Estimating Groundwater Withdrawals and Consumptive Use for Principal Aquifers

By R.T. Hanson, Wolfgang Schmid[1], and Gabriel Senay[2]

PROBLEM -- The USGS works in cooperation with local, State, and Federal agencies to compile and disseminate data on the Nation's water use. The annual water-use estimates are reported at the county, State, and national levels and provide fundamental input to regional hydrologic models. These estimates commonly represent the largest stresses in most aquifers and are needed by local managers to steward the resources and to support regional simulation of the resources to quantify the effects of this water use. For example, in the Principal Aquifers of the Central Valley (Faunt et al., 2009d) and the High Plains, groundwater pumpage for agriculture represents about 20 and 30 percent, respectively, of all groundwater used in the United States. Estimated groundwater withdrawals and consumptive use are commonly indirectly based on power records, land use, and census data. These methods have particular difficulties and often yield poor resolution spatial distributions of groundwater withdrawals or consumptive use that cannot be readily distributed for regional simulation with a hydrologic model. In addition, there is a need for monthly estimates of water use in many areas to help water managers have an accurate estimate of the supply and demand components of the hydrologic budget. Because different hydrologic settings of the different principal aquifers result in different combinations of consumptive use, a physically based approach used in combination with remote sensing to estimating water use may be required to support the ongoing application of hydrologic models to the principal aquifers. The proposed analysis could be performed at several different scales and would allow us to compare the distinctions required against other forms of estimation. The overall need is to integrate remotely sensed data into high resolution spatial and temporal estimates of land-use, distributions of natural vegetation and crop types, fractions of land available for transpiration and for evaporation, reference and actual evapotranspiration (ET_o, ET_{act}), and inefficient losses such as runoff that can be used as input or calibration data for a physically based hydrologic model that estimates consumptive use and groundwater withdrawals. MODFLOW with the Farm Process (MF-FMP) (Schmid and Hanson, 2009) is already being widely used at a variety of scales throughout the United States (fig. 1) and provides a physically based model that can provide the estimates of consumptive use and groundwater withdrawals.

OBJECTIVE -- The objectives of this study would be to develop tools and assess the utility of incorporating remotely-sensed information such as land use and actual ET data (ET_{act}) to support the application of hydrologic models of regional aquifer systems where agricultural water use is significant. These tools will become essential elements of broader Decision Support System (DSS) that incorporate the remotely sensed data, physically based hydrologic model, and related analysis into an integrated platform of water-use analysis and monitoring.

APPROACH -- For agricultural water use, a Simplified Surface Energy Balance (SSEB) model has been used to monitor and assess the performance of irrigated agriculture using a combination of 1-km thermal data and 250-m Normalized Difference Vegetation Index (NDVI) data, both from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor in combination with model-assimilated weather fields (high resolution (12.8 km) NLDAS (North-American Land Data Assimilation System for weather fields in place of the GDAS (100-km) data sets) (Senay et al., 2007). A major advantage of the energy-balance approach is that it can be used to quantify spatial extent of irrigated fields and their water-use dynamics without reference to source of water as opposed to a water-balance model which requires knowledge of both the magnitude and temporal distribution of rainfall and irrigation applied to fields. The disadvantage of this approach is that there is no distinction between water evaporated and transpired from the different sources such as precipitation, uptake of shallow groundwater, irrigation from surface-water deliveries or groundwater pumpage, and from changes in soil moisture storage.

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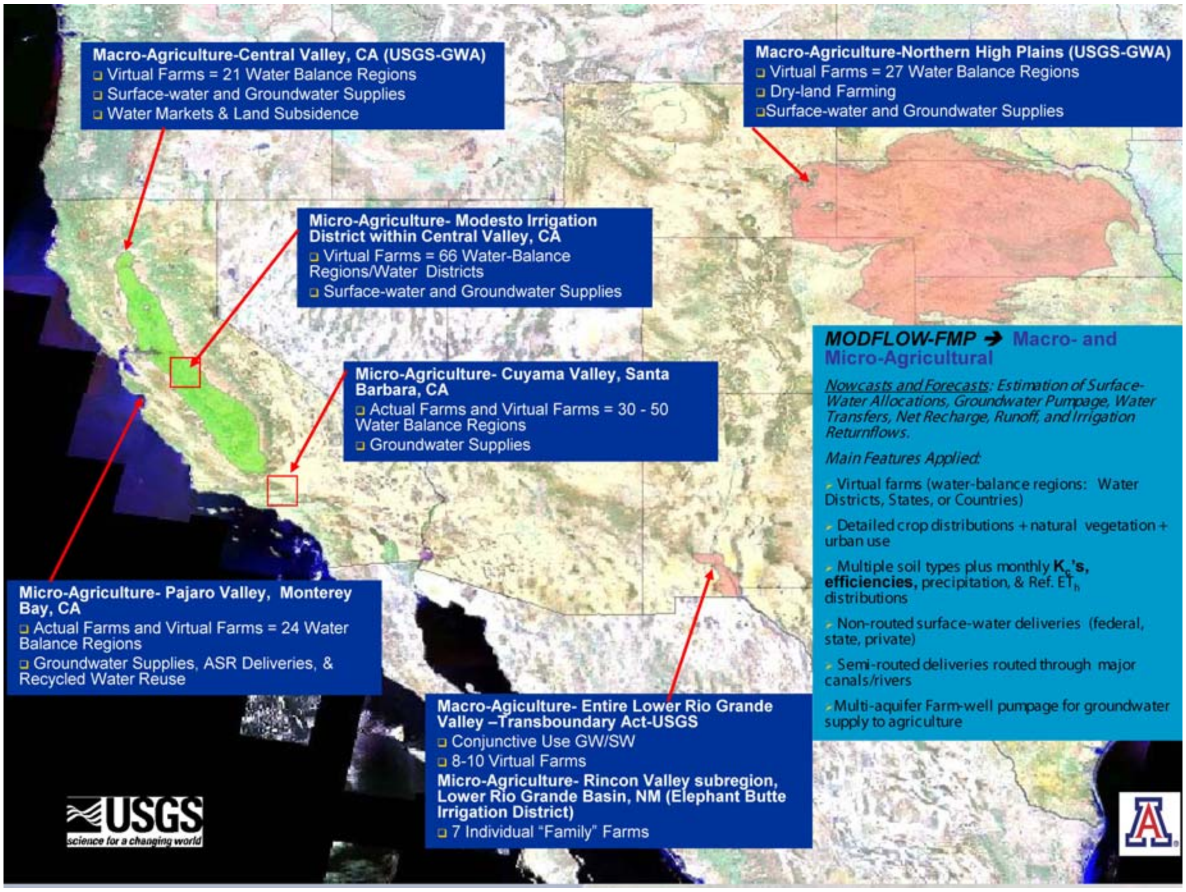
The proposed study would compare remotely sensed, land-use based, metered, and simulated estimates of pumpage. This approach would help delineate how modeling and remote-sensing techniques can augment, supplement, or be used in place of metered pumpage, which is still lacking in most regions.

Figure 1. -- Selected locations where hydrologic models using MODFLOW with the Farm Process are available for consumptive-use and groundwater withdrawal comparisons.



The analysis can be performed at different scales to see how accounting at these scales affects the accuracy and uncertainty of water use. Estimations of land use and local climate over selected periods will be used to further refine the water-use estimation techniques and assess the combined effects of uncertainty in climatic and land-use components of water use. The uncertainty of these estimates could be analyzed with respect to several areas where recent hydrologic models have been completed with MF-FMP. The approach would be twofold:

1) An assessment of consumptive use would be performed for selected models where MF-FMP has been applied at different scales. This would include assessment of consumptive use at the micro-agricultural scale in the Rincon Valley, New Mexico and in the Pajaro Valley (Monterey Bay), California where some metered pumpage also exists to help corroborate and calibrate the estimates of consumptive use from model results. Initial comparisons with metered pumpage indicate that substantial improvement could be achieved with more frequent estimates of crop distributions (fig. 2). This assessment of consumptive use from remotely sensed data would also include analysis at the macro-agricultural scale for the Northern High Plains, Central Valley (Faunt et al., 2009c-d), Columbia River Basin, and Lower Rio Grande where some remote sensing estimates and hydrologic model estimates using MF-FMP (and other techniques) have already been made or will be complete by the end of FY2010. This will allow a spatial and temporal assessment of the discrepancies between remotely sensed and model-based estimates.

2) Tools will be developed to use the remotely sensed changes in land use, changes in crops, changes in fractions of land available for transpiration and evaporation as MF-FMP model input data. In addition to direct use of these estimates, the SSEB model can also provide ET_{act} or ET_o that can be used directly within regional hydrologic models. Estimates of ET_{act} can be used as observations for parameter estimation of agricultural parameters such as crop specific crop coefficients, stress response coefficients, root depths, coefficients to calculate growing-degree days, or farm specific irrigation efficiencies, and other parameters that are used by MF-FMP to simulate consumptive use and unmetered pumpage. The use of metered pumpage has already been successfully used as observations for the Rincon Valley model (Schmid, 2009) and for the Pajaro Valley (Hanson et al., 2008) model (fig 2).

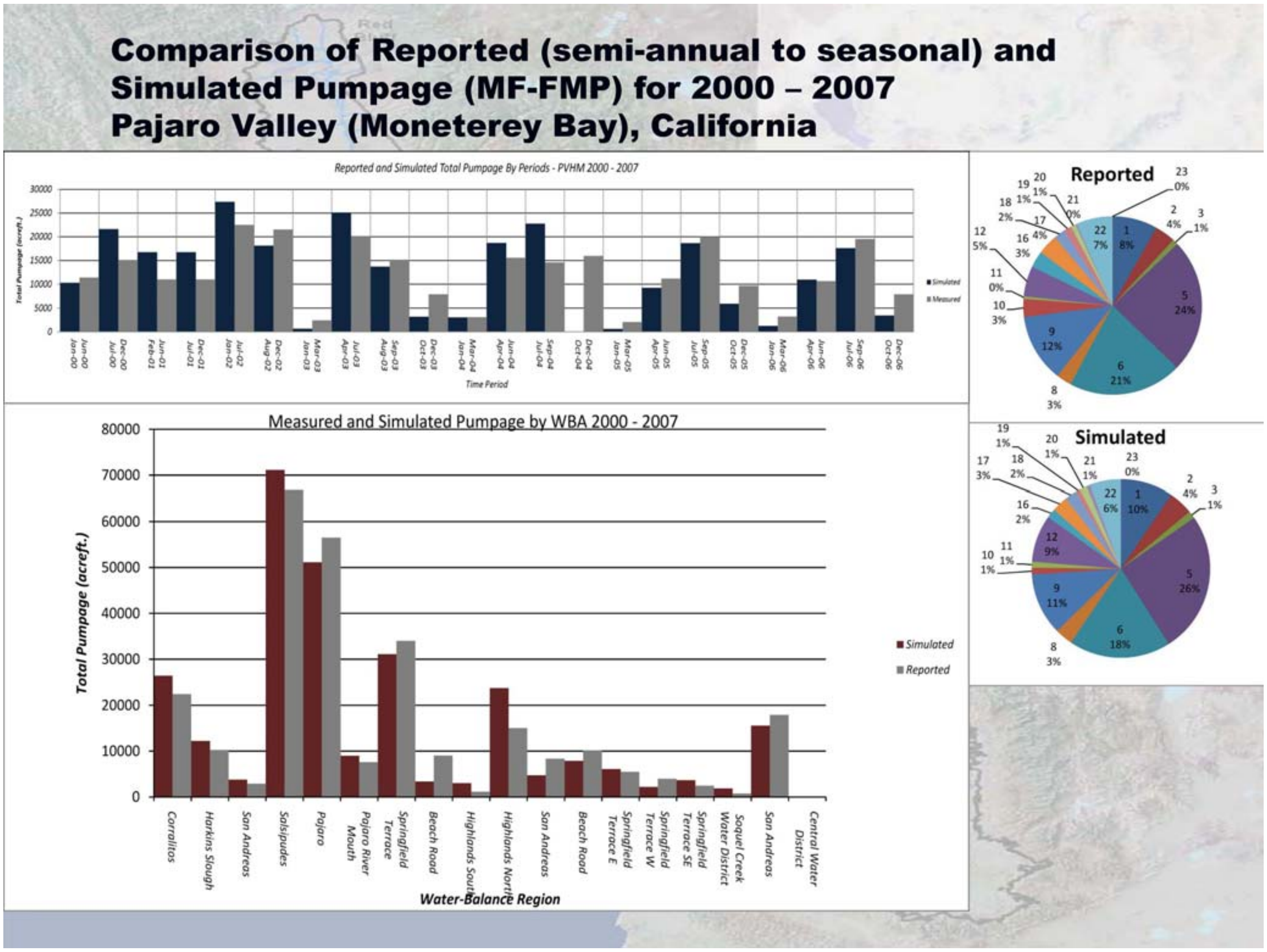


Figure 2. -- Comparison of groundwater pumpage (MF-FMP) for the Pajaro Valley, California.

PRODUCTS -- The products of this 3-year study will be a set of GIS tools and a USGS Techniques and Methods-series(TM) report. The GIS tools will be used to process recent, consecutive, or historical with existing remotely sensed data sets for:

(1) retrieve and process remotely sensed ET_{act}, crop, and land-use spatial data and prepare them for model input for use with the MF-FMP;

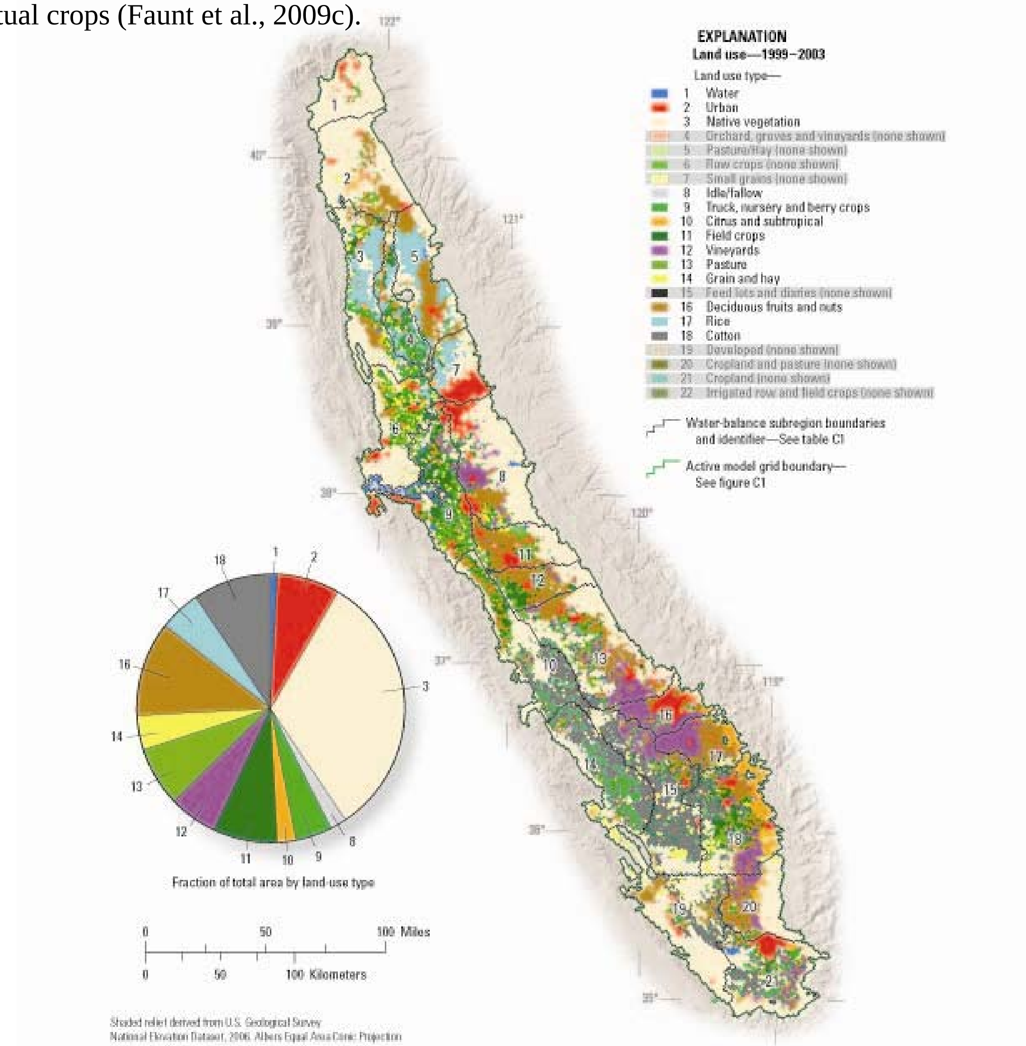
(2) analyze remotely sensed ET_{act}, crop, and land-use spatial data and prepare them for parameter estimation observation input data sets; and

(3) generate maps of crop types, land use, percentages of area subject to transpiration, percentages of model-cell area subject to evaporation, percentages or rates of surface-water versus groundwater deliveries (either as pie or bar charts per reference area), and other MF-FMP related attributes. Reference areas in these maps would relate to water accounting units used in the MF-FMP model, which can

represent spatial units delineated by natural features (subbasin, catchments, watersheds), water balance areas defined by common irrigation deliveries, or administratively defined areas (e.g., counties, states) as demonstrated for the Central Valley (Faunt et al., 2009a-d) (fig. 3).

(4) A TM-series report will document the use of remotely sensed data and modeling tools to estimate and calibrate consumptive use and unmetered pumpage for agricultural and urban settings.

Figure 3. -- Central Valley virtual crops for 2000, including a pie chart of percentage of different virtual crops (Faunt et al., 2009c).



BUDGET -- Working in conjunction with EROS and University of Arizona, this team will execute the project over a 3-year period at $100K per year (table 1). The project will complement the ongoing projects of the Groundwater Availability Program for the High Plains and the Columbia River Basin, as well as the ongoing work by Schmid and Hanson on the Transboundary Aquifer Assessment Act (TAA) modeling of the Lower Rio Grande. Other parallel projects that would supplement (leverage) this effort are the ongoing follow-up projects in the Central Valley that are using the Central Valley Hydrologic Model and will require this model to be maintained (periodically updated), and the proposed NASA ROSES proposal: "Integrating NASA eco-hydrological data into the MODFLOW decision support process" (Hanson et al., 2009) that would occur during the same time and use the same areas for research and development.

Table 1. Summary of proposed annual costs.

Expense Category	Costs per year
Labor - Research Hydrologist	$ 9,600
Labor - Geographer	$ 17,500
Travel	$ 2,200
Consultant to USGS (EROS)	$ 35,350
Consultant to USGS (U of A)	$ 35,350
FFY10 Grand Total	**$ 100,000**

PERSONNEL -- The principal investigator is Randall Hanson (CAWSC) and co-investigators are Dr. Wolfgang Schmid, Research Hydrologist , Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ and Dr. Gabriel Senay, Res. Physical Scientist, USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD. Additional collaborations will be involved from ongoing projects that will supplement this proposed research and development. These include Steve Peterson and Scott Christenson (USGS - High Plains), Steve Phillips and Claudia Faunt (USGS - Central Valley), Dave Morgan and Rick Dinicola (USGS - Columbia River Basin), Dr. Phil King and Dr. Max.P. Bleiweiss (NMSU) and Peggy Berroll (NMSEO) (Lower Rio Grande), Brian Lockwood (PVWMA) (Pajaro Valley), Dennis Gibbs (SBCPW) (Cuyama Valley), as well as Dr. Rama Nemani (NASA- TOPS Remote Sensing Research Group, Ames Res. Lab).

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