Consumptive Water Use and Groundwater Withdrawals in Irrigated Lands

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Problem.— In 1995 the USGS National Water Use Information Program (NWUIP) estimated that nearly half of freshwater withdrawals in the western US were consumptively used, primarily through evapotranspiration (ET) from irrigated areas. Few States monitor groundwater withdrawals for irrigation so the withdrawals have generally been only roughly approximated. Because consumptive use is difficult to accurately and consistently estimate, it has not been reported by NWUIP since 1995. Recent advances in remote-sensing technology and energy-balance methods now allow more accurate and repeatable estimates of ET for irrigated lands, and the required remote-sensing imagery are available from 1979 to present for the entire continental US. We thus have an opportunity to develop historical geospatial datasets of estimated consumptive use for irrigated lands throughout the Nation, and to further estimate groundwater withdrawals for irrigation on a regional scale consistent with the principal aquifers of the US. Refinement of these methods will result in an operational system for updating nationwide estimates of water use for irrigation that would have wide application for basin-scale and regional water availability assessments, as well as for a National Water Census.

Objectives.—We propose to develop and refine remote-sensing based methods to consistently estimate consumptive use (ET) of irrigation water on both National and regional scales. On a National scale, our objective is to demonstrate the utility of these methods for improving the accuracy and consistency of estimates of consumptive use of irrigation water, and to allow for better understanding of geographic and temporal trends. On a regional scale, we will incorporate remotely-sensed ET estimates into water-budget models to derive improved estimates of groundwater withdrawals and consumptive use for different hydro-climatic regions in the US and for selected principal aquifer systems including the Columbia Plateau and High Plains.

Approach.—The National and regional scale methods will both build on recent efforts to estimate monthly, seasonal, and annual ET using energy balance methods with remotely sensed thermal imagery (MODIS and AVHRR) (Senay et al, 2007; Allen et al, 2007). These methods have been applied to hydrologic budget analyses in many areas of the world and are being used in ongoing assessments of groundwater availability in the Columbia Plateau (fig. 1) and High Plains aquifer systems as part of the USGS Groundwater Resources Program.

Remote Sensing Estimates of ET

Evapotranspiration will be estimated using a combination of remote sensing datasets. A more-frequently sampled, coarse spatial scale dataset will be coupled with less-frequently sampled, fine spatial scale dataset to provide monthly estimates of ET at two spatial scales (1 km and ~100 m). Historical data from two sensors will be used: Advanced Very High Resolution Radiometer (AVHRR, 1980 – 2000) and Moderate Resolution Imaging Spectroradiometer (MODIS, 2000 – present). ET estimates will be made at five year increments from 1990 through 2005, with the option of including 1980 and 1985 if the older AVHHR are of reasonable quality.

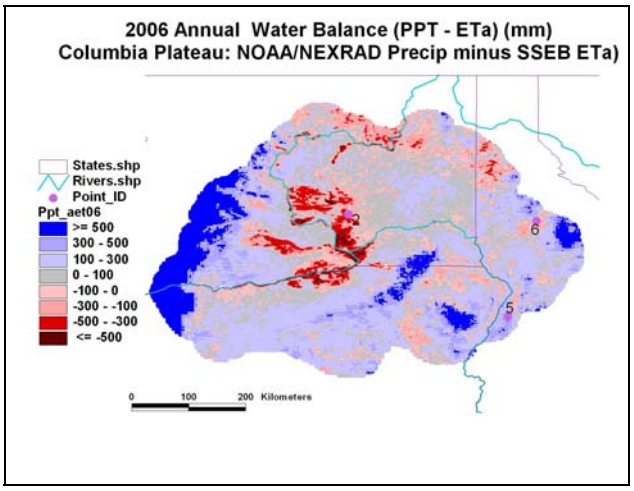

Figure 1. 2006 annual water balance (PPT-ET) for the Columbia Plateau, Washington. ET was estimated from SSEB model. Red areas are heavily irrigated, blue areas have substantial recharge from direct precipitation.

The Simplified Surface Energy Balance (SSEB) method (Senay et al, 2007) uses historical thermal AVHRR and MODIS data in combination with reference ET calculated from the Global Data Assimilation System (GDAS) climate parameters from NOAA (Senay et al, 2008) to produce high-precision estimates of actual ET. This method accurately represents landscape features approximately one kilometer in size using images collected daily. This method is being used successfully in the ongoing USGS Groundwater Availability Studies for the Columbia Plateau and the High Plains Regional Aquifer System. The monthly and seasonal ET maps, developed from the summation of 8-day ET images generated from the daily thermal images, show the spatial distribution of ET, with high ET values associated with forest cover, irrigation, and wetland environments, and extremely low ET values associated with semiarid grasslands. Model-derived ET estimates resolved 92% of the spatial variability in "reported/estimated" irrigation application in 13 Yakima irrigation basins (fig. 2). Because MODIS thermal data are only available since 2000, AVHRR datasets have been evaluated and are being used to produce monthly ET maps for the study area since the 1980s.

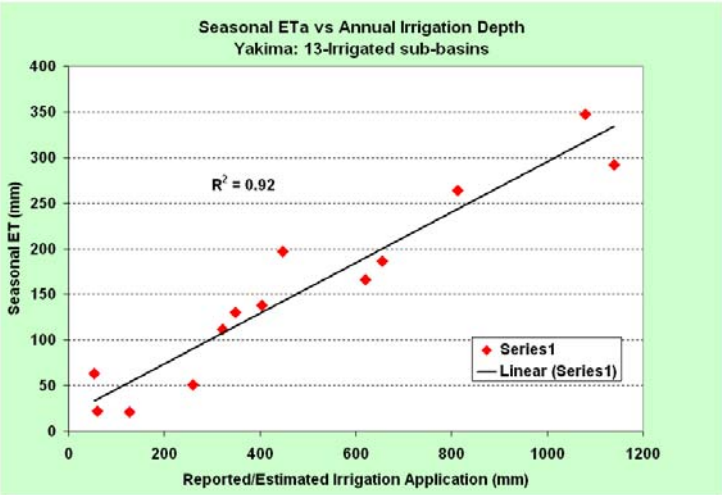

Figure 2. SSEB model estimated seasonal ET and reported irrigation application for 13 irrigated subbasins of the Yakima River Basin.

Consumptive Use on a National Scale

For this proposed investigation, we will improve the existing SSEB method by replacing GDAS climate data sets that have a spatial resolution of 100-km with the North-American Land Surface Assimilation Systems (NLDAS) climate data sets that have a spatial resolution of 12.8-km. The SSEB method will be used to estimate monthly and annual consumptive use for irrigation (ET) on a 1-km scale by hydro-climate zones across the US, and the ET data will be compiled and reported by principal aquifer and county every five years for the period 1990-2005 (with 1980 and 1985 optional) to correspond with the NWUIP 5-year compilations.

Selected consumptive use estimates made using the SSEB approach will be compared to measured freshwater irrigation withdrawals from the NWIUP for areas where such measurements are made, and to estimated consumptive use reported in pre-1995 NWIUP reports from counties or regions where ET from irrigation is the predominant consumptive use. These comparisons will allow us to evaluate the suitability of the method as an operational system for producing national consumptive use datasets. Substantial differences identified by this comparison will be explored using ancillary data such as the USGS National Land Use Trend analyses dataset.

Consumptive Use and Groundwater Withdrawals on a Regional Scale

In support of regional-scale water availability studies, an existing method that uses remotely-sensed ET estimates combined with a water balance model to estimate irrigation demand, consumptive use, and groundwater withdrawals will be refined. The benefits of downscaling the current 1-km resolution ET by incorporating 100-m resolution LANDSAT data into the method, and new methods to differentiate irrigation use by source (groundwater versus surface water) will be explored. A method to more accurately determine the fraction of estimated ET supplied by precipitation will be developed. And the various ET and groundwater withdrawal estimates will be compared to independent estimates or measurements of irrigation withdrawals and applications.

We are currently using ET estimated from the SSEB method as input to a distributed SOil WATer balance model (SOWAT) to estimate monthly irrigation water demand and groundwater flux (recharge and discharge) within the 160,000 km^2 Columbia Plateau regional aquifer system for the period 1989-2007. The SOWAT model computes soil water deficit or surplus using current month precipitation from PRISM (Parameter-elevation Regressions on Independent Slopes Model), ET from SSEB, and the previous month's soil moisture storage. In addition to ET and precipitation, data requirements include simplified land cover type, available soil water capacity from the STATSGO (State Soil Geographic) database, direct runoff fraction, minimum soil moisture for irrigated land, and irrigation efficiency. The spatial resolution of SOWAT is currently at the 1-km resolution of the MODIS/AVHRR imagery used to estimate ET.

We will refine the SOWAT water-balance model by incorporating 100-m resolution LANDSAT data to downscale the current 1-km resolution ET, monthly irrigation demand, and groundwater flux estimates. For selected highly heterogeneous watersheds and smaller wetlands in the Yakima Basin of the Columbia Plateau, the 1-km ET AVHRR products will be disaggregated (i.e., downscaled) using the high-spatial resolution Landsat Thermal datasets to

provide ET estimates at the 100-m resolution. Since the temporal frequency of Landsat data is low (every 16 days) compared to the daily coverage of AVHRR and MODIS, a relationship will be established to inherit the fine spatial-scale features from Landsat and fine temporal-scale from AVHRR to take advantage of the spatial and temporal resolutions from the different sensors. This approach will allow measurement of ET flux dynamics beginning in the 1980s on a monthly time scale at a 100-m resolution, although we propose to apply this approach for just a few years in order to validate the method and to determine if this finer-scaled approach is a justifiable improvement over the 1-km scale estimates for regional water balance studies.

The SSEB method currently utilizes supplied irrigation data from the well-monitored Yakima River Basin to validate the SSEB ET method, so the downscaling algorithm will be applied to these locations as part of the quality assurance and control. As an additional check on the reliability of the historical ET estimates, the SSEB results will be compared/calibrated to ET estimates from selected periods made using the approach by METRIC, a well established full-surface energy balance model by Allen and others (2007) that has been successfully applied to estimate crop water uses in different parts of the US.

Methods to partition total irrigation demand into groundwater and surface water components using readily available geospatial data will be explored. One method will use the National Hydrologic Dataset (NHD) coverage which has very detailed canal/drain networks for most areas of interest in the Columbia Plateau. We will evaluate using buffers around features to identify surface-water irrigated lands, as well as more sophisticated approaches like using 10-m digital elevation models to delineate “drainages” for canal systems with ARChydro tools.

Methods will be developed to determine the fractions of ET supplied by precipitation and by irrigation using a parallel water-balance model(s) that does not rely on the SSEB output. Possible models include the operational water balance model “VegET” that is run daily for the US. We will apply this approach to multiple hydro-climatic regions for just a few years to validate the method and determine regional differences in the precipitation contribution to ET.

Finally, the nationwide ET estimates will be used to explore the development of generalized relations between ET, groundwater withdrawals, and consumptive use for future applications. In non-irrigated areas the use of ET estimates and water balance models for computing groundwater flux (recharge or discharge) will be evaluated. Direct ET of shallow groundwater can be a significant flux and remote sensing may provide valuable information on location and rate of discharge over time.

Timeline and Products.—

The project would require three years to complete at an expense of $292,000. FY2010 work will focus on the extensive processing of the remote imagery data; FY2011 work will focus on the National scale comparison and regional scale water balance models; and FY2012 work will focus on product development. The following reports are planned:

1. USGS Fact Sheet comparing SSEB modeled ET and county-based NWUIP consumptive data sets (Third quarter FY2011)

2. USGS Scientific Investigations Map showing trends in consumptive water-use in the US, 1990-2005 including spatially explicit actual ET maps at 1 km resolution from 1990 through 2005 at five year intervals (First quarter FY2012)
3. USGS SIR describing the regional-scale methods and regional water-balance components for selected aquifers/basins (Note: Water-balance components for the Columbia Plateau and High Plains aquifer systems at a minimum will be incorporated directly into products planned for the on-going GW availability studies). (Fourth quarter FY2012)
4. USGS SIR/Journal article (or possibly an abstract depending on results) describing evaluation of high resolution 100 m vs 1 km ET products for use in water balance studies (Fourth quarter FY2012)

Budget.—

Budget Category	**FY2010**	**FY2011**	**FY2012**
PSC Services	$3,000	$5,000	$20,000
Labor and Leave	$56,000	$54,400	$38,500
Indirect Costs	$40,000	$39,900	$35,200
Total	$99,000	$99,300	$93,700

Personnel.—

Position	**FY2010 hours**	**FY2011 hours**	**FY2012 hours**
Dinicola (WAWSC)	160	180	160
Kenny (KSWSC)	80	90	40
Maupin (IDWSC)	80	90	40
Morgan (ORWSC)	160	180	160
Senay (EROS)	400	240	120

Rick Dinicola (WAWSC)--Project coordinator; refinement of the water balance model
Gabriel Senay (EROS)—SSEB and remote-sensing
Dave Morgan (ORWSC)--Water-balance models for the principal aquifers
Molly Maupin (IDWSC), Joan Kenny (KSWSC)--Comparison of estimated ET to NWIUP datasets

Literature Cited.--

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