2004 Water Use Efficiency Proposal Solicitation Package

APPENDIX A: Project Information Form

Applying for:	❑ Urban	☑ Agricultural

1. *(Section A)* ***Urban or Agricultural Water Use Efficiency Implementation Project***	❑(a) implementation of Urban Best Management Practice, #_________________________ ❑ (b) implementation of Agricultural Efficient Water Management Practice, #______________ ❑ (c) implementation of other projects to meet California Bay-Delta Program objectives, Targeted Benefit # or Quantifiable Objective #, if applicable ______________
1. *(Section B)* ***Urban or Agricultural Research and Development; Feasibility Studies, Pilot, or Demonstration Projects; Training, Education or Public Information; Technical Assistance***	❑ *(d) Specify other:* ___________________ ☑ (e) research and development, feasibility studies, pilot, or demonstration projects ❑ (f) training, education or public information programs with statewide application ❑ (g) technical assistance ❑ *(h) other*
3. Principal applicant (Organization or affiliation):	Foundation of California State University Monterey Bay
4. Project Title:	**Characterizing spatiotemporal variations in canopy density, soils, climate, and vineyard water balances to derive spatially-explicit irrigation strategies: Development of the VITicultural Information System (VITIS)**

5. Person authorized to sign and submit proposal and contract:

Name, title	Cynthia E. Lopez, Director, Grants & Contracts
Mailing address	100 Campus Center Seaside, CA 93955
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6. Contact person (if different):

Name, title.	Lars Pierce
Mailing address.	100 Campus Center
	Seaside, CA 93955
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7. Grant funds requested (dollar amount): **$399,701**
   (from Table C-1, column VI)

8. Applicant funds pledged (dollar amount): -0-

9. Total project costs (dollar amount): $399,701
   (from Table C-1, column IV, row n)

10. Percent of State share requested (%) 100%
    (from Table C-1)

11. Percent of local share as match (%) 0%
    (from Table C-1)

12. Is your project locally cost effective?
    Locally cost effective means that the benefits to an entity (in dollar terms) of implementing a program exceed the costs of that program within the boundaries of that entity.
    (If yes, provide information that the project in addition to Bay-Delta benefit meets one of the following conditions: broad transferable benefits, overcome implementation barriers, or accelerate implementation.)

    ☑ (a) yes
    ❑ (b) no

11. Is your project required by regulation, law or contract?
    If no, your project is eligible.

    ❑ (a) yes
    ☑ (b) no

    If yes, your project may be eligible only if there will be accelerated implementation to fulfill a future requirement and is not currently required.
    Provide a description of the regulation, law or contract and an explanation of why the project is not currently required.

12. Duration of project (month/year to month/year):	**12/05 – 11/07**
13. State Assembly District where the project is to be conducted:	**Funding (CSUMB): 27** **Work (Napa): 7**
14. State Senate District where the project is to be conducted:	**Funding (CSUMB): 15** **Work (Napa): 2**
15. Congressional district(s) where the project is to be conducted:	Funding (CSUMB): 17 Work (Napa): 1
16. County where the project is to be conducted:	Funding: Monterey Work: Napa
17. Location of project (longitude and latitude)	CSUMB: long=36 36 00N Lat=121 53 00W Napa: long=38 17 00N Lat=122 17 00W
18. How many service connections in your service area (urban)?	N/a
19. How many acre-feet of water per year does your agency serve?	N/a

20. Type of applicant (select one):

- ☐ (a) City
- ☐ (b) County
- ☐ (c) City and County
- ☐ (d) Joint Powers Authority
- ☐ (e) Public Water District
- ☐ (f) Tribe
- ☐ (g) Non Profit Organization
- ☑ (h) University, College
- ☐ (i) State Agency
- ☐ (j) Federal Agency
- ☐ (k) Other
  - ☐ (i) Investor-Owned Utility
  - ☐ (ii) Incorporated Mutual Water Co.
  - ☐ (iii) Specify ___________________

21. Is applicant a disadvantaged community? If 'yes' include annual median household income. (Provide supporting documentation.)

- ☐ (a) yes, ________ median household income
- ☑ (b) no (CSUMB is an Hispanic-Serving Institution)

2004 Water Use Efficiency Proposal Solicitation Package
APPENDIX B: Signature Page

By signing below, the official declares the following:

The truthfulness of all representations in the proposal;

The individual signing the form has the legal authority to submit the proposal on behalf of the applicant;

There is no pending litigation that may impact the financial condition of the applicant or its ability to complete the proposed project;

The individual signing the form read and understood the conflict of interest and confidentiality section and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant;

The applicant will comply with all terms and conditions identified in this PSP if selected for funding; and

The applicant has legal authority to enter into a contract with the State.

[signature]	Cynthia E. Lopez, Dir. Grants & Contracts	1/10/05
Signature	Name and title	Date

<u>California Dept. of Water Resources, Water Use Efficiency Program Proposal</u>

Characterizing spatiotemporal variations in canopy density, soils, climate, and vineyard water balances to derive spatially-explicit irrigation strategies: Development of the VITicultural Information System (VITIS)

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<u>Statement of Work, Section 1: Relevance and Importance</u>

Introduction

With its moderate climate and warm, dry summers, California is by far the top agricultural producer and exporter in the US. In 2003, California agricultural receipts topped $27 billion, twice as much as any other state (CASS, 2004). Given that most of these crops are irrigated, water drives California agriculture. In 2000, approximately 9.6 million acres of farmland were irrigated in California using about 33.7 million acre-feet of water (DWR, 2004). Agriculture uses 80% of developed freshwater resources in California, although population growth and greater in-stream flow requirements increasingly demand a larger share of the state's water resources. Recent warming trends also lead to greater uncertainties in how future climate change may impact California's water resources (Hayhoe et al., 2004).

Recent studies have shown that many types of crops benefit from targeted irrigation scheduling. Regulated deficit irrigation (RDI) has been used to improve the quality of many fruit and nut crops. These studies have shown that RDI applied during the period of slow fruit growth controls vegetative growth and improves crop quality without reductions in yield (Goodwin and Boland, 2002). RDI improves berry quality and color in wine grapes (McCarthy et al., 2002), improved husk splitting in almonds (Goldhamer et al., 2003), greater concentration of oils and reduced milling costs in olives (AOA, 2000), and faster drying time in prunes (Shackel, 2003). RDI has also been shown to improve cold hardiness of grapevines (Wample and Smithyman, 2002) and to provide better control of crop pests and diseases. Targeted irrigation schedules, when applied properly, can substantially decrease crop water use and improve crop quality, without substantial reductions in yield (DWR, 2004). Improvements in crop quality and reductions in costs derived from targeted irrigation strategies provide better margins for growers and lead to substantial savings in water and energy costs, reductions in agricultural runoff and improvements in water quality.

Statewide, Goldhamer and Fereres (2004) estimate that the use of RDI in crops where it has proven to be beneficial would save approximately 1.5 million acre-feet of water annually, or about 5% of all irrigation water in the state. However, a lack of information on spatial and temporal variations in climate, soils, and crop conditions across California farms precludes the widespread application of precise irrigation strategies. Climate controls both the supply (rainfall) and demand (evapotranspiration, ET) of water in crops, and growers can augment the supply of water via irrigation. Soils, because of natural variations in texture and depth, store varying amounts of water available for plant use. Dense crop canopies will use more water than sparse crop canopies. Crop variety and root stock control plant physiological properties such as stomatal conductance (which regulates ET) and rooting depth (which regulates access to soil water). Spatial and temporal variations in all of these properties lead to variations in plant water requirement within and across fields.

Agronomists have developed a "crop coefficient" (Kc) model for determining irrigation demand. In this easy-to-use model, Kc expresses crop ET over a given period as a proportion of potential ET from a reference canopy. Kc's have been empirically determined and published for many crops, and have proven useful as a simple and convenient way to form a 1st approximation of crop water demand. However, Kc's can vary spatially within a given crop type (e.g. due to soil variations) and temporally due to year-to-year differences in plant phenology (Grattan et al., 1998). Additional uncertainty can be introduced in ET estimates by failure to adequately interpolate a value for a given location from a measurement network.

Growers need accurate *spatial* information on crop, soil, and weather variations, and a way to consolidate all this information, to precisely define targeted irrigation strategies that save water and minimize the risk of crop (and revenue) loss due to water stress. We have found that remotely-sensed maps of Kc, and linking variations in Kc to crop water balance via a simple model, is valuable to the grower. Our recent studies, and work with our industry partners (Robert Mondavi Winery, Grayhawk Aerial Imaging, Hess Collection Winery), have led to the development and application of a suite of remote sensing, modeling, and information technology tools that are being developed and used within the wine industry to help with irrigation scheduling over hundreds of acres (Nemani et al., 2001; Johnson et al., 2001; Nemani et al., 2003; Johnson et al., 2002).

Our approach has been to combine widely used agricultural tools with state-of-the-art ecological tools to develop sophisticated, yet user-friendly applications that have directly helped in the management of wine grapes. We utilize remote sensing to map Kc over time in vineyards. We combine these Kc images with soils maps and daily weather data from the California Irrigation Management Information System (CIMIS) weather station network to drive a simple water balance model (VSIM – Vineyard Soil Irrigation Model) that simulates crop water balance across the vineyard. We have recently nested the VSIM model within the Terrestrial Observation and Prediction System (TOPS). TOPS automates web retrieval of meteorological and remote sensing data, and with our TOPS/VSIM prototype we have been able to automatically generate daily irrigation schedules for a 1000 acre Oakville vineyard in the Napa Valley utilizing 7-day National Weather Service forecasts. In limited testing of the VSIM model, we have found that RDI strategies developed using VSIM in a vineyard block reduced irrigation by 12% (see below). Additional water savings can be achieved by using VSIM-based RDI strategies that consider within-field crop and soil spatial variations .

We seek funding to continue the development and testing of our VSIM/TOPS water balance forecast model and to expand our application to the entire Napa Valley. The 426 sq. mile Napa River Watershed drains directly into the Bay-Delta System. The Napa River is a microcosm of many of the water-related conflicts that face California today, including increasing urban expansion, groundwater overdraft, sediment movement and water quality, and maintenance of in-stream flow requirements for threatened fish populations (Friends of the Napa River, 2004). Here, we propose the next logical step in linking TOPS and VSIM to develop the VITicultural Information System (VITIS).

VITIS is a web-based information and forecasting system that provides weather, soils, and crop canopy maps and data, and combines this information using a simple water balance model to create value-added products (e.g. phenology, Kc, water stress, soil moisture, irrigation) that Napa Valley vineyard managers can use to develop targeted irrigation schedules. We have identified the following tasks as critical to building VITIS:

a) retrieval of canopy density from remote sensing imagery and effects of scale,
b) develop techniques for building higher resolution farm soils maps by utilizing remote sensing imagery to drive soil sampling,
c) automate daily retrieval and interpolation of CIMIS meteorological data across the Napa Valley,
d) test the VSIM water balance model algorithms in vineyard blocks that represent a range of canopy densities and microclimates,
e) refine meteorological and remote sensing data linkages between TOPS and the VSIM model
f) Develop a two-way interaction between VITIS and grower databases

We will continue to rely on our industry partners to provide us with critical guidance, testing, and feedback on the development of VITIS so that we can maximize the utility of our irrigation decision support system. The proposed research addresses several elements of this California Water Use Efficiency (WUE) Program proposal solicitation, including a) estimation of past, present, and future water savings in agriculture, b) applied research on soil, water, plant issues as related to WUE, c) potential costs/benefits of improved crop water use practices, d) potential costs/benefits of employing remote sensing technology, and e) exploration of new technologies and water management practices. This proposal also addresses several elements of the CALFED Bay-Delta WUE Program Plan including a) reduce irrecoverable losses, b) achieve multiple benefits, c) use incentive-based actions, and d) build on existing WUE programs. VITIS will provide growers with the information necessary to develop spatially-explicit irrigation strategies that save water and money, improve crop quality, and reduce agricultural runoff.

Statement of Work, Section 2: Technical/Scientific Merit, Feasibility

VITIS combines elements from both the VINTAGE (Viticultural Integration of NASA Technologies for Assessment of the Grapevine Environment) and TOPS (Terrestrial Observation and Prediction System) projects. The NASA-funded VINTAGE Project (2000-2003) focuses on the use of remote sensing, CIMIS meteorological data, and water balance modeling to characterize how spatial and temporal variations in crops, soils, and climate influence crop water balance. The goal of the TOPS Project (ongoing) is to develop a distributed computing architecture for the production of ecological forecasts from satellite remote sensing data and other ancillary data sources (Nemani et al., 2003). Below we summarize our accomplishments to date from the VINTAGE and TOPS Projects.

Previous Work: Vineyard Remote Sensing

Given the spatial and temporal variations in canopy density, there is motivation to derive crop coefficients from direct biophysical observations of the crop at hand. For larger farms, or those with highly variable growing conditions, it may be impractical to collect sufficient point-based field measurements of canopy density and vine water stress to support operational irrigation scheduling needs. Prior research has shown that remote sensing images based on the NDVI (normalized difference vegetation index) can be used to map such canopy variables as LAI (leaf area index = leaf area / ground area; Figure 1) and percent shaded area (Johnson and Pierce, 2004; Johnson and Scholash, 2005). The NDVI is based on a ratio of near infrared and red reflectance – dense canopies absorb red light and reflect near infrared light, resulting in a higher NDVI. This results in an improved way to account for spatial and temporal variability in canopy density and crop coefficients, and deviations from idealized, average conditions. Vineyard managers are making increased use of commercial NDVI-based products for various aspects of decision support, and the improved ability to extract water budget information would add value to this existing agribusiness investment. For more information on VSIM and vineyard remote sensing products see http://geo.arc.nasa.gov/sge/vintage/vintage.html.

Previous Work: Vineyard Water Balance Modeling

We have developed the Vineyard-Soil Irrigation Model (VSIM) to quantify the effects of temporal and spatial variations in climate, soils, and the canopy on daily and seasonal vine water balance and water stress (Figure 2). VSIM has combined important pieces of a well-developed and tested ecosystem water balance model (BIOME-BGC; Running and Coughlan, 1988; Pierce, 2001) with a widely-utilized crop water balance model based on reference evapotranspiration (ETo) and a crop coefficient (k_c), where crop ET (ETc) = ETo * k_c. VSIM relies on remotely-sensed imagery and maps to quantify temporal and spatial variations in canopy density and crop coefficients within and across vineyard blocks (Johnson and Pierce, 2003). A time series of Kc can be defined using either monthly canopy density images or by using a growing degree-day model to grow the canopy to a maximum canopy density obtained via remote sensing from previous years.

In VSIM, daily ET (vine + ground evaporation) and runoff (RO) are subtracted from soil moisture (SM), while irrigation and rainfall are added to keep a daily running summation of soil moisture. We then estimate the daily soil/leaf water potential (LWP) from soil moisture using a relationship developed by Saxton et al. (1986) based on soil texture. We can also invert the Saxton et al. (1986) algorithm to estimate soil moisture given a target vine stress. By comparing this soil moisture estimate to current soil moisture, we can estimate the amount of irrigation necessary to maintain a target vine water stress.

In VSIM, the user can choose to modify k_c based on vine water stress to account for the effects of severe plant water stress on reductions in stomatal conductance (e.g. McCarthy et al., 2002). VSIM allows the user to change the cover crop, climate, soil properties, and canopy density to explore how these variables influence the vine water balance and simulated irrigation. We utilize meteorological data from the California Irrigation Management Information System (CIMIS) network to quantify spatial and temporal variations in weather. VSIM also requires information on soil texture and depth (e.g. from soil cores, STATSGO maps) and vine physiological parameters (rooting stock, canopy parameters). Given these inputs supplied by the user, VSIM can be used to simulate the spatial and temporal variations in the crop water balance and vine stress for any vineyard block. In recent tests, we have found that VSIM estimates of vine water stress compare favorably with measurements of stem water potential for a Cabernet Sauvignon (CS) block at Stags Leap during 2003 (Figure 3). A total of 260 mm of irrigation water was applied during this trial. An RDI strategy defined using the VSIM model to maintain a target vine water stress utilizes only 230mm of water over this same period, a 12% savings. This does not include additional savings that could potentially be achieved by considering within-field spatial variations in canopy and soil properties, and adjusting irrigation systems and field layout accordingly.

VSIM has also been used retrospectively to examine the effects of variations in climate, soils, and the canopy on vine water balance (e.g. Hubbard et al., 2003). Specific applications of VSIM include irrigation scheduling and vineyard planning (Figure 4), as well as quantifying the effects of year-to-year climate variations (e.g. vintage) on vineyard water stress. By combining remotely-sensed Kc maps and CIMIS data within VSIM, we have an advantage over other irrigation scheduling techniques in that we can directly track the crop coefficient as it varies by season, by canopy density and trellis-type, and by water stress effects on stomatal conductance. At the same time, the user has greater powers to manipulate the vineyard environment to explore the effects of climate, soil type, and cover crop and vine management strategies on the past, present, or future vineyard water balance. The power of the VSIM approach is that it helps the vineyard manager to combine and compare all of the various factors that control vine water stress by providing a more tractable and quantitative methodology for understanding vine water balance (Daniel Bosch, R. Mondavi vineyard manager, personal communication). A 1-dimensional version of VSIM running in MS Excel is available for download at http://geo.arc.nasa.gov/sge/vintage/vsim.html. The spatial (2D) version of VSIM that incorporates Kc and soil input maps currently runs in IDL and C.

Previous Work: Assessment of Climatic Change Impacts

Statistical analysis of long-term climate records and wine ratings show that inter-annual variability in climate has a strong impact on the economics and water use of the California wine industry. Warmer sea surface temperatures in El Nino years along the California coast were found to help wine quality by modulating humidity, reducing frost frequency, and increasing growing season length in the Napa and Sonoma Valleys of California between 1950 and 1997 (Nemani et al., 2001). So far, the climatic changes have been found to be beneficial to wine growers as these changes reduced frost frequency and increased growing season length (Table 1). Nemani et al (2002) also showed that between 1950 and 1994, climate has become warmer and drier over the western United States, with significant impacts on the growing season phenology and water balance. More importantly, the climatic changes encompass nearly all of the west coast agricultural areas. While the climatic changes may have spurred the expansion of vineyards into Oregon and Washington, they also present a potential problem given limited water resources. Additionally, continued changes in climate may also alter the competitiveness of certain appellations resulting from outbreaks of pests/diseases (including invasive species), insufficient water for irrigation, etc. It is important for California's agriculture that we understand the possible consequences of such changes to maintain and enhance global competitiveness.

Previous Work: The Terrestrial Observation and Prediction System (TOPS) Project

The latest generation of NASA Earth Observing System (EOS) satellites has brought a new dimension to continuous monitoring of the Biosphere. EOS data can now provide weekly global measures of vegetation productivity and ocean chlorophyll, as well as many related biophysical factors such as land cover changes or snowmelt rates. However, information with the highest value is forecasting impending conditions of the biosphere in an ecologically- and economically- meaningful way that would allow advanced decision-making to mitigate dangers, or exploit positive trends. An essential precursor to forecasting is the ability to monitor current conditions in near-real-time. TOPS (Figure 5) is an internet-based modeling software system that can collect and automatically process a variety of data sets (climate, remote sensing, etc.). TOPS integrates these data with simulation models allowing near-real-time monitoring of ecosystem processes that cannot be directly observed from satellites (Nemani et al., 2003). TOPS can then ingest weather or climate forecasts to predict future ecosystem conditions. Finally, both the current and future conditions can be expressed as anomalies from long-term data providing resource managers with actionable information.

TOPS is scale-independent and can be quickly adapted to any resolution given the availability of remotely sensed data for mapping vegetation conditions. We have recently nested the VSIM model within TOPS in order to automatically generate irrigation schedules for a 1000 acre Oakville vineyard in the Napa Valley utilizing 7-day National Weather Service (NWS) forecasts. TOPS automates web retrieval of critical VSIM model inputs (CIMIS meteorological data, NWS 7-day forecasts, and remote sensing imagery) and automatically runs VSIM to produce current and 7-day forecast maps and block summary tables of vineyard water balance variables such as soil moisture, vine water stress, and irrigation forecasts (Figure 6). We are currently working with our industry partners to refine the forecast maps and tables into formats that are most suitable for vineyard managers. Prototype maps are available for our Oakville study site at http://geo.arc.nasa.gov/sge/ecocast/vsim/index.html (note that 2004 simulations ceased in mid-October; 2005 simulations will commence in March).

Proposed Research Activities

We seek funding to develop the VITicultural Information System (VITIS), a web-based information and forecasting system that combines the VSIM and TOPS technologies and products. VITIS would provide a suite of climate-related (e.g. temperature, precipitation) and value-added (e.g. phenology, Kc, water stress, soil moisture, irrigation) products along with analysis of the potential impacts of long-term climatic change to Napa Valley vineyard managers. VITIS would exist as an interactive information and modeling system to be used by growers to develop precise, spatially-explicit irrigation schedules for individual vineyard blocks within the Napa Valley. VITIS would provide interpolated meteorological data, Kc imagery, STATSGO soils maps, and vineyard parcel maps to drive vineyard water balance simulations across the Napa Valley. We anticipate creating a mechanism whereby individual growers can interact with VITIS via a web-based interface (e.g. like CIMIS, Wateright) to incorporate more detailed, farm-specific information on crops, soils, and cultural practices (e.g. cover cropping, irrigation) into VITIS products specific to their farms.

Current prototype applications of VITIS (e.g. the TOPS-nested VSIM irrigation scheduling model) are limited to land parcels less than 1000 acres in size. The limited scale of this prototype application relies on data sources and assumptions that need to be evaluated at larger spatial scales. We have identified three main research themes focusing on remote sensing, meteorological data processing, and simulation modeling that will allow us to scale the current VITIS application to the Napa Valley. We will then evaluate the utility of VITIS in providing targeted irrigation scheduling capabilities that reduce irrigation water use across a variety of scales.

We will develop scaling principles using a nested sampling design. Intensive ground-based measurements will be recorded in six intensive study blocks that span a range of soils, climate, and canopy densities found within the Napa Valley. Our six study blocks consist of individual vineyard blocks that are ~3-5 acres in size nested within a larger vineyard ~300 acres in size. Three of our study blocks will be located at the milder southern portion of the Napa Valley (Hess Collection Winery American Canyon Ranch). The other three study blocks will be located further inland towards the central portion of the Napa Valley (Hess Collection Winery Mt. Veeder Ranch; Robert Mondavi Oakville Ranch). The southern portion of the Napa Valley has a moderate climate influenced by coastal fog and has clay soils. The central portion of the Napa Valley has warmer, more extreme climate with loamy soils. The study blocks at each vineyard span a range of LAIs (0.5-2.0 m2/m2) due to differences in spacing, trellis-type, and age.

We will sample canopy density, stem water potential, and soil texture at a number of locations within each vineyard study block. Within each study block we will locate a grid of 20 indirect measurement points where we will record indirect LAI measurements of the cover crop and vine canopy density using the Decagon Accupar, LiCor LAI-2000 Plant Canopy Analyzer, and paired canopy/ground digital photos (Figure 7). Four of these *indirect* measurement points (stratified by canopy density) will be co-located with four *direct* measurement points where intensive ground-based measurements will take place. At each direct measurement point we will collect a) cover crop LAI by clipping, drying, and weighing all above-ground biomass within a 0.25 m2 quadrat and using a weight-to-area conversion (monthly March-May), b) vine LAI by multiplying the number of leaves/vine by average leaf area (monthly April-October), c) stem water potential readings using a pressure bomb (following 3 irrigation events July-September), d) gravimetric soil moisture measurements (monthly March-October), and e) soil cores to determine soil texture and depth (one-time). These direct and indirect, ground-based measurements will be used to calibrate satellite maps of canopy density (Kc), test VSIM model estimates of vine water stress, and compare spatial relationships between canopy density and soil water-holding capacity. Specific research tasks, measurements, and their justification are listed below by theme.

Remote Sensing

Automated ingestion and calibration of a time series of NDVI images is a core component of VITIS. We have identified specific remote sensing tasks that will be necessary to scale our irrigation scheduling application to the Napa Valley and to provide vineyard managers with value-added products to help in canopy and water management.

Retrieval of Kc from remote sensing imagery: Within our current implementation of VSIM, the canopy expands through time for the current year based on a model that estimates daily canopy density as a function of cumulative growing degree days (GDDs) and prior-year maximum LAI. We plan to replace the GDD calculations with cover crop and canopy phenology estimates based on NASA/MODIS satellite imagery. The MODIS vegetation greenness and LAI products will be analyzed weekly from pre-season through harvest, and used to track crop phenology, and more particularly to estimate dates of bud-break and maximum foliar expansion. During the first year of the study, LAI maps will be collected and generated periodically to validate the MODIS phenology approach. We have previously observed that the relationship between NDVI and vine LAI (see Figure 1) is fairly robust over space and time (Johnson, 2003a,b). We have also observed a strong relationship between NDVI and vineyard shaded area, which is strongly related to Kc (Johnson and Scholasch, 2005; Williams, 2000). Both of these conversions will be explored using field data from the study sites as above.

Remotely sensed Kc maps over the growing season will be generated at high- and moderate-resolution. Portions of individual farms containing our study blocks will be mapped at high resolution, derived from imagery collected by commercial providers such as Grayhawk Airborne Imaging (1-2 m ground sampling distance, or GSD) and Space Imaging/IKONOS or DigitalGlobe (4 m GSD). Moderate-resolution maps will be generated for the entire Napa Valley using data from NASA's ASTER (15 m GSD) and LANDSAT (30 m GSD) satellites. These datasets will be pre-processed and transformed to NDVI. The NDVI will then be transformed to LAI and K_c maps based on the direct and indirect LAI measurements described above. Ultimately, if continued ground support is indicated, the process may be automated through the use of wireless, webcam-based digital photos of paired vine and ground conditions across a number of reference blocks. Therefore, we are comparing our indirect measurements of LAI obtained via the Accupar and LAI-2000 with digital photos of vine canopy light penetration and ground reflectance across a range in canopy densities. Photos of the ground near solar noon are useful for extracting percent shaded area, which has a strong linear relationship with both NDVI (Johnson et al., 2003) and Kc (Williams, 2000). Additional validation work will be performed to establish the influence of trellis type on the relationships between NDVI, LAI, shaded area, and Kc.

Year 1 effort will concentrate on verification of remote sensing techniques and protocols based on linkage of imagery with field data. During year 2, processed imagery will be used to drive VSIM-TOPS mapping simulations at high- and moderate-resolution. Simulation results will be posted to the Internet for public inspection.

Evaluation of canopy-soil spatial relationships: Information on vineyard soil texture is critical to making accurate irrigation forecasts. Soil texture and depth are important controls on soil water-holding capacity and runoff. Soil texture data is currently available at fine scales (e.g. individual rows, fields) from point-based soil cores and backhoe pits, or at coarse scales from county-wide soil surveys (e.g. STATSGO). However, there tends to be a lack of critical soil texture information at the farm scale where important irrigation decisions need to be made. We have noticed that in many cases variations in cover crop and canopy density seem to be correlated with variations in soil texture and depth (e.g. Hubbard et al., 2003) in flat areas, and with variations with drainage area networks in areas with topographic relief.

We propose to develop techniques for building higher resolution farm soils maps by utilizing NDVI imagery from early spring (cover crops) and mid-summer (vines), and digital elevation models (DEM) for stratified, and hence more *effective* soil sampling. We would like to know how much the spatial variations in soil water-holding capacity contribute to variations in canopy density. To accomplish this, in year 1 we will sample soil texture and depth at 4 locations (stratified by canopy density) within each of our 6 intensive study blocks. In the hilly topography of our 3 American Canyon (Carneros) study blocks, we will use the DEM to calculate the drainage area above each of the 4 soil sample sites in each block. Cover crops provide a good index of soil spatial variability because their cover in early spring is dependent almost solely on soil water-storage capacity. Vineyards, however, exhibit block-by-block variations in canopy density due to trellis-type, spacing, and cultural treatments. To account for this, we will process the NDVI imagery to map canopy density anomalies for each pixel ((pixel reflectance – mean block reflectance) / mean block reflectance). We will then correlate cover crop, vine, and soil spatial variations within each block. If spatial patterns in soils and canopies are well-correlated across our six intensive study blocks, we will expand our analysis to include a wider range of vineyard blocks at the farm-scale. We will use these relationships to produce farm-scale, high resolution soils maps that can be utilized in simulating precise irrigation schedules within and across vineyard blocks.

Meteorological Data

TOPS currently provides daily maps of important meteorological variables (Tmax, Tmin, radiation, humidity, precipitation) for California at 1km resolution. These maps are derived from the daily datasets produced by the NOAA Rapid Update Cycle (RUC) weather prediction system. Through agreements with CIMIS and the NWS, we utilize TOPS to automate the retrieval of daily CIMIS weather data and 7-day NWS weather forecasts in California.

Currently ETo is interpolated based on site-to-site differences in radiation. For CIMIS weather stations within the Napa Valley, daily changes in incident radiation (x) explain >95% of the daily variations in ETo (e.g. $y = 0.00322 * x^{(1.315)}$, R2 = 0.99, SEE = 0.34mm, Oakville CIMIS station 2003; Pierce et al., 2004). To spatially-interpolate ETo we need to know how radiation is changing due to topography and cloud cover. For extrapolating CIMIS estimates of ETo in hilly terrain (e.g. American Canyon, Mt. Veeder) we use a cosine correction based on day of year and vineyard slope and aspect. For calculating daily ETo forecasts we utilize the NWS cloud cover forecasts. We estimate the daily maximum incident radiation for a cloud-free sky from latitude and day of year using a maximum sin wave function based on multiple years of CIMIS station daily radiation measurements. We then use daily % cloud cover forecasts (x) to derive transmittance (e.g. y = 0.95 - 0.0015x - 0.000056x2, R2 = 0.90, SEY = 0.1, Napa Airport 2003; Pierce et al., 2004) and multiply estimated daily maximum radiation by transmittance to derive an estimate of daily incident radiation. We then use the radiation-ETo regression function above to forecast daily ETo for the week ahead.

Automate the interpolation of CIMIS meteorological data and NWS forecast data : We seek to automate the interpolation of CIMIS meteorological data (ETo, temperature, and precipitation) across the Napa Valley using the Carneros and Oakville CIMIS stations combined with additional NWS primary as well as Coop station data. TOPS uses three methods for gridding surface weather conditions, including co-krieging, truncated Gaussian filter, and inverse distance method. A cross-validation routine determines which of the three methods best represents the observed conditions. Much of this work is done using historical data, so Nowcast and Forecast runs are more efficiently executed. Using TOPS, we will automate the production of daily maps of current and forecast ETo, average temperature (Tavg), and precipitation (Ppt) for the Napa Valley at the desired spatial scale. TOPS uses a DEM of desired resolution to map the gridded fields. Therefore, no additional work is needed to change the resolution of gridded weather data from 30m to 1km except using the appropriate DEM. The topographic complexity at higher resolutions (e.g. 30m) requires far more computational resources. Currently, NWS forecasts are produced at 4km resolution. We will treat each 4km forecast as station data in the Napa Valley and execute our spatial gridding routines to get finer resolution data. These meteorological maps will be used to drive VSIM simulations across the Napa Valley, and they will also be made available online to provide a prototype 7-day time series of forecast ETo, Tavg, and Ppt maps.

Water Balance Modeling

The VSIM water balance model is a core component of VITIS. It has limited testing in a few vineyard blocks within the Napa Valley (e.g. Figure 3). We seek to more rigorously test the algorithms that comprise the VSIM water balance model across vineyard blocks that comprise a range in LAI, soils, and climates. We also seek to refine and automate a number of critical input data linkages between TOPS and the version of VSIM nested within TOPS that comprises the heart of VITIS. Finally, we would like to develop a 2-way user interface to VITIS so that vineyard managers can also upload to VITIS critical information on soils, crops, and cultural practices that are critical to improving VITIS-based irrigation scheduling.

Test VSIM water balance algorithms: VSIM is designed to simulate soil moisture and vine water stress and to derive deficit irrigation schedules based on a target vine water stress value. Soil moisture and vine water stress are dependent on a number of critical crop water balance processes (e.g. runoff, ET, canopy LAI), and therefore provide a good metric for assessing model behavior and reliability. Measurements of stem water potential (SWP) provide the best daily measure of vine water stress. In each block, SWP will be measured monthly (mid-May, mid-June) until the target water stress is reached at the end of June. Then SWP will be measured every 4 days during the first irrigation event (~early July), an irrigation event in early-August, and an irrigation event in September. SWP will be measured 2 days before irrigation, and then at 2 and 6 days after irrigation at each of the 4 direct measurement sites in each study block using a pressure bomb. Gravimetric samples of soil moisture will also be taken monthly from March to November at each of the 4 direct measurement sites. Depth-to-groundwater will be monitored monthly from existing access tubes at each vineyard. For each block, VSIM estimates of vine water stress and soil moisture will be compared to measured

SWP and soil moisture using regression analysis to evaluate the effectiveness of the VSIM water balance model in simulating soil moisture and vine water stress.

Refine TOPS-VSIM meteorological and remote sensing linkages: Currently we utilize a GDD model and daily average temperature to 'grow' the canopy in the current year to its maximum Kc (where the max. Kc image is derived from the previous year). We would like to alter VSIM so that it can accept a time-series of Kc images and only rely on the GDD model to 'grow' the canopy between monthly Kc images. Currently the ETo interpolation is conducted in VSIM. We would like to conduct the ETo interpolation outside of VSIM and within VITIS, and then alter VSIM so that we can drive daily simulations using input maps of ETo, T, and Ppt.

Develop a two-way interaction between VITIS and grower databases: In the prototype version of VITIS, the vineyard manager can download daily maps of critical water balance variables to help in RDI scheduling. VITIS also provides summary tables of these variables by block, which are more useful in developing block-wide RDI schedules. The manager has little control over current simulations. Vineyard managers, however, control a variety of block-scale information that is critical to improving the accuracy of block-scale water balance simulations. This information includes cultural practices that have been applied to individual blocks, such as cover crop management, vine pruning, trellising, vine spacing, and irrigation practices. Vineyard managers sometimes have more detailed, block-scale soil texture and depth information, as well as measurements of vine water stress or soil moisture that could be used for model calibration and testing.

We would like to develop an interface that would allow the vineyard manager to better control water balance simulations across individual fields by altering major model parameters over time (e.g. variety, rooting depth, spacing, target vine water stress, etc.), and by entering detailed data, if available, on block-specific cultural practices. After setting up the initial subscription, the vineyard manager would submit a vineyard block map to VITIS. The vineyard manager would also submit a high resolution NDVI image of the vineyard (if already purchased), or would contract with a local airborne image provider (e.g. Grayhawk) to collect imagery. We envision two types of tables that the vineyard manager would complete and submit to VITIS. The first table would list all major model parameters on the x-axis and block number/code on the y-axis. Default values would be listed by parameter and block, and the user would be allowed to alter these. The second table would list cultural practices along the x-axis and block no./code on the y-axis. The user would define cultural practices in terms of relative changes in Kc values (for mowing and pruning), additions of water (supplemental irrigation), etc., and the date on which the practice was implemented. These tables would then be used as inputs to the daily VSIM water balance simulations.

Statement of Work, Section Three: Monitoring and Assessment

Implementation of VITIS and Project Plan

Our goal at the end of year 2 is a fully-functional and tested VITIS application across the Napa Valley. We envision that VITIS will have two levels of product. A public archive product will be available that provides gridded maps of soil texture and depth (STATSGO), low-resolution, remotely-sensed Kc maps derived from currently-available public archives, current and forecast gridded meteorological data (ETo, temperature, precipitation, and departures-from-normal), and current and forecast simulated vineyard water balance maps (soil moisture, vine water stress, date of stress onset, total simulated irrigation needs, and departures-from-normal) for the Napa Valley. The public archive would also contain an MS Excel-based copy of the VSIM model (1-dimensional that can be run for individual blocks/fields) with comprehensive instructions on how to a) use field measurements to parameterize the VSIM model (e.g. where and how to obtain climate, soil, canopy information for specific blocks), b) run the VSIM model for a specific block (e.g. dates, target vine stress, etc.), and c) interpret VSIM outputs for defining an irrigation schedule. This public-archive would directly link to CIMIS and would automate the retrieval of CIMIS data for running the VSIM model to explore crop water balance and irrigation needs in current or past years. A private archive (discussed above) will also be available through a password-protected subscription service that will allow Napa Valley growers to customize VITIS information and water balance simulations for their particular vineyards. We anticipate that VITIS will be ready for beta-testing by a select set of vineyard managers by the end of year 2.

In year 1 we would like to continue to refine our VITIS prototype to develop irrigation schedules for our vineyard study areas. In year 1 we will also establish and measure canopy density, soils, and vine water stress in our six intensive vineyard study blocks to further test the VSIM model and to explore the effects of scale on the Kc-NDVI relationship at our study sites. In year 2, we will initiate both the public and private VITIS archives and expand our vineyard-scale irrigation scheduling across our American Canyon study vineyard. We will also split our study blocks into control and treatment subblocks in order to evaluate the effectiveness of a VITIS-based regulated deficit irrigation (RDI) schedule on reducing water use in comparison to standard irrigation schedules. We will also finalize our analysis of the spatial relationships between vineyard NDVI and soil texture/depth in order to develop higher-resolution soils maps for VITIS private archive irrigation scheduling. A project timeline with specific tasks can be found in Table 2.

Block-scale Assessment of Water Savings

If the VSIM model proves successful in simulating seasonal trajectories of soil moisture and stem water potential in year 1 across our 6 intensive study blocks, then in year 2, we will use VITIS to develop regulated deficit irrigation (RDI) schedules on 1/2 of each of our 6 intensive study blocks (treatment). The RDI schedules for the treatment half-block would also consider spatial variations in canopy density and soil textures. The other (control) half of each block would receive the standard irrigation (control). Each treatment block would receive the VSIM-simulated cover crop and RDI schedule to maintain the target vine water stress between berry set and veraison. We will again collect measurements of stem water potential and soil moisture in year 2 in each block to compare with model estimates. In year 2, daily VSIM simulations will be run in VITIS for each treatment block using measured ETo, temperature (T), and rainfall (R) from the nearby CIMIS station, and NWS forecast data for the next 7 days. A second VSIM model run will use historical averages of ETo/T/R over the same period so that we can calculate block-scale water balance anomalies for the current year. Treatment blocks will receive the appropriate cover crop or irrigation management strategy over the next 7 days predicted using VSIM. At harvest, we will collect yield and fruit quality metrics in each treatment and control block which include berry and cluster weight and size, and must analysis (Brix, TA, and pH). The yield/quality metrics will be compared between treatment and control subblocks to evaluate the effectiveness of using VITIS in developing RDI schedules that maximize fruit quality. We will also quantify the water savings that results from spatially-based RDI schemes in comparison to standard irrigation practices, and how these water savings are influenced by soil, climate, and canopy variations. It is important to recognize that a major incentive for implementing RDI, and hence reducing water use, is the improvement in crop quality.

Farm-scale Assessment of Water Savings

In year 1, we will perform a model-based assessment of the potential of spatially-based RDI strategies to save water at the farm/ranch scale. This assessment will be based on two previous years, a dry year and a wet year. We will run the VSIM model to simulate spatially-based RDI irrigation schedules for each block of our study vineyard during a dry and a wet year. We will use July NDVI imagery to define maximum Kc, our growing degree-day canopy phenology algorithm to define canopy phenology over the growing season (see above), and historical CIMIS weather data to drive the spatially-based VSIM simulations. We will use either STATSGO soils data or higher-resolution soils maps (if available) to represent soil variations at the ranch-scale. We will then simulate the spatially-based RDI schedule across all the blocks on the ranch for both the dry and wet years. We will compare total irrigation water use of the spatially-based RDI strategy to records of actual irrigation amounts in order to evaluate the potential of RDI to save water at the farm-scale across a range of soils and climates.

Valley-wide Assessment of Water Savings

Upon implementation of VITIS in year 2, we will assess the potential water savings from the implementation of targeted irrigation strategies implemented across the 40,000 acres of vineyards that comprise the Napa Valley. To do this, we will compare valley-wide irrigation water use under a ‘standard’ irrigation scenario with water use under an RDI irrigation scenario defined using VITIS. Growers often irrigate as a proportion of ETo (~50%, although this varies), so our ‘standard’ irrigation scenario will be based on water replacement as a proportion of ETo. We will then define a target vine water stress within VSIM, and then let VSIM define the RDI irrigation scenario. We will use 30m LANDSAT imagery to map canopy density for the Napa Valley, STATSGO soils maps, and CIMIS weather data. We will then use VITIS to simulate both irrigation scenarios on a block-by-block basis for the Napa Valley. We will compare potential irrigation water use under both scenarios with valley-wide precipitation inputs to develop a valley-wide water budget analysis for wet, dry, and average years.

<u>Qualifications of the Applicants</u>

Expertise

The applicants have been working in the fields of ecology, modeling, and remote sensing over the past 2 decades. Initial applications of the remote sensing, modeling, and ecocasting were developed for understanding ecological processes in natural ecosystems. More recent research has transferred much of this technology to the agricultural arena. L.

Pierce (PI) has researched the use of ecosystem models to explore water, carbon, and nutrient interactions in natural and agricultural ecosystems. He has taken the lead on developing the VSIM water balance model and linking it to remote sensing-based maps of canopy density. He has applied and tested the VSIM model at study sites in the Napa and Salinas Valleys, and has worked to provide the VSIM model to vineyard managers.

L. Johnson has taken the lead on the development of ground- and image-based canopy density measures (leaf area index, Kc) in agricultural ecosystems. He has been working in vineyards in the Napa and Salinas Valleys over much of the past decade. His initial applications of remote sensing to monitor vineyard canopies as part of the GRAPES and VINTAGE NASA Projects have lead to the standardized use of NDVI imagery in the management of vineyards, and have helped to spawn an industry of aerial image providers.

R. Nemani has developed much of the remote sensing and modeling core of the Terrestrial Observation and Prediction System (TOPS). TOPS utilizes distributed computing architecture for the automated production of ecologically-based forecasts (ecocasts) from satellite remote sensing data and other ancillary data sources. Applications of the Ecocast technology include fire forecasting, crop water use forecasting, snowpack and flood monitoring, and identification of anomalies in the carbon cycle and other biospheric processes.

Project Management and Responsibilities

L. Pierce, CSUMB (Modeling): Overall project administration and management; Development, testing, and scaling of the VSIM model; Improving VSIM, TOPS, VITIS linkages; Ground measurements for model testing; Assistance with remote sensing and scaling; Education, Outreach.

L. Johnson, NASA-Ames (Remote sensing): remote sensing and scaling of satellite-derived VSIM inputs; ground measurements for remote sensing; assistance with ground measurements for model validation; development of remote sensing capabilities within TOPS; Outreach.

R. Nemani, NASA (VITIS): Development of VITIS software and hardware tools; Embedding climate, remote sensing, and the VSIM model within TOPS; Development of VITIS web site; Outreach

Equipment and Computing Facilities

L. Pierce (CSUMB) will provide the field equipment and lab space necessary for conducting and processing plant and soil measurements. This includes a LiCor leaf area meter, LiCor LAI-2000 and a Decagon Accupar plant canopy analyzers, PMS pressure bombs/tanks, Trimble GPS units, digital camera, and soil augers (as well as clippers, scales, tapes, etc.). He will also provide the hardware (Compaq Presario R3000 w/ Pentium 4 HT) and software (MS Excel, SPSS) necessary to run the VSIM model and perform data/model intercomparisons.

The Ecosystem Science and Technology Branch Computational Facility at NASA Ames Research Center supports a variety of computational tasks. Computing capabilities include Personal Computers and UNIX workstations running a variety of image processing (ERDAS-IMAGINE, IDL-ENVI), GIS (ArcGIS, ArcView, GRASS) and modeling/statistical (IDL, S+6) software. The NASA Ames supercomputer (Columbia) is configured as a cluster of 20 SGI Altix 3700 and 3700BX2 computers, each with 512 Intel Itanium2 processors and 1,056 gigabytes of global shared access memory. The total system has 10,240 processors and 21 terabytes of memory.

Outreach, Community Involvement, and Acceptance

Our experience in the VINTAGE and TOPS projects has allowed us to set up the initial infrastructure necessary for the successful development of applications (see *previous work*). This infrastructure involves the development and testing of products on the ground with our wine industry partners (Hess, Mondavi), and then the commercial development and distribution of ground-tested products via value-added geospatial consulting partners (Grayhawk). We plan to continue to utilize this commercialization pipeline, as it has proven successful in the development of commercially-applicable technologies.

Our public/private partnership will also continue to actively engage in outreach to the wine industry, state/federal research and policy programs, resource conservation groups, and the general public. We will participate in appropriate education and outreach workshops (UC Extension; State), and publish the results of our research in the scientific, trade, and industry literature (e.g. American Journal of Enology and Viticulture, IEEE Remote sensing journals, California Farmer, NASA Technical Memoranda, etc). Progress and results will be orally presented at industry meetings and scientific symposia. Popular press will be periodically stimulated by press release from the involved universities and/or NASA. A workshop will be sponsored to convey results to the wine industry, third-party commercial providers, National Program representatives, and other interested parties. A UC Davis Professional Development Extension Course will be offered (this will serve to update a course already developed and presented in May, 2002). Where appropriate, our outreach activities will be coordinated with, and enabled by U.C. Cooperative Extension Agents from Napa County.

Our public/private research team will engage in technology transfer of developed methods to our commercial geospatial data partner, to enable them to meet end-user product/service demand stimulated by the project. Ultimately, we envision that VITIS would be run by a public/private partnership that would provide the products we've listed above through a membership-based, web-oriented service to all facets of the California wine industry, with the potential to expand to other types of controlled-irrigation agriculture.

Innovation

The CA DWR OWUE Agricultural Water Use Program has identified irrigation scheduling as an important agricultural water conservation initiative (DWR, 2004). However, current technologies for RDI-based irrigation scheduling do not adequately represent spatial variations in canopy and soil properties. Additionally, most growers lack access to a) the necessary spatial/temporal information, and b) the ability to process this information, in order to implement precise, spatially-explicit irrigation strategies. The VITicultural Information System (VITIS) proposed here would provide the data and tools necessary to allow growers to tailor targeted irrigation strategies to account for spatial and temporal variations in climate, soils, and canopy density. The strength of the proposed study is that we have already developed a prototype that has caught the attention and interest of the California wine industry. Several of the critical pieces have been tested and are in place. Funding from the CA DWR OWUE would pull the major components of VITIS together, field-test these components, and get feedback from the industry as to how best to develop VITIS to maximize its usefulness in irrigation scheduling. Innovative VITIS-based technologies include:

a) the use of remote sensing to define spatial patterns in canopy density and soils,
b) the automated retrieval and mapping of climatic and forecast data,
c) input of grower-defined cultural practices, and
d) the ingestion of all of these data sources within a water balance model that can provide critical irrigation scheduling information, and
e) irrigation scheduling that is sensitive to spatial and temporal variations in canopy density, soils, and climate.

Although VITIS is being developed for vineyards, it can be implemented in other types of controlled-irrigation crops. VITIS provides the necessary information that allows growers to more precisely define irrigation based on plant needs as defined by spatial variations in canopy and soil properties, and short-term weather forecasts. Vineyard managers can adjust individual drip emitters, add additional drip line, and/or alter the timing and amount of irrigation to maximize irrigation efficiency and reduce runoff. VITIS also provides critical planning information that would inform the design and layout of vineyards and other agricultural crops. Finally, VITIS would provide a way for growers to quantitatively evaluate the effects of weather from previous years, or projected future variations in weather and climate, on irrigation water use.

Costs and Benefits

The potential benefits from the implementation of targeted irrigations schedules in California croplands using controlled irrigation is large. Targeted irrigation strategies reduce water use, save energy through reduced pumping costs, reduce agricultural runoff, and improve crop quality without substantial reductions in yield. In 2000, there was an estimated 9.6 million acres of irrigated agriculture in CA (DWR, 2004); 2.4 million of these acres (25%) are devoted to fruit and nut crops (CASS, 2004) many of which have been shown to benefit from targeted irrigation strategies. Given a total irrigation water use in 2000 of 33.7 million acre-feet (DWR, 2004), and assuming that a) 25% of this total is used for fruit & nut crops, and b) that average irrigation efficiencies under targeted irrigation strategies could improve 20% (Kirda, 2002), we can estimate that the total water savings would be on the order of 1.7 million acre-feet, or 5% of all irrigated water in CA (Goldhamer and Fereres, 2004). In limited testing, we have found that RDI strategies developed using VSIM could reduce irrigation by 12% (see above). Additional savings can be achieved by using VITIS-based RDI strategies that consider spatial variations in canopy density, soils, and climate.

The proposed project applies specifically to the 40,000 acres of vineyards that comprise the Napa Valley. The costs of implementing VITIS decrease substantially over time. VITIS technologies are scalable and expansion to irrigated croplands beyond the Napa Valley will become more cost-effective over time. However, even the current project has the potential to realize an annual savings of up to 12,500 acre-feet of irrigation water. This assumes 40,000 acres of wine grapes in the Napa Valley (0.5% of total CA irrigated cropland), using 125,000 acre-feet of irrigation water (0.5% of irrigation water used in CA), and a modest 10% improvement in irrigation efficiency. VITIS could easily be adapted to other wine-growing regions in California. Vineyards occupy 880,000 acres in California, or just under 10% of all irrigated agricultural land in the State (CASS, 2004). Beyond water savings, a improved understanding of canopy, soil, and microclimatic variations, and the effects of these variations on vine water balance and grape quality, will continue to yield improvements in California wine quality, marketing of California wines, and maintaining California's share of the global wine market. This is significant in that government-based funding of wine research in other countries (e.g. Australia) is substantial. VITIS will also be able to add value to the existing NDVI imagery investment already made by many growers.

Modeling provides an inexpensive assessment and planning tool to evaluate the effects of spatial and temporal variations in canopy density, soils, and climate on agricultural water use. VITIS provides the necessary spatial and temporal information, and a way to process this information, allowing growers to precisely define targeted irrigation schedules, manage risk and uncertainty, and enhance water resource planning capabilities in an era of increasing population, water demand, and climate change.

Budget

Budget Narrative

Salaries, wages (Year 1 = $105,326; Year 2 = $110,592; Total = $215,919)**:** The project will span 2 years (12/05 – 11/07). Year 2 of salaries & wages includes a 5% increase to accommodate any standard wage increases. L. Pierce will serve as co-PI and take the lead on project management and modeling at approximately 35% effort. L. Johnson will serve as co-Principal Investigator and take the lead on remote sensing at approximately 33% effort. A. Michaelis (R. Nemani) will devote approximately 30% effort to this project and take the lead on VITIS development. Two student lab & field assistants are also requested.

Fringe Benefits (Year 1 = $23,544; Year 2 = $24,721; Total = $48,265): Full-time employee fringe benefits are calculated at the Foundation of CSUMB standard rate of 35%. This rate is applied to L. Johnson and A. Michaelis. Part-time employees and faculty overload fringe benefits are calculated at the standard rate of 11%. L. Pierce will be working in accordance with the additional employment (overload) clause of the California Faculty Association agreement with the California State University Chancellor's Office. The student assistants will be part-time employees during the school year, and full-time during summer.

Supplies (Year 1 = $28,400; Year 2 = $26,500; Total = $54,900): Maintenance of the LAI-2000 & Accupar plant canopy analyzer, and the PMS pressure bomb is anticipated during year 1 only. Field (sample bags, notebooks, clippers, etc.) and lab (hydrometer, graduated cylinders, computer supplies, etc) supplies are required for both years 1 and 2. A software license for IDL/ENVI is budgeted at $900 for year 1 only. $15,000/year is requested for moderate- and high-resolution imagery. The cost of office rental for L. Johnson and A. Michaelis is requested at $9,000/year for both years. Publication and team communication costs are estimated at $1,500/year for 2 years.

Consulting Services (Year 1 = $0; Year 2 = $1,500; Total = $1,500): Funds are requested for consulting services for grape yield/quality measurements in year 2.
Travel (Year 1 = $6,500; Year 2 = $7,000; Total = $13,500): We will require several trips between Monterey (CSUMB), Mountain View (NASA), and Napa (field sites) for team meetings and the collection of field data. Travel to meetings & conferences for purposed of outreach, education, and presentation of results is budgeted in years 1 and 2:
Other: Indirect costs are included at 20% of Modified Total Direct Costs (Total Direct Costs minus the cost for Office Rental). Year 1 = $31,154; Year 2 = $32,463; Total = $63,617.
Report Preparation: Funds are requested to support time and materials for preparation of quarterly reports to DWR.

CSUMB CA DWR Water-use Efficiency Proposal Budget (Pierce, Johnson, Nemani)

		12/05-11/06	12/06-11/07	Total
Salaries, Wages, Benefits				
Professional (L. Pierce)	0.35	$31,500	$33,075	$64,575
Professional (L. Johnson)	0.33	$31,106	$32,661	$63,768
Professional (A. Michaelis for R. Nemani)	0.30	$18,720	$19,656	$38,376
Student Lab/Field Assistants	2.00	$24,000	$25,200	$49,200
Fringe Benefits (L. Johnson, A. Michaelis)	35%	$17,439	$18,311	$35,750
Fringe Benefits (L. Pierce, Students)	11%	$6,105	$6,410	$12,515
Total Salaries		**$128,870**	**$135,314**	**$264,184**
Supplies and Expenses				
Equip. Maintenance (LAI-2000, Accupar, PMS)		$500		$500
Field and Lab supplies		$1,500	$1,000	$2,500
Software License (IDL/ENVI)		$900		$900
Image Data		$15,000	$15,000	$30,000
Office rental (L. Johnson, A. Michaelis)		$9,000	$9,000	$18,000
Publication and Communication		$1,500	$1,500	$3,000
Total Supplies and Expenses		**$28,400**	**$26,500**	**$54,900**
Consulting Services				
Grape yield/quality measurements			$1,500	$1,500
Total Consulting Services		**$0**	**$1,500**	**$1,500**
Travel				
Travel to field sites		$5,000	$5,000	$10,000
Travel to meetings/conferences		$1,500	$2,000	$3,500
Total Travel		**$6,500**	**$7,000**	**$13,500**
Report Preparation		**$1,000**	**$1,000**	**$2,000**
Total Direct Costs		$164,770	$171,314	$336,084
Indirect @ 20% MTDC (minus Office rental)		$31,154	$32,463	$63,617
Total		**$195,924**	**$203,777**	**$399,701**

Table C-1: Project Costs (Budget) in Dollars - CSUMB

	Category (I)	Project Costs $ (II)	Contin-gency % (ex. 5 or 10) (III)	Project Cost + Contin-gency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)
	Administration[1]					
	Salaries, wages	$215,919	0	$215,919	$0	$215,919
	Fringe benefits	$48,265	0	$48,265	$0	$48,265
	Supplies	$54,900	0	$54,900	$0	$54,900
	Equipment	$0	0	$0	$0	$0
	Consulting services	$1,500	0	$1,500	$0	$1,500
	Travel	$13,500	0	$13,500	$0	$13,500
	Other	$0	0	$0	$0	$0
(a)	Total Administration Costs	$334,084		$334,084	$0	$334,084
(b)	Planning/Design/ Engineering	$0	0	$0	$0	$0
(c)	Equipment Purchases/ Rentals/Rebates/Vouchers	$0	0	$0	$0	$0
(d)	Materials/Installation/ Implementation	$0	0	$0	$0	$0
(e)	Implementation Verification	$0	0	$0	$0	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0
(g)	Structures	$0	0	$0	$0	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0
(i)	Environmental Compliance/ Mitigation/ Enhancement	$0	0	$0	$0	$0
(j)	Construction	$0	0	$0	$0	$0
(k)	Other (Specify)	$63,617	0	$63,617	$0	$63,617
(l)	Monitoring and Assessment	$0	0	$0	$0	$0
(m)	Report Preparation	$2,000	5	$2,100	$0	$2,100
(n)	**TOTAL**	$399,701		$399,701	$0	$399,701
(o)	Cost Share -Percentage				0	100

1- excludes administration O&M.

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Attachments
Tables (2) and Figures (7)
CVs for Lars Pierce, Lee Johnson, and Rama Nemani
Letters of Support: Ed Weber (UCEE), Jay Hutton (Grayhawk), Richard Camera (Hess), Daniel Bosch (Mondavi)

Table 1. Climatic variables important for vintage quantity and quality: 1951–1997 increases; mean and standard deviation (ó) before and after the 1976–1977 regional Pacific climate shift. Differences significant at p > 0.99. DTR is diurnal temperature range, and GSL is growing season length.

Parameter	1951–1997 changes	1951–1976 Mean	1951–1976 σ	1977–1997 Mean	1977–1997 σ
Winter T_{min} (°C)	2.39	3.74	0.88	5.06	1.16
Spring T_{min} (°C)	2.44	8.04	0.63	9.42	0.77
Summer DTR (°C)	–3.14	19.00	0.85	17.50	0.98
Number of frosts yr^{-1}	–20.00	22 .00	9.00	10.00	9.00
Frost-free GSL (d)	65.00	272 .00	18.00	311.00	29.00
Growing degree days	240.00	1714.00	102.00	1830.00	112.00
VPD (kPa)	–0.159	2.41	0.12	2.29	0.15

VITIS Project Tasks & Timeline Task	Yr 1: 12/05-11/06 W	 Sp	 Su	 F	Yr 2: 12/06-11/07 W	 Sp	 Su	 F
Remote Sensing								
Establish sampling grid at intensive study blocks	■							
Measure monthly canopy density in study blocks		■	■			■	■	
Develop high res. Kc maps for study farms			■	■			■	■
Investigate Kc scaling and imagery resolution				■	■			
Develop low res. Kc maps for study farms					■			
Develop low res. Kc maps for Napa Valley								■
Compare canopy/soil patterns in study blocks				■	■			
Add'l soil sampling across study farms							■	
Compare canopy/soil patterns across study farm								■
Modeling								
Refine prototype VSIM/TOPS at study farm	■	■						
Model-based assess. of RDI water savings	■	■						
Measure soil characteristics in study blocks		■						
Measure monthly soil moisture, vine water stress		■	■			■	■	
Model vs. data comparison in study blocks				■				■
Split blocks and define/implement RDI schedules						■	■	
Monitor irrigation in treatment/control subblocks						■	■	
Measure grape quality/yield								■
Compare irrig. + qual./yield betw. subblocks								■
VITIS Development								
Design and create initial VITIS web site	■	■						
Implement 1st generation VITIS web site		■	■					
Develop ETo gridding schemes				■				
Populate VITIS public archive (NWS/soil/MODIS)				■	■			
Develop VITIS private archive at study farms					■	■	■	
Develop 2-way grower/VITIS interface						■	■	
Soil moisture, irrigation maps for Napa Valley							■	■
Complete beta implementation of VITIS								■
Valley-wide assess. of RDI water savings								■

Table 2. VITIS project tasks and timeline. Winter is Dec-Feb, spring in Mar-May, summer is June-August, and fall is Sept-Nov.

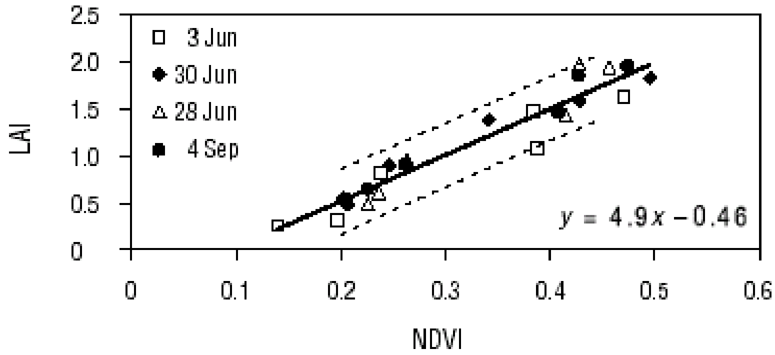

Figure 1. Temporal stability of the NDVI-LAI relationship for Napa Valley vineyards (6 blocks x 4 dates). Dashed lines show 95% confidence interval. From Johnson (2003).

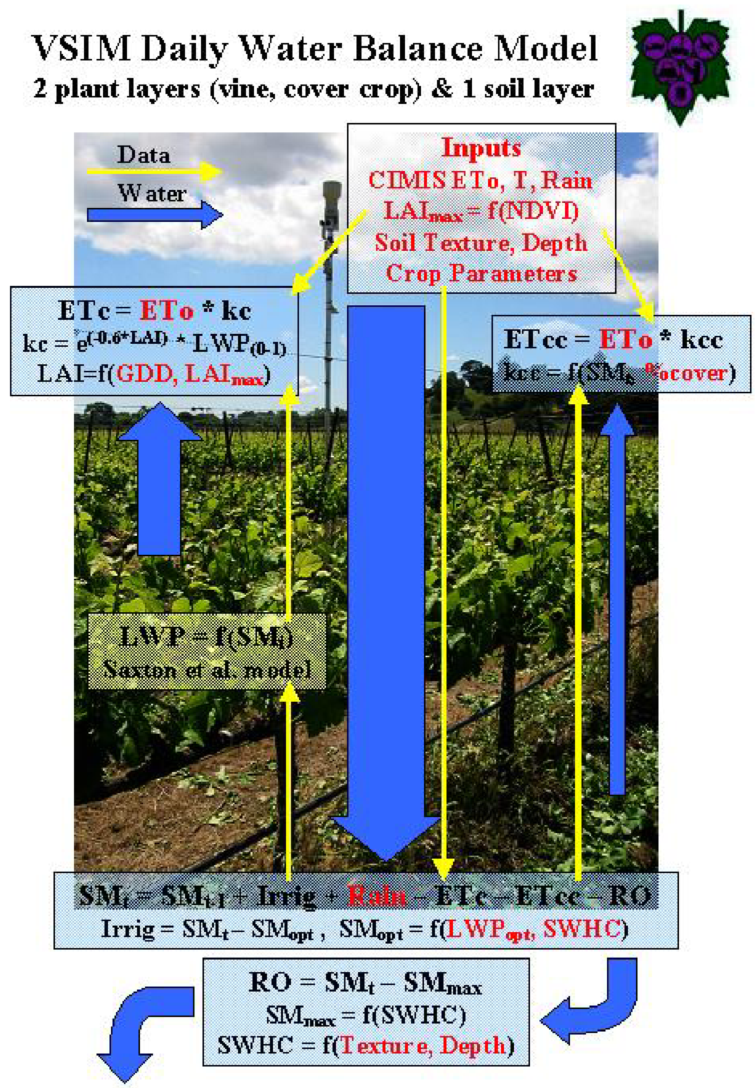

Figure 2: The flow of water and information in the VSIM vineyard water balance model. Canopy density and k_c are derived from remotely sensed NDVI imagery, climate inputs are derived from daily CIMIS weather data, and soil water-holding capacity is derived from measurements of soil texture and depth. VSIM calculates daily soil moisture and uses Saxton et al. (1986) to relate soil moisture to daily plant water stress as a function of soil type. VSIM can be used to schedule irrigations given a target crop water stress. A 1D version of VSIM runs in MS Excel and a spatially-explicit 2D version runs in the IDL/ENVI image processing package.

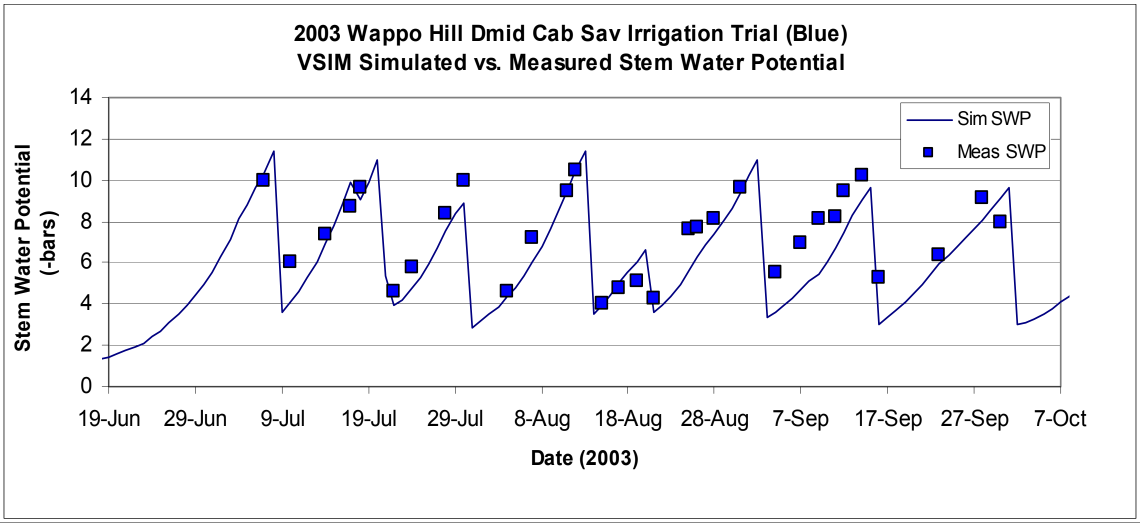

Figure 3: Simulated vs. measured stem water potential for a Cabernet Sauvignon (CS) block in the Stag's Leap District of the Napa Valley, 2003 (R2 = 0.85). Approximately 32mm of irrigation was applied every 2 weeks (spikes) to the CS block after the critical water stress was first achieved in mid-July.

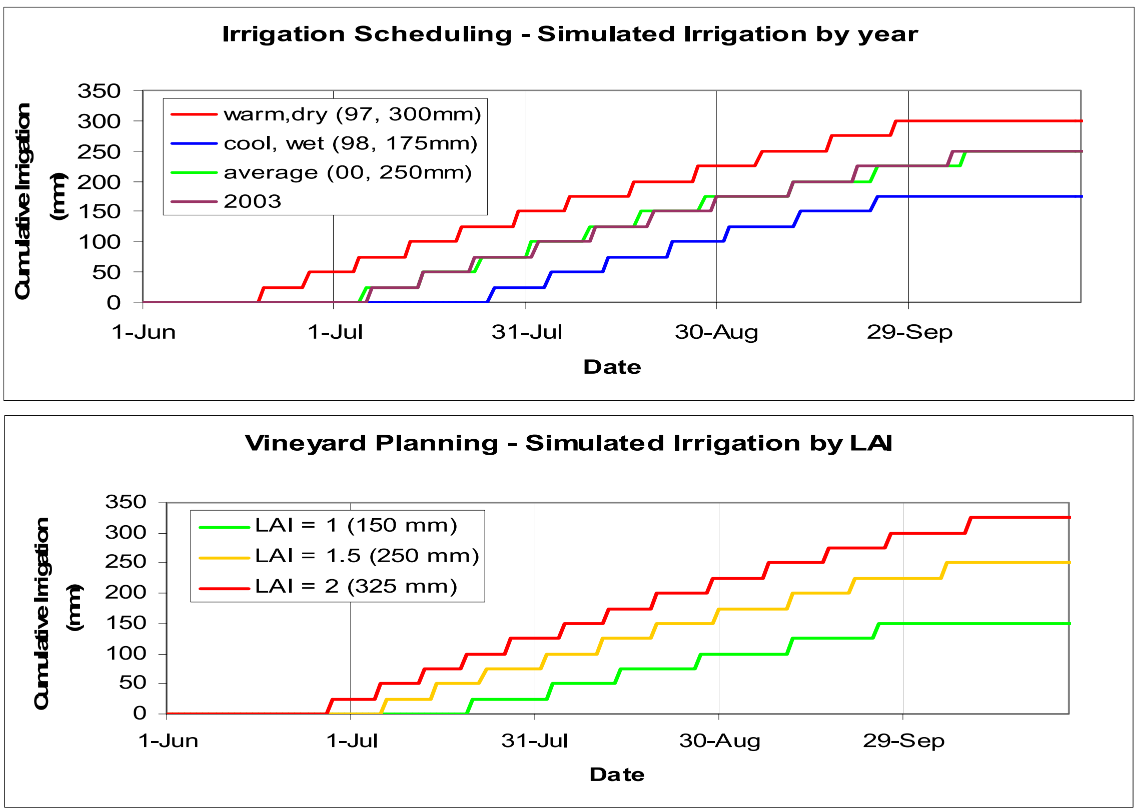

Figure 4: Examples of how the VSIM vineyard water balance model can be used in irrigation scheduling and vineyard planning for a Cabernet Sauvignon block in Napa Valley. The upper figure shows the effects of annual variations in climate on the total amount and timing of irrigation. The lower figure shows the effects of vine spacing and canopy density (as these affect Leaf area index; LAI, leaf area / ground area) on the amount and timing of irrigation. Total irrigation values in parentheses.

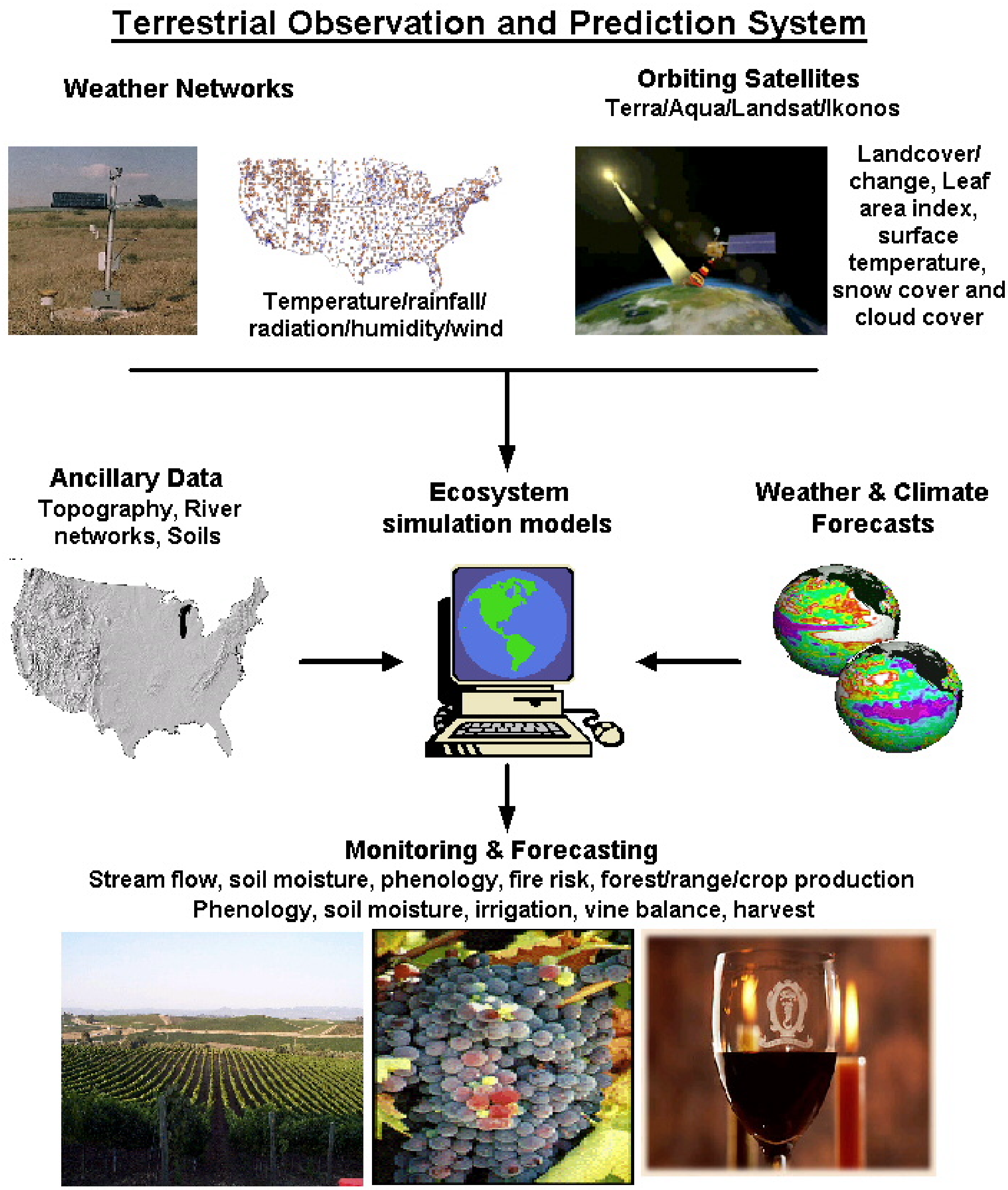

Figure 5. Automated web-based data assimilation and modeling capabilities of the Terrestrial Observation and Prediction System (TOPS). We have nested the VSIM water balance model within TOPS to begin the development of automated irrigation scheduling for Napa Valley vineyards. For more information see the TOPS web site at http://geo.arc.nasa.gov/sge/ecocast/index.html.

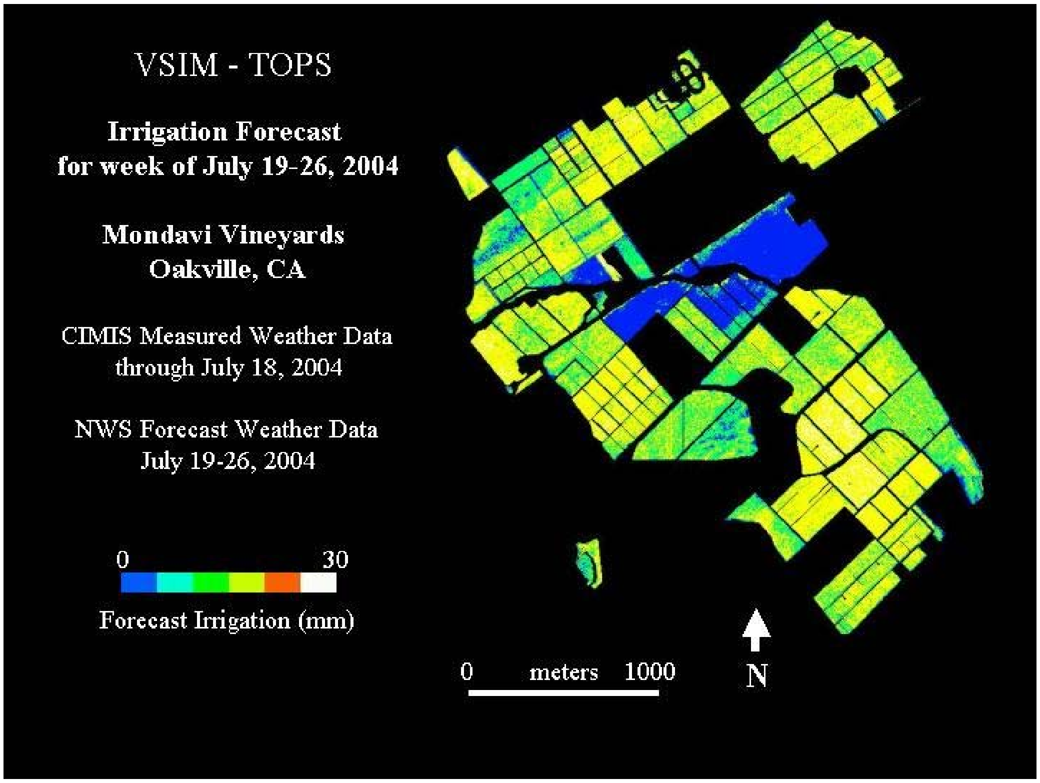

Figure 6. An example of an irrigation forecast map produced using the VITIS prototype for July 19-26, 2004 for a 1000 acre vineyard in the Napa Valley. Input canopy density maps from satellite imagery, NRCS STATSGO soils maps, measured CIMIS met data, and NWS forecast met data were used to drive the simulation.

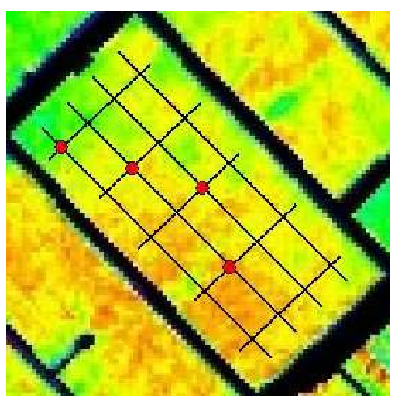

Figure 7. Example of our sampling design layout within a vineyard block. Intensive, direct measurements of canopy density, soils, and vine water stress will me made at 4 sample points (dots) distributed by canopy density. Indirect canopy density measurements will be made at 20 points throughout the block (grid intersections).

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Research Experience
Remote sensing of plant communities (leaf area index, vegetation type)
Modeling of ecosystem energy, water, carbon, and nutrient dynamics
Measurement and modeling of vineyard water balance

Education
Ph.D. Forest Ecology; University of Montana, 1993. Advisor: Dr. Steve Running
Thesis: Scaling Ecosystem Processes from Forest Stands to Regions.
M.S. Wildland Resource Science, Remote Sensing emphasis; UC, Berkeley, 1986
B.S. Geography and Environmental Studies; UC, Santa Barbara, 1982.

Courses Taught
Introduction to the Atmosphere, California Ecosystems, Ecological Modeling, Field Methods, Senior Thesis Seminar

Journal Reviews
Ecological Applications, Global Biogeochemical Cycles, Global Change Biology, Remote Sensing of Environment, International Journal of Remote Sensing, Journal of Geophysical Research, New Phytologist.

Proposal Reviews (2000-present)
USGS, Global Change Research in Biology, Integrated Research Themes, 2003.
NASA Terrestrial Ecology Program, 2002.
Nat'l Institute for Global Env. Change, Western Regional Center (WESTGEC), 2001-02.
NASA, New Investigator Program, 2000.
NSF, Biocomplexity Program, 2000.

Grants Received
2004 Ft. Ord Reuse Authority, Prescribed fire in maritime chaparral ($18k, ongoing).
2003 NASA Terrestrial Observation and Prediction System (ongoing contract)
2000-2002 State Water Resources Control Board, Salinas Sediment Study ($150k, Co-I).
2000 - U.S. Dept. of Agriculture, NRCS - EQIP grant ($10k, participant).
1998-2001 NASA/EPA Joint Program on Ecosystem Restoration, $700k (PI).
1998-1999 NSF, Age-related Decline in Ecosystem Productivity, NCEAS.
1995-2000 CO2 Models/Experiments Activity for Improved Links, Dept. of Energy.
1991-1993 NASA Graduate Student Fellowship in Global Change Research.

Related Experience

2002-pres. Assoc. Professor, Earth Systems Science & Policy, Cal State Monterey Bay.
1997-2002 Asst. Professor, Earth Systems Science & Policy, Cal State Monterey Bay.
1995-96 Postdoctoral Research Associate, Biological Sciences, Stanford University.
1994 Postdoctoral Research Associate, School of Forestry, University of Montana.
1991-93 NASA Global Change Research Fellowship, University of Montana.
1990 Visiting Scientist, CSIRO Division of Water Resources, Canberra, Australia.
1988 Visiting Scientist, ECOSat Branch, NASA Ames Research Center.
1986-89 Staff Scientist, School of Forestry, University of Montana.
1984-1986 Grad. Research Assistant, Dept. of Forest. & Resource Mgmt, UC Berkeley.

Relevant Publications

Running, S.W., R.R. Nemani, D.L. Peterson, L.E. Band, D.F. Potts, L.L. Pierce, and M.A. Spanner, 1989. Mapping regional forest evapotranspiration and photosynthesis by coupling satellite data with ecosystem simulation, Ecology 70(4):1090-1101.

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Johnson, L., L. Pierce, J. DeMartino, S. Youkhana, R. Nemani, and D. Bosch, 2003. Image-based decision tools for vineyard management, 2003 Amer. Soc. Agric. Engin. Int'l Meeting.

Hubbard S., L. Pierce, K. Grote , and Y. Rubin, 2003. Assessing the relative importance of incorporating spatial and temporal variability of soil and plant parameters into local water balance models: investigations within a California Vineyard , Eos. Trans. AGU 84(46), Fall Meet. Suppl., Abstract H42m-01, 2003.

Pierce, L., R. Nemani, and L. Johnson, 2004. Geospatial applications in the management of vineyard water balances, Napa GIS User Group Meeting, July 2004 (invited).

Pierce, L., 2004. Understanding Vine Water Use Over Space and Time, Geophysics of Winemaking Media Field Trip, Amer. Geophysical Union Fall Meeting (invited).

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RESEARCH EXPERIENCE:

--Agricultural applications of remotely sensed data.
--Remote sensing of canopy leaf area index and canopy structure.
--Empirical and model-based spectral assessment of leaf and plant canopy biochemistry.
--Investigation of sun & view angle effects on plant canopy reflectance.

CURRENT POSITION:

NASA/Ames Research Center, Earth Science Division

-Sr. Remote Sensing Research Scientist, Calif. State Univ., 7/97 - present
-Sr. Remote Sensing Research Scientist, JCWS Inc., 9/96 - 7/97
-Remote Sensing Research Scientist, JCWS Inc., 5/90 - 9/96

PRIOR POSITION:

NASA/Jet Propulsion Laboratory, Observational Systems Division, Member of Technical Staff, 1983-1990.

EDUCATION:

B.A. (double), Geography & Economics, UCLA, 1979.
M.A., Geography, UC Santa Barbara, 1982

AWARDS:

NASA Group Achievement Award, 1989, 1998, 2003.
NASA/Ames Contractor Certificate of Excellence, 1993.

INVITED PRESENTATIONS (recent):

National Alliance of Independent Crop Consultants, 2005
American Society of Enology & Viticulture, 2004
Chilean Ministry of Agriculture, Chile, 2004
Napa Valley Vineyard Technical Group, 2003
Australian National Wine and Grape Industry Centre, 2000

JOURNAL PUBLICATIONS (Agriculture):

Johnson, L, and T. Scholasch. Remote sensing of shaded area in vineyards. *HortTechnology* (accepted)

Nemani, R., L. Johnson and M. White. Application of Remote Sensing and Ecosystem Modeling to Vineyard Management. In: Precision Farming: A Global Perspective, A. Srinivasan, Ed., Haworth Press, NY (in press).

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Peterson, D. and L. Johnson, 2000. The application of Earth science findings to the practical problems of growing winegrapes, *Geographic Information Sciences*, 6:181-187.

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Education:
A.P. Agric.University, Hyderabad, A.P, India, Agric. Sciences, B.Sc (1979)
Punjab Agric.University, Ludhiana, Punjab, India, Agric. Meteorology, M.Sc (1982)
University of Montana, Missoula, MT, U.S.A., Remote Sensing and Forestry, Ph.D (1987)

Appointments:

Research Scientist, NASA Ames Research Center, Moffett Field, CA., (2003-present)
Research Associate Professor, University of Montana, Missoula, MT (1997-2002)
Research Assistant Professor, University of Montana, Missoula, MT (1991-1996)

Related Publications:

Band, L.E., D.L. Peterson, S.W. Running, J.C. Coughlan, R. Lammers, J.Dungan, and R.R. **Nemani**. 1991. Forest ecosystem processes at the watershed scale: Basis for distributed simulation. *Ecological Modeling*, 56: 171-196.

Nemani, R.R., S.W. Running, L.E. Band and D.L. Peterson. 1993. Regional Hydro-Ecological Simulation System: An illustration of the integration of ecosystem models in a GIS. In: *Environmental modeling with GIS*, Eds: M. Goodchild, B. Parks and L. Steyaert, Oxford, London.

Band, L.E., P. Patterson, R.R. *Nemani* ***and S.W. Running. 1993. Forest ecosystem processes at the watershed scale: 2. Adding hillslope hydrology." Agricultural and Forest Meteorology, 1993, v.63, p.93-126***

Nemani, R.R., L.L. Pierce, L.E. Band and S.W. Running. 1993. Forest ecosystem processes at the watershed scale: Sensitivity to remotely sensed leaf area index estimates. *International Journal of Remote Sensing*, 14: 2519-2534.

Other publications:

Nemani, R.R., and S.W. Running. 1989. Testing a theoretical climate-soil-leaf area hydrologic equilibrium of forests using satellite data and ecosystem simulation. *Agricultural and Forest Meteorology*, 44: 245-260.

Nemani, R. and S.W. Running. (1995). Satellite monitoring of global land cover changes and their impact on climate. *Climate Change* **31**: 395-413.

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Myneni, R.B., C.D. Keeling, C.J. Tucker, G. Asrar and R.R. **Nemani**. 1997. Increase plant

growth in the northern high latitudes from 1981-1991. *Nature* (April 17), 386: 698-702.

Myneni, R.B., **Nemani, R.R**., and Running, S.W. (1997). Algorithm for the estimation of global land cover, LAI, and FPAR based on radiative transfer models. *IEEE Trans. Geoscience and Remote Sensing*, 35: 1380-1392.

Nemani, R.R., M.A. White, D.R. Cayan, G.V. Jones, S.W. Running and J.C. Coughlan. 2001. Asymmetric climatic warming in coastal California and its impact on the premium wine industry. Climate Research, 19: 25-34.

Nemani ***R., M. White, P. Thornton, K. Nishida, S. Reddy, J. Jenkins, and S. Running, 2002. Recent trends in hydrologic balance have enhanced the terrestrial carbon sink in the United States, Geophys. Res. Letters, 29 (10), doi:10.1029/2002GL014867.***

Nemani, R.R., C.D. Keeling, H. Hashimoto, M. Jolly, S.W. Running, S.C. Piper, C.J. Tucker and R. Myneni. 2003. Climate driven increases in terrestrial net primary production from 1982 to 1999. Science 300, 1560-1563.

Running, S.W., **Nemani**, R. R., Heinsch, F. A., Zhao, M., Reeves, M., Jolly, M. 2004) A continuous Satellite-derived measure of global terrestrial primary production. *Bioscience*, 54(6): 547-560.

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Synergistic Activities

Public outreach: interviews with NPR, BBC, CNN and many other news outlets,

Reviewer for Science, Nature, Journal of Geophysical Research-Atmospheres, Geophysical Research Letters, Global Biogeochemical Cycles, Global Change Biology, Remote Sensing of Environment, Int. J. Remote Sensing

Collaborators:

Dr. Charles D. Keeling (Scripps Institution of Oceanography, La Jolla, CA); Dr. Daniel R. Cayan (Director, Climate Research Division, Scripps Institution of Oceanography, La Jolla, CA); Dr. Compton Tucker (NASA Goddard Space Flight Center, Greenbelt, MD); Dr. Ranga B. Myneni (Department of Geography, Boston University, Boston, MA); Dr. Steven W. Running (School of Forestry, University of Montana, Missoula, MT); Dr. Chris Elvidge (National Geophysical Data Center, NOAA, Boulder, CO)

Advisors: Harpal Singh (M.S), Steve Running (PhD)
Advisees: Michael White (PhD), Peter Thornton (PhD), Hirofumi Hashimoto (PhD), Galina Churkina (PhD), Matt Jolly (PhD), Matt Reeves (PhD), Patricia Andrews (PhD), Kazuhito Itchii (post-doc)

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Water Use Efficiency Program
Calif. Dept. Water Resources
PO Box 942836
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2 January 2005

Dear Reviewers:

I am writing to express support for the proposal, "VITicultural Information System (VITIS)" submitted by Prof. Lars Pierce et al., in response to the 2004 Water Use Efficiency Proposal Package.

UC Cooperative Extension (UCCE) links federal, state, county and private resources to engage in applied agricultural research and educational outreach. UCCE's interests include the improvement of production practices and resource management.

In Napa County, a substantial number of growers currently use airborne and satellite remotely sensed imagery for various aspects of decision support in their vineyard management operations. The R&D effort proposed here will develop higher-level remote sensing based products for use in water balance calculation and irrigation scheduling. Irrigation management is one of the most critical aspects of grape growing for high quality wine production. New technology to assist growers in this effort will be quickly embraced by growers.

U.C. Davis, in concert with the Calif. Dept. of Water Resources, developed and operates the California Irrigation Management Irrigation System (CIMIS). CIMIS consists of a statewide network of computerized weather stations coupled with an on-line delivery mechanism, freely available to growers and other members of the public. The modeling component of the proposed research potentially adds value to the CIMIS data stream for growers and resource managers in Napa and other viticultural regions, as well as to broader irrigated agriculture within California.

I have worked with this research team in past projects in Napa County and they have an excellent track record for successfully completing projects and generating useful, applied products. NASA Ames Research Center will support the project with innovative processing, visualization and data delivery methods.

University of California and United States Department of Agriculture Cooperating

UCCE in Napa County will assist the research team, as needed, with professional education and public outreach aspects to include, for example, speaking engagements at the Napa Valley Vineyard Technical Group and sponsorship of a UC Extension Course in vineyard remote sensing and modeling.

Thank you for your consideration of this project and please feel free to contact me if needed.

Sincerely,

Ed Weber
County Director & Viticulture Farm Advisor

Airborne Imaging
Vineyard Vigor Scale ™ Imaging
NDVI Plant Vigor Indexed Images
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Vertical Color/B&W Film Photography
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3 January 2005

Lars Pierce, Associate Professor
Division of Science & Environmental Policy
California State University Monterey Bay
100 Campus Center
Seaside, CA 93955-8001

RE: Characterizing spatiotemporal variations in canopy density, soils, climate, and vineyard water balances to derive spatially-explicit irrigation strategies: Development of the VITicultural Information System (VITIS) by L. Pierce, L. Johnson, R. Nemani

Dear Lars:

GrayHawk (an airborne remote sensing company) is pleased to participate in the above proposal to the CA Water Use Efficiency Program, designed to further develop remote sensing and water balance modeling technologies to enhance water savings and winegrape quality. I am excited about VITIS in that it provides a value-added, irrigation management product to imagery that I currently provide to growers. VITIS combines a number of important datasets (remote sensing, weather, soils) within a water balance model framework that provides growers with important information on past, present, and/or future vine water needs.

At GrayHawk, we utilize our own, in-house camera/sensor, aircraft platform, and software/hardware to provide vineyard managers with maps of canopy density and vine vigor in the Napa and Sonoma Valleys (and beyond). GrayHawk has been providing growers with imagery since 2001. We currently have over 200 clients in the North Coast region that use these maps to manage canopy and crop spatial variability. In response to your previous outreach efforts in the North Coast region, I have been in contact with a number of growers (e.g. The Hess Collection Winery, Kendall Jackson, and Joseph Phelps and others) that have recognized the potential of the VITIS decision support system in managing irrigation. These growers manage vineyards across the Napa and Sonoma Valleys and have expressed a strong desire to participate in the development of VITIS technology that can assist with vineyard irrigation management decisions.

GrayHawk would enjoy providing the following support to your proposed project: assistance with acquisition and interpretation of high-resolution imagery for vine mapping at your proposed study sites, b) contact, coordination, and follow-up support in working with specific growers to implement VITIS, and c) expert opinion and guidance on the development of VITIS in linking with remote sensing data and in providing value-added vineyard mapping and management capabilities to growers in the North Coast region.

Sincerely,

Jay Hutton, Principal
GrayHawk

THE HESS COLLECTION

3 January 2005

Lars Pierce, Associate Professor
Division of Science & Environmental Policy
California State University Monterey Bay
100 Campus Center
Seaside, CA 93955-8001

RE: Characterizing spatiotemporal variations in canopy density, soils, climate, and vineyard water balances to derive spatially-explicit irrigation strategies: Development of the VITicultural Information System (VITIS) by L. Pierce, L. Johnson, R. Nemani

Dear Lars:

The Hess Collection Winery strongly supports the above proposal to the CA Water Use Efficiency Program, designed to further develop remote sensing and water balance modeling technologies to enhance water savings and winegrape quality. Remotely - sensed canopy density maps, combined with CIMIS weather data within the Vineyard – Soil Irrigation Model (VSIM), hold significant potential value for the wine industry as a vineyard planning and irrigation scheduling decision-support tool. One particularly powerful aspect of this approach is the coupling of weather data and airborne/satellite imagery (already procured by many growers for vineyard management) within an irrigation scheduling framework.

The Hess Collection Winery will make any necessary access, time, and personnel contributions in support of the proposed project in 2006 and 2007, as follows: a) provide access to six (6) study blocks in North Coast vineyards for purposes of non-destructive vine and soil measurements, b) support spatially-based irrigation trials within the 6 study blocks in 2007 (as defined in the attached proposal, and provided that the VSIM model proves successful in simulating vine water stress in 2006), c) provide access to any relevant current or historical measurements and/or records in the 6 study blocks, d) provide access to vineyard blocks, beyond the 6 study blocks, for purposes of non-destructive soil/vine sampling in support of farm-scale irrigation decision support, and e) provide expert opinion and guidance in development and analysis of VITIS irrigation decision support tools. Any data provided by The Hess Collection Winery is to remain confidential; publication of data would be reviewed on a case-by-case basis. Researchers will be required to sign an indemnity release waiver prior to initiating the proposed project. In return, The Hess Collection Winery will have access to all of their farm data collected, and will receive assistance, support, and training in the use of VITIS to support vineyard management.

Sincerely,

Richard L. Camera

Richard Camera
VP, Director of Vineyard Operations

The Hess Collection Winery
4411 Redwood Road • P.O. Box 4140 • Napa, California 94558 • Telephone (707) 255-1144 • Facsimile (707) 253-1682

ROBERT MONDAVI VINEYARDS

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7 January 2005

Lars Pierce, Associate Professor
Division of Science & Environmental Policy
California State University Monterey Bay
100 Campus Center
Seaside, CA 93955-8001

RE: CA DWR WUE Proposal: Development of the VITicultural Information System (VITIS) by L. Pierce, L. Johnson, R. Nemani

Dear Lars:

The Robert Mondavi Winery (RMW) strongly supports the above California Water Use Efficiency Program proposal to further develop the VSIM water balance model and the Terrestrial Observation and Prediction System (TOPS) within the Napa Valley. VSIM and TOPS, which were developed and initially validated through grants from NASA's Earth Science Enterprise, will be useful tools for the wine industry as a vineyard planning and irrigation scheduling decision-support tool. One particularly powerful aspect of VSIM/TOPS is an optional coupling with airborne/ satellite imagery, as already procured by many growers for mapping vineyard variability.

As the Director of Vineyard Operations, I have enjoyed working with Lars, Lee, and Rama on providing access to RMW vineyards, sharing data, discussing ideas, using the VSIM model, and in providing industry feedback. I look forward to continued participation in the VITIS Project. The irrigation decision support tools proposed in VITIS are beginning to yield value-added products that are useful in developing deficit irrigation schedules. Support provided by the Dept. of Water Resources Water Use Efficiency Program would help to ensure the development and application of these tools in the wine industry and beyond.

Sincerely,

Daniel Bosch

Daniel Bosch
Director of Vineyard Operations