Understanding impacts of climate change, urbanization, and water management on habitats and ecology of waterfowl, shorebirds, and other waterbirds:

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
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Understanding impacts of climate change, urbanization, and water management on habitats and ecology and 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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Executive Summary: This update describes the project's background and summarizes progress and data produced. Additional project information is available at: http://www.werc.usgs.gov/Project.aspx?ProjectID=204

Background: Most waterfowl habitats in the Central Valley of California rely on managed surface water supplies stored in reservoirs and delivered via a complex system to a wide array of competing water users. Water supplies vary with snow pack, temperature, and precipitation, all of which are projected to change substantially under some global climate models; land use and water management decisions also greatly impact water supplies. Led by USGS-Western Ecological Research Center, this multi-partner project (California Landscape Conservation Cooperative, USFWS, CVJV, California Dept. of Fish and Game, Ducks Unlimited, Delta Waterfowl, Stockholm Environment Institute, PRBO Conservation Science, and University of California-Davis) is developing necessary data and adapting and applying the Central Valley Water Evaluation and Planning (WEAP) model to investigate impacts of various climate, urbanization, and water management scenarios on waterfowl habitats and ecology in the Central Valley. For each scenario, water supplies and demands are modeled in WEAP to estimate resulting landscape change. The amount, timing, and location of supported waterbird habitats based on WEAP results are then included in bioenergetics models to evaluate adequacy of food supplies to support waterfowl populations under each scenario. Two bioenergetics modeling approaches are being used; the traditional TRUEMET accounting of waterfowl food supplies and population demands and a spatially-explicit Agent-Based Modeling (ABM) approach that models ecology of individual and allows an evaluation of not only changes in the amount of food-producing habitat but also changes in the spatial and temporal distribution of all habitats and behavioral responses of waterbirds to those habitat changes.

Progress: The project is progressing as planned and has essentially met project deliverables goals to date which included modeling of the 2-3 Central Valley basins. As described in the 2011 progress report, after initially modeling 31 Butte Basin scenarios (see earlier progress reports for details), we substantially refined our approach to simulate surface and ground water supplies and water demands completely within the WEAP model framework and streamline our evaluation of model scenarios. To do so, we recruited additional funding from the Delta Waterfowl Foundation to support collaboration with the developers of the WEAP model framework (Stockholm Environment Institute [SEI]) to adapt and improve WEAP-CV and more fully utilize the capabilities of the model. Although considerable upfront work is required to adapt WEAP-CV to accurately model waterbird habitats in each basin (e.g., adding winter-flooded agricultural habitats that had not been represented, updating/correcting area of wetland habitats, distinguishing certain water supply sources not specifically represented, combining multiple land cover datasets in a GIS to better calculate areas of various land cover classes at a finer spatial resolution, other changes), the result is a model that produces accurate estimates of water needs for waterbird habitats. These improvements to WEAP-CV are important not only for this project but also when the model is used in the future by the State of California and others for planning water use in the Central Valley.

In addition to adapting WEAP-CV to more accurately model Central Valley water supplies for habitats of importance to waterbirds, we have compiled and included necessary data and used our refined modeling approach to evaluate 12 additional Butte Basin scenarios through year 2065 for projections combining the following factors of a) climate (downscaled 12 km GFDL1-A2, PCM1-B1, and historical) b) urban development ("expansive growth", "strategic growth", and no growth), and c) water management (Butte Basin rice-land idling, Butte Creek Instream Flow Requirement [IFR], and existing water management specification). We have also recruited Delta Waterfowl Foundation funding to support collaboration with UC Davis researchers and expand our ability to evaluate ecological impacts of projected habitat changes. Our UCD collaborators have tested and confirmed the feasibility of Agent-Based Modeling

(ABM) to simulate the effect of landscape changes on energetics and carrying capacity of foraging waterbirds and are using the approach to simulate impacts of landscape changes from select scenarios that we have modeled. While TRUEMET is the primary tool used by the CVJV to compare food supplies vs. needs and will continue to be relied upon in this project to estimate impacts of habitat change on waterfowl food supplies during the non-breeding season, ABM allows spatially-explicit analysis, expands the capacity across taxa, and incorporates other important determinants of species habitat use and landscape carrying capacity such as distribution of sanctuaries.

Our efforts in recent months have been focused primarily at expanding the geographic and temporal scope of our scenario modeling. We have adapted the WEAP-CV model for Sutter and Colusa Basins in the Sacramento Valley and the San Joaquin Basin in the San Joaquin Valley. We have also worked with SEI collaborators to extend scenario evaluations to year 2099. In addition we have evaluated additional scenarios focusing on changes in water supply management resulting in increased rice-land fallowing and reduction in wintering habitats for waterbirds in Butte Basin and we have gathered information for scenarios in other basins. In all the water management scenarios, we also accounted for projected climate and urbanization. Selected scenarios evaluated in WEAP were further evaluated in the TRUEMET bioenergetics model to investigate impacts on ecology of ducks in the Butte Basin. We are currently summarizing projected scenario impacts for Sutter Basin habitats.

Results: Modeling has indicated that under some scenarios, water supplies will not be adequate to maintain waterfowl habitat and food supplies at the levels necessary to support Central Valley Joint Venture (CVJV) goal populations of waterfowl throughout the wintering interval. For the Butte Basin set of modeled scenarios that are the most complete, the additional impact of projected climate on waterfowl food habitats was relatively small compared to projected urbanization and some water supply management options that we evaluated. Scenarios including water supply management involving extensive fallowing of rice-land to allow the transfer of additional water to western San Joaquin Valley agriculture produced the greatest impacts on habitats and ecology of waterbirds. Across all scenarios, the greatest reduction in food habitat area resulted from loss of rice habitat. However, all scenarios we evaluated so far represent current (and relatively high) water supply prioritization of most public and some other wetlands relative; reduction in supply priority for wetlands or key agriculture would result in additional impacts.

Future Direction: The project goal is to complete evaluation of a wide range of climate, urbanization, and water management scenarios for hydrological basins throughout the Central Valley. Assuming continued project funding support, our future work will include a) continued geographic expansion into all Central Valley regions, b) modeling of additional water supply management scenarios of interest, c) extending modeling projections [currently through 2065] to year 2099, d) expanding translation of changes in water supplies and habitats supported by those water supplies into impacts on avian ecology by not only continuing TRUEMET evaluations for waterfowl but expanding TRUEMET for shorebirds and other waterbirds and applying ABM approaches for all waterbirds, and e) 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. Operational funding was provided by the California LCC, USFWS, Central Valley Joint Venture, and Delta Waterfowl (via grants from S.D. Bechtel Jr. Foundation and the California Duck Stamp Program) with in-kind salaries or other logistical support provided by all project partners including USGS-WERC, Ducks Unlimited Inc., SEI, PRBO Conservation Science, and UC Davis. Ben Gustafson and Bill Perry (USGS-WERC) provided GIS support.

BACKGROUND

WATERBIRD HABITATS

Waterbird habitats in the Central Valley of California (Figure 1) 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). Thus, like other North American Waterfowl Plan (United States Fish and Wildlife Service and Canadian Wildlife Service 1986) Joint Ventures focused on habitat conservation in the wintering and migration regions, the Central Valley Joint Venture (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 use patterns and North American Waterfowl Management Plan population goals, are set. Next, using daily energy requirement for individuals of each species, the amount of required energy to sustain for those goal "use-days" is determined. Finally, using data on food density produced by each type of waterbird habitat (e.g., wetland and flooded agriculture) the TRUEMET model (CVJV 2006) 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. While the TRUEMET model is the primary modeling tool currently used by the CVJV to compare food supplies vs. needs during the non-breeding season, another option is to use an Agent-Based Modeling (ABM) approach that models individual bird responses to landscape changes (Goss-Custard et al. 2006, Nonaka and Holme 2007). Advantages of the ABM approach are that it allows spatially-explicit analysis, expands the capacity across taxa, and incorporates other important determinants of species habitat use and landscape carrying capacity such as distribution of sanctuaries.

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). Climate-induced changes in water demand and soil moisture 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.

CLIMATE CHANGE PROJECTIONS

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).

Climate Change Projections: Cayan et al. (2007) selected four climate model-CO_2 level combinations (i.e., PCM-B1, GFDL-B1, PCM-A2, GFDL-A2) 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. We included all four combinations and recent (1971-2000) historical climate (for comparison) in our initial modeling (see 2011 Progress Update) but focused on PCM-B1 and GFDL-A2 (with 1971-2000 climate for comparison) in our refined modeling. Among the four combinations, PCM-B1 represents the less sensitive model to greenhouse gas emissions-low CO2 emissions projection whereas GFDL-A2 represents the more sensitive to greenhouse gas emissions-high CO2 emissions projection. (Note some recent data suggests likelihood of even higher CO2 emission levels than the A2 scenario which would likely result in greater habitat impact than even our GFDL1-A2 modeling indicates.)

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

We used the Water Evaluation and Planning (WEAP) system software developed by 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 and others for water supply management and planning in the Central Valley (e.g., Joyce et al. 2010 and Yates et al. 2009). In addition to modeling watershed hydrology, WEAP-CV contains the major components of water supply management and delivery systems, and water demands within "Planning Areas" (used by the California Department of Water Resources) within the Central Valley (Figure 2). 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. Water delivery system constraints are reflected in model variables including supply priority, water supply preferences, and maximum flow limits. Supply priority represents the priority of water allocation among all demand sectors (Table 1). 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 rate of a potential supply is represented as the maximum amount (% or flow rate) of a demand site's water demand that can be supported by a particular water supply. 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). More recently (2011), WEAP-CV developers also have included 12 climate change scenarios projecting to year 2099 in the model.

PROJECT GOALS

The goals of this project are to develop landscape change scenarios based upon impacts of: climate on water availability and water demand, urban encroachment on habitats and related changes in water availability, and water management changes in supply allocation. Using a scenario analysis approach, we aim to investigate impacts of these factors on habitats, food supplies, and ecology of waterfowl, shorebirds, and other waterbirds in the Central Valley. Specific project goals are to:

- Develop and evaluate scenarios of Central Valley landscape change based upon projected changes in water availability and demand influenced by climate, urbanization, and water supply management.
- Use bioenergetics modeling and ecological relationships of waterfowl, shorebirds, and other waterbirds and their habitats to investigate impacts on key bird metrics (i.e., abundance, distribution, body condition, and survival) under different scenarios in the Central Valley.
- Identify type, timing, and locations of critical waterfowl, shorebird, and other waterbird resources in the Central Valley that are most at risk due to climate change and other factors.
- Develop adaptive management strategies for waterbird habitat conservation planning in the Central Valley that can address potential impacts of climate change and other factors.

ACCOMPLISHMENTS

SUMMARY OF ACCOMPLISHMENTS

The project is progressing as planned and has essentially met project deliverables goals to date which included modeling of the 2-3 Central Valley basins. To date, we have:

- Adapted the Water Evaluation and Planning model for the Central Valley Planning Area (WEAP-CV) used by the State of California and US Bureau of Reclamation to better estimate water supplies for wetlands and agricultural habitats of importance to waterfowl and other waterbirds in the Butte and Sutter Basins;
- Achieved substantial progress in adapting the WEAP-CV for Colusa Basin and San Joaquin Basins;
- Achieved substantial progress in extending the modeled time series through year 2099 (currently through 2065);
- Applied the Adapted WEAP-CV model to investigate water supply amounts and timing for each habitat in Butte and Sutter Basins under combinations of projected climate, urbanization, and changes in water supply management;
- Estimated area of key waterbird habitats in Butte and Sutter Basins supported by water supplies available under 12 scenarios of varying climate, urbanization, and water management (Figure 3);
- Produced methods for integrating projected habitat data with the TRUEMET model;
- Applied the TRUEMET model to evaluate adequacy of food supplies in Butte Basin resulting from selected scenarios representing a range of conditions to support wintering ducks at CVJV-goal population levels;
- Produced methods for integrating habitat data in with the ABM;
- Achieved substantial progress in developing and testing a prototype of the ABM;
- Initiated drafting a manuscript for publication documenting our scenario modeling approach potentially guiding similar habitat conservation projects; and
- Reported project information at numerous venues including:
    - Nov 2012: Provided information for Delta Waterfowl magazine article
    - Oct 2012: Oral presentation at Bay Delta Science Conference, CA-LCC Special Session on Climate Change
    - Oct 2012: Wrote article for Pintail Action Group Annual Newsletter
    - Sep 2012: Oral presentation at USGS Bay-Delta Executive Board Meeting
    - Aug 2012: Oral presentation at CVJV Waterfowl and Shorebird Working Groups Joint Meeting
    - Jul 2012: Project Webpage updated
    - April 2012: Poster at Interagency Ecological Program (IEP) Workshop
    - April 2012: Poster at CA Water & Environmental Modeling Forum Ann. Meeting
    - Mar 2012: Provided information for CA-LCC Website feature article.
    - Feb 2012: Poster at The Wildlife Society-Western Section Annual Meeting
    - Nov 2011: Poster at The Wildlife Society Annual Conference.
    - Sep 2011: Project Webpage updated
    - Aug 201: Oral presentation at the CVJV Waterfowl Working Group Meeting
    - July 2011: Oral presentation at the CVJV Water Committee Meeting
    - June 2011: Poster at the CA-LCC Open House
    - Feb 2011: Progress Update-Data Summary
    - Nov 2010: Created Project Webpage http://www.werc.usgs.gov/Project.aspx?ProjectID=204

ADAPTING WEAP-CV

At a higher spatial resolution than exists in WEAP-CV, we have adapted the WEAP-CV to accurately model Central Valley waterbird habitats and related processes influencing water availability for habitats. The most recent adaptations include: 1) adding winter-flooded agricultural habitats not previously represented in the WEAP-CV, 2) modifying land cover represented in WEAP-CV to also include wetland habitats based on the CVJV Implementation Plan, 3) distinguishing certain water supply sources not specifically represented in WEAP-CV, 4) characterizing drainage areas/systems and water delivery constraints within basins to be consistent with the pertinent spatial resolution.

We had previously made several changes in our initial approach to adapting the WEAP-CV model to assist streamlining model development and to accommodate the scenarios that we intend to evaluate. Changes to the model included: 1) modeling all surface supply water sources within WEAP rather than integrate the Basin Characterization Model (BCM) with WEAP, 2) model water demands (except for "Urban Indoor") in WEAP as "Catchment" nodes rather than "Demand Site" nodes, 3) combine multiple land cover datasets in a GIS to better calculate areas of various land cover classes at a finer spatial resolution than CVJV basins, or DWR Planning Areas existing in the WEAP-CV model.

After evaluating a set of scenarios for Butte Basin using this modified approach, we have applied this approach to other basins. In contrast to our previous BCM approach, our current approach allows us to simulate surface and ground water supplies and water demands completely within the WEAP model framework. This results in lower spatial resolution of surface runoff that supplies basins than we were formerly able to model using the BCM. However, surface water supplies entering basins are either produced at high elevation a great distance from valley habitats and generally are stored in reservoirs or are available as rainfall and rainfall runoff, which varies in timing and amount relatively little across the valley. Additionally, the water sources already identified and simulated in WEAP-CV are also the primary water sources used for waterbird habitats. Consequently, we believe that the spatial resolution of the adapted WEAP-CV adequately simulates available water supplies for CV habitats. Our initial previous approach of adapting WEAP-CV to integrate runoff and climatic water deficit results produced from the BCM required supplemental calculations and untested structural changes to WEAP-CV. Focusing less on structural changes to WEAP-CV to integrate BCM results will allow us to apply more effort evaluating additional WEAP scenarios. (Note: it is possible that some situations could benefit from finer spatial resolution of runoff, climatic water deficit, and/or evapotranspiration, in which case, if necessary we still will be able to use the BCM to provide input data to WEAP.)

Hydrologic Unit Landcover Disaggregation and Model Specification: The "disaggregation" of land cover areas to a finer spatial resolution was necessary to be able to simulate hydrology (including surface water runoff previously calculated separately in the BCM) and water demands using WEAP "Catchment" nodes. Using GIS, we were able to calculate land cover areas of hydrologic units (HUs) within CVJV basins and intersecting Planning Areas represented in WEAP-CV. For example, we used GIS to delineate the boundaries of each area of intersecting CVJV subbasin (Upper Butte and Butte Sink), DWR Planning Area, Butte Creek Watershed boundary area, Upper watershed of West Branch of Feather River, and 500-meter elevation contours related to Butte Basin hydrology and water demands. The resulting GIS layer delineating HUs was then intersected with GIS land cover data for various agricultural crops, wetlands, urban areas, and other, non-irrigated areas. The final layer combining HU and land cover information was used to calculate distributions (i.e., proportions of each land cover class among HUs), which were multiplied with areas of each type of land cover (km^2) already represented in the WEAP-CV model. Excluding wetlands, the resulting land cover areas representing irrigated, non-irrigated, and urban areas for each HU were then included in the

WEAP adapted model as Catchments. In contrast, seasonal and semipermanent/permanent wetland distributions calculated using GIS were multiplied with wetland areas summarized in the Implementation Plan. Catchments were also used in WEAP to represent wetlands within each HU of the adapted model. Using Catchments in WEAP differs from the former approach of using "Demand Sites" and is an efficient and flexible way to model both hydrology and water demand. Using Catchments also is consistent with the existing structure of WEAP-CV model, which will reduce required structural changes to the model. Directly simulating hydrology using Catchments, and not manually specifying surface runoff and infiltration to groundwater, will allow more efficient modeling of available water supplies. Water demands simulated using Catchments will automatically respond to projected changes in climate that are set for each scenario; thus additional manual adjustment for climate effects on demands will not be needed.

Basin Drainage and Water Supply Systems: We have further adapted the WEAP-CV model to better represent localized, managed drainage systems, and water supply and delivery constraints in Sacramento Valley basins. The same process used for these basins is currently being used for the San Joaquin Basin. The following describes this process in greater detail.

Valley Drainage Areas and Systems: The spatial relationships between drainage areas/managed drainage systems on the valley floor and waterbird habitats influence availability of drainage water usable by waterbird habitats. The amount of drainage water available to habitats depends on the location and size of drainage systems and associated area of local urban, agricultural, or other land-cover. Habitats within and downstream of drainage areas/systems have greater access to water collected within and draining from these systems. Return flows (e.g., unconsumed return flows during the agricultural growing season) and local natural runoff are important water sources for many habitats, especially certain wetlands essentially supplied entirely with return flows and local natural runoff. Therefore, we conducted additional research to identify the spatial extents and points of outflow (into major tributaries specified in the model) of local drainage systems. Because topography on the valley floor has been greatly altered for agricultural and urban development, it varies little and cannot be used reliably to delineate valley drainage areas. Consequently, we reviewed the literature to identify drainage areas and points of outflow. This drainage information was then used in a GIS to delineate and intersect drainage areas with other layers related to groundwater, DWR Planning Areas (distinguishing regions by water sources and demands), and CVJV basin boundaries to produce a layer defining the HUs of each basin.

Water Delivery Constraints: Maximum limits on the amount of water deliverable by individual water sources to water demands in the WEAP-CV model reflect physical limits of supply and delivery systems at the spatial scale of DWR Planning Areas. However, spatial resolution of HUs is much higher than Planning Areas and substantial variation in water sources exists among HUs. Therefore, based on the best available information we assessed water sources provided to basin water demands. Using multiple GIS datasets delineating land cover, water agencies, water supply sources, and HUs, we quantified the area of each land cover (classified as agriculture, private wetland, public wetland, or urban) in each HU by water source used. For each HU, the quantified area of a cover class receiving a given source was assumed to be proportional to the amount of water demand supported by that source. We estimated the fraction of a cover class's water demand supported by each source as the fraction of land cover area receiving each source. In specific situations, we adjusted water source fractions based on information from the literature that was believed to be more accurate than calculations. Calculated water source fractions were included in the model as constraints on the maximum amount of water supplied by each available source. This was accomplished by including water source fractions in the variable "Maximum flow (percent of demand)" of each Transmission Link joining a source to a Catchment node. Additionally, if research indicated limits in physical capacity of major water delivery infrastructure, we included this information in "Maximum flow (volume)". Water sources were identified to the level specified in the adapted model and included groundwater.

Central Valley Habitats: Central Valley habitats important for waterbirds during the wintering period include certain crop fields following harvest and wetlands (CVJV 2006). In Sacramento Valley and Delta basins, rice and corn fields and wetlands are the predominant foraging habitats. In the Suisun, San Joaquin, and the Tulare basins wetlands are the predominant foraging habitats; although in the Tulare basin, grain and other fields that have been flooded after harvest or pre-irrigated in late-winter before planting also provide foraging habitat for wintering waterbirds. Seasonal wetlands are the primary wetland type providing food for wintering waterbirds. While apparently not providing as much food as seasonal wetlands, semipermanent and permanent wetlands provide other important habitat such as roosting sanctuaries when birds are not foraging, especially during the waterfowl hunting season.

Wetland Habitats: Within a given basin, we classified 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 (Central Valley Wetlands Water Supply Investigations [CVWWSI] 2000) provided detailed information about basin wetlands. Based on this information we were able to distinguish several wetland habitat types providing food for waterbirds (Table 2). Wetland classifications were based on ownership, regional differences in water supply sources, water supply reliability, irrigation schedule, and demand priority (many public wetlands have a priority of "1" indicating first priority, while private wetlands have a priority of "3", equivalent to agriculture) (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. Conversely, privately-owned wetlands with a "Low" reliability classification were primarily supported by irrigation return flows (CVWWSI 2000). Consequently, "Low" reliability wetlands were considered to have relatively less reliable supplies and are specified in the model as being solely dependent on return flows, unless there were other reasons for this classification (Table 2). We classified the wetlands with unknown water reliability into high- and low-reliability classes for each region by assuming that the actual areas of wetlands with high- and low-reliability supply were proportional to areas of known reliability.

Public and privately-owned seasonal wetland areas were further divided into monthly amounts according to timing of initial flooding provided in the CVJV Plan. Flooding of both types were assumed to be maintained through March and to receive irrigation in April or May after drawdown to allow food plant germination (CVWWSI 2000). Areas of permanent and semi-permanent wetlands were combined and the irrigation schedule for semi-permanent wetlands was adopted because only a small proportion of the combined area was permanent wetlands (Mark Petrie, personal communication, October 6, 2010). (For an example of a wetlands irrigation schedule indicating the timing, monthly, and annual amounts of water required for optimal wetland management see Table 3.) Areas of wetlands reported in the Water Report (CVWWSI 2000) 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 (CVWWSI 2000) and provided by Mark Petrie.

Agricultural Habitats: We classified agricultural foraging habitats for wintering waterbirds in Sacramento Valley basins as: winter-flooded rice; unplowed, winter-dry rice; and unplowed winter-dry corn (in Sacramento Valley no corn was flooded after harvest) based on habitats identified in the CVJV Plan. Other agricultural habitats in the Central Valley also exist, but are available primarily later in the year during the growing season and outside of the Sacramento Valley in Delta and Tulare basins. Similar to seasonal wetlands, we divided total area of winter-flooded rice into monthly amounts for October through March according to timing of initial flooding (CVJV 2006).

Calculating Habitat Areas: Multiple steps were required to calculate new wetland areas and disaggregate areas of other land cover in the WEAP-CV to a finer spatial resolution required for the Adapted Model. We used GIS and multiple land cover layers to calculate areas of habitats and other land cover within HUs and DWR Planning Areas. GIS output was then post-processed to calculate the distributions (i.e., fractions) of land covers within HUs. Crop and wetland distributions of HUs were respectively multiplied with crop and wetland areas already existing in the WEAP-CV or provided in the CVJV Plan to calculate final areas of HU land covers. Land cover areas were entered for representative Catchment nodes for each HU.

Model Calibration: Following revising the WEAP-CV model to include additional habitats, water supplies, and water delivery constraints represented at the appropriate spatial resolution, we have been calibrating modeled water supplies and habitat demands. Calibration generally involves comparing output from model simulations with observed measurements or other "best estimates" to evaluate accuracy under recent historical conditions in climate and water demands, and adjusting model parameters to improve model performance. We have compared differences in model output and stream gauge and reservoir storage measurements between the unrevised WEAP-CV and revised Adapted model to assess their relative performance. Thus far, the Adapted Model has generally performed better in tracking patterns and magnitudes of measurement data than the WEAP-CV model. In calibrating wetland soil, irrigation, and pond depth parameters, we have compared modeled monthly and annual water deliveries (acre-feet/acre) to wetlands with water application rates reported in the Water Report for optimal management of wetlands (CVWWSI 2000). In calibrating irrigation and pond depth parameters for winter-flooded rice, we have compared modeled water deliveries (acre-feet/acre) during Oct-Feb, to reported deliveries over the same period (California Department of Water Resources draft memorandum 2003). Calibration of habitat parameters produced differences between modeled and reported deliveries that were acceptable.

SCENARIO MODELING

We are applying the adapted WEAP model to investigate impacts of various climate, urbanization, and water management scenarios on waterfowl habitats and ecology in the Central Valley projected for 2005-2099. For each scenario, water supplies and demands are modeled in WEAP to estimate resulting landscape change.

Climate Projections: Water runoff from drainages throughout the model spatial extent have been estimated based on 12 km x 12 km downscaled climate model projections of temperature and precipitation patterns. We are currently using two climate change projections (representing upper and lower climate change projections of the 4 projections Cayan et al [2007] considered for California) and recent historical climate (1971-2000) for comparison. The climate scenarios that we have thus far examined using our refined approach are: a) Recent Historical Climate (years 1971-2000), b) PCM-B1 (less sensitive model to greenhouse gas emissions-low missions); c) GFDL-A2 (more sensitive model to gas emissions-medium-high emissions). (Note: If funding are adequate we hope to evaluate additional projections as they become publicly available [most are indicating higher CO_2 emissions]).

Time Projections: Modeling provided results for monthly historical (1971-2000) and future (2005-2099) climate- and urban-related changes within basins. Modeling results for each of the two climate change projections was subsequently divided into "projection" periods 2006-2035 (30 years), 2036-2065 (30 years), and 2066-2099 (34 years). To date, we have successfully modeled scenario projections through year 2065 (see "Challenges to adapting the WEAP-CV Model" below for information about modeling through 2099).

Urban Growth Projections: See "Challenges to adapting the WEAP-CV Model" below for additional information. Increase in urban area and corresponding reduction in agricultural land (equally among all crops) varies substantially between the two urban growth projections evaluated- "strategic" and "expansive". For example, depending on region within Butte Basin, crop area under strategic and expansive growth rates was projected decline between 7 and 14 percent, and between 29 and 44 percent, respectively, by year 2100.

Water Supply Management: In addition to the climate change, urbanization, and wetland restoration scenarios evaluated in previous analyses, we have identified multiple other scenarios that we have already evaluated or will evaluate in the future. These scenarios primarily focus on changes in water supply management and their projected impacts in combination with projected climate and urbanization. Elements of model specification are described in more detail below in discussion about specific scenarios.

Butte Creek stream flow requirement scenarios: This set of scenarios reflects on-going conservation efforts to augment flow in Butte Creek for spring-run Chinook salmon and steelhead trout migration and rearing (http://www.buttecreek.org/documents/ButteCreekAnadromousFishRestoration.pdf). Conservation of the salmonid population on Butte Creek has remained a significant priority of resource management agencies and conservation groups (http://www.buttecreek.org/documents/ButteCreekAnadromousFishRestoration.pdf (California Department of Fish and Game memorandum 2008). Past efforts have attempted to secure a minimum flow rate of 40 cubic feet per second (cfs) or the natural flow (whichever is less) to remain in Butte Creek, Butte Slough, and Sutter Bypass to its confluence with Sacramento Slough between October 1 and June 30. We are producing scenarios representing successful implementation of the efforts indicated above to understand how local water supplies and waterbird habitats might be affected. The dedication of a proportion of natural flow in Butte Creek and flow in Sutter Bypass for migrating salmonids, may limit water for other lower-priority demands (e.g., privately-owned wetlands, winter-flooding of rice) depending on Butte Creek supply. The Adapted CV Model represented Butte Creek as a "River" link with tributary inflow into the existing WEAP-CV Sutter Bypass Diversion link. We modeled a minimum flow rate requirement of 40 cfs or the natural flow (whichever is less) during October through June in Butte Creek, above the confluence of Butte Creek with the Butte Slough/Sutter Bypass, restricting water diversion from Butte Creek. In the same scenario, we similarly modeled a minimum flow rate requirement of 40 cfs or the natural flow (whichever is less) in the Sutter Bypass downstream to Sacramento Slough, restricting water diversion from Sutter Bypass.

Water allocation for the environment scenarios: Scenario variations will reflect different potential policies in prioritization of water management for environmental purposes (i.e., public wetlands v. fish protection), some of which may result in greater fish protection at the expense of reduced water supplies for public wetlands. Prioritization in allocation of water supplies in the model will be adjusted through changing the relative supply priorities for public wetlands and fisheries in-stream flow requirements. The set of scenarios that will be evaluated are as follows:

1) <u>Secure public wetland supply</u>: In WEAP-CV, public wetlands are specified to have greater water supply security reflected in a higher supply priority (i.e., "1") than stream flow requirements (i.e., "2"). Supply priority of public wetlands remains a priority of "1", and stream flow requirements for fish protection remains a priority of "2". The lower priority for stream flow requirements will result in available water for fish protection subsequent to full allocation of available water for public wetlands (and urban

indoor use). Supply priorities of other demands in the model will be maintained, including a priority of "3" for private wetlands.

2) Equal security supply: Supply priority of public wetlands declines to a "2", while stream flow requirements for fish protection remains a priority of "2". Equal priority will result in equal sharing (and equal deficit) of water supplies for public wetlands and fish protection. Supply priorities of other demands in the model will be maintained, including a priority of "3" for private wetlands.

3) Secure flow for fish: Supply priority of public wetlands declines to a "2", while stream flow requirements for fish protection advances to a priority of "1". The lower priority for public wetlands will result in available water for public wetlands subsequent to full allocation of available water for fish protection (and urban indoor use). Supply priorities of other demands in the model will be maintained, including a priority of "3" for private wetlands.

Rice-land idling scenarios: Because rice-land provides a large proportion of the food habitat for some waterbirds, including ducks, we evaluated two water supply management scenarios potentially impacting amount of rice habitat. These two scenarios were ones that allowed unmet water demands of western San Joaquin Valley agriculture to be supported through increased fallowing of rice-land in Butte Basin and allowing the transfer of more water through the delta to that western San Joaquin Valley demand area. More specifically, this set of scenarios simulated the transfer of water normally used for rice in Butte Basin to western San Joaquin Valley agricultural demands in DWR Planning Area 702 under GFDL-A2 climate and Expansive urban growth (EG) and existing model physical, operational, and regulatory constraints. One scenario allowed proportional fallowing of rice-land area across the Sacramento Valley (equating to a maximum fallowing of 20% of rice-land in Butte Basin). The second scenario allowed unlimited fallowing of rice-land in Butte Basin to meet the water demand. In these scenarios, we assume that a use of water transferred from the Sacramento River system is preferable compared to other available water supplies (i.e., groundwater, which is of poor quality in the Western San Joaquin Valley region, and unreliable Kings River flood-water). In these scenarios, all water is transferred solely during the months of July-September when current transfer policy allows, directly to PA 702 agriculture, and no additional water was transferred to storage in San Luis Reservoir throughout the year.

Specific changes were made to the model structural components and model constraints to appropriately simulate the amount of supply that could be transferred based on scenario assumptions. SWP and CVP diversions were disconnected from the Sacramento-San Joaquin Delta. We replaced Delta-diversion connections with two demand site nodes and related return flow links. The indicated links/nodes were used to represent the total flow into project diversions under GFDL-A2, EG conditions. We added a complex of transmission links/nodes, demand site node, return flow links/nodes, and diversion link to represent additional water transferred from the Sacramento River system to PA 702 agriculture. Before simulating a south-of-delta transfer, initial model output from GFDL-A2, EG was exported to data files that were then used in adding new constraints to the model in subsequent simulation. Output from the GFDL-A2, EG scenario simulation (in the absence of additional transfer of rice irrigation water modeled in the subsequent simulation) was: 1) projected amounts of water conveyed through State and Federal project facilities to south-of-delta users, 2) water delivered to PA 702 from the Sacramento River system vs. all other sources, and 3) the relative fraction of water from each surface water source (Sacramento River, Butte Creek/Sutter Bypass, and Feather River) delivered to irrigate rice-land in Butte Basin. Each rice-land idling scenario was evaluated in two separate subsequent model simulations. For both scenarios, in these subsequent simulations, we constrained water transfer amounts: 1) conveyed through the State and Federal project pumping facilities in the delta to the remaining operational capacity of the projects, 2) to PA 702 agriculture based on remaining water requirement of PA 702 agriculture not supported through projected contracted delta deliveries each month, and 3) transferred from each of the three Sacramento River system sources to reflect the proportion of water from each source typically allocated to rice in Butte Basin.. Additionally, for the scenario allowing proportional rice-land idling throughout the Sacramento Valley, we limited the transfer of water to an annual maximum limit of 101,045 acre-foot based on a 3.3 acre-foot credit per acre of rice (20% of total area of Butte Basin rice, or 30,620 acres) fallowed under current DWR transfer policy. Similarly, for the scenario allowing unlimited rice-land idling in Butte Basin, we limited the transfer of water to an annual maximum limit of 505,227 acre-feet based on 153,099 rice acres in Butte Basin fallowed under current DWR transfer policy. We accounted for assessed 20% carriage water loss of water transferred through the delta (Nancy Quan, personal communication, May 9, 2012) by adjusting model return flow link routing accordingly. Although the simulated transfers were limited solely to months July-Sep, water deliveries to rice Catchment nodes from the three Sacramento River system sources were deactivated in the model and rice could solely receive water from groundwater and some local natural runoff and return flows throughout the time series.

The modeling of this scenario may actually underestimate the impact of an actual transfer policy focused on rice land-idling, because as modeled, solely Sacramento Valley water users have access to some water that is typically used for rice flow-through practices and that isn't included in the 3.3 AF/acre credit allowed for transfer; in practice this "flow-through water" would be available to be distributed among south-of-delta users also.

In post-processing of results, the calculated amount of rice water transferred (including carriage water) was equated to area of rice land idled at a rate of 3.3 AF/acre. The rice area not flooded in winter was partitioned according to the proportion of rice area that is generally flooded in each month between October and February for the Sacramento Valley (CVJV 2006). Unlike other scenarios, water transfer scenarios represent conditions which predetermine total area of rice planted at the beginning of the growing season. Thus, we partitioned the supported flooded and non-flooded rice area in each month of the wintering period based on the flooding schedule parameterized in the model.

Hybrid scenarios: We plan to produce scenarios that combine additional components of "Water allocation for the environment" and "Rice-land idling" scenarios. Such hybrid scenarios would allow us to evaluate the potential combined effects of increased priority for allocating water for fish protection and for high-priority crops.

SCENARIOS MODELED

Based on the above, we estimated effect of urbanization and climate change on areas and water supply available versus need for waterbird food habitats across 12 scenarios through year 2065 for <u>Butte Basin</u>:

1) Recent climate;
2) Recent climate + Strategic urban growth projection + Butte Cr. IFR;
3) Recent climate + Expansive urban growth projection;
4) Recent climate + Expansive urban growth projection + Butte Cr. IFR;
5) PCM-B1 projected climate + Strategic urban growth projection;
6) PCM-B1 projected climate + Expansive urban growth projection;
7) GFDL-A2 projected climate + Strategic urban growth projection;
8) GFDL-A2 projected climate + Strategic urban growth projection + Butte Cr. IFR;
9) GFDL-A2 projected climate + Expansive urban growth projection;
10) GFDL-A2 projected climate + Expansive urban growth projection + Butte Cr. IFR;

11) GFDL-A2 projected climate + Expansive urbaniz. + Butte Basin rice-idling (max. 20% area)/south-of-delta transfer;
12) GFDL-A2 projected climate + Expansive urbanization + Unlimited Butte Basin rice-idling/south-of-delta transfer.

Similarly, we have estimated projected habitat areas across 3 scenarios (with initial focus on greatest potential climate and urbanization impacts) through year 2065 for Sutter Basin:

1) Recent climate;
2) GFDL-A2 projected climate + Expansive urban growth projection;
3) GFDL-A2 projected climate + Expansive urban growth projection + Butte Cr. IFR.

MODELING CHALLENGES

Adapting the WEAP-CV Model: We have encountered certain challenges in the process of adapting WEAP-CV for CVJV basins. Some challenges, indicated below, have occurred during our work to identify and evaluate a diverse array of scenarios applying to area both inside and outside of basins being adapted. Our primary interest in adapting the WEAP-CV model for the Butte Basin before expanding to other basins relates to Butte Basin's: 1) great diversity and abundance of agricultural and private and public wetland habitats; 2) its substantial diversity of available water supplies; and 3) its general importance to wintering waterbirds (e.g., Butte Sink contains one of the largest contiguous complexes of wetlands in California). We recognized that such diversity in habitats and water supplies and possible future impacts to certain important water supplies (e.g., Butte Creek runoff and agricultural return flows) and habitats (e.g., low-priority agriculture and wetlands) may require substantial effort in adapting WEAP-CV relative to that of many other basins. Additional model adaptation generally unrelated to Butte Basin required substantial effort as well. Required changes to the model were elucidated through research on production of WEAP-CV and correspondence with parties involved with producing WEAP-CV (i.e., DWR, SEI, CH2M Hill, and RAND Corporation).

Other challenges have involved our efforts to extend the time period of existing WEAP-CV scenario projections to year 2099. A primary asset of WEAP software is the ability to flexibly model future projections. Our initial understanding of WEAP-CV was that urbanization scenarios projecting to year 2099 were already included in the model, when they actually extended no later than through 2050. To our current understanding, the producers of WEAP-CV are in the process of producing extending projections to year 2099, but time of final production is uncertain. WEAP-CV producers have calculated the projected total crop area converted to urban landscape within each PA through 2099, but have not translated that to change in area of each crop type for the three urbanization scenarios. To our current knowledge, WEAP-CV producers will be using the Statewide Agricultural Production (SWAP) Model (http://swap.ucdavis.edu/) to develop projections of the relative areas (km^2) of crop types within Central Valley PAs through 2099. Although, we may include these projections in future scenarios when these projections are completed, we have produced separate crop projections. Our crop projections through 2099 produce uniform reductions in areas of all crop types by the proportion of projected total crop area reduction of the respective PA. Although all projections of urbanization and climate have been developed through year 2099 and for the complete spatial extent of the model, additional work is required to model period 2066-99 of the time series. Recently SEI has improved the WEAP software that should allow us to overcome previous impediments resulting from the complexity of WEAP-CV and our subsequent model adaptations. In general, challenges to WEAP-CV adaptation have included:

- Establishment and model calibration of Butte Creek stream flow contributing to Butte Basin water supply;

- Research and model specification of all Catchment and Catchment parameters including water management (i.e., depth and season of flooding) of wetlands and winter-flooded rice;
- Calibrating model parameters relating to water supplies and habitat demands;
- Research of water drainage and supply distribution systems and model specification of delivery constraints on managed water supplies at the appropriate spatial resolution.
- Research and model specifications of in-stream flow requirements dedicated to fish in Butte Creek;
- Calculating and introducing projections for conversion of crop areas to urban landscape through year 2099 for CVJV basins and PAs throughout the complete spatial extent of WEAP-CV;
- Obtaining and introducing projections of urban indoor water use consistent with increases urban landscape through year 2099; and
- Modeling projected impacts extending later than year 2065.

Scenario Development and Evaluation: Substantial research is required to identify factors potentially affecting water supply reliability, to translate these factors into meaningful WEAP scenarios, and to develop the structure in WEAP for efficient and flexible evaluation of scenarios. We modified the structural elements (links and nodes) and specified related parameters in the model based on our understanding of the complete set of scenarios that we wished to evaluate. Minor differences in model design can effectively result in different scenarios being evaluated, or result in more or less flexibility to evaluate similar scenarios.

CALCULATING FOOD HABITAT SUPPORTED BY MODELED WATER SUPPLIES

Adapted Model output was post-processed in spreadsheets to translate amount and timing of water available, compare availability with water needed to support optimal management of each habitat type, and calculate area of food habitats supported under each scenario. Modeling scenarios of interest provided output on water availability for each scenario. However, additional steps were needed to calculate the water requirement for optimal habitat management. First, we made changes to the model ensuring that habitats received full supply requirements in every month. Then we modeled the delivery of the full water requirements to habitats under each climate projection and historical climate because water demand varies with climate. Calculations were initially performed for each habitat type that combines land cover (e.g., seasonal wetland), irrigation schedule (e.g., October-March), ownership (e.g., private), water-reliability (e.g., low-reliability), supply priority (e.g., 1), and geography (e.g., Upper Butte Basin in Planning Area 507w within the Butte Creek watershed). Information at this most distinguishing level could be used in the ABM for which spatial-explicitness is important. However, for the TRUEMET model we further reduced the number of habitat groups to the spatial level of individual basins. We used WEAP output on monthly amount of supply delivered (acre-feet) and total area of each habitat (acres) to calculate monthly unit area rates of water delivery (acre-feet/acre). Calculating unit area rates allowed us to broadly compare water availability in each scenario with water required in situations for which projected habitat areas change with different rates of urbanization. Because water supplied to users is generally based on annual (not monthly) water allocations depending on environmental conditions (e.g., dryness of year), we further calculated annual unit area rates of water deliveries. For each habitat, the ratio of available water to required amount of water (both in acre-feet/acre units) represents the fraction of total annually available area of habitat. We also account for temporal variation in harvest of rice (J. Fleskes, unpublished data) and corn (USDA 2010) and timing of normal flooding of fields post-harvest and wetlands (CVJV 2006). Ultimately, we produce projections of the amount of habitat available each month of the wintering period from August through March under each scenario. These habitat projections are subsequently used in avian bioenergetics models (i.e., TRUEMET or ABM) to translate scenario impacts on habitats into impacts on waterbird food supplies to better understand future potential threats to waterbirds.

BIOENERGETICS MODELING WITH TRUEMET

The TRUEMET model (CVJV 2006) provides an estimate of population food energy demand and food energy supplies for specified time periods and is the primary bioenergetics model currently used by wintering and migration Joint Ventures, including the CVJV. Thus, we have focused primarily on using TRUEMET to evaluate adequacy of habitat conditions under each scenario for wintering waterfowl; to date, our work has focused on ducks.

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. There are six explicit inputs required for each model run:

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

- *Habitat Availability:* Habitat availability is a function of habitat area (e.g. hectares) on the landscape and the ability of waterfowl to access foods produced in a habitat type. For example, managed wetlands may total 500 hectares on the landscape but these habitats may only become available after October 1 when they are intentionally flooded and in some years or under some scenarios water supplies may be adequate to only flood 250 hectares. For agricultural habitats such as rice; water supplies may limit area planted as well as area and timing of post-harvest flooding and availability to waterfowl and other waterbirds.
- *Biomass and Nutritional Quality of Foods:* TRUEMET requires information on the biomass of foods in habitats, and the nutritional quality of those foods. 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 (Baldassarre 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 (Baldassarre 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.

We have used the TRUEMET model to evaluate the waterfowl carrying capacity of existing landscapes and adequacy of landscapes to support goal waterfowl populations produced under a variety of climate, land use, and water supply management scenarios. Scenarios we have modeled thus far using TRUEMET vary only in habitat area and timing (i.e., *Habitat Availability*) supported by water supplies under each scenario; other factors are assumed to be the same as currently existing. However, as additional information on how water supplies and climate may impact the amount and quality of food produced by habitats, these data can be incorporated to refine modeled impact estimates. In addition, the ABM approach we are currently applying allows variation in *Waterfowl Daily Energy Requirements* in response to changing landscape conditions under each scenario.

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 continue to evaluate accuracy of and refine these results.)*

Preliminary results for Butte Basin suggest that substantial changes in water supply management (e.g., extensive fallowing of rice-land) can greatly impact habitats and food supplies available to waterbirds. In Butte and Sutter Basins, an “expansive” level of urban growth has significant and cumulative impact on habitat. Compared to historical climate (1971-2000), projected climate through 2065 will have minimal-to-moderate impact on waterbird habitat in Butte and Sutter Basins through 2065. However, we expect projected climate impacts to be more severe as we extend our evaluations beyond 2065 and into the San Joaquin Valley, where water supply restrictions and climate projections are more severe.

BUTTE BASIN

1) Scenarios including GFDL-A2 produced a slightly greater average reduction (about 1% greater) in total waterbird habitat area than PCM-B1 and historical climate scenarios. Total habitat reduction (relative to existing habitat area) in dry water-years under:
    - GFDL-A2 climate ranged between 6 and 16%.
    - PCM1-B1 climate ranged between 9 and 12%.
    - Historical climate ranged between 6 and 19%.

    However, climate impacts on waterbird habitats were more frequent and generally more severe in scenarios including GFDL-A2 projections relative to other climate projections (Figure 4).
2) Comparing among scenarios with similar other factor levels, including expansive urbanization produced a moderate cumulative reduction in total waterbird habitat area (Figure 4). Average annual reduction for the 2036-65 period were:
    - Expansive urbanization = 7-8%.
    - Strategic urbanization = 2-3%.
3) Scenarios including a proposed enhanced Butte Creek in-stream flow requirement for fisheries did not differ greatly from similar scenarios that excluded the flow requirement (Figure 4). Total habitat reduction (relative to existing habitat) in dry water years were:
    - Butte Creek in-stream flow requirement ranged between 12 and 16%.
    - Models with climate change and urbanization but no enhanced Butte Creek flow requirements ranged between 12 and 15%.
4) Modeled changes in water supply management to facilitate increased rice-land idling in the Butte Basin and allow the transfer of those water supplies to fulfill unmet water needs in western San Joaquin Valley agriculture produced the greatest reduction in total habitat among factors evaluated (Figure 5, Table 4).
    - A scenario representing proportional fallowing across the Sacramento Valley (i.e., allowing a maximum fallowing of 20% of Butte Basin rice-land) produced a 26% decline in total habitat area by 2065 (Figure5).
    - A scenario allowing unlimited fallowing of Butte Basin rice-land produced a 76% decline in total habitat area by 2065 (Figure 5).
5) Depending on the scenario, impacts on total area of waterbird habitat in Butte Basin were generally 2- 4 times greater for the time period 2036-65 than for 2006-35, reflecting cumulative impacts of urbanization and changing climate. Across all scenarios evaluated, mean annual habitat reduction relative to the existing habitat area were:
    - Projected years 2006-35 = 0% to 59% decline.
    - 2036-65 = 0% to 65% decline.
6) During projected drought, reduction in area varied among habitats (Table 4):
    - Across scenarios, decline in rice area contributed most to habitat area reduction.
    - Wetland habitats declined comparatively little because of top water demand prioritization of many wetlands and much water demand occurs when evapotranspiration is limited and precipitation is relatively substantial.
7) Other habitat impacts include dry-year effects in delaying availability of habitats:
    - Relative to its existing area, post-harvest flooded rice declined by a maximum of between 4% and 89% in October depending on scenario.
8) Impacts on food supplies for wintering waterfowl:

- Recent TRUEMET bioenergetics modeling for selected scenarios (Figs. 7-11) projected a food energy deficit for ducks during Mid-December through March resulting from extensive rice-land idling (Figure7).

SUTTER BASIN

For the Sutter Basin, temporal reductions in total habitat area related to projected GFDL-A2 climate were similar in pattern but marginally larger than for Butte Basin (Figure 6). Similar to Butte Basin, the instream flow requirement on lower Butte Creek and Sutter Bypass was projected to cause little impact to Sutter Basin habitats. Like Butte Basin, a greater amount of rice habitat (primarily during the growing season) than wetland habitat in Sutter Basin was impacted during drought (Table 5). Although seasonal wetlands in Sutter Basin generally lacked the high demand prioritization of Butte Basin wetlands, based on modeling natural runoff and agricultural return flows appear to be sufficient in the basin.

FUTURE WORK

CONDUCT ADDITIONAL MODELING

While we are expanding our modeling approach for other basins, we are also continuing to model new scenarios focusing on water management and interactions between water management and other factors such as changing climate. The following are scenarios that we are planning to evaluate in the future:

1) Additional climate model scenarios with even greater projected changes in climate than moderately-high GFDL1-A2 scenarios
2) Congressional bill H.R.1837 proposed changes in water management, and in combination with climate and urban development projections.
3) Conveyance facility (or “Peripheral Canal”) allowing isolation of Central Valley and State Water Project diversions from the Sacramento-San Joaquin Delta, potential related changes in water management, and in combination with climate and urban development projections.
4) Proposed Yolo Basin floodplain restoration allowing more frequent and longer inundation of the Yolo Bypass, which could affect seasonal wetland productivity and accessibility of rice and wetland food supplies to waterbirds.
5) Variations in water supply prioritization among fishery flow requirements, wetlands, and agriculture, and in combination with climate and urban development projections.
6) Inclusion of proposed flow requirements for protection of the Sacramento-San Joaquin Delta ecosystem, and in combination with climate and urbanization development projections.

TRANSLATING CHANGES IN WATER SUPPLIES INTO IMPACTS ON ECOLOGY

We are utilizing three approaches for assessing impacts of landscape changes in on ecology of waterfowl and other waterbirds. First, most of our efforts to date have focused on inputing 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 for each guild. Thirdly, our new partnership with UC Davis is allowing us to apply ABM (Goss-Custard et al. 2006, Nonaka and Holme 2007). Our new UC Davis partners have developed a prototype ABM to simulate the effect of 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 CA-LCC, CVJV, and others in the research and management communities at conferences and workshops on project progress and help adapt results into conservation planning. The website we established describing project goals and methods will be updated periodically 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. 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 receiving water through Central Valley Project Improvement Act (CVPIA) contracts were assumed to have the same demand priority (i.e., 1), but other public wetlands and managed privately-owned wetlands were assumed to have the same demand priority as agriculture (i.e., 3).

Table 2. Wetland classifications (excluding basin hydrologic unit geography) used in the WEAP-CV Adapted Model.

Ownership	Water Supply[a] Reliability	Irrigation Schedule	Demand Priority[b]
Public (CVPIA)	High-reliability	Seasonal	1
Public (CVPIA)	High-reliability	Semipermanent	1
Public	High-reliability	Seasonal	3
Public	High-reliability	Semipermanent	3
Private	High-reliability	Seasonal	3
Private	High-reliability	Semipermanent	3
Private	Low-reliability	Seasonal	RF
Private	Low-reliability	Semipermanent	RF

[a] Adapted from Water Report (CVWWSI 2000). Reported "High" and "Moderate" reliability were classified herein as "High-reliability".

[b] 1 = highest, 3 = equivalent to agriculture, RF = relies on agricultural return flows. Public wetlands with Central Valley Project Improvement Act (CVPIA) contracts have water supplies that are more secure than other public wetlands, thus, the difference in demand priority.

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

Table 3. Wetlands irrigation schedules for optimal wetland management in the Butte Basin (adapted from Water Report).

	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 4. Reduction in Butte Basin habitats (hectares) during the most severe projected drought period in each scenario through year 2065.

Habitat	**Historical climate, no growth**	**GFDL-A2 + Expansive growth**	**GFDL-A2 + Expansive growth + Butte Cr. IFR**	**GFDL-A2 + Expansive growth + max. 20% Rice idle**	**GFDL-A2 + Expansive growth + Rice idle**
Unplowed winter-dry corn	208	284	291	226	123
Unplowed winter-dry rice	4,636	4,752	4,757	4,241	12,374
Early winter-flooded rice	1	1,416	1,416	3,430	10,009
Late winter-flooded rice	0	4,030	4,030	9,762	28,488
Seasonal wetlands	42	28	67	184	265
Total	4,888	10,510	10,561	17,843	51,260

Table 5. Reduction in Sutter Basin habitats (hectares) during the most severe projected drought period in each scenario through year 2065.

Habitat	**Historical climate, no growth**	**GFDL-A2 + Expansive growth**	**GFDL-A2 + Expansive growth + Butte Cr. IFR**
Unplowed winter-dry corn	457	437	415
Unplowed winter-dry rice	3,388	3,242	3,161
Early winter-flooded rice	164	565	613
Late winter-flooded rice	8	1,061	1,061
Seasonal wetlands	2	2	2
Total	4,019	5,308	5,252

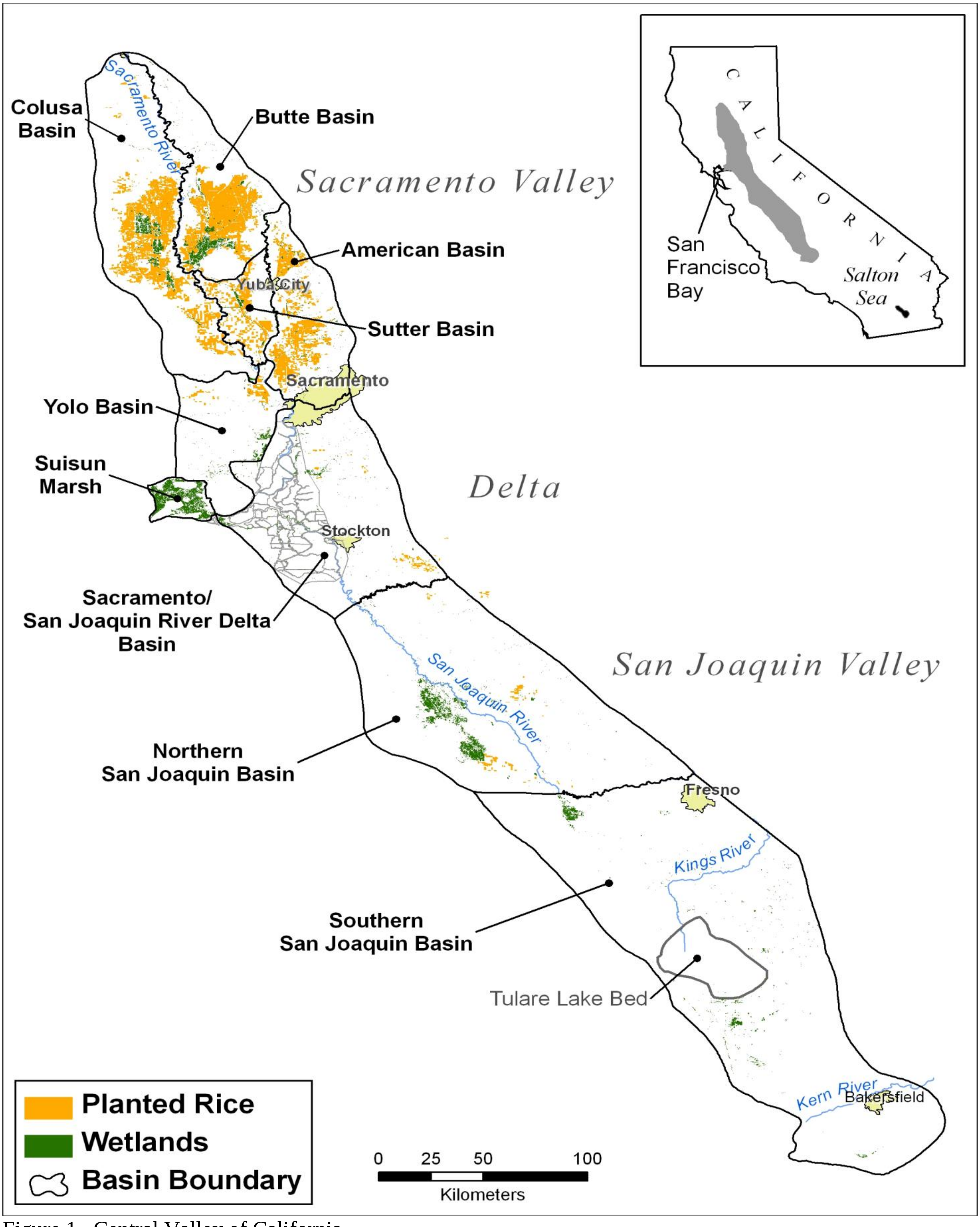

Figure 1. Central Valley of California.

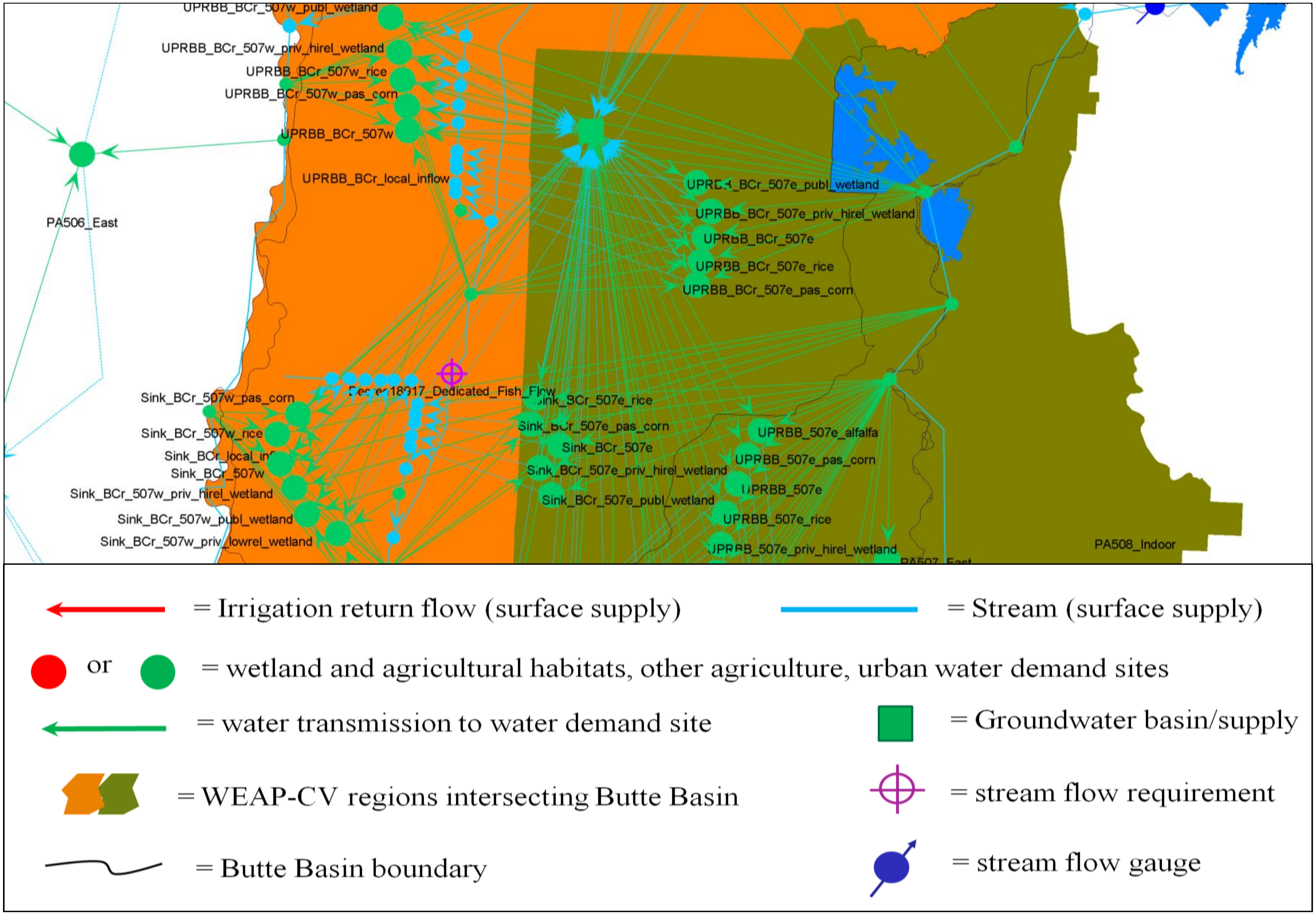

Figure 2. water supplies, demands, and delivery in a portion of Butte Basin represented in WEAP as a system of links and nodes.

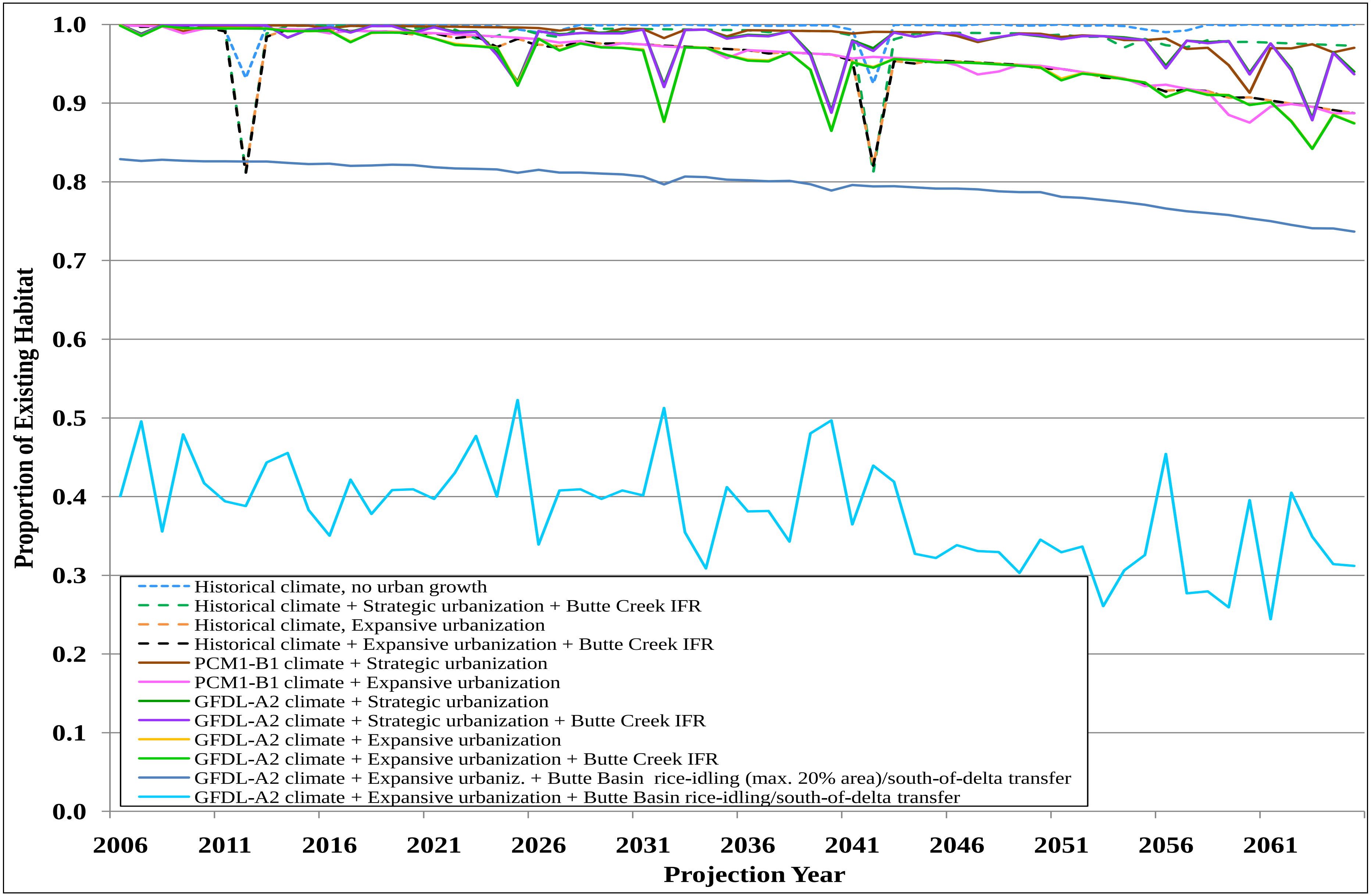

Figure 3. Proportion of existing waterbird habitat in Butte Basin projected under each of 12 scenarios evaluating impacts of climate, urbanization, and a variety of water supply management practices. Note: rice-idling scenario "…(max. 20% area)/south-of-delta transfer" results are expected to change with further model improvements pertaining to other Sacramento Valley basins.

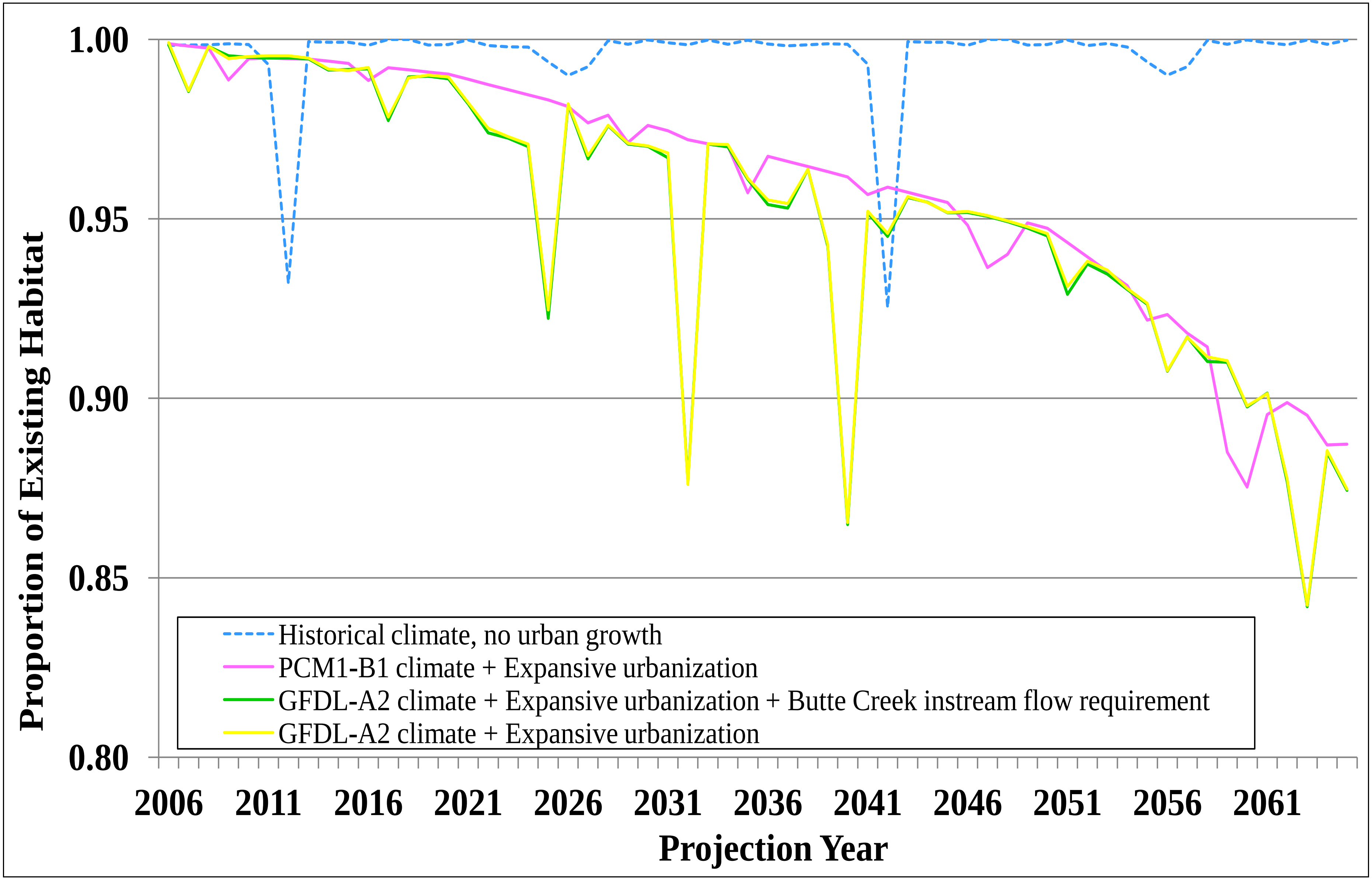

Figure 4. Proportion of existing waterbird habitat in Butte Basin projected under each scenario evaluating impacts of climate, urbanization, and proposed enhanced instream flow requirement of 40 cfs on Lower Butte Creek, October through June.

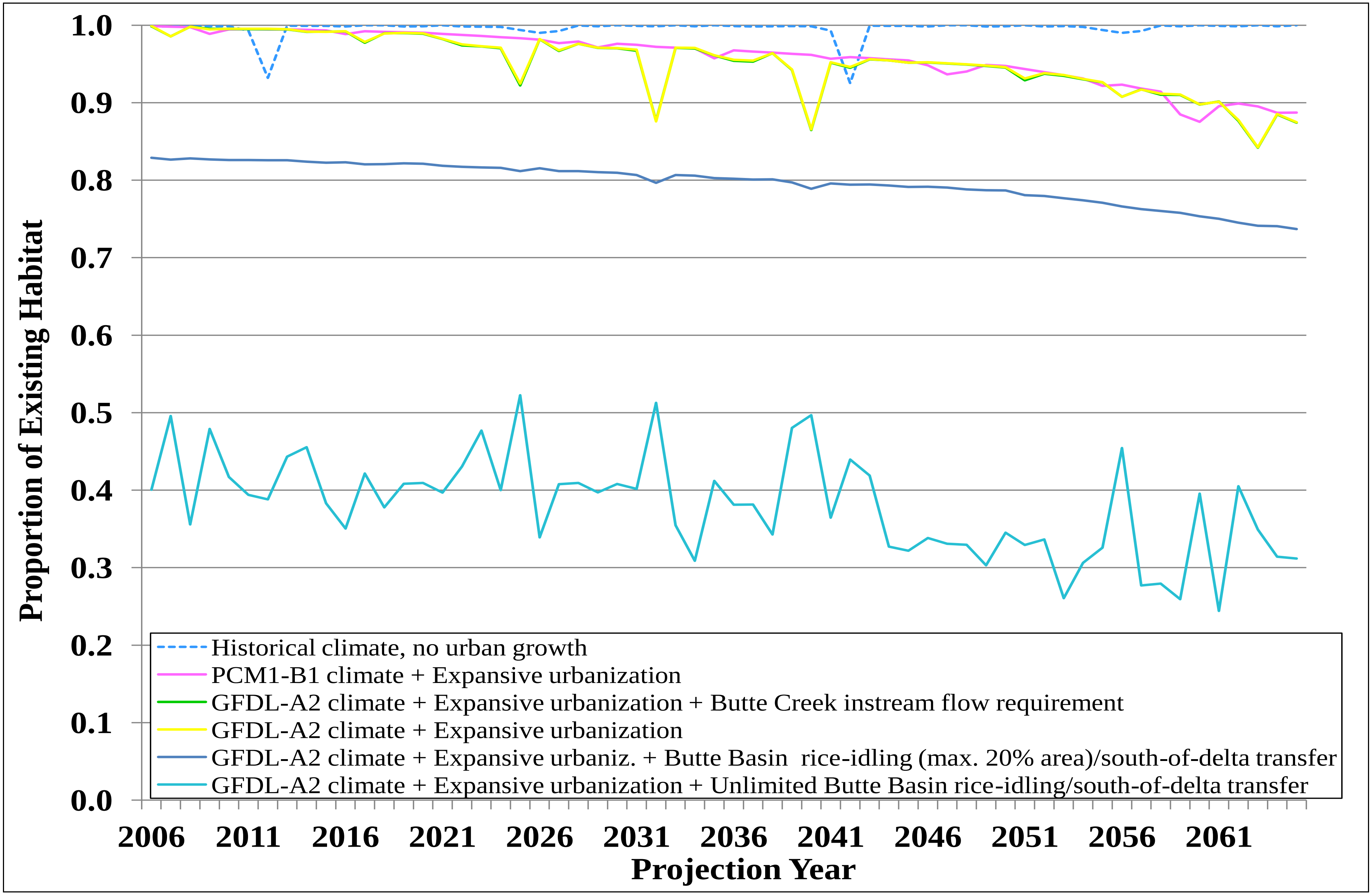

Figure 5. Proportion of existing waterbird habitat in Butte Basin projected under each scenario evaluating impacts of climate, urbanization, a proposed enhanced instream flow requirement of 40 cfs on Lower Butte Creek from October through June, and water management allowing increased rice-idling. Note: rice-idling scenario "…(max. 20% area)/south-of-delta transfer" results are expected to change with further model improvements pertaining to other Sacramento Valley basins.

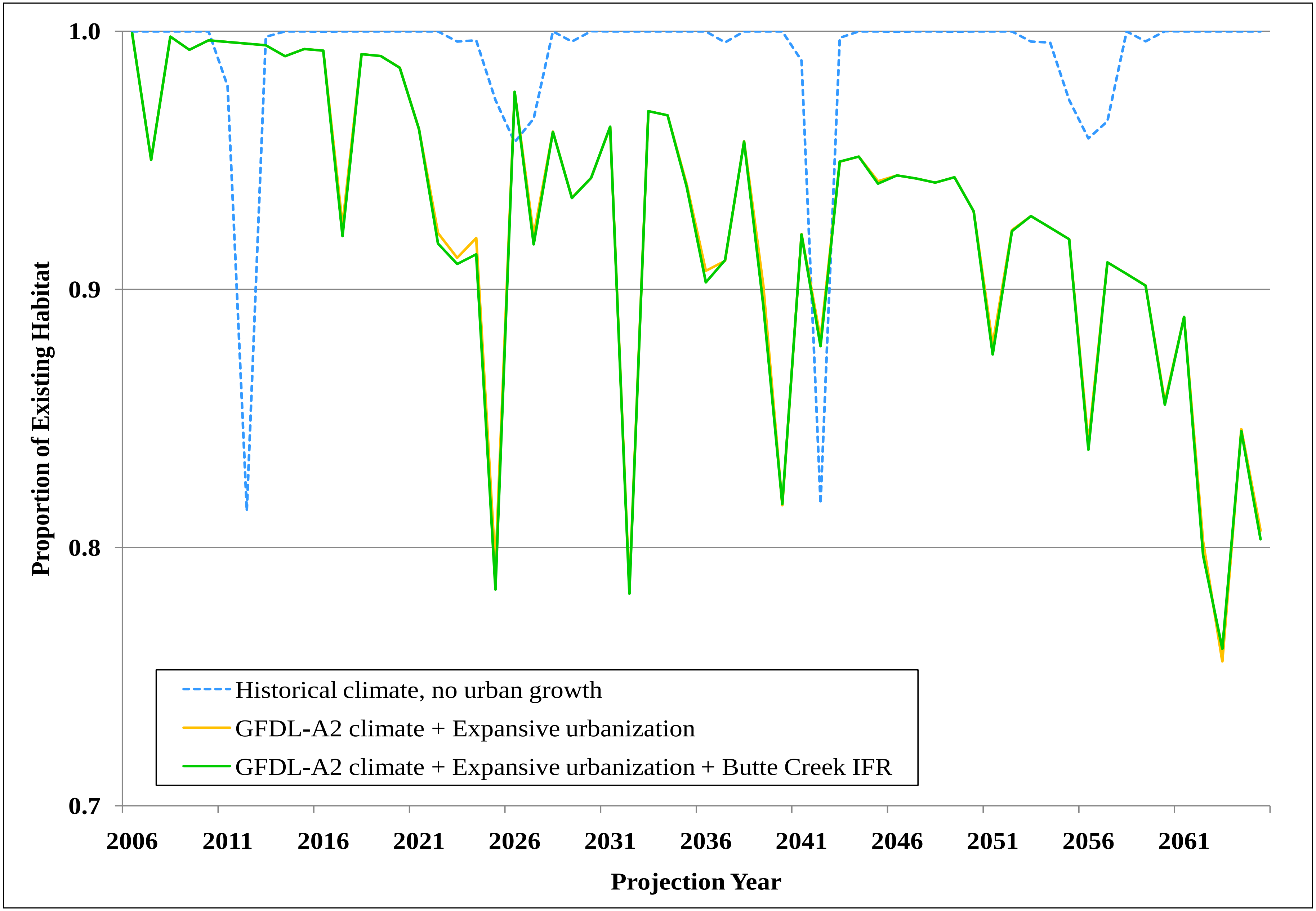

Figure 6. Proportion of existing waterbird habitat in <u>Sutter Basin</u> projected under each scenario evaluating impacts of climate, urbanization, a proposed enhanced instream flow requirement of 40 cfs on Lower Butte Creek and Sutter Bypass from October through June.

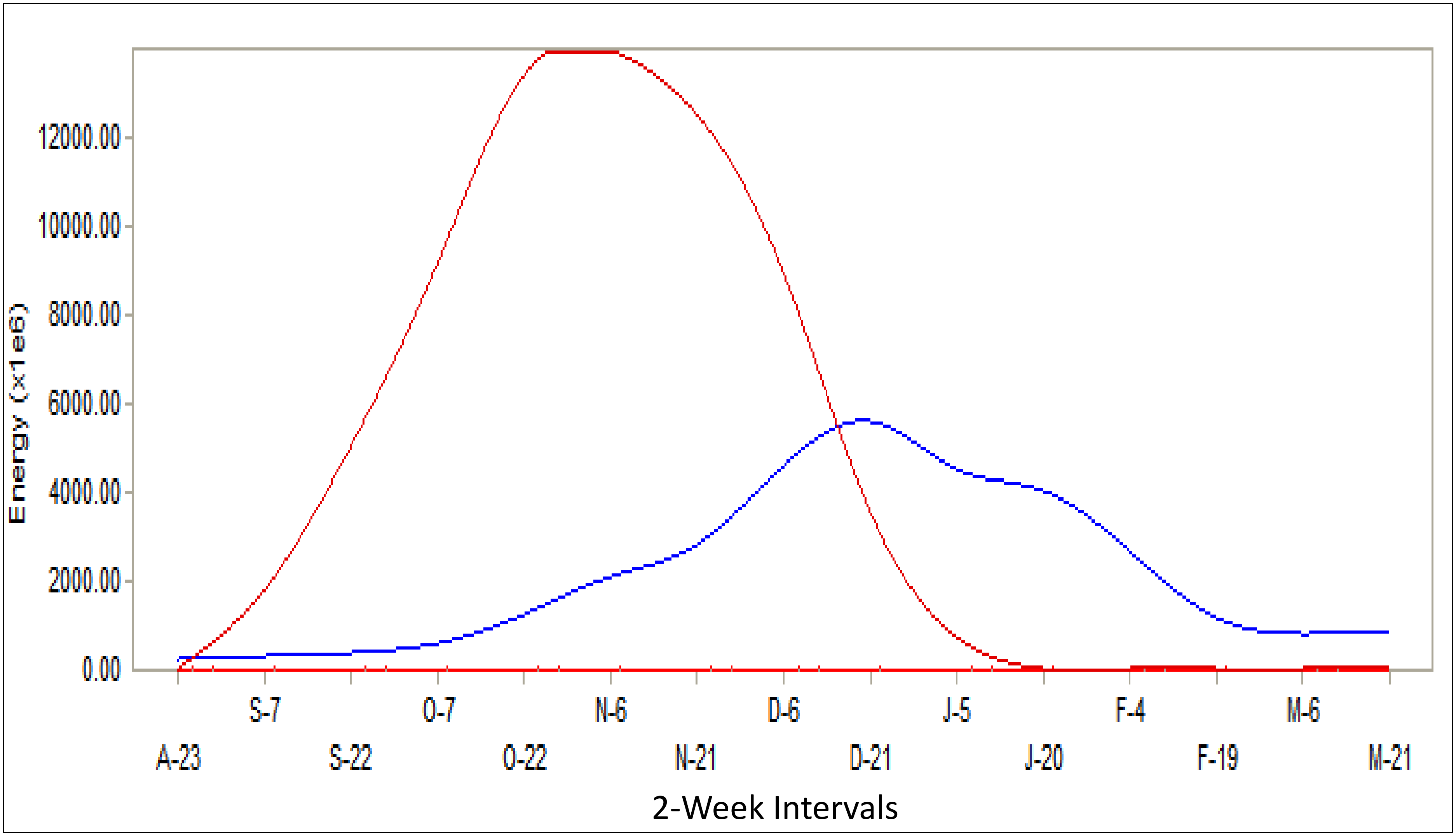

Figure 7. TRUEMET bioenergetics model output for the **GFDL-A2 climate + Expansive urbanization + Unlimited Butte Basin rice-idling/ south-of-delta transfer** scenario comparing available food supply (red curve)and goal duck population food demand (blue curve) in Butte Basin. Output represents the most severe annual reduction in total habitat during the projected time period through year 2065 as modeled in the Adapted WEAP Model. The wintering period in two-week intervals extends from August 23 through March 21.

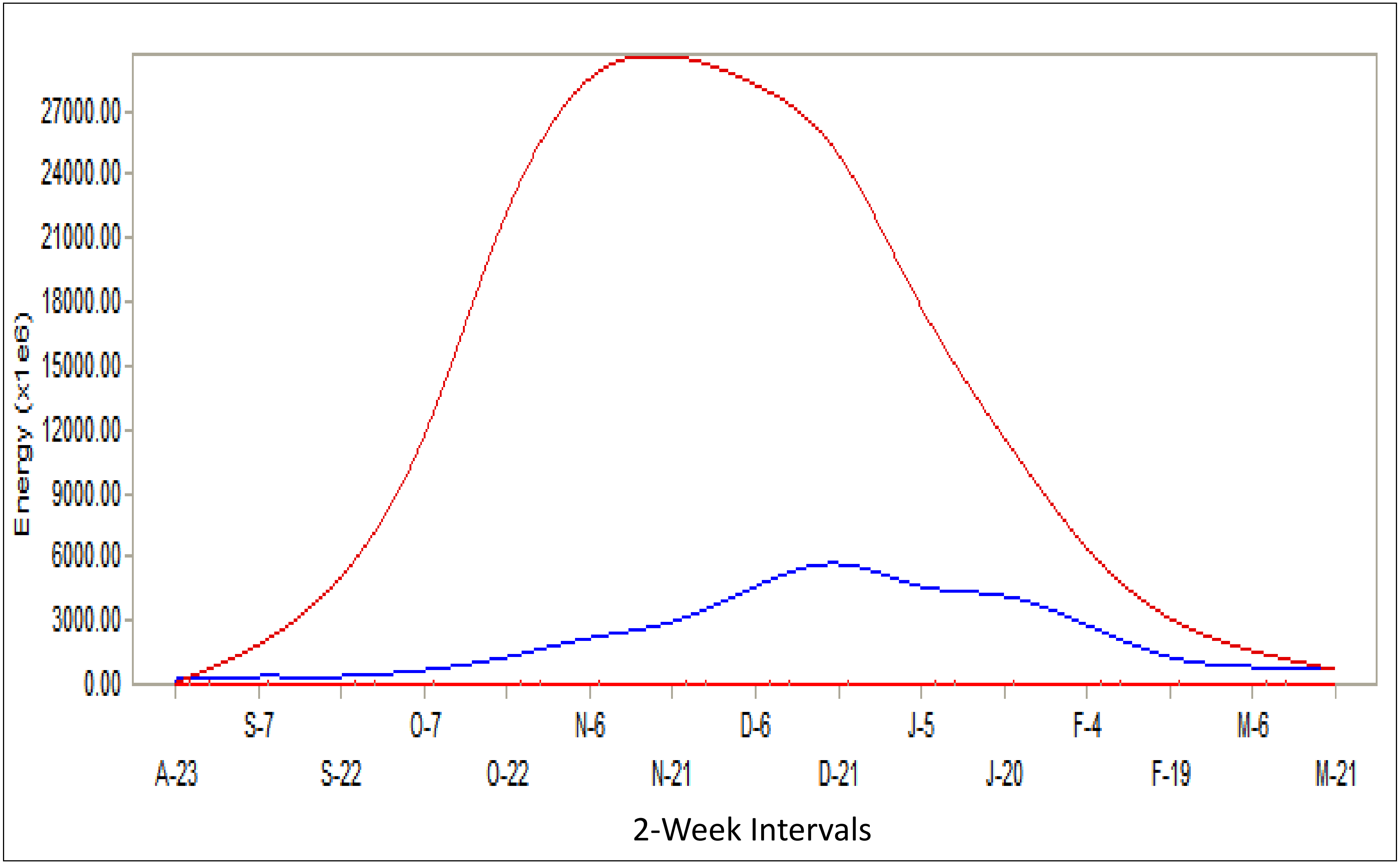

Figure 8. TRUEMET bioenergetics model output for the **GFDL-A2 climate + Expansive urbanization + Butte Basin rice-idling (max. 20% area)/south-of-delta transfer** scenario comparing available food supply (red curve)and goal duck population food demand (blue curve) in <u>Butte Basin</u>.. Output represents the most severe annual reduction in total habitat during the projected time period through year 2065 as modeled in the Adapted WEAP Model. The wintering period in two-week intervals extends from August 23 through March 21.

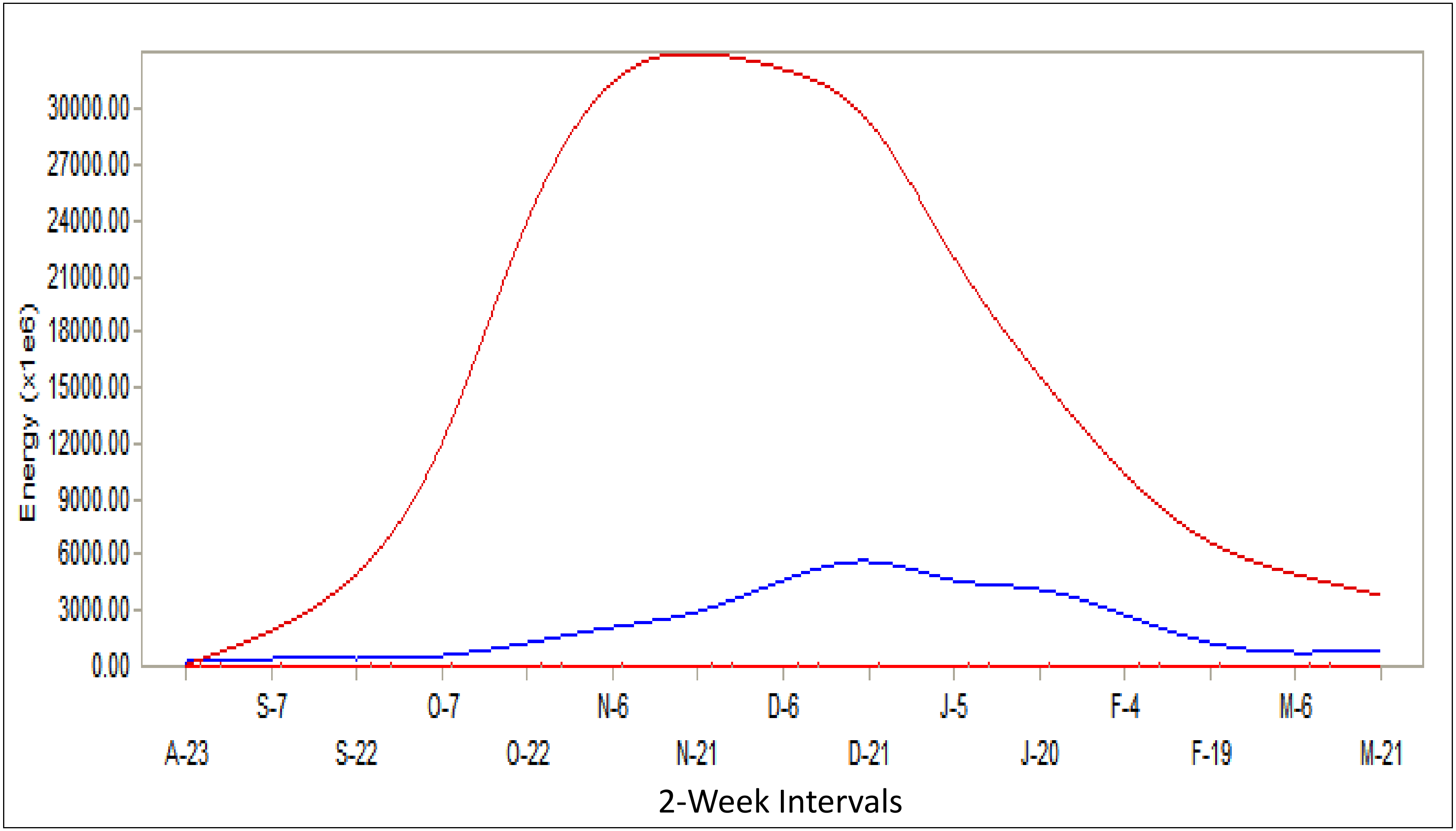

Figure 9. TRUEMET bioenergetics model output for the **GFDL-A2 climate + Expansive urbanization + Butte Creek instream flow requirement** scenario comparing available food supply (red curve) and goal duck population food demand (blue curve) in Butte Basin. The proposed enhanced instream flow requirement prescribed 40 cfs on Lower Butte Creek from October through June. Output represents the most severe annual reduction in total habitat during the projected time period through year 2065 as modeled in the Adapted WEAP Model. The wintering period in two-week intervals extends from August 23 through March 21.

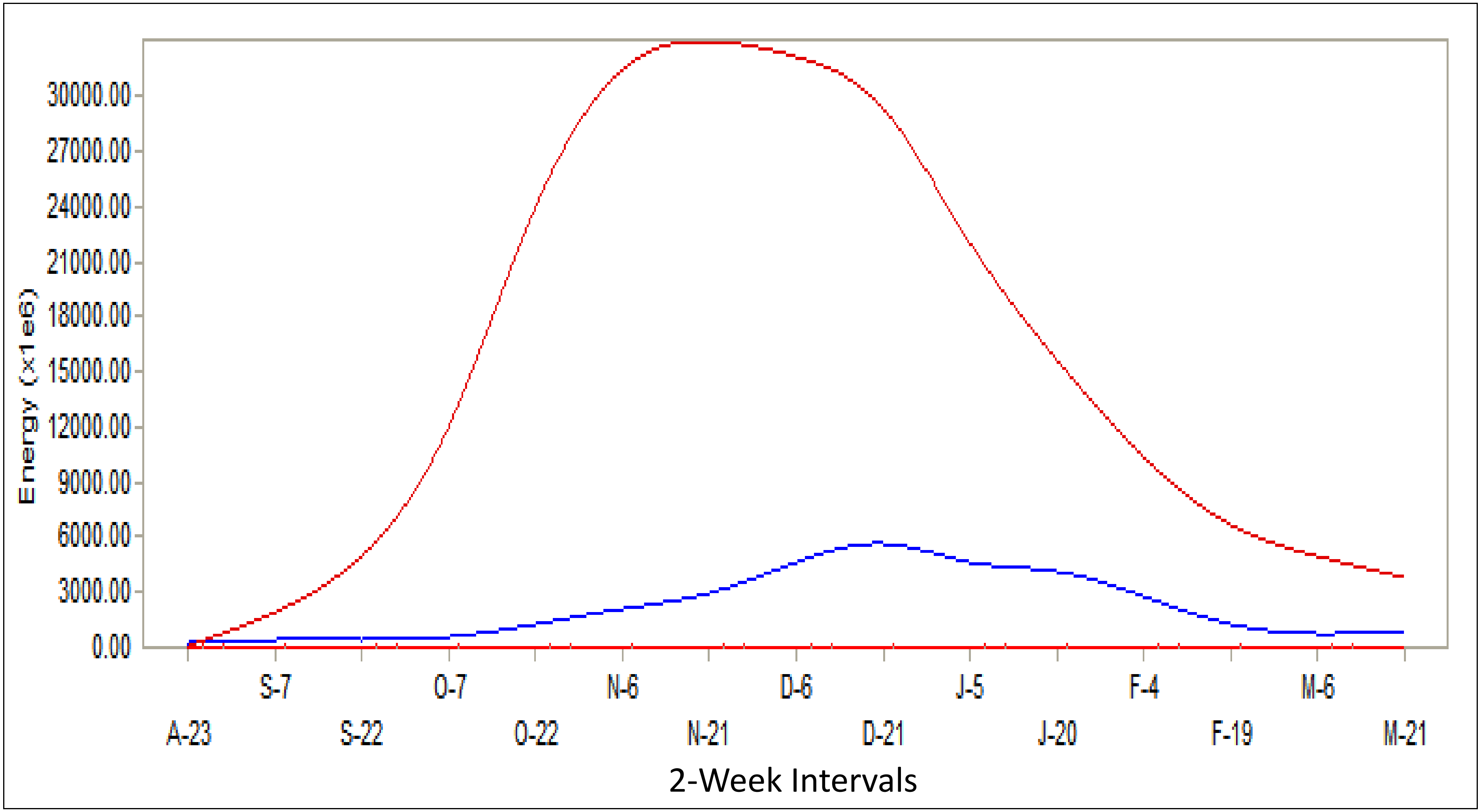

Figure 10. TRUEMET bioenergetics model output for the **GFDL-A2 climate + Expansive urbanization** scenario comparing available food supply (red curve)and goal duck population food demand (blue curve) in <u>Butte Basin</u>. Output represents the most severe annual reduction in total habitat during the projected time period through year 2065 as modeled in the Adapted WEAP Model. The wintering period in two-week intervals extends from August 23 through March 21.

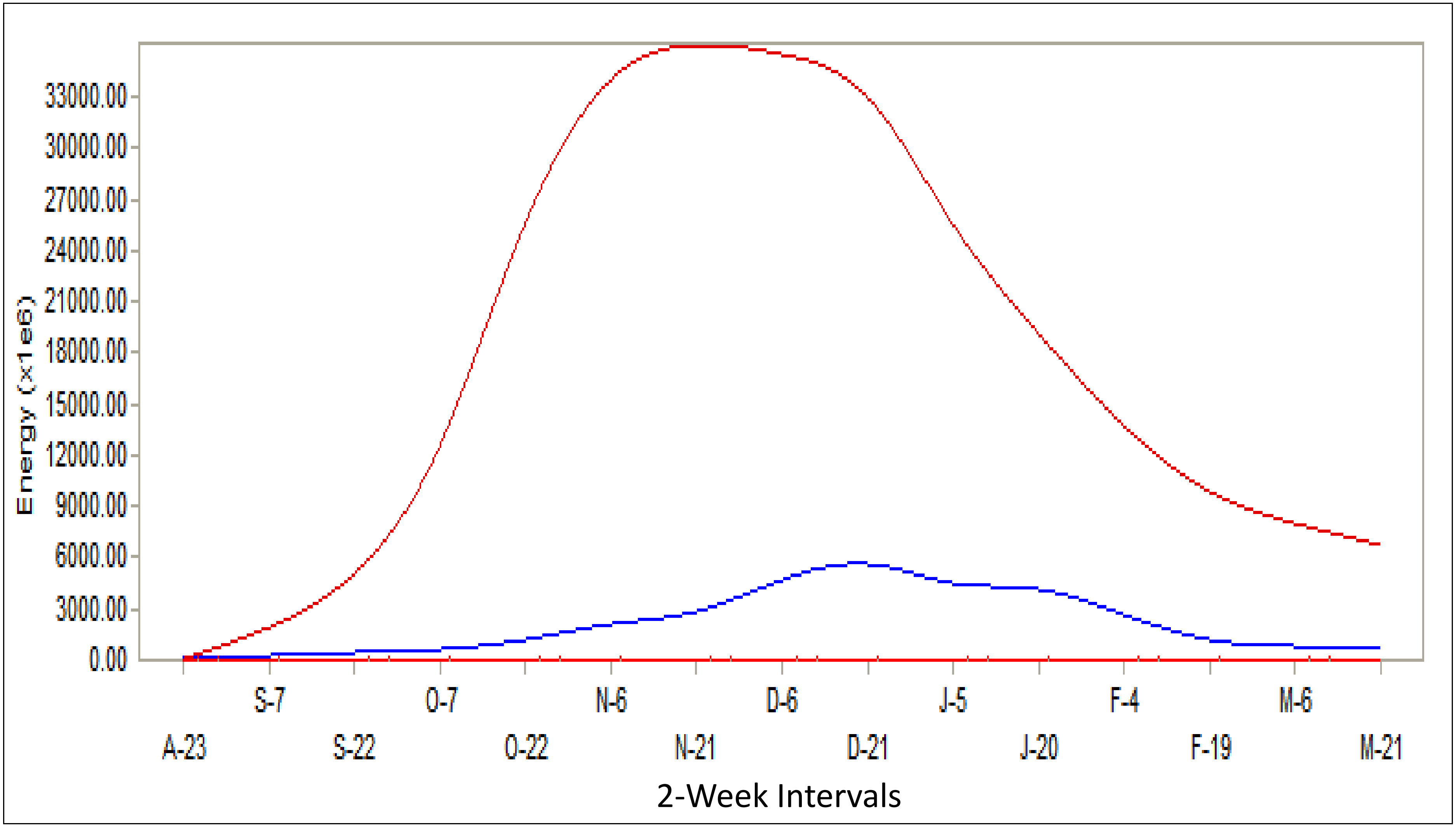

Figure 11. TRUEMET bioenergetics model output for the **Historical climate, no urban growth** scenario comparing available food supply (red curve)and goal duck population food demand (blue curve) in Butte Basin. Output represents the most severe annual reduction in total habitat during the projected time period through year 2065 as modeled in the Adapted WEAP Model. The wintering period in two-week intervals extends from August 23 through March 21.