV-goal food habitat and dry water-year conditions, indicate that additional impact of projected climate on waterfowl food habitats in Butte Basin was relatively small compared to projected urbanization and water-year wetness with the greatest reduction in food habitat area resulting from loss of rice habitat. However, these scenarios all assume present-day water supply prioritization and loss of top demand priority for public wetlands or lowering priority of private wetlands or agriculture would result in additional impacts.

EXISTING FOOD HABITATS AND AVERAGE WATER-YEAR CONDITIONS

WEAP-CV Adapted Model results indicate that assuming present-day water supply prioritization as defined in the model and existing food habitat area and average water-year conditions:

- Private wetlands that depend upon low-reliability water supplies will decline marginally because of the additional effect of projected change in climate on water supplies and demands.
- Public wetlands and private wetlands with high-reliability water supplies will remain largely unaffected by projected changes in land use and climate because public managed wetlands currently share top priority for water supplies with indoor urban use and have a diversity of water supply options.
- Agricultural food habitats will decline substantially because of projected conversion of these habitats into urban land use with some additional loss due to effect of climate change on water supplies and demands**.**
- Under existing conditions, recent climate, and average water-year conditions, food supplies easily meet wintering waterfowl demand, even at CVJV goal population

Based on this and other research (CVJV Plan), food habitats in Butte Basin are predicted to be negatively affected by projected changes in land use and climate. Projected conversion of agricultural habitats to urban landscape is expected to have a relatively strong direct effect in reducing areas of agricultural habitats (Methods and Table 7). The additional effects of changing climate and indirect effects of urban development caused by reducing water supplies needed by food habitats were much less significant. In considering a time series reflecting multiple years of average water supplies and demands across climate scenarios and accounting for projected urban development, WEAP-CV Adapted Model results indicated that some food habitats may be marginally limited by projected changes in climate. Based on results from recent climate scenarios, a future climate reflecting the recent climate combined with a projected increase and corresponding decrease in urban and agricultural water uses, respectively, may not limit water supplies to a level of reducing areas of any food habitats we examined (Table 7). Based on model results, public wetlands and private wetlands with high-reliability supplies would be unaffected by projected changes in land use and climate and therefore were not indicated in Table 7. In contrast, results from climate change-CO_2 model scenarios indicate that projected changes in climate may limit water supplies to a level that marginally reduces areas of some wetland and all agricultural habitats (Table 7). Among existing food habitat scenarios, model results indicated a predicted maximum reduction of 5,980 acres total of wetland and agricultural food habitat related to projected change in climate.

Water supply shortfall (mean of shortfall values between August and March) may be the greatest in September for early- and late-flooded seasonal wetlands, and in October for semipermanent wetlands. Results for the latest temporal projection of GFDL-A2 climate scenario indicates that water supply shortfall for wetlands with low-reliability water supplies may increase by a maximum of 5-6% relative to recent climate (Table 7). This potential shortfall increase corresponds with maximum reductions of 127 acres of early-flooded seasonal wetlands, 28 acres of late-flooded seasonal wetlands, and 26 acres of semipermanent wetlands (Table 7). Considering projected climate change, agricultural habitats are projected to have a water supply shortfall in July and August. Similar to low-reliability wetlands, water supply shortfall of agricultural habitats may increase by a maximum of 5% relative to recent climate based on multiple temporal projections of climate change scenarios (Table 7). This increase in shortfall corresponds with maximum reductions of 4,512 acres of winter-flooded rice, 1,316 acres of unplowed-winter-dry rice, and 114 acres of unplowed-winter-dry corn (Table 7). Due to existing high abundance of rice agriculture and under present-day water supply prioritization existing food supplies are more than adequate to support CVJV goal populations of wintering waterfowl during average water-year conditions (Fig. 6).

CVJV-GOAL FOOD HABITAT AND AVERAGE WATER-YEAR CONDITIONS

WEAP-CV Adapted Model results indicate that assuming present-day water supply prioritization as defined in the model and at CVJV goal food habitat levels and average water-year conditions:

- Area of public wetlands and private wetlands with high-reliability water supplies will remain unaffected by projected changes in land use and climate.
- Consistent with results for existing food habitat scenarios, area of agricultural food habitats will decline substantially because of projected conversion of these habitats into urban land use with small additional effect of climate change on water supplies and demands.
- Projected restoration of wetlands on existing areas of food habitats will also result in substantial reductions in agricultural food habitats (see Methods).
- Despite little impact of projected change in climate or urbanization on wetland area in general, existing low-reliability supplies are currently limited and will provide little support for additional restored wetland area.
- Under average water-year conditions and present-day water supply prioritizations, water supplies available for food habitats at CVJV goal levels will produce food supplies adequate to maintain CVJV-goal populations of wintering waterfowl even for GFDL-A2 projected climate.

Under average water-year scenarios, food habitats in Butte Basin based on goal food scenarios are predicted to be greatly affected by projected land use and marginally additionally affected by projected climates (Tables 7 and 8). Food habitats that were limited in existing food habitat scenarios were also the sole food habitats limited in the goal food scenarios. Among goal food habitat scenarios, model results indicated a predicted maximum reduction of 5,206 acres total of wetland and agricultural food habitat related to projected change in climate. Independent of climate change projection, a substantial proportion of water needed to support additional areas of restored low-reliability wetlands may be lacking (Table 8).

When comparing projected climate scenarios with recent climate scenarios, results did not indicate that water supply shortfall for seasonal wetlands with low-reliability water supplies would increase relative to recent climate (Table 8). However, results for the latest temporal projection of GFDL-A2 climate scenario indicates that water supply shortfall for semipermanent wetlands with low-reliability water supplies may increase by a maximum of 5% relative to recent climate (Table 8). This potential shortfall increase corresponds with a maximum reduction of 25 acres of semipermanent wetlands (Table 8). Similar to existing food habitat scenario results, water supply shortfall of agricultural habitats may increase by a maximum of 5% relative to recent climate based on multiple temporal projections of climate change scenarios (Table 8).

This increase in shortfall corresponds with maximum reductions of 3,100 acres of winter-flooded rice, 1,316 acres of unplowed-winter-dry rice, and 114 acres of unplowed-winter-dry corn (Table 8). Under present-day water supply prioritization as defined in our adapted WEAP-CV model, water supplies available for food habitats at CVJV goal levels will produce food supplies adequate to maintain CVJV goal populations of wintering waterfowl during average water-year conditions under recent historical climate (Fig. 7) and GFDL-A2 projected climates for 2001-30 (Fig. 8), 2031-60 (Fig. 9) and 2061-99 (Fig. 10).

CVJV-GOAL HABITAT AND DRY WATER-YEAR CONDITIONS

WEAP-CV Adapted Model results for the 2 dry water-year scenarios that we analyzed indicate that assuming present-day water supply prioritizations as defined in the model:

- Multiple consecutive years of drought would substantially reduce water supplies available for CVJV-goal area of food habitats relative to average climate scenarios and projected change in climate would further reduce supply, but to a much lesser extent.
- The effect of climate change on water available for food habitats at CVJV-goal levels varies little between average and dry water-year scenarios.
- Public wetlands at CVJV goal levels will remain largely unaffected by projected changes in land use and climate even in extended periods of drought.
- During extended periods of drought, substantial reduction in areas of both agricultural and wetland food habitats may be exacerbated by long-term changes in climate, but to a much lesser extent than that from the drought itself.
- During extended periods of drought, the combined effects of urbanization and GFDL-A2 projected climate is projected to result in a deficit of food supplies for wintering waterfowl after late January.

Multiple consecutive years of drought would substantially reduce water supplies available for food habitats relative to average water-year conditions during both recent climate scenarios and projected GFDL-A2 scenarios (Table 9). Additional, but lesser, impacts of the GFDL-A2 projected climate were also evident. Based on recent climate scenarios, extended drought alone may reduce food habitats about 22,748 acres more than in average water-year situations (Tables 8 and 9). As well as drought-related reduction in food habitat areas, model results indicated an additional reduction of about 3,522 acres of food habitat, most of which is post-harvest rice, related to projected GFDL-A2 climate (Table 9). The effect of climate change on water available for food habitats may vary little between average and dry water-year scenarios. More specifically, the difference in water supply shortfall for food habitats between recent and projected GFDL-A2 climates varied relatively little between average and dry year scenarios (Tables 8 and 9). Relative to GFDL-A2 climate-related water supply shortfall (maximum of 5%) produced for average water-year scenarios, GFDL-A2 climate-related shortfall for dry water-year scenarios was slightly reduced (i.e., maximum of 3%). Model results indicated that solely public wetlands may remain unaffected by extended periods of drought and projected changes in land use and climate. During extended periods of drought, the combined effects of urbanization and GFDL-A2 projected climate is projected to result in a deficit of food supplies for wintering waterfowl after late January (Fig. 11; only time period 2031-2060 was modeled).

FUTURE WORK

Assuming continued project funding support, our future work will include a) an evaluation of our work to-date to ensure accuracy, improve efficiency, and refine focus our future modeling efforts on the most informative scenarios, b) continuing with additional modeling into other Central

Valley regions guided by the evaluation of our work to-date, c) continued and expanded translation of changes in water supplies and habitats supported by those water supplies into impacts on ecology of waterfowl, shorebirds, and other waterbirds; and d) continuing to update the CA-LCC and CVJV on project progress and help adapt results into conservation planning.

EVALUATE COMPLETED MODELING

We will first focus on conducting a critical review of the Butte Basin modeling that we have conducted during the first six months of the project to evaluate its accuracy and guide our future modeling. Utilizing the enhanced WEAP modeling expertise provided by our new project partner SEI, we will first evaluate our adaption of WEAP-CV. This will include assessments of a) the efficiency, accuracy, and possible alternative of our adaption approach, b) accuracy and possible alternatives for each new assumption required, and c) accuracy and possible alternatives for new data sources we utilized. Our current approach of conducting Basin-specific analysis (e.g., Butte Basin, then Colusa Basin, then other basins) was designed to match the Basin-specific habitat conservation planning approach of the CVJV. However, we have discovered that this approach requires a large number of adaptations to the WEAP-CV model and additional assumptions that increase the complexity of the overall modeling effort compared with the more regionally-generalized approach (e.g., Sacramento Valley, San Joaquin Valley, Delta-Suisun) already employed in WEAP-CV. Thus, we will re-assess the advantages and disadvantages of these two approaches, in regards to modeling feasibility and information necessary for conservation planning, and determine the best approach for our future modeling efforts.

We will next evaluate the scenarios that we modeled to judge the informative value of each and help identify additional scenarios for future analysis. During the first 6 months of the project, we used our adapted WEAP-CV model to evaluate 31 scenarios of water-supplies to support existing or CVJV-goal wintering waterfowl food habitats resulting from 5 climate scenarios (recent historical and four CO2-Climate Model climate projections) for 4 time periods, 2 water-year wetness levels, and 3 projected levels of urbanization. We used TRUEMET to compare food energy and waterfowl population energy demand for 7 of these scenarios. Results of some of these scenarios were very similar and some scenarios required assumptions for which data were scarce. Thus, some scenarios may be excluded in the future to allow inclusion of other, more informative or data-rich scenarios. Only 2 of the scenarios we modeled evaluated water supplies and food habitats after a series of dry water years; thus modeling of additional dry water-year scenarios will likely be conducted. New scenarios that may be added include evaluating effects of proposed changes in allocation or prioritization of water supplies among water users or regions. These could include changes in agriculture water return flow supplies for wetlands to reflect changes in land use due to water transfers of varying levels or implementation of additional stream flow requirements or other changes in water management to enhance fisheries conservation.

CONDUCT ADDITIONAL MODELING

Once evaluation of our completed modeling is complete and our modeling approach and suite of scenarios is updated, we will continue forward with additional modeling to estimate water supplies and habitat area supported by these water supplies for waterfowl, shorebirds and other waterbirds. We expect that with the enhanced WEAP modeling expertise provided by our new project partnership with SEI, the efficiency with which we are able to link water supply estimates resulting from downscaled climate data into the adapted WEAP-CV model will increase. The regional sequence with which we plan to conduct modeling is Sacramento Valley, San Joaquin Valley and Delta-Suisun.

TRANSLATING CHANGES IN WATER SUPPLIES INTO IMPACTS ON ECOLOGY

We will utilize three approaches for assessing impacts of changes in landscape due to urbanization and climate change on ecology of waterfowl and other waterbirds. First, we will continue with our approach to input estimates of habitat area supported by modeled water supplies (from the adapted WEAP-CV model) into TRUEMET to compare avian food energy supply vs. energy demand of CVJV-goal wintering populations. TRUEMET is used by the CVJV (and other Joint Ventures) for conservation planning of wintering waterfowl and — although less completely developed — shorebirds (CVJV 2006). The approach is also possible for other wintering waterbirds but was not applied for conservation planning by the CVJV due to lack of information on existing and goal populations and other data. Secondly, for waterbird guilds for which the TRUEMET approach is not well developed but for which CVJV habitat goals are established (i.e., breeding waterfowl and shorebirds; other waterbirds), we will compare habitat area supported by water supplies under each scenario vs. CVJV habitat goals. Thirdly, our new partnership with UC Davis will allow us to also investigate the feasibility of agent-based modeling (Goss-Custard et al. 2006, Nonaka and Holme 2007). Our new UC Davis partners have developed a prototype agent-based model to simulate the effect of wetland habitat change on energetics and carrying capacity of foraging waterbirds. This approach offers a significant improvement on our current TRUEMET model in: a) allowing spatially-explicit analysis of the effects of alternative water-management regimes on spatial juxtaposition and distribution of wetland habitats, b) expanding the capacity to generalize across taxa, including waterfowl, shorebirds and other wetland-dependent wildlife, c) incorporating other important determinants of species habitat use and carrying capacity, such as disturbance and dispersion of non-foraging (refuge) habitat, and d) offering the potential to integrate more directly and completely with existing models of water management and in-stream fish habitat.

CONSERVATION PLANNING

We will continue to provide periodic project updates to the CA-LCC and CVJV on project progress and help adapt results into conservation planning. The website we established describing project goals and methods will be updated with new information on partners, results, and management implications. Once project results are finalized, we will work with the CVJV and their partners to apply results to aid development of management strategies that address critical waterfowl, shorebird, and other waterbird resources that are most at risk due to climate change and other factors.

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Table 1. Scenarios used in the WEAP-CV Adapted Model to evaluate impacts of climate, projected urban development, and water year wetness on habitat area and water supplies needed to support wetland and agricultural habitats at either existing or CVJV-goal acreages. Food supplies provided by these habitats vs. demand needed to feed wintering waterfowl at CVJV goal population levels were also compared using TRUEMET for selected scenarios (*).

Time Period	Climate	Projected Urban Development	Water-year Wetness	Habitat Acreage
recent	recent	existing urbanization	average	existing*
2040	recent	2040 urbanization	average	existing
2099	recent	2099 urbanization	average	existing
2001–2030	PCM-B1	2040 urbanization	average	existing
2001–2030	GFDL-B1	2040 urbanization	average	existing
2001–2030	PCM-A2	2040 urbanization	average	existing
2001–2030	GFDL-A2	2040 urbanization	average	existing
2031–2060	PCM-B1	2040 urbanization	average	existing
2031–2060	GFDL-B1	2040 urbanization	average	existing
2031–2060	PCM-A2	2040 urbanization	average	existing
2031–2060	GFDL-A2	2040 urbanization	average	existing
2061–2099	PCM-B1	2099 urbanization	average	existing
2061–2099	GFDL-B1	2099 urbanization	average	existing
2061–2099	PCM-A2	2099 urbanization	average	existing
2061–2099	GFDL-A2	2099 urbanization	average	existing
2040	recent	2040 urbanization	average	CVJV goal*
2040	recent	2040 urbanization	dry	CVJV goal
2099	recent	2099 urbanization	average	CVJV goal
2001–2030	PCM-B1	2040 urbanization	average	CVJV goal
2001–2030	GFDL-B1	2040 urbanization	average	CVJV goal
2001–2030	PCM-A2	2040 urbanization	average	CVJV goal
2001–2030	GFDL-A2	2040 urbanization	average	CVJV goal*
2031–2060	PCM-B1	2040 urbanization	average	CVJV goal
2031–2060	GFDL-B1	2040 urbanization	average	CVJV goal
2031–2060	PCM-A2	2040 urbanization	average	CVJV goal
2031–2060	GFDL-A2	2040 urbanization	average	CVJV goal*
2031–2060	GFDL-A2	2040 urbanization	dry	CVJV goal*
2061–2099	PCM-B1	2099 urbanization	average	CVJV goal
2061–2099	GFDL-B1	2099 urbanization	average	CVJV goal
2061–2099	PCM-A2	2099 urbanization	average	CVJV goal
2061–2099	GFDL-A2	2099 urbanization	average	CVJV goal*

Table 2. Water demand priority and supply source preference associated with food habitats and other agriculture within the Butte Basin as specified in the WEAP-CV Adapted Model.

Demand Site	Demand Priority	Water Supply Source	Preference	Maximum Flow (percent of demand)
State and federal wildlife refuges	1	Feather River	1	
	1	Sutter bypass	2	
	1	Butte groundwater	3	4
Upper Butte private wetlands	3	Feather River	1	
	3	Butte Creek	1	
	3	Sacramento River	2	
	3	Butte groundwater	3	4
Butte Sink high-reliability private wetlands	3	Feather River	1	
	3	Butte Creek	2	
	3	Butte groundwater	3	4
Butte Sink low-reliability private wetlands	limited to return flows	Irrigation return flows	1	
All Butte Basin agriculture	3	Sacramento River	1	70
	3	Feather River	1	30
	3	Sutter bypass	2	15
	3	Butte groundwater	2	50

Table 3. Demand priorities in the WEAP-CV Model.

Demand Sector	Demand Priority
Urban Indoor	1 (highest priority)
Managed Wetland[a]	1[a]
Instream Flow	2
Agriculture	3
Urban Outdoor	3
Hydropower	4
Reservoirs	14-20
Flood control outside of bypasses	98
Sutter and Yolo flood bypass systems	99

[a] WEAP-CV Model only defines public wetlands. For the WEAP-CV Adapted Model, managed public wetlands were assumed to have the same demand priority (i.e., 1), but managed privately-owned wetlands were assumed to have the same demand priority as agriculture (i.e., 3).

Table 4. Wetland classifications and areas of water Demand Sites in the Butte Basin specified for the Current Accounts year of the WEAP-CV Adapted Model.

Ownership	Region in Butte Basin	Water Supply[a] Reliability	Irrigation Schedule	Demand Priority[b]	Annual Activity Level[c] (acres)
Public	Throughout Butte Basin	High-reliability	Early-flooded seasonal	1	5,736
Public	Throughout Butte Basin	High-reliability	Late-flooded seasonal	1	1,434
Public	Throughout Butte Basin	High-reliability	Semipermanent	1	1,266
Private	Upper Butte	High-reliability	Early-flooded seasonal	3	2,458
Private	Upper Butte	High-reliability	Late-flooded seasonal	3	614
Private	Upper Butte	High-reliability	Semipermanent	3	542
Private	Butte Sink	High-reliability	Early-flooded seasonal	3	8,382
Private	Butte Sink	High-reliability	Late-flooded seasonal	3	2,096
Private	Butte Sink	High-reliability	Semipermanent	3	1,849
Private	Butte Sink	Low-reliability	Early-flooded seasonal	RF	2,096
Private	Butte Sink	Low-reliability	Late-flooded seasonal	RF	524
Private	Butte Sink	Low-reliability	Semipermanent	RF	462

[a] Adapted from Water Report (2000).

[b] 1 = highest, 3 = equivalent to agriculture, RF = relies on agricultural return flows.

[c] Area in years 2003-04 as reported in CVJV Plan (2006).

Table 5. Wetlands irrigation schedules for water Demand Sites in the Butte Basin specified for the Current Accounts year of the WEAP-CV Adapted Model.

	Water Use Rate (acre-feet/acre)												
Irrigation Schedule	Annual Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Early-flooded seasonal wetland	5.6	0.5	0.4	0.2	0.2	0.2	0.2	0.0	1.0	0.0	0.0	0.9	2.0
Late-flooded seasonal wetland	5.4	2.0	0.5	0.4	0.2	0.2	0.2	0.0	1.0	0.0	0.0	0.0	0.9
Semipermanent wetland	7.4	3.0	0.4	0.2	0.2	0.2	0.4	0.5	0.5	1.0	1.0	0.0	0.0

Table 6. Agricultural classifications and areas of water Demand Sites in the Butte Basin specified for the Current Accounts year of the WEAP-CV Adapted Model.

Agricultural Land Use[a]	Annual Activity Level (acres)
Rice- Unplowed Winter-dry	29,019
Rice- Plowed Winter-dry	9,673
Rice- Winter-flooded	99,494
Corn- Unplowed Winter-dry	2,510
Corn- Plowed Winter-dry	2,509
Other Agriculture	113,720

[a] Total rice = plowed and unplowed winter-dry and winter-flooded rice, total corn = plowed and unplowed winter-dry corn.

Table 7. Effects of projected urban development and climate on area and water supplies of existing waterfowl food habitats based on climate-urban development scenarios modeled in the WEAP-CV Adapted Model assuming average water-year conditions. Habitats with areas and water supplies unaffected by projected urban development and climate (i.e., public wetlands and private wetlands with high-reliability water supplies) were not included in the table.

	Food Habitat								
	Low-reliability Supply, Early-flooded, Seasonal Wetlands			Low-reliability Supply, Late-flooded, Seasonal Wetlands			Low-reliability Supply, Semipermanent Wetlands		
Climate-urban Development Scenario	Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]	Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]	Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]
Recent Climate									
Existing urbanization	0	-228	11	0	-57	11	0	0	0
2040 urbanization	0	-228	11	0	-57	11	0	0	0
2099 urbanization	0	-228	11	0	-57	11	0	0	0
PCM-B1 Climate									
2040 urbanization, 2001-2030 climate	0	-226	11	0	-57	11	0	-1	0
2040 urbanization, 2031-2060 climate	0	-245	12	0	-60	11	0	-1	0
2099 urbanization, 2061-2099 climate	0	-232	11	0	-57	11	0	0	0
GFDL-B1 Climate									
2040 urbanization, 2001-2030 climate	0	-237	11	0	-59	11	0	-2	0
2040 urbanization, 2031-2060 climate	0	-247	12	0	-60	12	0	-3	1
2099 urbanization, 2061-2099 climate	0	-243	12	0	-58	11	0	0	0
PCM-A2 Climate									
2040 urbanization, 2001-2030 climate	0	-236	11	0	-59	11	0	-1	0
2040 urbanization, 2031-2060 climate	0	-240	11	0	-60	11	0	-4	1
2099 urbanization, 2061-2099 climate	0	-246	12	0	-61	12	0	-3	1
GFDL-A2 Climate									
2040 urbanization, 2001-2030 climate	0	-201	10	0	-50	10	0	0	0
2040 urbanization, 2031-2060 climate	0	-257	12	0	-62	12	0	-4	1
2099 urbanization, 2061-2099 climate	0	-356	17	0	-85	16	0	-26	6

Table 7. Continued.

Climate-urban Development Scenario	Food Habitat: Winter-flooded Rice[d] Urbanization Effect (acres)[a]	Winter-flooded Rice[d] Climate Effect (acres)[b]	Winter-flooded Rice[d] Water Supply Shortfall (%)[c]	Unplowed Winter-dry Rice[d] Urbanization Effect (acres)[a]	Unplowed Winter-dry Rice[d] Climate Effect (acres)[b]	Unplowed Winter-dry Rice[d] Water Supply Shortfall (%)[c]	Unplowed Winter-dry Corn[d] Urbanization Effect (acres)[a]	Unplowed Winter-dry Corn[d] Climate Effect (acres)[b]	Unplowed Winter-dry Corn[d] Water Supply Shortfall (%)[c]
Recent Climate									
Existing urbanization	0	0	0	0	0	0	0	0	0
2040 urbanizaton	-9,253	0	0	-2,699	0	0	-234	0	0
2099 urbanization	-22,910	0	0	-6,682	0	0	-578	0	0
PCM-B1 Climate									
2040 urbanization, 2001-2030 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2040 urbanization, 2031-2060 climate	-9,253	-1,193	1	-2,699	-348	1	-234	-30	1
2099 urbanization, 2061-2099 climate	-22,910	-3,829	5	-6,682	-1,117	5	-578	-97	5
GFDL-B1 Climate									
2040 urbanization, 2001-2030 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2040 urbanization, 2031-2060 climate	-9,253	-4,512	5	-2,699	-1,316	5	-234	-114	5
2099 urbanization, 2061-2099 climate	-22,910	-3,829	5	-6,682	-1,117	5	-578	-97	5
PCM-A2 Climate									
2040 urbanization, 2001-2030 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2040 urbanization, 2031-2060 climate	-9,253	-4,512	5	-2,699	-1,316	5	-234	-114	5
2099 urbanization, 2061-2099 climate	-22,910	-3,829	5	-6,682	-1,117	5	-578	-97	5
GFDL-A2 Climate									
2040 urbanization, 2001-2030 climate	-9,253	-1,376	2	-2,699	-401	2	-234	-35	2
2040 urbanization, 2031-2060 climate	-9,253	-4,512	5	-2,699	-1,316	5	-234	-114	5
2099 urbanization, 2061-2099 climate	-22,910	-3,829	5	-6,682	-1,117	5	-578	-97	5

[a] Represents the change in habitat area caused by direct conversion of habitat to urban land use and changes in water demands related to conversion of habitat. An urbanization effect of less than zero and a water supply shortfall value of zero indicates a projected loss in habitat because of conversion of habitat to urban development and not from changes in water supply.

[b] Calculated as the difference between the area of habitat adjusted based on level of urbanization and mean area of irrigated habitat for a given scenario. Mean areas were calculated across months August-March of the following year for wetlands and September-March for agricultural habitats, which were not harvested and did not provide feeding habitat until September.

[c] Represents the mean proportion of water optimally available for habitat that was not delivered to the habitat. Mean shortfall was calculated across months across months August-March of the following year for wetlands and September-March for agricultural habitats, which were not harvested and did not provide feeding habitat until September.

[d] Limited water supply during the growing season (5% water supply shortfall in August) was assumed to reduce available habitat post-harvest, even though there was no shortfall during the following months.

Table 8. Effects of projected urban development and climate on area and water supplies of waterfowl food habitats needed to support Central Valley Joint Venture goal waterfowl populations. Effects were based on climate-urban development scenarios modeled in the WEAP-CV Adapted Model assuming average water-year conditions. Habitats with areas and water supplies unaffected by projected urban development and climate (i.e., public wetlands and private wetlands with high-reliability water supplies) were not included in the table.

	Food Habitat								
	Low-reliability Supply, early-flooded, Seasonal Wetlands			Low-reliability Supply, Late-flooded, Seasonal Wetlands			Low-reliability Supply, Semipermanent Wetlands		
Climate-urban Development Scenario	Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]	Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]	Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]
Recent Climate									
2040 urbanization	0	-2,432	57	0	-539	50	0	-52	10
2099 urbanization	0	-3,984	68	0	-879	60	0	-52	10
PCM-B1 Climate									
2040 urbanization, 2001-2030 climate	0	-2,159	50	0	-472	44	0	-43	8
2040 urbanization, 2031-2060 climate	0	-2,175	51	0	-473	44	0	-38	7
2099 urbanization, 2061-2099 climate	0	-3,720	64	0	-812	56	0	-42	8
GFDL-B1 Climate									
2040 urbanization, 2001-2030 climate	0	-2,387	56	0	-527	49	0	-45	9
2040 urbanization, 2031-2060 climate	0	-2,192	51	0	-478	44	0	-45	9
2099 urbanization, 2061-2099 climate	0	-3,799	65	0	-830	57	0	-42	8
PCM-A2 Climate									
2040 urbanization, 2001-2030 climate	0	-2,197	51	0	-481	45	0	-44	8
2040 urbanization, 2031-2060 climate	0	-2,294	53	0	-505	47	0	-47	9
2099 urbanization, 2061-2099 climate	0	-3,745	64	0	-818	56	0	-46	9
GFDL-A2 Climate									
2040 urbanization, 2001-2030 climate	0	-2,142	50	0	-475	44	0	-34	6
2040 urbanization, 2031-2060 climate	0	-2,351	55	0	-517	48	0	-47	9
2099 urbanization, 2061-2099 climate	0	-4,110	70	0	-907	62	0	-77	15

Table 8. Continued.

Climate-urban Development Scenario	Food Habitat: Winter-flooded Rice[d] Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]	Unplowed Winter-dry Rice[d] Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]	Unplowed Winter-dry Corn[d] Urbanization Effect (acres)[a]	Climate Effect (acres)[b]	Water Supply Shortfall (%)[c]
Recent Climate									
2040 urbanization	-9,253	0	0	-2,699	0	0	-234	0	0
2099 urbanization	-22,910	0	0	-6,682	0	0	-578	0	0
PCM-B1 Climate									
2040 urbanization, 2001-2030 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2040 urbanization, 2031-2060 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2099 urbanization, 2061-2099 climate	-22,910	-2,557	5	-6,682	-1,732	5	-578	-97	5
GFDL-B1 Climate									
2040 urbanization, 2001-2030 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2040 urbanization, 2031-2060 climate	-9,253	-3,100	5	-2,699	-2,100	5	-234	-114	5
2099 urbanization, 2061-2099 climate	-22,910	-2,557	5	-6,682	-1,732	5	-578	-97	5
PCM-A2 Climate									
2040 urbanization, 2001-2030 climate	-9,253	0	0	-2,699	0	0	-234	0	0
2040 urbanization, 2031-2060 climate	-9,253	-3,100	5	-2,699	-2,100	5	-234	-114	5
2099 urbanization, 2061-2099 climate	-22,910	-2,557	5	-6,682	-1,732	5	-578	-97	5
GFDL-A2 Climate									
2040 urbanization, 2001-2030 climate	-9,253	-300	0	-2,699	-203	0	-234	-11	0
2040 urbanization, 2031-2060 climate	-9,253	-3,100	5	-2,699	-2,100	5	-234	-114	5
2099 urbanization, 2061-2099 climate	-22,910	-2,557	5	-6,682	-1,732	5	-578	-97	5

[a] Represents the change in habitat area caused by direct conversion of habitat to urban land use and changes in water demands related to conversion of habitat. An urbanization effect of less than zero and a water supply shortfall value of zero indicates a projected loss in habitat because of conversion of habitat to urban development and not from changes in water supply.

[b] Calculated as the difference between the area of habitat adjusted based on level of urbanization and mean area of irrigated habitat for a given scenario. Mean areas were calculated across months August-March of the following year for wetlands and September-March for agricultural habitats, which were not harvested and did not provide feeding habitat until September.

[c] Represents the mean proportion of water optimally available for habitat that was not delivered to the habitat. Mean shortfall was calculated across months August-March of the following year for wetlands and September-March for agricultural habitats, which were not harvested and did not provide feeding habitat until September.

[d] Limited water supply during the growing season (5% water supply shortfall in August) was assumed to reduce available habitat post-harvest, even though there was no shortfall during the following months.

Table 9. Effects of recent (years 1971-2000) and projected GFDL-A2 climate (for years 2031-2060) on area and water supplies of waterfowl food habitats needed to support Central Valley Joint Venture goal waterfowl populations. Effects were based on scenarios modeled in the WEAP-CV Adapted Model assuming dry water-year conditions and 2040 urban development. Urbanization effect (not indicated) was only related to agricultural habitats and was the same as in Table 7. Habitats with areas unaffected by climate (i.e., public wetlands) were not included in the table.

	Recent Climate		GFDL-A2 Climate		
Food Habitat	Climate Effect (acres)[a]	Water Supply Shortfall (%)[b]	Climate Effect (acres)[a]	Water Supply Shortfall (%)[b]	Difference in Climate Effect (acres)[c]
Upper Butte Basin, High-reliability Supply, Early-flooded, Seasonal Wetlands	-117	2	-198	4	-81
Upper Butte Basin, High-reliability Supply, Late-flooded, Seasonal Wetlands	-29	2	-49	4	-20
Upper Butte Basin, High-reliability Supply, Semipermanent Wetlands	-14	2	-17	3	-3
Butte Sink, High-reliability Supply, Early-flooded, Seasonal Wetlands	-3,931	23	-4,439	26	-508
Butte Sink, High-reliability Supply, Late-flooded, Seasonal Wetlands	-568	13	-682	16	-114
Butte Sink, High-reliability Supply, Semipermanent Wetlands	-179	8	-183	9	-3
Low-reliability Supply, Early-flooded, Seasonal Wetlands	-2,432	57	-2,351	55	80
Low-reliability Supply, Late-flooded, Seasonal Wetlands	-539	50	-517	48	22
Low-reliability Supply, Semipermanent Wetlands	-52	10	-47	9	5
Winter-flooded Rice[d]	-10,448	17	-12,140	20	-1,692
Unplowed Winter-dry Rice[d]	-7,078	17	-8,224	20	-1,146
Unplowed Winter-dry Corn[d]	-384	17	-446	20	-62
Total	-25,771		-29,293		-3,522

[a] Calculated as the difference between the area of potential habitat (post-2040 urbanization) and mean area of irrigated habitat. Mean areas were calculated across months August-March of the following year for wetlands and September-March for agricultural habitats, which were not harvested and did not provide feeding habitat until September.

[b] Represents the mean proportion of water optimally available for habitat that was not delivered to the habitat. Mean shortfall was calculated across months August-March of the following year for wetlands and September-March for agricultural habitats, which were not harvested and did not provide feeding habitat until September.

[c] Calculated as Climate effect$_{\text{GFDL-A2 climate}}$ – Climate effect$_{\text{Recent climate}}$.

[d] Limited water supply during the growing season (i.e., 17-20% water supply shortfall in July) was assumed to reduce available habitat post-harvest, even though there was no shortfall during the period of interest (September-March).

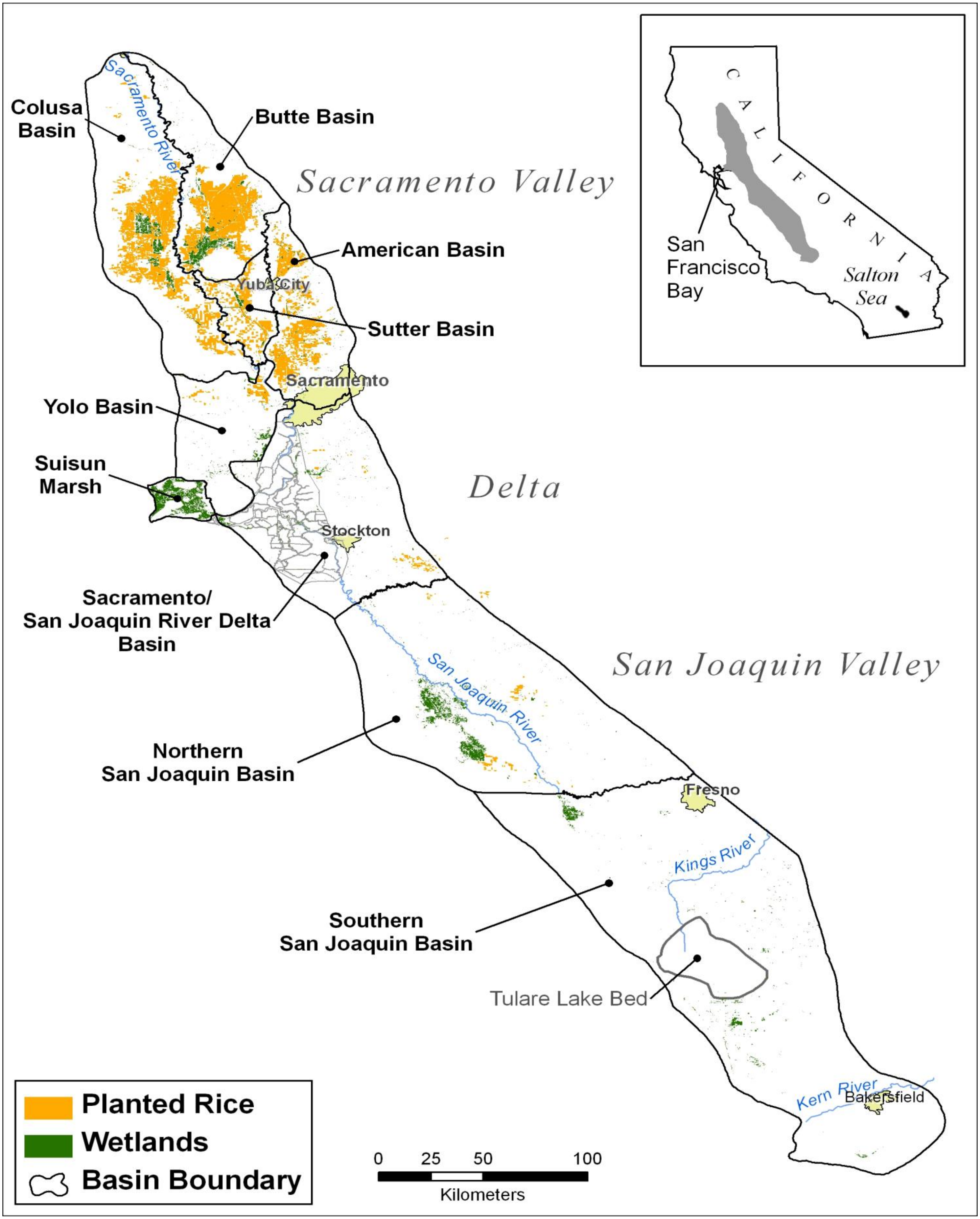

Figure 1. Central Valley of California.

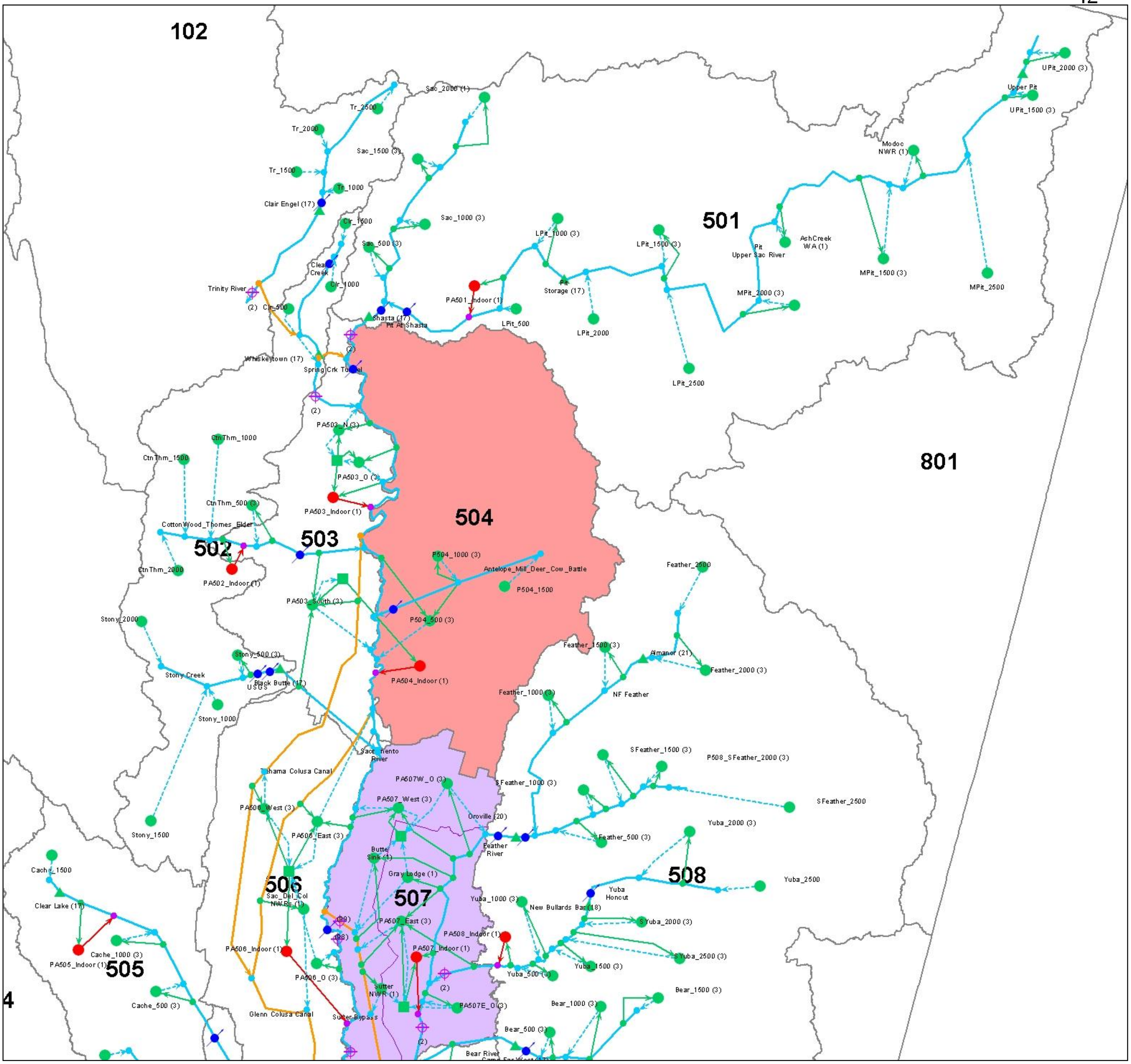

Figure 2. WEAP-CV model structure overlying Planning Areas surrounding and containing the Butte Basin (Planning Area numbers in bolded font) including Demand Site (red circle), Catchment (green circle), Reservoir (green triangle), Flow Requirement (purple hatched circle), River (blue arrow-line), Groundwater (green square), Other Supply (green diamond), Return Flow from urban indoor use (red arrow-line), Runoff/infiltration (blue dash arrow-line), Transmission Link (green arrow-line), Diversion (orange arrow-line), and Streamflow Gage (blue circle-arrow) WEAP objects.

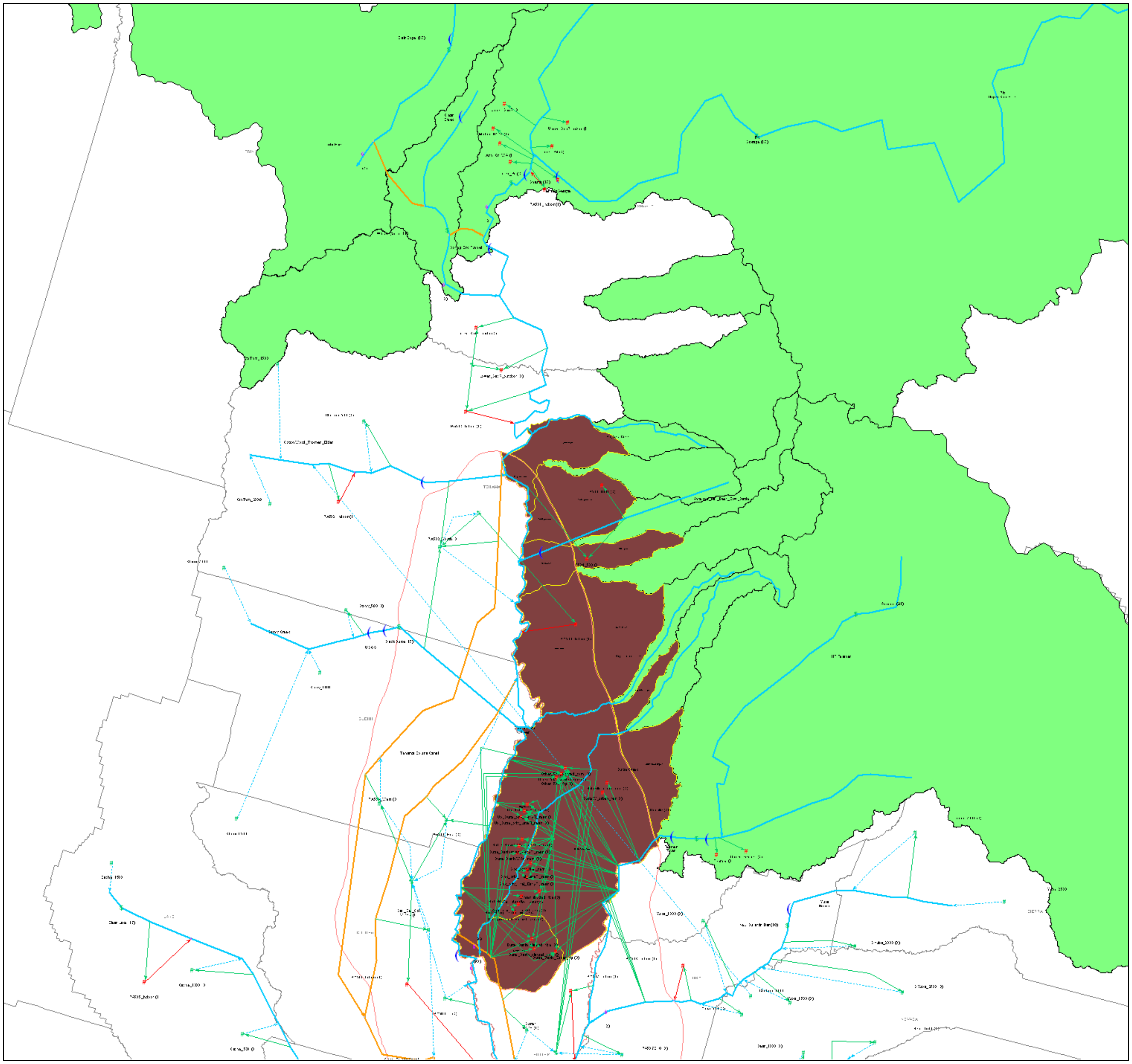

Figure 3. Adapted Model structure of watershed area (green fill) supplying Butte Basin (brown fill within the Basins boundary area [pink line]) including Demand Site (red circle), Catchment (green circle), Reservoir (green triangle), Flow Requirement (purple hatched circle), River (blue arrow-line), Groundwater (green square), Other Supply (green diamond), Return Flow from urban indoor use (red arrow-line), Runoff/infiltration (blue dash arrow-line), Transmission Link (green arrow-line), Diversion (orange arrow-line), and Streamflow Gage (blue circle-arrow) WEAP objects.

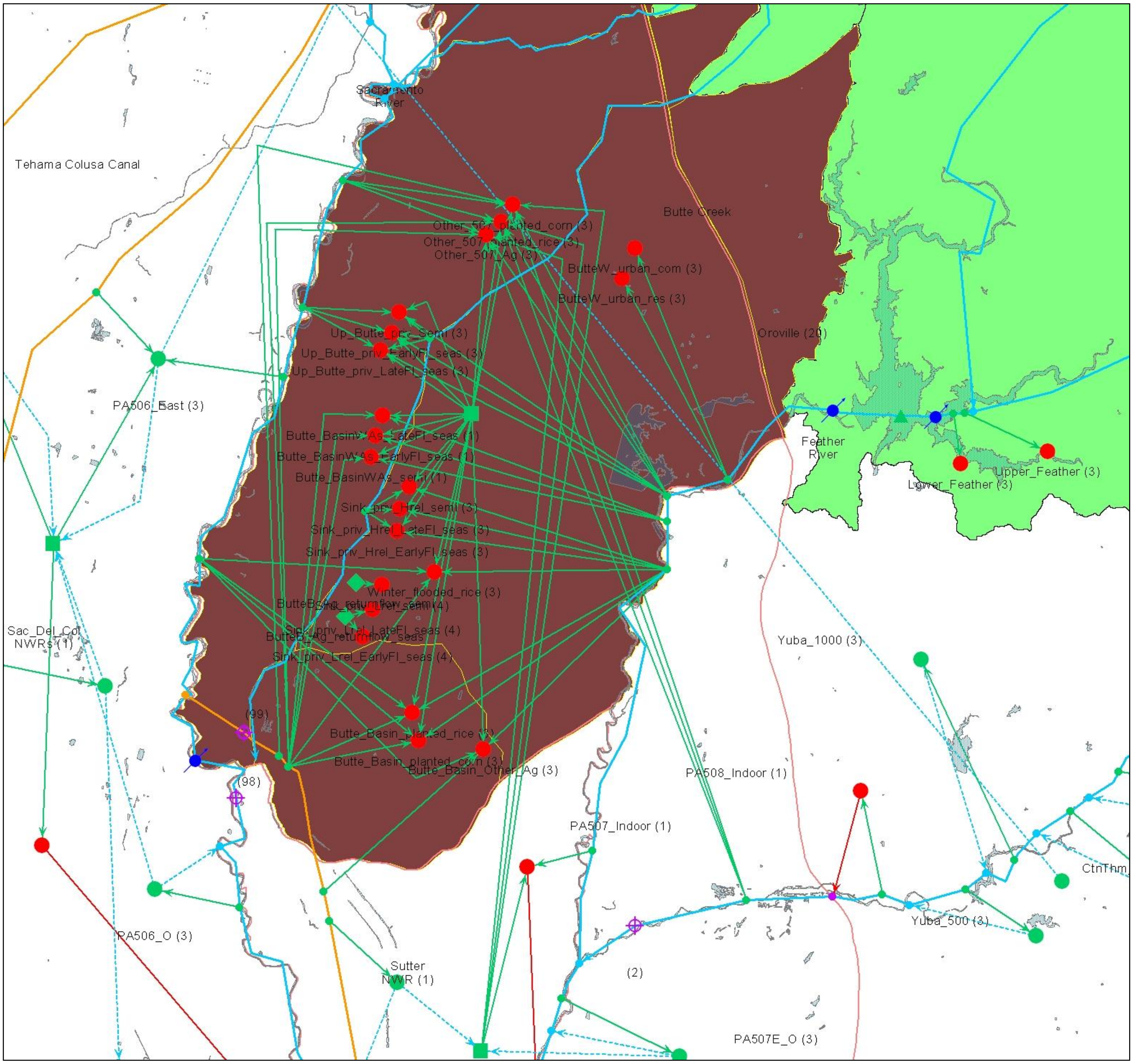

Figure 4. Adapted Model structure of the focal area of Butte Basin (brown fill southwest of pink line) including Demand Site (red circle), Catchment (green circle), Reservoir (green triangle), Flow Requirement (purple hatched circle), River (blue arrow-line), Groundwater (green square), Other Supply (green diamond), Return Flow from urban indoor use (red arrow-line), Runoff/infiltration (blue dash arrow-line), Transmission Link (green arrow-line), Diversion (orange arrow-line), and Streamflow Gage (blue circle-arrow) WEAP objects.

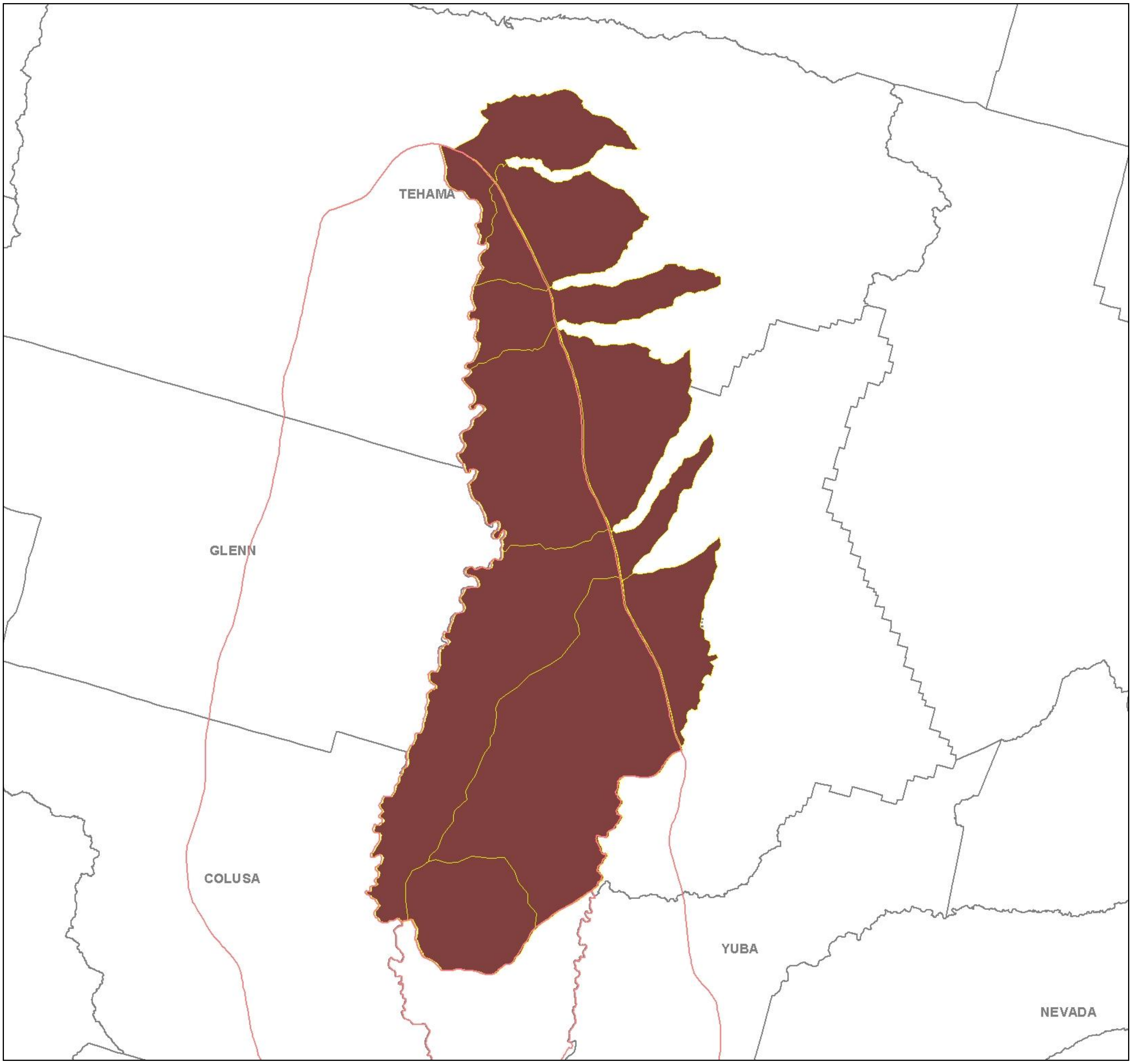

Figure 5. Regional differences in climatic water deficit (delineated by yellow lines) within the Butte Basin (brown fill within Basin boundary area delineated by pink lines).

Figure 6. Butte Basin: Food Supply with Recent Historical Climate and Existing Habitat vs. Demand By Waterfowl at CVJV-Goal Population

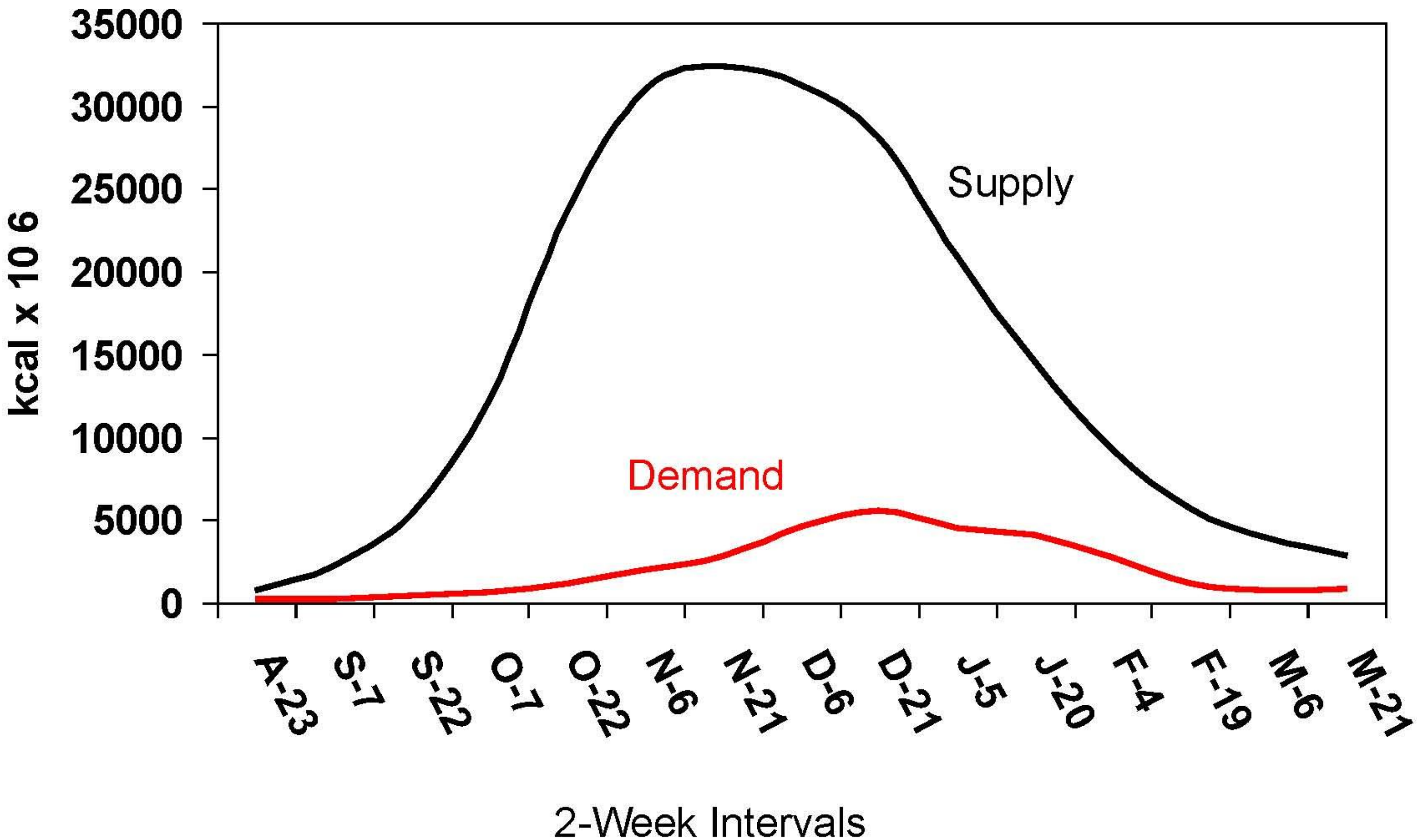

Figure 7. Butte Basin: Food Supply with Recent Historical Climate and Habitat at CVJV-Goal vs. Demand by Waterfowl at CVJV-Goal Population

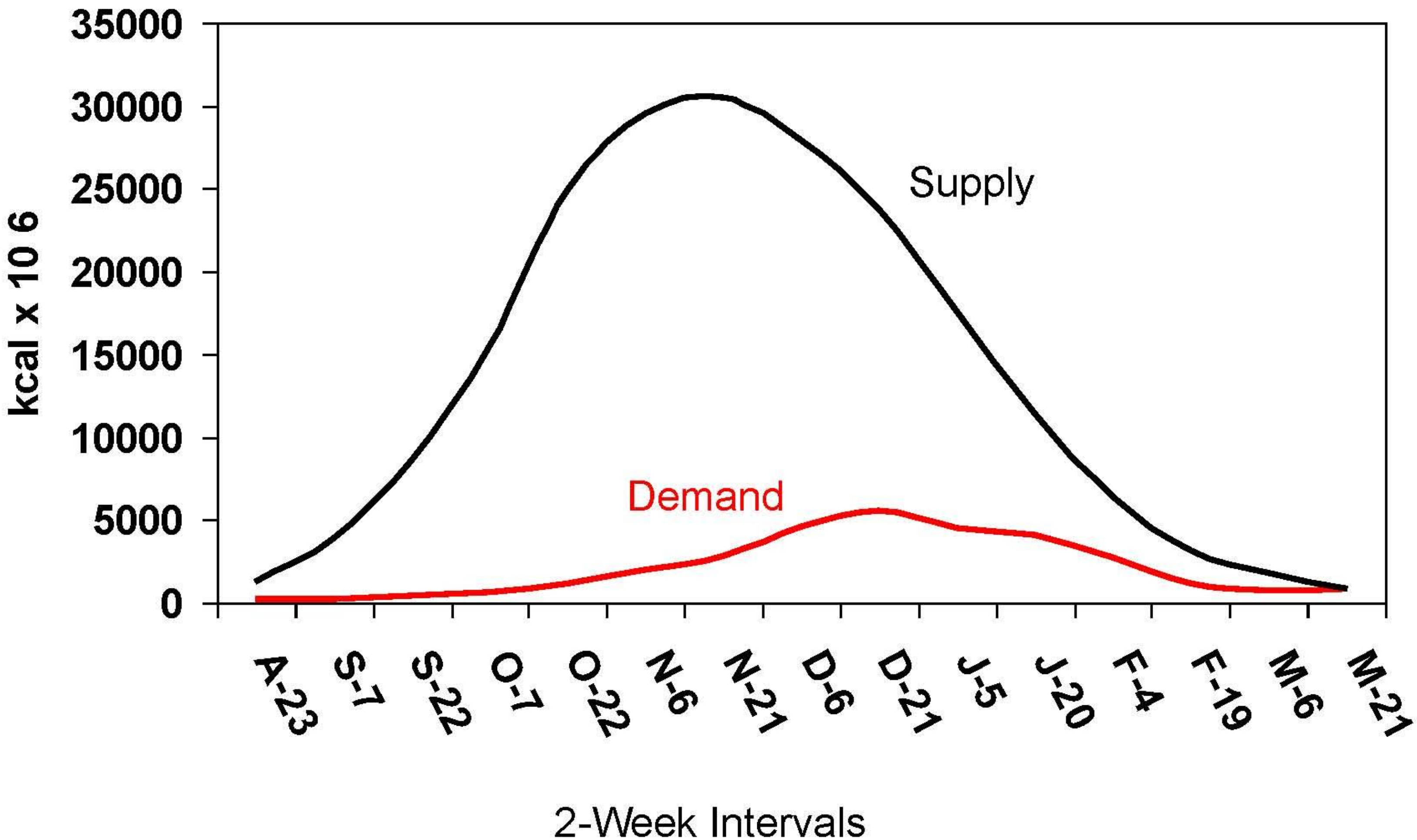

Figure 8. Butte Basin: Food Supply vs. CVJV-Goal Population Demand For Climate Scenario GFDL-A2 in Time Period 2001-2030 Under Average Water Year Conditions

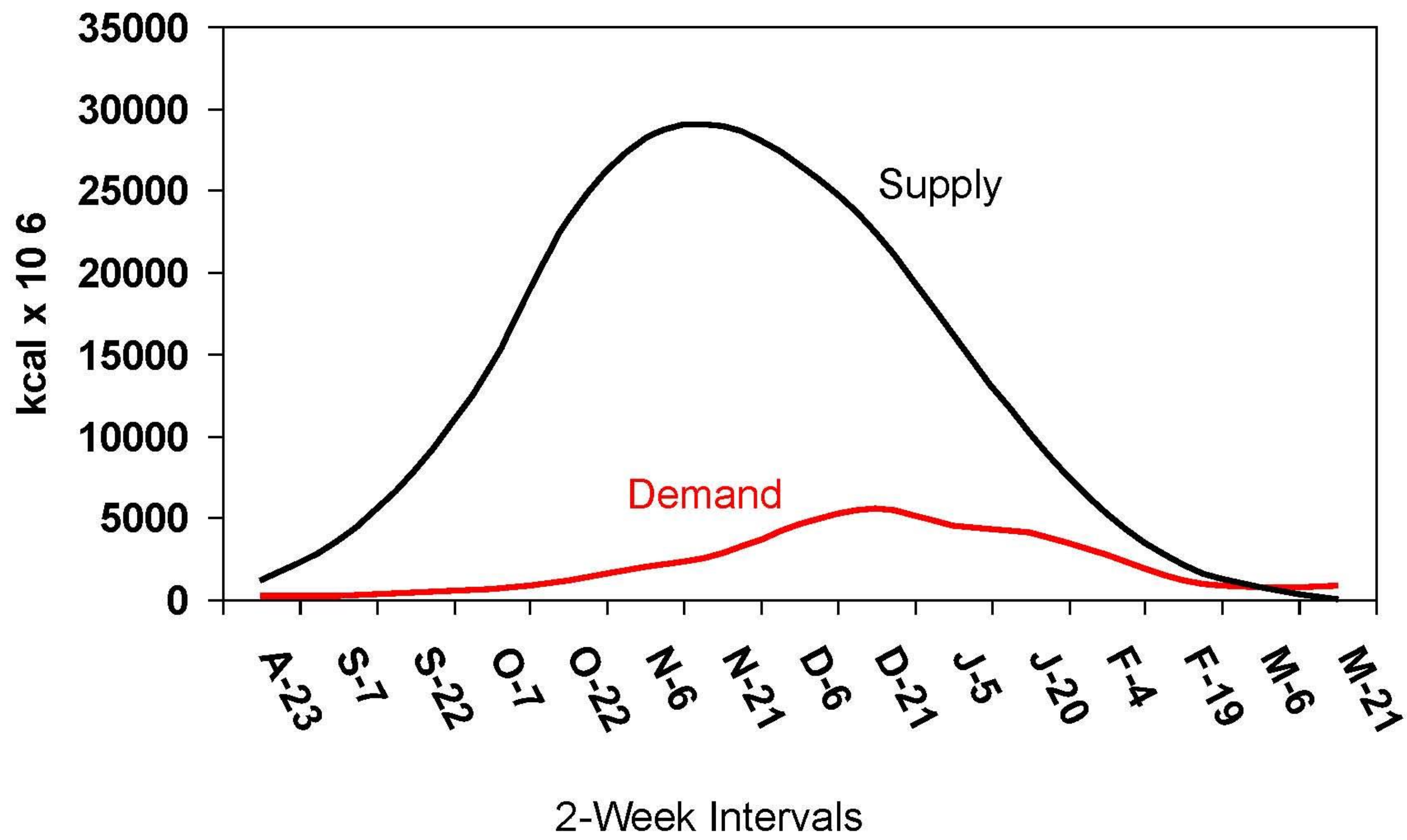

Figure 9. Butte Basin: Food Supply vs. CVJV-Goal Population Demand For Climate Scenario GFDL-A2 in Time Period 2031-2060 Under Average Water Year Conditions

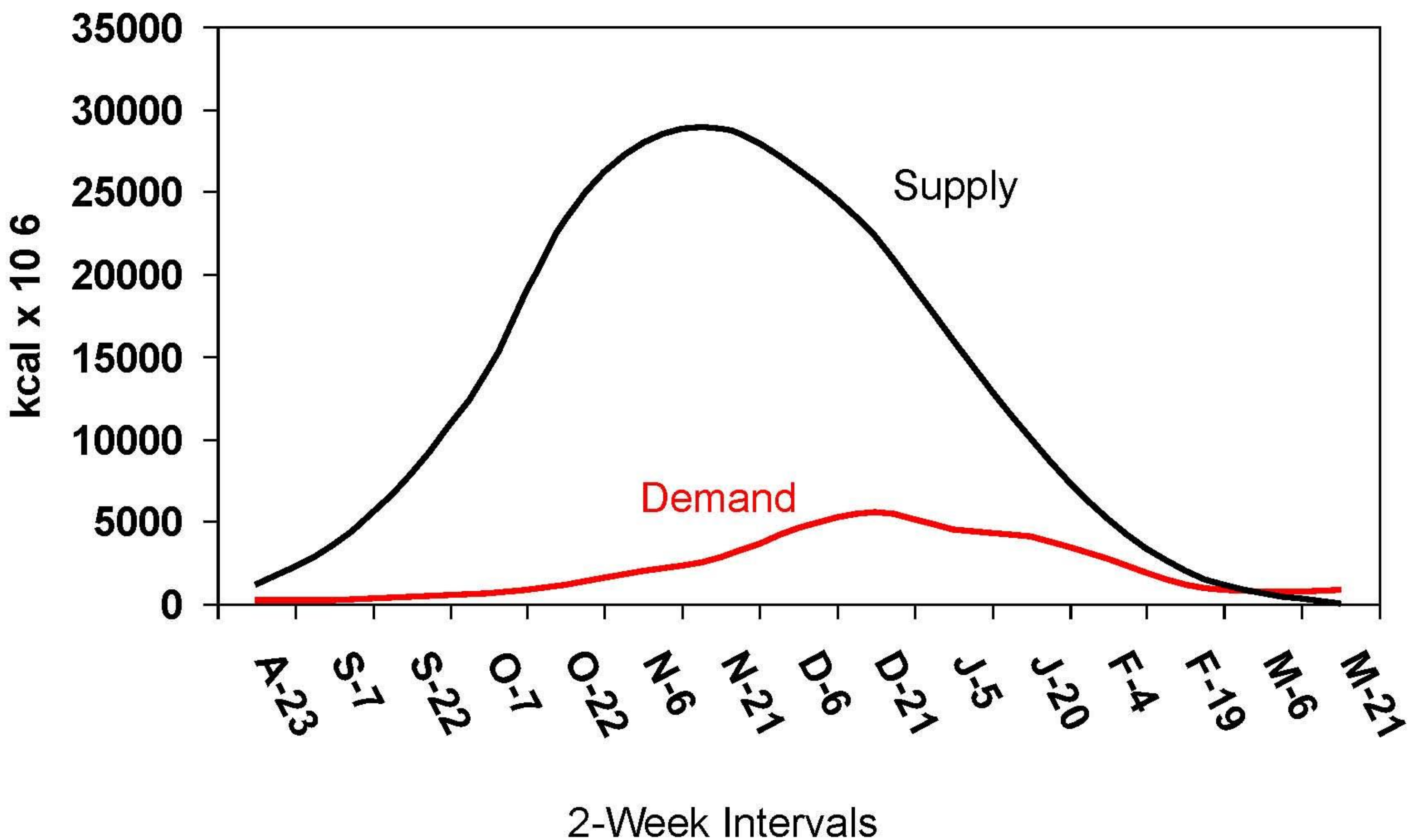

Figure 10. Butte Basin: Food Supply vs. CVJV-Goal Population Demand For Climate Scenario GFDL-A2 in Time Period 2061-2099 Under Average Water Year Conditions

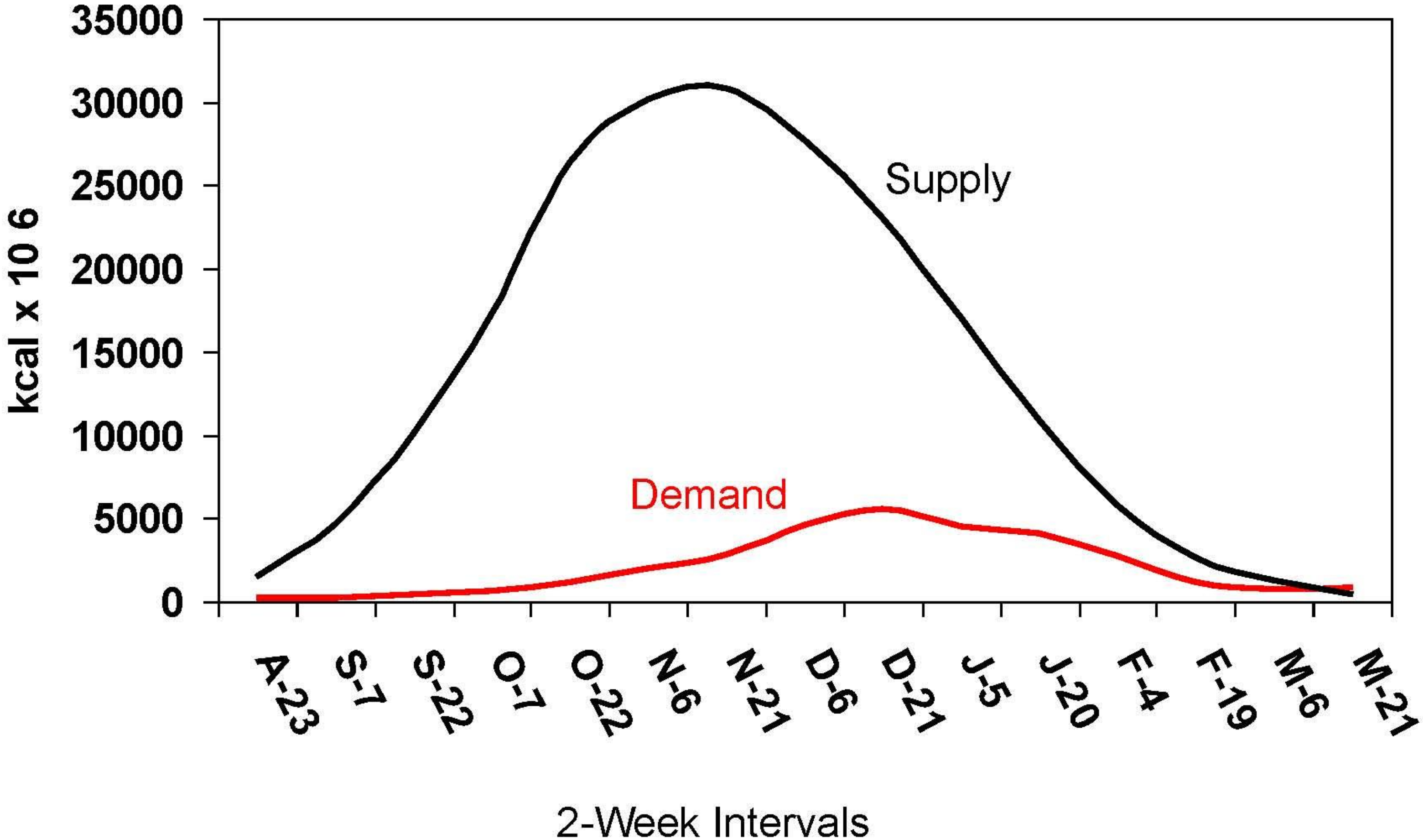

Figure 11. Butte Basin: Food Supply vs. CVJV-Goal Population Demand For Climate Scenario GFDL-A2 in Time Period 2031-2060 Under Dry Water Year Conditions