As described in our letter of transmittal (attached), Washington State University (WSU) would be pleased to partner with the Office of Columbia River (OCR) for the 2016 Long-Term Water Supply and Demand Forecast. We propose to focus the 2016 Forecast around six key issues as described in detail below.

1. Update and expand the 2011 water forecast (3-tier analysis)

This project comprises three types of updates to the 2011. WSU will 1) update the existing forecast estimates for the Columbia River Basin using improved modeling capabilities (see description below), 2) extend the forecast window forward 5 years while using future climate projections from the most recent Coupled Model Inter-comparison Project (CMIP5); and 3) begin the preliminary work to eventually extend the forecast to Western Washington WRIAs. With the third option, this effort includes coordination with west side watershed planning, Puget Sound Partnership, King County demand projections, etc. This work will provide a (nearly) geographically complete summary of water forecasts in the State of Washington and could form a foundation for a geographically complete Washington State Water Plan.

The update to the 2011 report will focus on the WRIA specific forecasts of the discrepancy between water availability and water demand. This analysis combines hydrological and economic modeling and was done for approximately 20 WRIAs in Eastern Washington. Changes in the crop mix were based on forecasts of economic drivers of food demand. Downscaled climate models were incorporated into VIC-CropSyst to simulate physical water supply throughout the year on a daily time step. The impact of water shortages were incorporated based on the curtailment of interruptible rights holders in a spatially explicit way based on available water rights data. The integrated hydrology/crop growth/economic modeling framework has developed significantly since the previous forecast under the BioEarth and WISDM projects funded by the USDA (http://www.cereo.wsu.edu/bioearth/ and http://www.cereo.wsu.edu/wisdm/). The updated forecast will benefit substantially from this.

Description of Integrated Modeling Framework

The following elements are new for the 2016 Forecast:

- A tighter integration between hydrologic and cropping models (resulting in VIC-CropSyst v2.0)
- Development and incorporation of a mechanistic irrigation module for improved simulation of consumptive loss
- Improvement in reservoir and curtailment modeling for specific locations; e.g., main-stem modeling at weekly time-steps (rather than monthly) and incorporation of RiverWare modeling over the Yakima River basin (which includes projects specific to the Yakima Integrated Plan)
- Utilization of improved climate forecasting data and tools

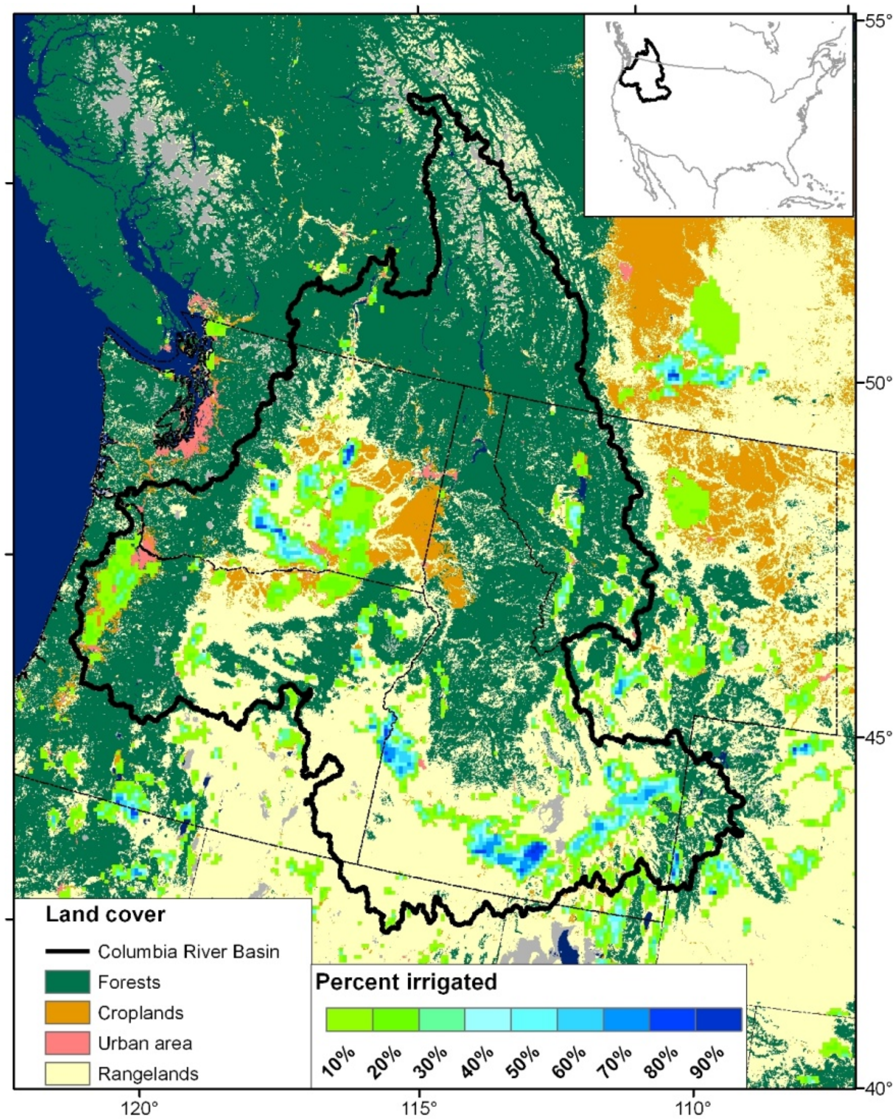

Figure 1. To simulate flows into the state, we will perform simulations for the entire Columbia River basin as well as all of Washington State. The irrigation maps are from MODIS (Ozdogan and Gutman, 2008) and GMIA (Siebert et al., 2005) and land cover are from National Land Cover Dataset (NLCD), the USDA Cropland Data Layer (CDL), and MODIS.

Figure 2 illustrates the integration details for the biophysical modeling framework. VIC-CropSyst provides runoff, baseflow, aquifer recharge, and top-of-crop irrigation demand; this information is passed to the reservoir models. RiverWare and/or ColSim (for the Yakima and Columbia Rivers, respectively) route runoff and baseflow through the surface flow network, and simulates reservoir management. The top of the crop irrigation demands provided by VIC-CropSyst are separated into surface vs. groundwater demands and extracted from the system accordingly. Irrigation canal conveyance losses are also accounted for. The reservoir model deducts surface water irrigation diversions and gives estimates of resulting surface water volumes, which is then used to inform reservoir operations and water rights curtailment decisions. For this forecast, we will enhance our water management simulations by acquiring and integrating newer water rights information in addition to automating and discretizing (in time) our reservoir simulations.

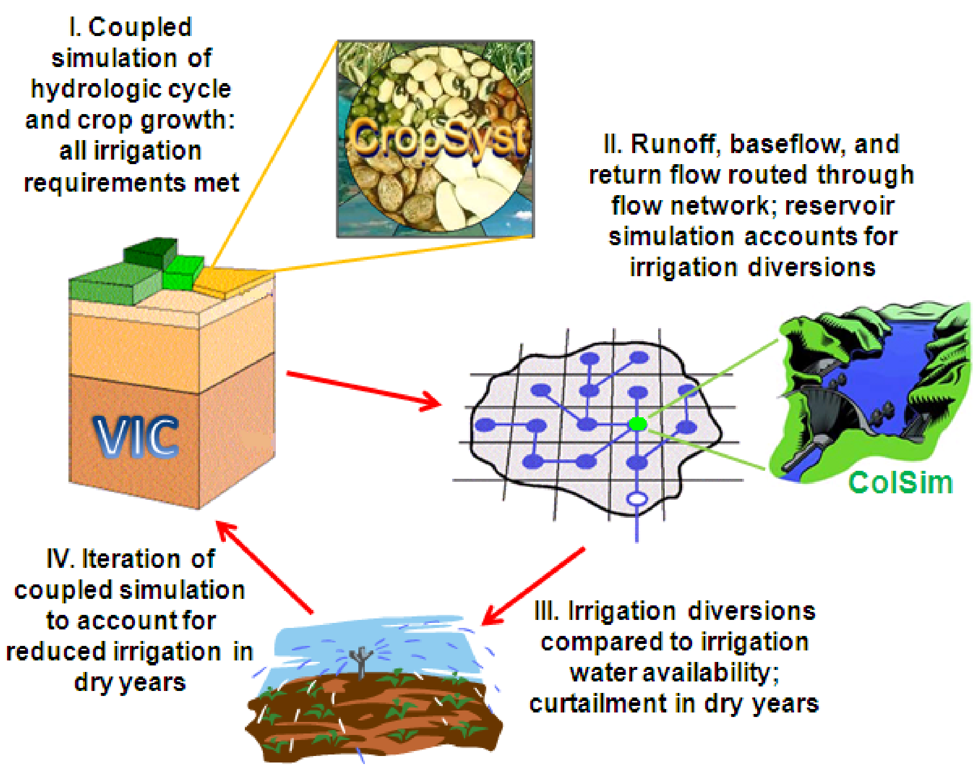

Figure 2. Integrated biophysical modeling framework to account for coupled dynamics between hydrology, cropping systems, and water management.

Figure 3 demonstrates the passing of information between coupled biophysical models and economic modeling regarding short-run producer response in irrigation management and long-run response in cropping decisions. Economic modeling provides decisions on deficit irrigation management in the event of water scarcity and the entire biophysical model is rerun under deficit irrigation to quantify the impacts on crop productivity and downstream water availability.

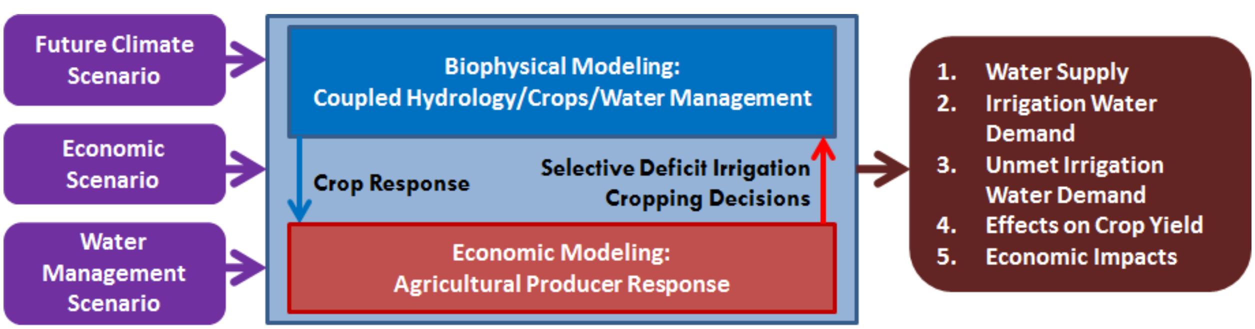

Figure 3. Coupled biophysical and economic modeling schematic.

Individual Model Descriptions

Large-Scale Hydrology. The Variable Infiltration Capacity (VIC; Liang et al., 1994) large-scale model will be used to simulate the broad aspects of climate change on regional land surface hydrology, including shallow subsurface moisture dynamics, but not deep groundwater dynamics. The VIC model is a fully-distributed, physically-based model which solves water and energy budgets at every time step (from 1-24 hours) and for every grid cell. It was developed for large-scale applications ($1/16^{th}$ ° for this project) with sub-grid variability based on statistical relationships for land cover, elevation, saturated extent, and a number of other variables.

Cropping Systems. CropSyst is bio-physically based and uses hourly and daily time steps to capture diurnal progression of various biological, physical and chemical processes. The "growth engine" in the model is based on a combination of radiation-use efficiency (solar radiation capture) and transpiration-use efficiency (water capture), which are modulated by weather conditions affecting atmospheric evaporative demand and vapor pressure deficit, and by soil conditions and irrigation management affecting available soil water. This approach permits a tight integration of crop production, weather and management with atmospheric warming and atmospheric carbon dioxide concentration (e.g., El Afandi et al., 2010; Abraha and Savage, 2006; Stöckle et al., 2010), including responses to increased frequency of drought induced water shortages.

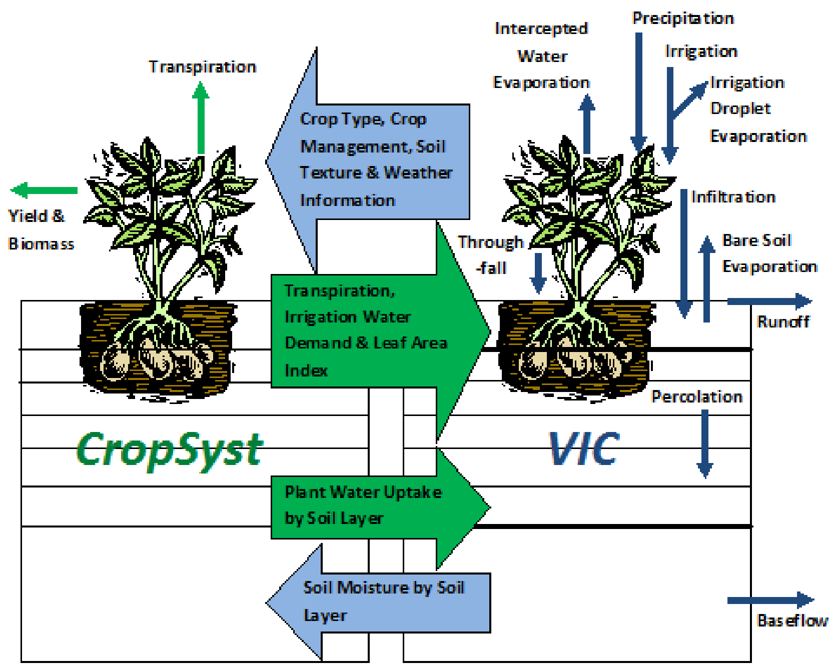

Figure 4. VIC-CropSyst integration details.

VIC-CropSyst Integrated Model. We have completed a fully dynamic coupling between VIC and CropSyst where CropSyst plugs into VIC as a dynamic vegetation cycling module, providing to VIC plant water uptake for transpiration by soil layer, water demand for irrigation, and leaf area index (Figure 4). VIC is modified to simulate crop-specific potential evapotranspiration and to represent irrigation technology-specific evaporation of irrigation water droplets in addition to bare soil and canopy-interception evaporation losses (see Figure 5 for details). CropSyst also simulates crop yields which are needed by the economic model. VIC invokes CropSyst for each of its sub-grid classes that are occupied by a crop land cover. In informing crop producer decisions, VIC-CropSyst does not resolve individual farms because these farms are represented implicitly as sub-grid classes within a grid cell. Instead, VIC-CropSyst's strength lies in producing information as to the broader implications of widespread changes in irrigation, fertilization, or crop management decisions. However, issues of aggregation of production from the individual farm to the regional scale are handled explicitly within the economic modeling.

Reservoirs and Pro-ratable Water Rights Curtailment. We will use a combination of water management modules. The physical system of reservoirs and dams are represented using the Columbia Simulation Reservoir Model (ColSim) (Hamlet et al. 1999) which models the main storage reservoirs and run-of-the-river reservoirs on the Columbia River main stem. It also includes the Snake, Kootenai, Clark Fork and Pend Oreille tributaries. Smaller tributaries like the Yakima River are ignored. For the 2016 Forecast, we will update this model from a monthly to a weekly tiem-step to use routed, bias corrected VIC-CropSyst simulated stream flow as its input. Operation rules for hydropower production, flood evacuation and major flow targets are considered. In addition to ColSim, we have a simple reservoir model for the Yakima River subbasin. Multiple reservoirs in the Yakima are operated together as one system and we model the combined storage of these reservoirs based on a simplified set of operating rules as described in USBR (2002). The system is modeled to reach reservoir refill in June and simultaneously ensure that there is free reservoir space available to capture any flood events. Finally, we can also drive the Yakima RiverWare model by our VIC-CropSyst flows and demands.

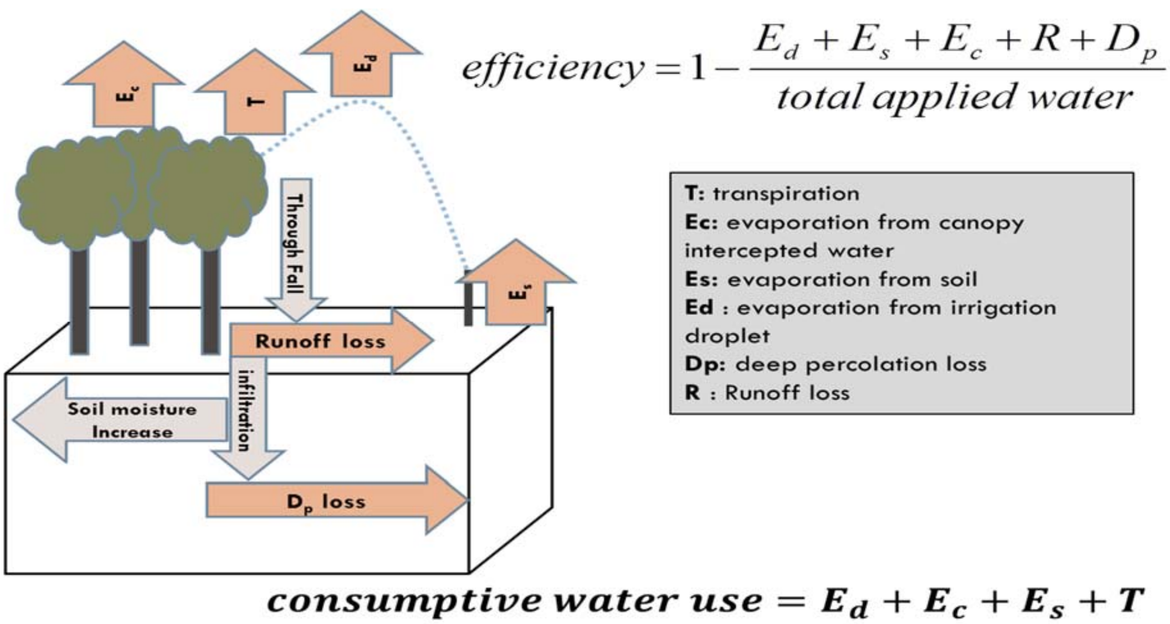

Figure 5. Details for the development of a mechanistically-based irrigation module for VIC-CropSyst.

Model Inputs

Weather. For historical weather information (daily maximum and minimum temperatures, relative humidity, precipitation, and wind speed), we will apply the 4-km gridded product developed by Abatzoglou (2011) for the period of 1979-2010, which is a combination of *in situ* observations and reanalysis data. For future (2036-2075) weather, we will apply a 4-km gridded product in which GCM results from the Coupled Model Intercomparison Project 5 (CMIP5) have been downscaled for 3 Representative Concentration Pathways (RCPs 4.5, 6.0, and 8.5) using the Multivariate Adapted Constructed Analogs (MACA) downscaling approach as implemented by Abatzoglou and Brown (2011). MACA preserves dynamical relationships between variables and has been demonstrated to be useful for ecological applications (Abatzoglou and Brown, 2011).

Historical Land Cover and Use. Land use has been taken from the Washington State Department of Agriculture (WSDA) agricultural land use geodatabase, which combines USDA-NASS Cropland Data Layer (CDL) with 1 meter National Agriculture Imagery Program (NAIP) imagery, FSA/USDA Common Land Unit field boundaries, and ground truthing. WSU extension personnel have provided information regarding planting, emergence, flowering, yield formation, and maturity. The WSDA data include information on irrigated extent.

2. Pilot Application of METRIC in Washington State

We will develop a scientifically defensible modeling tool combining water resources modeling with remote sensing validation methodologies to predict agricultural crop demands, irrigation return flows, and stream discharges at reach to watershed scales. Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC) is a satellite based image processing methodology that calculates spatial distribution of field scale (~30 m) evapotranspiration as a residual of surface energy balance (Allen et al. 2007). It is a variant of the Surface Energy Balance Algorithm for Land (SEBAL) model where near-surface temperature gradients are expressed as indexed function of radiometric surface temperature (Bastiaanssen et al. 1998). The primary METRIC inputs are short- and long- wave thermal images from satellite imagery (e.g., Landsat), a digital elevation model, and ground based weather data measured within the area of interest.

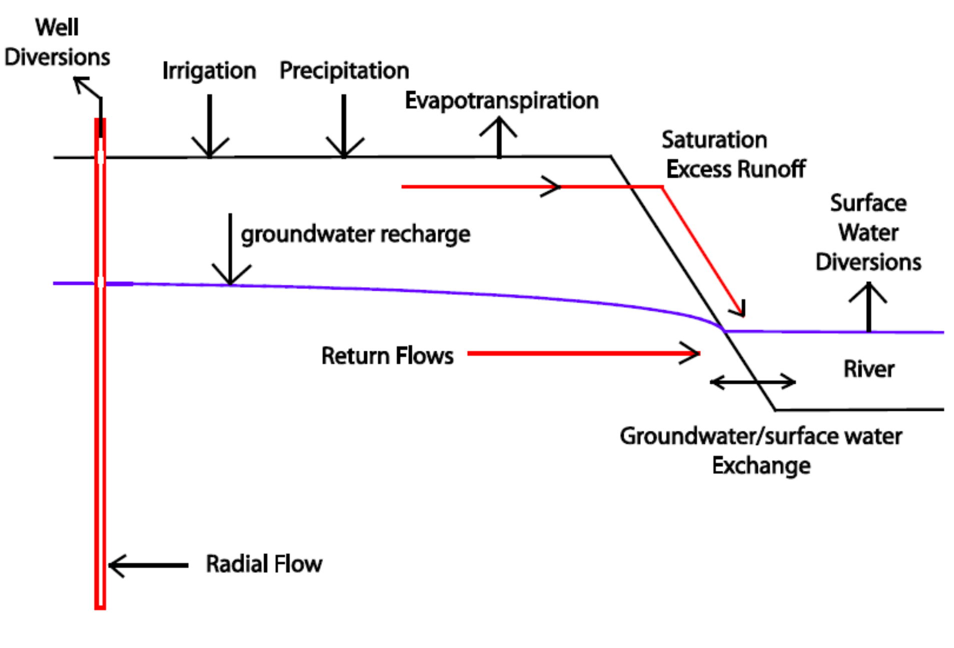

Figure 6. Water balance depicting important components for irrigated agriculture.

Evapotranspiration at Watershed Scale

A relatively large uncertainty in the water budget occurs due to the inherent variability in ET and associated errors in computational approaches, parameter estimation, tracking of state variables, available forcing meteorology, atmospheric feedbacks, and process definition (Pomeroy et al. 2010). Processes to use satellite imagery have been shown to improve evapotranspiration estimates although "nudging" of modeled soil moisture to an assumed climatology and precipitation bias did not fully account for the overestimation of summer ET (Maurer et al. 2001).

In their analysis of ET uncertainty, Kingston et al. (2009) concluded that choice of ET method can determine the direction of future water resources projections. Accurately defining the complete water balance requires extrapolation of evapotranspiration (ET) estimates from point (or lysimeter scale) to irrigation acreage throughout the basin.

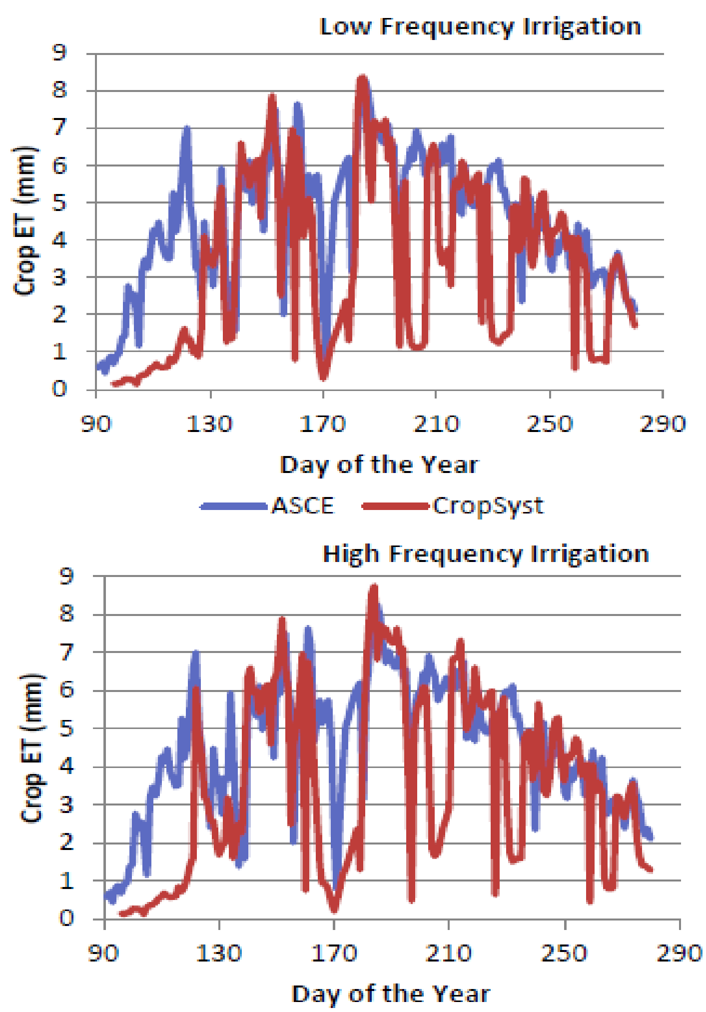

Figure 7. Comparison of daily ET estimates from ASCE and CropSyst for clipped alfalfa under low- and high- frequency irrigation.

CropSyst evapotranspiration methodology is based on the United Nations Food and Agriculture Organization (FAO) procedure described in the FAO Irrigation and Drainage Paper No. 56 (FAO 1998). This document defines a hypothetical short grass with prescribed characteristics as a reference crop (ETo). CropSyst determines a daily value of maximum crop ET at full canopy by multiplying ETo by a crop specific coefficient. The actual daily crop ET is based on simulation of crop growth, ground canopy cover, and water uptake and soil water evaporation in the context of a complete soil profile water balance. The current revision of the Washington Irrigation Guidelines (WIG) is based on an alfalfa reference crop (ETr) standardized by the American Society of Civil Engineering (ASCE 2005), with crop ET determined by multiplication of ETr by a crop coefficient that fluctuates throughout the growing season. The ASCE-based methodology in the WIG is intended to establish a long-term average estimation of ET for the purpose of providing guidance for irrigation design and definition of water rights. The methodology in CropSyst can be used for the same purpose, but in addition it allows calculating ET for irrigation scheduling, accommodating different irrigation methods and management practices such as deficit irrigation. These two methods produce somewhat different reference ET values (ETr > ETo), but these differences are compensated by a different set of crop coefficients (Kc) specified for each method.

Figure 7 shows daily crop ET values for a clipped alfalfa (multiple cuttings) reference crop in Prosser, WA (Yakima River basin) using daily climate data from the WSU AgWeatherNet. The CropSyst Kct evolves more slowly to reach an upper value, while the ASCE Kc predicts faster initial development. In addition to early season discrepancies, Alfalfa ET is notably different when alfalfa harvest events (clipping) are considered. Overall, CropSyst ET is slightly lower than the ASCE values for both low- and high- frequency irrigation for alfalfa. The differences can be seen across crop types. Table 1 shows yearly and ten-year average ET calculated using the ASCE methodology and CropSyst simulations. Grain corn ET estimated by ASCE is low compared to CropSyst, with the bulk of the difference based on lower ET early in the season when soil water evaporation can be an important component depending on irrigation frequency and irrigation method. CropSyst ET using drip irrigation, where soil water evaporation is only a minor fraction of ET, is close to grain corn ET estimated by ASCE.

Scaling CropSyst point ET estimates to the watershed scale while retaining predictive power for future operational scenarios requires extensive calibration and field data. Coupling the model with the METRIC remote sensing methodology will greatly reduce the uncertainty associated with this process. METRIC calculates instantaneous ET through a series of computations to estimate net surface radiation, soil heat flux, and sensible heat flux to the air. An advantage of METRIC is that calibration is done internally using reference ET values rather than evaporative fractions. Also, the crop coefficient curves, crop development stage, and the crop type need not be known as the images reflect these parameters. Along with ET estimates, these parameters will be used to verify the CropSyst model prediction.

Although METRIC is compatible with any satellite having thermal sensors, Landsat data is commonly used due to the high resolution of short wave and thermal bands which facilitates detailed ET information from agricultural fields. The drawbacks of using Landsat images are the 16 day revisit time and the difficulty in processing images during cloudy days. The lack of daily images requires interpolation of ET using a gridded reference ET data for the days in between the revisit period. Uncertainties exist in selection of dry and wet conditions in the image for calibration thereby in the estimation of individual fluxes of the energy balance. However, as ET is calculated as residual of energy balance, a less biased estimate of ET is generated. Currently, METRIC is being used in Idaho to monitor water rights, quantify net ground water pumping and to estimate recharge from surface irrigated lands (Allen et al. 2005) and has been successfully defended in court proceedings.

Coupling the CropSyst and METRIC models will enable accurate predictions of changes in irrigation practices and crop rotation and allow development of more robust parameters in CropSyst. This is imperative for projecting the future effects of climate variation since the METRIC methodology cannot be used to evaluate future scenarios.

Table 1. Ten-year seasonal ET (mm) of grain corn, alfalfa, and apple at Prosser, WA as estimated by the revised Washington Irrigation Guideline methodology (ASCE) and CropSyst simulations (HF = high-frequency irrigation; LF = low-frequency irrigation; D = drip irrigation; U = unclipped; C = clipped).

Grain Corn				Alfalfa					Apples			
ASCE	CropSyst			ASCE	CropSyst				ASCE	CropSyst		
	HF	LF	D		U-HF	U-LF	C-HF	C-LF		HF	LF	D
575	741	587	549	941	1141	1102	853	766	897	846	741	606
526	711	589	530	862	1013	971	820	746	819	897	747	622
531	716	586	538	894	1168	1142	941	832	862	898	751	621
552	805	680	618	922	1119	1041	875	802	880	987	759	651
623	823	676	624	1008	1265	1198	977	779	969	1019	837	698
570	791	638	599	915	1124	1080	902	764	896	969	797	670
531	752	619	561	854	1068	1044	851	767	832	904	738	630
519	719	601	548	842	1042	999	842	758	813	914	697	615
525	699	571	525	838	1082	1053	878	776	813	890	688	600
507	747	604	552	858	1022	972	821	759	823	923	760	634
Average												
546	750	615	564	893	1104	1060	876	775	860	925	752	635

3. Integrating groundwater and surface water accounting in the CRB

In the *2006 Water Supply and Demand Forecast*, WSU simulated surface water supply and out-of-stream demands with an integrated computer model that simulated the relationships between water supply, climate, hydrology, irrigation water demand, crop productivity, economics, municipal water demand and water management over three geographic tiers. The integrated model included curtailment rules based on water rights that were interruptible to adopted instream flows, and basins where surface rights were routinely regulated (e.g. Yakima Basin 1905 proratables). However, the integrated model did not include groundwater/surface water interactions and presumed groundwater was not limiting when hydrating water rights.

Groundwater is limiting in many areas of the state and that limitation has impacts on:

- Individual farmer crop choices (e.g. orchard/grape versus row crop)
- Economics (e.g. employment and tax contributions in areas where long term intensive water use may not be sustainable).
- Surface water supplies – both for instream and out-of-stream uses (as they are re-routed and hence diminished to hydrate declining groundwater).
- Public water supplies (where clean groundwater is more advantageous and economic than treating surface water).

Numerous areas of declining groundwater are known or suspected and in some cases have been / are being studied by Ecology, USGS, local water purveyors, and others, including:

- The Odessa Subarea, where OCR is making active investments in developing groundwater source substitution using Columbia River supplies.
- The 2011 USGS *Columbia Plateau Groundwater Availability Study*[1], which looked at declining groundwater areas throughout Eastern Washington.
- The Horse Heaven Hills area in Klickitat and Benton Counties, where OCR is studying the potential for either source replacement of existing agricultural supplies with Columbia River supply and/or aquifer storage and recovery.
- The West Plains area in Spokane County, which has documented groundwater declines and is the subject of a groundwater study by Spokane County.
- The Moxee Black Rock area, which is covered under the Integrated USGS Groundwater Study in the greater Yakima Basin.
- Saddle Mountain Basalt aquifers in West Richland, which are the subject of ongoing monitoring by the City of West Richland as a requirement of a new water right the City obtained in 2010.
- Aquifers in the City of White Salmon, which are the subject of a pilot ASR project.
- Lincoln County where OCR is funding a study to evaluate passive rehydration of streams, lakes, and aquifers from the Columbia River.
- Walla Walla alluvial and basalt aquifers where Ecology is funding water banking efforts, passive hydration of the alluvial aquifer to restore instream flows, and aquifer storage and recovery of basalt aquifers to support municipal supplies.

WSU will perform the following to begin integrating groundwater availability into the model forecast:

1. Using Ecology databases and water availability focus sheets, USGS and other scientific literature review, we will compile existing information on declining groundwater into a GIS framework, including available groundwater data sets,

[1] http://www.ecy.wa.gov/programs/wr/cwp/USGS_Study.html

documenting study / modeling efforts (who, when, type, level of effort, limitations), etc.

2. For each area where groundwater availability is likely to be limiting in the future, we will perform a gap analysis on the current state of existing knowledge and recommendations for future work (including budgetary cost estimates). This could include recommendations on expanded well water level monitoring, development of new models or updating of existing models, and exploratory drilling / pump testing to characterize uncertain structural features (such as that funded by OCR for the Horse Heaven Hills in 2014).
3. For each area where groundwater availability is likely to be limiting in the future, we will identify likely water rights at risk of curtailment. This task will include delineation of water rights at risk, sorting them by priority, overlaying potential curtailment rules based on models of sustainable yield if available , ranking of rights in risk categories (e.g. low, medium, high), and identifying the economic impact associated with the no action alternative (e.g. farms fallowed or converted to dryland, houses relocated, senior water rights reallocated to "higher" uses).
4. Based on Ecology input, select geographic areas of groundwater declines will be identified for integration into the forecast model. Actual integration may be done by developing localized curtailment rules based on likely future priority enforcement or developing (linkage between an existing groundwater model and the surficial forecast model.
5. Based on existing and future conjunctive use solutions to declining groundwater bodies through ASR, passive rehydration, source substitution or other projects, we will forecast potential impacts to surface sources.

Beginning to integrate groundwater availability and effect on surface water supply into the model will better predict future water demand and the reliability of existing water rights. Beyond improving the accuracy of future water needs, this integration will give Ecology tools to engage on key policy issues, such as:

- Where are the most at risk areas of groundwater declines based on existing water rights that use them?
    - Are permit exempt wells continuing to be developed in these bodies and as the most junior priority water rights are these domestic supplies at risk of curtailment?
    - Are high value crops at risk of loss and what impact does that have on the local economy?
    - What public water systems are at risk and what is their level of engagement on aquifer reliability?
    - What senior water rights exist that are likely to call for curtailment or be part of a water bank supply solution?
    - What demand-side solutions (e.g. conservation, xeriscaping, closures to new exempt wells) and what supply-side solutions (e.g. ASR, source substitution, public water system service) exist in each area?

    - Where should OCR and Ecology prioritize investments in water supply development?
- What is the current state of the science now and what is needed to fully understand the scope of the problem?
    - What staff and capital expenditures are committed now to study and solve these problems?
    - How much is needed in the future?
    - What are the likely sources of funds to head off economic impacts?
    - When are those funds needed?
    - How does that level of investment compare to allowing market forces to dictate outcomes (e.g. the do-nothing alternative)?

4. Water banking options for Washington State and Department of Ecology

Although the trust water program was authorized in 1991, water banks have only significantly expanded in the last 10 years in response to Ecology actions to close basins (e.g. Upper Kittitas), as instream flows have been adopted (e.g. Dungeness, Wenatchee), in response to local collaboration to solve water supply problems (e.g. Walla Walla), and through new legislative focuses (e.g. Office of Columbia River (OCR), Cabin Owners). While Ecology has a statutory role in setting up water banks, day-to-day administration of the banks range from full Ecology involvement (e.g. Cabin Owners in Yakima Basin) to 3rd party administration (e.g. Washington Water Trust in the Dungeness).

Because of staff limitations, future water bank success is likely dependent on the ability of Ecology to step back from day-to-day administration and focus on setting up bank architecture, negotiation of sound trust water agreements that set the framework for bank operations, and establishing criteria for bank administration. This void will be replaced by other entities that can reliably fill this function in a way that meets the public trust standard. These could include non-profit NGO's such as Washington Water Trust or Trout Unlimited, local government such as counties or conservancy boards, or a certification program for private companies or individuals.

We will provide a summary of existing Washington State banks, how they were created, and how they are operated. For each bank, we will quantify the Ecology "footprint" to determine the investment in creation and administration the State has made, along with a 20-year forecasted State expenditure moving forward. We will also characterize each bank's success, including decisions issued, water banked, water transacted, cost of water, and other factors. Building on and updating work done by West Water Research in 2004, we will contrast Washington State structures with a survey of water banking nationally, including a survey of economic literature on water market and water bank designs. One goal of this study is to forecast Ecology resources required to meet current banking needs, and future resources needed to maintain and expand them. Other goals of this characterization are to identify how bank design and operation affects success in water transactions and how to reduce transaction barriers and costs (statutory, fiscal, educational) to improve operation, and to examine the potential for improving and expanding the portfolio of water contract options.

We will also coordinate with Ecology to determine where new banks are needed, and provide recommendations on structure and operations. For example, Ecology has developed water availability focus sheets that document where water shortages exist in the State. These areas have the initial impetus for water bank creation in order to avoid adverse economic impacts associated with lack of preparation in the face of potential water closures. We will identify where a more "regional" approach (e.g. multi-basin per OCR, or county-led or WRIA-led focus) or a site specific approach (e.g. Black Rock area of Moxee Basin) to water banking is likely to be more successful.

With the results of this task, Ecology will be able to:

1. Document the hidden cost of water banking on existing staff and the opportunity cost it represents in terms of other Ecology work.
2. Forecast future Ecology resource impacts just to keep existing banks operating.
3. Identify permit processing times for each bank, and whether those times are bank-structure-limited, water-supply-limited, Ecology-staff-limited, or limited due to other factors.
4. Contrast public vs. private banking models and how existing banks are working (e.g. permits issued, water made available, at what price).
5. Identify and prioritize opportunities for future bank creation, the resource gaps needed to establish banks (e.g. who will operate, what supplies exist to seed banks), and the likely future Ecology economic impact associated with banking expansion.
6. Using a survey of existing banks both locally and nationally, identify opportunities to expand banking as a tool while limiting or recovering Ecology staff impact, and preserving the integrity of water right permitting through clearly defined business rules administered by 3rd parties.

5. Evaluating How the Cost of Water is Influencing Ecology's Backlog

When Ecology's and its predecessor agencies mission was to authorize water rights to support development of the west, water was essentially free. Application costs were low (e.g. $2), and staff to evaluate the 4-part test to issue a water right was completely subsidized by the State. While statutory processing fees are similarly low today (e.g. generally $50 for most application), reimbursement costs for water supply development and priority processing administrative costs are approaching the "true market cost" of water. As a result, in the past 10 years where the administrative and transactional fees have approached true market cost, more applicants have declined water when made available and declined processing when opportunities arise. This negative response to Ecology's efforts to apply true market costs are adversely affecting the agency's ability to reduce it's backlog of water rights in the face of Legislative pressure to meet annual permit processing targets.

The 2016 Water Supply and Demand Forecast should begin to take into account the true cost of processing and developing water supplies as it forecasts future water demand for Washington State, particularly given 2010 legislative amendments authorizing OCR to recover the cost of developing water supplies. General observation of the relationship between water demand and pricing suggests that future demand when applying market based pricing may be considerably less than previously estimated based on the long standing practice of subsidizing the administrative and transactional cost of water. Previous forecasts in 2006 and 2011 have presumed that when water is made available to applicants, they would accept processing of their application and implement their project. Actual behavior by applicants tells a different story. WSU will evaluate Ecology case studies to assess the effect of water pricing on demand, and its associated impact on Ecology backlog. The following case studies will be examined, including elements such as water price, administrative processing cost, geography, purpose of use, age of applications, and other factors:

- Lake Roosevelt Incremental Releases Project[2]: Ecology's Office of Columbia River (OCR) developed 25,000 acre-feet of new supply for municipal, domestic, and industrial uses (e.g. M&I purposes). Applicants would be processed by OCR staff for the statutory filing fee, which for most applicants had been paid decades ago at a cost of $2 or $10 per application. Applicants were limited to specific M&I purposes and to water users generally within one mile of the Columbia River above Bonneville Dam. Applicants were required to enter into OCR water service contracts to reimburse OCR for Bureau of Reclamation operation and maintenance costs at a rate of approximately $35 / acre-foot / year plus inflationary adjustments.

  When applicants were offered to be processed, OCR found that approximately one-half of applicants declined. We will compile the results of this effort, survey declining parties on their decision, and contrast the cost of water for this case study against other similar instances of water pricing affecting applicant processing.

- Sullivan Lake Water Supply Project[3]: Like the Lake Roosevelt Project, OCR developed approximately 9,400 acre-feet for new applicants in six counties in NE Washington. One-half of this supply (4,700 acre-feet) is available only for municipal, domestic, and industrial uses, and another 4,700 acre-feet for other purposes including irrigation. While processing is again "free" by OCR staff, applicants are required to enter into a 25 year water service contract repaying OCR's water supply development costs at $60 / acre-foot / year, after which payments will cease.

  OCR's offering of this supply to applicants has similarly resulted in some processing declines. This case study offers an opportunity to contrast with the Lake Roosevelt Project, because different purposes of use (and therefore returns on investment) are eligible, the geography is different (NE Washington only), and pricing is different (25 year term instead of perpetual Reclamation repayment).

- Wenatchee Basin Coordinated Cost-Reimbursement Program[4]: Chelan County, OCR, and Ecology Water Resources are teaming to process all pending applications in the

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[2] http://www.ecy.wa.gov/programs/wr/cwp/cr_lkroos-permit.html
[3] http://www.ecy.wa.gov/programs/wr/cwp/sullivan-permit.html
[4] http://www.ecy.wa.gov/programs/wr/cwp/wccr.html

Wenatchee Basin. Applicants would either receive firm water rights if they qualify under the 4 cfs reserve set forth in WAC 173-545, the instream flow rule Ecology adopted in 2006, or an interruptible water right. No water service contract is required for the use of the water, but processing of the applicants themselves are subject to fees under RCW 90.03.265. Depending on the complexity of the application (e.g. surface vs. groundwater source, purpose, type of project), application processing is on the order of $5,000 to $15,000 per application.

When 110 applicants were contacted, only 51 applicants (less than 50 percent) were willing to participate in the program (e.g. pay for water). Again, this case study offers a different geographic area, a different fee structure (upfront payment instead of term as in the Lake Roosevelt and Sullivan Lake Projects), a broader suite of purpose of use, opportunities for both firm and interruptible water which affect the end value of water received by applicants. A survey of declining parties may reveal greater insight into motivation for declines (was it too expensive, was their project not ready, do they think they'll get water for free someday, etc.).

- Cabin Owner Mitigation Program[5]: Following a Yakima County Superior Court decision to regulate junior surface water users (mostly cabins on Forest Service land) during 2001 and 2005 drought years, Ecology developed a mitigation program using 60 acre-feet of senior water rights they retired into the trust water program. Unlike the case studies above, nearly 100 percent of those offered this water accept it and demand continues to outpace supply. Processing costs under cost-reimbursement are on the order of $1,500, and cost-recovery for the initial acquisition of senior water rights are on the order of $3,500 / consumptive acre-foot of water.

  This case study offers a much higher participation rate (i.e. expressed demand), which provides a good contrast with case studies with lower demand. The real threat of curtailment likely influences the participation rate, although other factors may also be useful to understand, such as the demographics of this group compared to the general applicant pool, the cost for water and structure of the repayment terms, and other factors.

- Yakima Sub-Basin Mitigation Program: Ecology is currently running a program to contact applicants in Yakima subbasins where water availability is known to be of concern. Applicants are given the opportunity to mitigate for their application, place their application on-hold while they pursue applications, process their application without mitigation (likely a denial), assign their application to another party, or withdraw their application (cancel their project). Mitigation costs are likely on the order of $1,000 to $3,000 per consumptive acre-foot for processing, and applicants would bear the additional cost of finding and permitting their mitigation, as opposed to the State-run mitigation models described above. Data from 4 subbasins are now available to contrast with the State-run models.

[5] http://www.ecy.wa.gov/programs/wr/cro/sb6861.html

We will survey responders to better understand their motivations. Does a State-administered or individual-led mitigation program create better processing results? How does the cost of water affect processing? How does the potential for the Yakima Integrated Plan and its water supply development affect users choosing to place their application "on-hold"? At what point are "old" applications more likely to be untenable and be cancelled by applicants or their successors? How long will Ecology allow applicants to serially reject offered mitigation or fail to self-mitigate for their projects?

By evaluating recent case studies, WSU can better forecast "real" water demand that Ecology and OCR should be targeting. If charging for water and recovering the cost for water supply development is the new norm, then the existing backlog is not a good indicator of future demand. Market forces for water are highly influenced by geography, by Ecology water availability decisions (e.g. Kittitas rule-making, cabin-owner curtailments), and by the structure of water pricing (up-front larger payments as in Wenatchee coordinated cost-reimbursement versus "forever" term costs as in Lake Roosevelt contracts). OCR's statutory goal is to process new out-of-stream uses while also improving instream flows. Understanding your customers is key to defining cost recovery and processing programs that attract customers rather than turn them away. We will provide recommendations on how to design future cost-recovery programs to best meet applicant needs.

6. Research Relating to the Yakima River Basin Integrated Plan

We will perform service and research on two different fronts relating to the Yakima Basin Integrated Plan (YBIP).

1. **Review of Benefit-Cost Analyses for YBIP Projects costing over $100 Million.** As legislatively mandated in 2013 Legislative bill 5367-S2.SL (section 10), the State of Washington Water Research Center (SWWRC) will perform and/or coordinate reviews of benefit-cost analyses of YBIP projects with a cost greater than $100 million. There are two such projects for which reviews will need to be provided in this funding cycle: the Keechelus to Kachess Conveyance, and the Kachess Drought Relief Pumping Plant. The SWWRC will enlist a group of four specialists in the fields of engineering, hydrology, biology, and economics or other appropriate fields to perform the reviews as necessary.
2. **Long run water needs and the value of relaxing water constraints: climate and long run agricultural response under the YBIP.** The existing YBIP economic analyses and infrastructure design plans are based on a goal of assuring against curtailment of proratable water rights below 70% of full entitlements, and provide estimates of the extent to which the YBIP projects provide that assurance, and account for climate and the potential for climate change in very limited ways. A legislatively mandated study underway by the SWWRC can address these questions in only very

limited ways due to funding and time limitations, as legislatively mandated. We propose here to examine long-run outcomes much more rigorously, by incorporating more sophisticated and complete climate change scenarios, and address an important limitation of the agricultural response analysis that will be performed for the ongoing YBIP economic analysis. An important limitation of the analysis of the YBIP study being reviewed as part of the legislative request is the decision to keep important farm level adaptation decisions fixed including crop mix, irrigation technology, and crop yields. As part of the next forecast we propose to extend the YBIP analysis to incorporate the effect of these "long-run responses". The previous modeling of agriculture impacts used what economists would call a "short-run" model in that the only response to drought was fallowing of acres in the year as required to meet the water budget at the irrigation district level. If droughts increase in frequency and magnitude, as is expected under a changing climate, then a complete analysis would also consider that farmers will adjust their crop mix to put in more drought tolerant crops and invest in more efficient irrigation systems. Modeling tools being develop under the BioEarth project funded by USDA will be used to incorporate long-run responses to provide more precise and accurate estimates of the marginal value of reducing water constraints for irrigated agriculture in particular, which is the primary water user in the basin. We will utilize this more sophisticated agricultural response model by applying it to a more robust set of climate change scenarios than can be done under the existing (ongoing) YBIP study.