UNIVERSITY OF CALIFORNIA, DAVIS

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David Ricci, Contracts and Grants Analyst
Office of Research
One Shields Avenue
Davis, California 95616-8671

Sponsored Programs, 118 Everson Hall
Telephone: (530) 752-9753
Fax: (530) 754-9233
e-mail: fdricci@ucdavis.edu

January 4, 2005

California Department of Water Resources
Office of Water Use Efficiency
Attn: Ms. Debra Gonzalez
1416 Ninth Street, Room 338
Sacramento, CA 95814

Dear Ms. Gonzalez:

Letter in Support of Project Entitled
"Updating Crop Coefficient Information to Improve Crop Water Use Estimation"
Principal Investigator- Dr. Richard L. Snyder, UCD

It is our pleasure to forward institutional support and approval of the research project by UCD's Dr. Snyder on the referenced research project to the CA Department of Water Resources under the FINAL 2004 Water Use Efficiency Proposal Solicitation.

Please note that UCD takes exception to some of the provisions and language in the Solicitation. Specifically we call your attention to the following:

Section A-9/ B-9: Paragraph B Reports (Request replacing with GIA 101)
Section A-11/ B-11: Intellectual Property Rights (Request replacing with GIA 101)

Please note that agreements with the above considerations have previously been negotiated with CADWR on behalf of the University of California and agreeable language has been included in current agreements with UC Davis.

Should the Department make an award to the University, we would anticipate negotiating terms that comply with University and federal guidelines as they pertain to the higher learning institutions and retention of intellectual property rights.

Please contact the principal investigator for scientific information. Administrative questions may be directed to me by telephone, facsimile or electronic mail at the numbers cited above.

Sincerely,

David Ricci
Contracts & Grants Analyst

cc: Dr. Snyder

UNIVERSITY OF CALIFORNIA
COOPERATIVE EXTENSION

DAVIS, CALIFORNIA
Dept.: Land, Air and Water Resources
Office: 243 Hoagland Hall
Phone: (530) 752-4628
FAX: (530) 752-1793
Email: rlsnyder@ucdavis.edu

REPLY TO:
University of California
One Shields Avenue
Land, Air and Water Resources
Davis, CA 95616-8627
January 4, 2005

Debra Gonzalez
California Department of Water Resources
Office of Water Use Efficiency
P.O. Box 942836,
Sacramento, CA 94236-0001

Dear Ms. Gonzales:

Please find enclosed one original, eight photocopies, and an electronic version of the proposal entitled "**Updating Crop Coefficient Information to Improve Crop Water Use Estimation**".

Please feel free to contact me at (530) 752-4628 if you have any additional questions.

Sincerely,

Richard L. Snyder

University of California and the United States Department of Agriculture cooperating

2004 Water Use Efficiency Grant Proposal

for

Updating Crop Coefficient Information to Improve Crop Water Use Estimation

A Section B Research Proposal submitted by

by

Richard L. Snyder

University of California
One Shields Avenue
Land, Air and Water Resources
Davis, CA 95616-8627

To the
California Department of Water Resources

Pursuant to the

Final 2004 Water Use Efficiency Proposal Solicitation Package

January 2005

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 _____ ☐ (d) Specify other: _____	
2. (Section B) **Urban or Agricultural Research and Development; Feasibility Studies, Pilot, or Demonstration Projects; Training, Education or Public Information; Technical Assistance**	☒ (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):	Richard L. Snyder, University of California, Davis Department of Land, Air and Water Resources	
4. Project Title:	**Updating Crop Coefficients Information to Improve Crop Water Estimation**	
5. Person authorized to sign and submit proposal and contract:	Name, title Mailing address Telephone Fax. E-mail	David Ricci Contracts and Grants Analyst Office of the Vice Chancellor for Research Sponsored Programs, 118 Everson Hall University of California One Shields Avenue Davis, California 95616-8671 (530) 752-9753, FAX (530) 754-9233 fdricci@ucdavis.edu

Mailing address _____

_____

Telephone _____

Fax. _____

E-mail _____

7. Grant funds requested (dollar amount): $298,058
(from Table C-1, column VI)

8. Applicant funds pledged (dollar amount): $90,900 (Cooperator Cost Share)

9.Total project costs (dollar amount): $388,958
(from Table C-1, column IV, row n)

10. Percent of State share requested (%) 77%
(from Table C-1)

11. Percent of local share as match (%) 23% (Cooperator Cost Share)
(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.

☐ (a) yes

(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.)

☒ (b) no

11. Is your project required by regulation, law or contract? ☐ (a) yes
If no, your project is eligible.

If yes, your project may be eligible only if there will be accelerated implementation to fulfill a future requirement and is not currently required. ☒ (b) no

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): Jan. 2006 –December 2007
13. State Assembly District where the project is to be conducted: Statewide

14. State Senate District where the project is to be conducted: Statewide

15. Congressional district(s) where the project is to be conducted: Statewide

16. County where the project is to be conducted: Statewide

17. Location of project (longitude and latitude) Statewide

18. How many service connections in your service area (urban)? Not Applicable

19. How many acre-feet of water per year does your agency serve? Not Applicable

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

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	**David Ricci** **Contracts and Grants Analyst** Name and title	1/4/05 Date

A. PROJECT SUMMARY

Accurate crop coefficients are vital to the fundamental water balances underlying all the quantifiable benefits. This applied research proposal will test remote sensing as an innovative method to develop crop coefficients and stress coefficients based on a large area of crops and actual management conditions. The crop coefficients developed will also enable improvement of real-time irrigation scheduling, an important aspect of water management services to growers. These services to growers are an important aspect of the third Efficient Water Management Practice (EWMP) on List A and an entire category of quantifiable benefits across all the CALFED sub-regions. This is one of the EWMPs required to be implemented by all signatories to the Agricultural Water Management Council (AWMC) Memorandum of Understanding (MOU). The purpose of this applied research study is to begin to update and improve the crop coefficients in use in California.

Inaccuracies in crop and landscape coefficients can result from many reasons or combinations of reasons. One of the most common is use of the crop coefficient with a reference evapotranspiration (ET_o) other than the one used to develop the crop coefficients. Differences in the crop season length, poor accounting of drainage in early studies, different irrigation methods and frequencies can all affect the accuracy or appropriateness of a crop coefficient. Recent research conducted in California has found lower crop coefficients for rice, corn and cotton compared to traditionally accepted values. One reason for these differences may be more accurate crop ET (ET_c) measurement as measurement methods have evolved and improved over the years.

This research will begin with an extensive literature review of crop coefficient research to compile and assess the accuracy of a list of available crop coefficients. From the literature review, correction factors for within crop variations that can impact crop coefficient values will be developed. The different methodologies to estimate crop coefficient curves, i.e. growth stage versus growing degree days, will be compiled and evaluated.

Due to the difficulties of measuring ET_c, most crop coefficients are based on a small spatial area within a larger field. Remote sensing of ET_c offers a new and innovative method to develop and refine crop and stress coefficients by utilizing a much larger spatial sample of ET_c. Surface Energy Balance Algorithm for Land (SEBAL), under continuous development and refinement over the last 15 years, is one of the oldest, most thoroughly validated remote sensing methods for computing ET_c. This research will first compare SEBAL ET_c computations against ground–based measurements, including the University of California (UC) Davis lysimeters. Next, the data from images processed will be utilized with California Department of Water Resource (CDWR) digital land use surveys to refine the crop coefficients found by the literature review.

B. STATEMENT OF WORK

B.1. Relevance and Importance

B.1.a. Problem statement and project goal

Proven crop coefficients are vital to the fundamental water balances underlying all the quantifiable benefits and irrigation management services utilizing the California Irrigation Management Information System (CIMIS) to improve on-farm irrigation management benefiting an entire category of quantifiable objectives across all the CALFED sub-regions. The water balances underlying the development of the targeted benefits are based on crop coefficients developed for “pristine” conditions on small crop areas. The total crop water use computed is then discounted for non-pristine conditions. This applied research proposal will test remote sensing as an innovative method to develop crop coefficients and stress coefficients based on a large area of crops and actual management conditions. The crop coefficients developed will also improve real-time irrigation scheduling, an important aspect of water management services to growers. These services to growers are an important aspect of the third EWMP on List A and an entire category of quantifiable benefits across all the CALFED sub-regions.

The California Irrigation Management Information System (CIMIS) was developed during the period 1982-85 to provide California growers and landscape professionals with access to reference evapotranspiration (ET_o) information. This information can be used to estimate crop evapotranspiration for use in irrigation scheduling and water resource planning. When estimating crop (ET_c) or landscape (ET_L) evapotranspiration one multiplies the daily ET_o rate by a crop (K_c) or landscape (K_L) coefficient. The K_c or K_L coefficient to employ depends on particular plant canopy characteristics and management (i.e., canopy size and orientation, stomatal responses to the environment, surface and plant wetness, and plant age). While much information on K_c and K_L values was available during the early development of CIMIS, there are many crops with unknown or questionable crop and landscape coefficient information. Inaccuracies in crop and landscape coefficients are due to a variety of reasons including:

1. Coefficients were developed using a different ET_o estimation method
2. Changes in the length of cropping seasons
3. Lack of accounting for drainage in older experiments
4. Changes in the irrigation method
5. Changes in irrigation frequency
6. Neglecting the effects of rainfall
7. Neglecting the effects of slope and orientation on available energy

There is clearly a need to update and improve coefficients for most of the crops and landscape plants grown in California. This is true on a national and international level as well. For example, the Task Committee on Crop Coefficients, which is a subcommittee of the Evapotranspiration in Irrigation and Hydrology Task Committee of the American Society of Civil Engineers – Environmental Water Resources Institute was recently

formed to update and improve crop coefficients on a national level for the Society. Since California has the largest number of crops and the greatest need for the crop coefficient information, this committee has agreed to work with us on updating crop and landscape coefficients.

A good example of the need for crop coefficient updating comes from recent research on the ET_c for citrus orchards. Until recently, the midseason K_c value for mature citrus orchards was commonly reported as $K_c \approx 0.67$. In four years of research (2001-04), it was reported that the K_c values were about 0.85 after severe pruning and topping of mature naval orange trees to slightly higher than 1.00 after two years of regrowth. The $K_c = 0.67$ was developed many years ago when the orchards were infrequently watered by furrow irrigation. Now, it is common to irrigate citrus orchards with microsprinklers once or twice per week. The more frequent microsprinkler irrigation results in more vigorous trees and more soil evaporation with higher ET_c rates. Another example is the midseason crop coefficient for rice, which is now reported to be about $K_c \approx 1.05$. In the past, the K_c for rice was reported to $K_c \approx 1.28$. Midseason crop coefficients for corn have changed from $K_c = 1.22$ to $K_c = 1.05$ and for cotton the reported crop coefficients have changed from $K_c = 1.28$ to $K_c = 1.05$. The large difference is likely due to ET_c measurement method differences and the ET_o equation used.

In addition to problems with accuracy of the K_c value itself, there are considerable differences in the lengths of growth stages reported in the old and current literature. The rate of crop growth is important because the K_c values generally increase as a canopy develops. On the other hand, a shorter season or a growing season that lies more in the spring or fall and less in the summer will reduce ET_c. In general, many crops have been bred to shorten their seasons, so the old number-of-days in a growth period are often not valid for predicting changes in canopy development and seasonal K_c changes. Clearly, there is a need for a significant upgrade of crop coefficient and growth information to better characterize crops and landscape plants.

Recently, the Task Committee on Reference Evapotranspiration, which is a subcommittee of the Evapotranspiration in Irrigation and Hydrology Task Committee of the American Society of Civil Engineers – Environmental Water Resources Institute completed their work on the ASCE Standardized Reference Evapotranspiration Equation and a draft report was prepared and is available at the following URL http://www.kimberly.uidaho.edu/water/asceewri/. In the next edition, the standardized method will be incorporated into the ASCE Manual 70 on *Evapotranspiration and Irrigation Water Requirements*. In the Standardized Reference Evapotranspiration Equation report, the committee provides equations for two reference surfaces (i.e., short 12-cm and tall 50-cm canopies with fixed canopy resistance). Although the surfaces are hypothetical, the reference ET values approximate the ET of a 12 cm tall cool-season grass and a 50 cm tall alfalfa crop. The Task Committee on Reference Evapotranspiration gave the symbols ET_o and ET_r to the reference evapotranspiration of short and tall canopies, respectively. The ET_o is the same as used in the CIMIS network in California.

Agreeing on the standardized reference evapotranspiration equation was the first step towards improving the estimation of crop evapotranspiration, but, because there are two reference ET equations and many crop coefficient (K_c) values are known for one and not the other equation, work is needed to develop K_c values for each of the reference equations. Therefore, a second task committee called the Task Committee on Crop Coefficients, with a three-year term was established by EWRI. The main duties of the TC are to review and update K_c related issues and feed that information to the Technical Committee on the revision of Manual 70.

While K_c values are known for major crops, the values are often specific to a reference evapotranspiration equation. For example, K_c values specific to the Kimberley Penman equation, which gives reference ET approximately equal to 50 cm tall alfalfa, are widely used in Idaho. The K_c values for a wide range of crops provided in the FAO Irrigation and Drainage Papers 24 and 56 are specific to a short canopy like 12 cm tall grass. However, many of these K_c values were developed long ago when varieties, cropping patterns and irrigation management were different. Because of these factors and the fact that the Standardized ET_o and ET_r equations do not give exactly the same results as other reference ET equations (e.g., Kimberley Penman, Hargreaves-Samani, Priestley-Taylor, Jensen-Haise, etc.), there is clearly a need to revise and update crop coefficients to be able to transfer K_c values from ET_r to ET_o for use in California. In addition, to developing K_{co} and K_{cr} values, the task committee will also attempt to simplify the methodology to transfer usable K_c values to growers to help improve their irrigation management. They will also investigate different methods to predict crop growth and relate the canopy size and structure to K_c values.

B.1.b. Project hypotheses and objectives

The **hypothesis** of the project is that remote sensing can provide accurate and useful information to refine crop coefficients by increasing the spatial base of actual ET used to compute the crop coefficients.

Therefore, the **objectives** of the project are to:

1. Compile the most extensive literature review of crop coefficients available.
2. Estimate K_{co} and K_{cr} values during midseason of known crops along with information on how to correct for differences in ground cover, foliage density, and irrigation management.
3. Estimate of K_{co} and K_{cr} curves during the season of all crops reviewed and one or more methodologies to estimate changes in the curves during a cropping season.
4. Assess confidence in the crop coefficient information for all crops reviewed.
5. Recommend what crops, irrigation methods, etc. need more research to improve the crop coefficients.
6. Demonstrate SEBAL's ability to spatially quantify ET_c over a large area in California

7. Compare SEBAL ET estimates to lysimeter and other ground-based estimates within the SEBAL image processed (path/row 43/33) across daily, monthly, seasonal and annual time scales.
8. SEBAL crop coefficient and analysis for the ten crops with the most area in image, including development of pixel- and field-scale (average of all pixels in defined fields):

    a. "pristine" crop coefficients,
    b. average-stress coefficients, and
    c. high-stress coefficients.

The project will be conducted over two years by the Department of Land, Air and Water Resources at University of California, Davis, in collaboration with SEBAL North America, Inc. (SNA). *Short- and long-term benefits* of this study include developing improved crop coefficients that can be applied across all CALFED Bay-Delta regions to increase water use efficiency on-farm through improved irrigation scheduling.

B.1.c. Support of California Bay-Delta Program Goals

This project improves the water balances that are fundamental to all the California Bay-Delta Program quantifiable objectives. The results also provide improved information on which to base comparison of potential actions and benefit/cost analyses of these actions to meet the quantifiable objective goals.

The goals of the Water Use Efficiency Program as defined by the California Bay-Delta Program "include water quantity, water quality, and in-stream flow and timing improvements that directly or indirectly provide benefits to the Bay-Delta". The project objectives, described above, also contribute directly to these goals by improving the water balances upon which the quantifiable objectives are based and by improving irrigation water management to meet these objectives.

Improved crop coefficients result in a better match of applied irrigation water to crop water requirements resulting in less runoff or deep percolation. These crop coefficients contribute to meeting the increased flow category of targeted benefits across all CALFED Bay-Delta sub-regions and EWMP number 3 on List A of the AWMC.

B.1.d. Integration with Local and Regional Integrated Water Resources Plans

The proposed research is expected to be consistent with the Yolo County Integrated Water Resources Plan (under development) and the Northern California Water Association Integrated Water Management Plan.

<u>Yolo County Integrated Water Resources Plan</u>

Improved crop coefficients enabling growers to better match irrigation water deliveries to crop water requirements facilitates the increased water use efficiency objective of the Integrated Water Resources Plan that is under development.

Northern California Water Association Integrated Water Management Plan
This proposal is consistent with the water use efficiency part of the Northern California Water Association (NCWA) integrated water management program.

B.1.e. Demand Management Activities

Improved crop coefficients are important for irrigation scheduling, an important aspect of agricultural demand management activities.

B.1.f. Linkage to Existing Water Management Activities

Improved crop coefficients link directly to efforts to improve on-farm irrigation efficiency. The on-farm irrigation efficiency that can be achieved is directly linked to the confidence the grower and/or irrigation-scheduling consultant has in the crop coefficient.

B.2. Technical/Scientific Merit, Feasibility

B.2.a. Methods, procedures, equipment

This project proposes to compile a literature of crop coefficients including information on how to correct for differences in ground cover, foliage density, and irrigation management. Furthermore, the project will test and evaluate remote sensing of ET as a method to develop and refine crop coefficients on a spatially larger data set by first, assessing the accuracy of remote sensing of ET by comparing remote sensing estimates to ET measurements from the lysimeter at UCDavis. Additional ground-based measurements of ET within row/path 43/33 available for the year chosen will also be compared to the remote sensing ET.

For estimating crop evapotranspiration (ET_c), there are two approaches that are commonly used. One method is called the single K_c approach and the other is called the dual K_c approach. The two methods are described in the United Nations FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). In the single K_c approach, a crop coefficient is selected based on the crop growth stage, canopy cover and management. In this method, the K_c averages together the effects of soil evaporation and plant transpiration. In the dual method, there is an attempt to separate the crop coefficient into a basal coefficient, which accounts for the crop transpiration with a dry soil, and an evaporation coefficient that accounts for soil wetness. However, the EWRI is currently investigating possible new methods to further improve the computation of K_c values.

When estimating ET_c using K_c values, the assumption is that there is no transpiration reducing water stress, so ET_c represents a well-watered condition for a crop. However, some crops are purposely stressed for a variety of reasons. When this occurs, the actual crop evapotranspiration (ET_a) is less than the well-watered ET_c. A stress coefficient (K_s) value is used as a factor to estimate ET_a from ET_c as: $ET_a = K_s \times ET_c$.

Crop coefficients are based on measurements or estimates of crop ET under “pristine” conditions (i.e., well-watered with no salinity stress and free of disease and pest infestations). Crop ET measurement/estimation techniques include lysimeters, eddy correlation, Bowen ratio, surface renewal and water balance methods. All of these methods except the water balance method cover a small spatial area ranging from a few square meters to a few hundred square meters for lysimeters and Bowen ration, respectively. The water balance method can be applied on a much larger scale; however, due to the difficulty of understanding the groundwater balance, it is most often applied at a small scale.

Remote Sensing

Remote sensing offers the promise of obtaining consumptive use and other water resource data over large areas at regular intervals. Thus, remote sensing offers an opportunity to develop and refine crop coefficients (Allen et al, 2003) based on crop ET measurement/estimation over a much larger area and across a much wider management spectrum. One of the most tested and accepted methods of computing crop ET from satellite remotely sensed data is SEBAL (Surface Energy Balance Algorithm for Land). This algorithm uses data gathered by satellite-based sensors to compute the energy balance at the earth’s surface. Evapotranspiration (ET) of crops and natural vegetation is predicted as a residual of the energy balance.

SEBAL was developed by Dr. Wim Bastiaanssen of The Netherlands and refined by Dr. Rick Allen of the University of Idaho for applications in mountainous terrain and to incorporate internal calibration to land-based reference evapotranspiration. SEBAL uses spectral radiances recorded by satellite-based sensors, plus ordinary meteorological data, to solve the energy balance at the earth's surface. Its primary outputs are actual evapotranspiration (ET_a) or water consumption (i.e., not reference or potential evapotranspiration, although both reference and potential evapotranspiration are computed during the process) and biomass production of agricultural crops and native vegetation, pixel by pixel.

SEBAL applies radiative, aerodynamic, and energy balance physics in a series of 25 computational steps. Evapotranspiration is computed as a residual of the surface energy balance. Knowledge of land use and crop types is not needed, since all information, with exception of ground-based weather data, is obtained from the satellite image. The calculation of ET_a is primarily driven by the thermal channels of the satellite sensor. By solving the energy balance for a "dry" and "wet" pixel, SEBAL does not depend upon the absolute calibration of the thermal channels (Tasumi, et al., 2003).

Instantaneous and daily ET_a outputs are computed directly by SEBAL. These results can be extrapolated to longer time periods of weeks or months using ratios of ET_a from SEBAL to reference ET computed from ground-based weather stations. Integration over time provides accurate seasonal and annual estimates of ET_a with the same spatial resolution of the source image.

SEBAL is the culmination of 15 years of research and thorough validation; its use in practical water resources and irrigation management applications is growing worldwide.

B.2.b. Task list, schedule, projected costs, and deliverables

Task 1 – Compile literature review on crop coefficients
An extensive literature review will be conducted to collect all available information on crop coefficients, including the reference ET the coefficient is based on and additional factors that may affect the coefficient.

Task 2 – Estimate midseason crop coefficients and related correction factors
Crop coefficients can be affected by differences in ground cover, foliage density, and irrigation management. These factors have been traditionally accounted for by correction factors applied to midseason crop coefficients. This task will compile and develop these correction factors, for the crop coefficients collected during the literature review.

Task 3 – Compile methods to estimate crop coefficient changes during the growing season
Crop coefficient values change during the season. Different methods have been utilized to change the curves during the season. The methods that have been used will be compiled, described, and assessed for accuracy and advantages and disadvantages.

Task 4 – Assess the confidence in the crop coefficient information compiled
Crop coefficient accuracy for each crop found will be assessed and documented. This will include summarizing the actual ET measurement method(s), the number of data sets, the climatic range of the data sets and the variability in crop coefficients computed from the data sets for each crop.

Task 5 – Recommend additional research required to improve crop coefficients
Based on the compiled literature additional research will be recommended to improve crop coefficients for the crops and irrigation methods where more accurate information would be of value.

Task 6 – Process up to two Landsat and two MODIS images per month to compute remote sensed ET estimates
This task is divided into two subtasks to facilitate partial funding should full funding not be available. The budget for each subtask is equal, so under full funding both tasks will be completed. Should partial funding be required, the budget for task 6 can be halved and only one subtask will be completed. The year(s) and Landsat row/path(s) selected will depend on the availability of lysimeter data, other ground-based ET measurements and DWR land use data.

Subtask 6.1 Process images covering a 12-month time period for one Landsat row/path
Purchase and process required satellite images to cover and compute actual ET for a 12-month period. Depending on the availability of cloud-free images, two Landsat

images will be processed for each summer month and one Landsat image and one MODIS image will be processed for each winter month. If sufficient cloud-free Landsat images are not available in a month, they will be replaced by MODIS images. Processing includes time integration between images and the deliverable will be ArcGrid files containing actual ET values for each pixel for the instant of each image, the day of each image and the two-week time period of each image. One ArcGrid file will contain the cumulative ET values for each year processed.

Subtask 6.2 Process images covering a 12-month time period for one Landsat row/path
Same as subtask one for a different 12-month at the same Landsat row/path as subtask 6.1, or the same or different 12-month time period for a second Landsat row/path.

Task 7 – Compare remote sensed ET estimates to ground-based estimates
Compare remote sensed ET estimates to ground-based ET estimates over five different time scales: 1) the moment of the image, 2) daily, 3) monthly, 4) seasonal, and 5) annual. One year of images from the Landsat row/path combination 43/33 that includes the UCDavis lysimeters will be selected for processing. The year chosen for processing will be based on available DWR digital land use coverages and the availability of lysimeter data. The ET estimates from SEBAL and the ground-based measurements will be exchanged and two independent comparisons conducted and reconciled. The expected result of this comparison is a graphical and tabular depiction of how the percent difference between the ground-based and remote-sensed estimates of ET varies with different time scales.

Task 8 – Develop and refine crop coefficients
SEBAL computes actual ET, reference ET and potential ET for each pixel. From these values for ET, the crop coefficient (potential ET/reference ET) and the stress coefficient (actual ET/potential ET) can be computed for each pixel. These values, computed for each pixel, will be analyzed in conjunction with available land use coverages (DWR and possibly others that may be available) to develop and refine crop and stress coefficients. These values will also be summarized to a field scale based on available land use coverages and field-scale crop and stress coefficients will be computed. This analysis will include development of pixel- and field-scale (average of all pixels in defined fields):

1. “pristine” crop coefficients,
2. average-stress coefficients, and
3. high-stress coefficients.

Frequency and cumulative distributions of both the pixel- and field-scale crop and stress coefficients will be developed and analyzed to provide quantitative information on the effects of spatial scale on crop and stress coefficient development. The crop coefficients developed will be compared to the crop coefficients and accuracies found by the extensive literature review.

Task 9 – Final report and other publications
A final report documenting the results of all the tasks will be compiled and produced. Journal publications and other publications will be written and published based on the research results.

The schedule and estimated costs and deliverables for the above-described tasks is presented in Attachments 1 through 4.

B.2.c. Environmental documentation

This is not a CEQA project as defined by the California Code of Regulations, Title 14, Division 6, Chapter 3, Section 15378.

B.3. Monitoring and Assessment

This is a research project that contributes information for use in monitoring and assessment of Water Use Efficiency (WUE) implementation projects. The final report will contain an example of how the results of this project can be used in WUE implementation projects for monitoring and assessment of water savings.

Monitoring and assessment of this project will include documenting results from each task and inclusion of deliverables in quarterly reports submitted to DWR. Evaluation of the project will also be conducted quarterly and after completion of each task. As indicated previously, the Task Committee on Crop Coefficients, a subcommittee of the Evapotranspiration in Irrigation and Hydrology Task Committee of the American Society of Civil Engineers – Environmental Water Resources Institute has agreed to work with UCDavis on updating crop coefficients. The participation of this committee of crop coefficient experts in a review and sounding board capacity is unique and ensures a high quality research product.

Other measures of the effectiveness of this project will include:

- the number of hits on the crop coefficient pages of the CIMIS, University of California extension and ASCE Task Committee web sites where the updated crop coefficients are expected to be posted,
- the number of papers accepted in refereed journals, and
- the number of course and conferences where papers are presented and the crop coefficient technical materials are distributed.

C. QUALIFICATIONS OF THE APPLICANTS AND COOPERATORS

C.1. Resumes of project manager and co-investigators

See attachment 5 for resumes of Richard L. Snyder (UCDavis), Wim Bastiaanssen (SNA) and Bryan Thoreson (SNA).

C.2. Role of external cooperators

SEBAL North America, Inc

SEBAL North America (SNA) is the sole licensed user of SEBAL, the Surface Energy Balance Algorithm for Land, in the United States, Canada and Mexico. SNA supports progressive, sustainable management of the Earth's finite water resources through provision of unbiased information on evaporative depletion and agro-ecological production. *SNA provides the first independently validated alternative to the "K_c ET_o" approach that has long been the standard for water depletion studies in the U.S. and elsewhere.* The spatially discrete information generated by SEBAL supports water management innovation at the farm, district, river basin, national and international scales. Wim Bastiaanssen, SNA's Director of Technology, is the developer of the SEBAL algorithm and over the past 15 years has applied and directed dozens of applications of the algorithm worldwide. He will supervise the computation of actual ET for this study.

SNA's role is to process satellite images to provide computed actual ET and potential ET and reference ET for each pixel in the image. Because the comparison of SNA compute ET values to ground-based ET measurements has some value to SNA (as noted SNA has many of these comparison worldwide, but none in California), SNA is providing a 50% discount on normal processing prices as a cost share on this project.

C.3. Previous water use efficiency grant projects

None of the Principle Investigators have been involved in any previous water use efficiency grant projects.

D. OUTREACH AND DISSEMINATION

The improved crop coefficients developed will be made available to growers and irrigation scheduling consultants through the CIMIS web site and University of California extension activities. These results will also be disseminated through the ASCE Task Committee on Crop Coefficients. Project findings will be disseminated to DWR, irrigation districts, cooperators, public, and the scientific community. Research results will be published through popular trade/local journals to inform the public on (1) the literature review of crop coefficients and (2) on the remote sensing based crop coefficients that are based on a much larger area spatially than the traditionally developed crop coefficients. Research papers will also be published in refereed journals to document the methods and results obtained from this study to the scientific community. The project work will also be presented at professional and technical

meetings using maps, photographs, posters, and slides. The level of details and scientific concepts will be based on the target audience.

E. INNOVATION

Remote sensing is an innovative method to develop and refine crop coefficients offering the promise of obtaining consumptive use and other water resource data over large areas at regular intervals. Thus, remote sensing offers and opportunity to develop and refine crop coefficients (Allen et al, 2003) based on crop ET measurement/estimation over a much larger area and across a much wider management spectrum. One of the most tested and accepted methods of computing crop ET from satellite remote sensed data is SEBAL (Surface Energy Balance Algorithm for Land). This algorithm uses data gathered by satellite-based sensors to compute the energy balance at the earth's surface. Evapotranspiration (ET) of crops and natural vegetation is predicted as a residual of the energy balance.

F. BENEFITS AND COSTS

F.1. Project Costs (Budget)

The budget for this project is presented in Attachment 1. The overall funding request is $298,058, which will be divided over the two years of the project. Table C.1. is Attachment 6. The details of the expenditures are presented below.

a. Salaries and Wages
$95,944

b. Fringe Benefits
$29,743

c. Supplies
$4,000

d. Equipment
$4,000

e. Consulting Services
Consulting services of $119,700 are broken down by task in attachment 1. The total image processing costs are $181,000 of which SNA is cost sharing by providing a 50% discount off the normal processing costs, so that the project cost in $90,900. The remaining $28,800 is for analysis assistance to UCDavis. The image processing task is divided into two subtasks with image processing costs of $90,500 each, such that one subtask can be eliminated, if funding is not available. This would reduce the project costs of image processing to $45,450 with SNA still providing a 50% cost share.

f. Travel
Costs of $2000 per year for domestic travel and presentations of findings to the co-investigators, cooperators, and researchers during meetings and conferences.

g. Other administrative costs
Indirect costs for state agency of 25% of salaries and wages, fringe benefits, supplies, equipment and travel. Indirect costs for consulting services are the 25% of the first $25,000 for a total of $40,671.

h. Planning/Design/Engineering

i. Materials/Installation/Implementation

j. Other costs

k. Total Costs
$298,058

l. Cost sharing
SNA will provide a 50% discount on the image processing costs resulting in a cost share of $90,900. Thus, the total project cost is $398,958, $90,900 of which is obtained as a cost share and $298,058 is the funding request. Additional detail is shown in Attachment 1.

F.2. Potential benefits of study and estimates of total expected water savings

This study has the potential to save thousands of acre-feet of water through the development and utilization of improved crop coefficients through irrigation scheduling. ET from irrigation has been estimated as 21 million acre-feet in a typical year (Burt, et al., 2002). If an average efficiency of 75% is assumed, 28 million acre-feet of applied water results. If improved crop coefficients result in a reduction in applied water of one percent, this is a savings of 280,000 acre-feet. Considering the cost of this study, this is roughly $1 per acre-foot.

Reduced water applications resulting from more accurate crop coefficients are expected to result in reduced irrigation diversions, leading to increased in-stream flows. These in-stream flow increases can be expected anywhere in the state that the more accurate crop coefficients are put in use. These benefits are expected to initially be small and increase with time as more growers and consultants learn of and adopt the improved crop coefficients. (Table C.5. Attachment 7).

G. REFERENCES

Allen, R.G., A. Morse, and M. Tasumi. 2003. Application of SEBAL for Western Water Rights Regulation and Planning. Proceedings ICID Workshop on Remote Sensing of ET for Large Regions, 17 September, 2003.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop Evapotranspiration. Guidelines for computing crop water requirements. *Irrig. and Drain. Paper 56*, Food and Agriculture Organization of the United Nations, Rome, Italy, 143.

ASCE-EWRI (2004). The ASCE Standardized Reference Evapotranspiration Equation. Technical Committee report to the Environmental and Water Resources Institute of the American Society of Civil Engineers from the Task Committee on Standardization of Reference Evapotranspiration. 173 p.

Burt, C.M., A. Mutziger, D.J. Howes and K.H. Solomon (2002). "Evaporation from irrigated agricultural land in California". *Irrigation Training and Research Center*, San Luis Obispo, CA, 144 p.

Doorenbos, J. and Pruitt, W.O. (1977). "Guidelines for predicting crop water requirements". *Irrig. and Drain. Paper 24*, Food and Agriculture Organization of the United Nations, Rome, Italy, 143.

Tasumi, M., R. Trezza, R.G. Allen, R.G., and J.L. Wright. 2003. U.S. validation tests on the SEBAL model for evapotranspiration via satellite. Proceedings ICID Workshop on Remote Sensing of ET for Large Regions, 17 September, 2003.

Ventura, F., Faber, B.A., Bali, K.M., Snyder, R.L., Spano, D., Duce, P. and Schulbach, K.F. (2001). "Model for estimating evaporation and transpiration from row crops." *J. of Irrig. and Drain. Engng.*, ASCE , 127(6): 339-345.

Attachment 1

Table 1. Task Budget and Deliverables

Task No.	Task	Budget		
		UCDavis	**SNA**	**SNA (Cost Share)**
1	Compile literature review on crop coefficients	$ 21,615		
2	Estimate midseason crop coefficients and related correction factors	$ 21,615		
3	Compile methods to estimate crop coefficient changes during the growing season	$ 21,615		
4	Assess the confidence in the crop coefficient information compiled	$ 21,615		
5	Recommend additional research required to improve crop coefficients	$ 21,615		
6	Process up to 2 Landsat or 2 MODIS images per month to compute remote sensed ET estimates for 24 months (48 images will be processed and time integration performed)	$ 6,250	$90,900	$90,900
7	Compare remote sensed ET estimates to ground-based estimates	$ 10,803	$9,600	
8	Develop and refine crop coefficients	$ 21,615	$9,600	
9	Final report, journal publications and outreach	$ 31,615	$9,600	
	Total	$178,358	$119,700	$90,900
	Grand Total	$388,958		
	PSP Grant Requested	**$298,058**		

Attachment 2. UC Davis Budget by Year

2006 Budget

No.	Item	Cost
1	Computer, software and printer with scanner (equipment)	$4,000
2	1.5 Junior Specialist Salary* (18 months at $2,638.74/month)	$47,497
3	Benefits (31%)	14,724
4	Travel	2,000
5	Supplies and Expenses for literature review, publication costs, mailing, etc.	2,000
6	Subtotal	70,221
7	Indirect Costs for State Agency (25% of subtotal)	17,555
8	Total Cost	$87,777

***One JS all year and one from Jul. 1 to Dec. 31**

2007 Budget

No.	Item	Cost
1	1.5 Junior Specialist Salary* (18 months at $2,691.51/mon)	$48,447
2	Benefits (31%)	15,019
3	Travel	2,000
4	Supplies and Expenses for literature review, publication costs, mailing, etc.	2,000
5	Subtotal	67,466
6	Indirect Costs for State Agency (25% of subtotal)	16,866
7	Total Cost	$84,332

***One JS all year and one from Jan. 1 to Jun. 30**

Consulting Fees over two years	Cost
Processing up to 24 Landsat images and some MODIS images	$90,900
Crop coefficient analysis	$28,800
Subtotal	$119,700
Overhead on Indirect Costs (25% of first $25,000)	$6,250
Total	$298,059

Project Budget Total	Cost
Total	$298,059

Attachment 3.

Deliverables	Progress Tracking Dates
1. A compilation of the most extensive literature review of crop coefficients available.	31-Dec-06
2. An estimation K_{co} and K_{cr} values during midseason of known crops along with information on how to correct for differences in ground cover, foliage density, and irrigation management.	30-Jun-07
3. Estimates of K_{co} and K_{cr} curves during the season of all crops reviewed and one or more methodologies to estimate changes in the curves during a cropping season.	30-Jun-07
4. An assessment of the confidence we have in the crop coefficient information for all crops reviewed.	30-Jun-07
5. Recommendations on what crops, irrigation methods, etc. need more research to improve the crop coefficients.	30-Jun-07
6. Processed images and computed actual ET at various time scales required for the ET comparison as ArcGrid coverages	30-Sep-06
7. A comparison of SEBAL ET estimates to lysimeter and other ground-based estimates within the SEBAL image processed (path/row xx/xx) across daily, monthly, seasonal and annual time scales.	31-Dec-06
8. SEBAL crop coefficient and analysis for the ten crops with the most area in image, including development of pixel- and field-scale (average of all pixels in defined fields): a. “pristine” crop coefficients, b. average-stress coefficients, and c. high-stress coefficients.	31-Sep-07
9. Final Report	31-Dec-07

Attachment 4.

Table 2. Task Schedule

Task No.	Task	2006				2007			
		Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
1	Compile literature review on crop coefficients								
2	Estimate midseason crop coefficients and related correction factors								
3	Compile methods to estimate crop coefficient changes during the growing season								
4	Assess the confidence in the crop coefficient information compiled								
5	Recommend additional research required to improve crop coefficients								
6	Process up to 2 Landsat and 2 MODIS images per month to compute remote sensed ET estimates								
7	Compare remote sensed ET estimates to ground-based estimates								
8	Develop and refine crop coefficients								
9	Final report, journal publications and outreach								

Attachment 5. Resumes

Richard L. Snyder
Biometeorology Specialist
University of California
Department of Land, Air and Water Resources
243 Hoagland Hall
Davis, California 95616-8627
Phone: (916) 752-4628; Fax: (916) 752-1793; Email: rlsnyder@ucdavis.edu

Education

Iowa State University, Ph.D. Agricultural Climatology, 1980; Iowa State University, M.S., Agricultural Climatology, 1978; University of Northern Iowa, B.A., Mathematics, 1971; North Iowa Area Community College, A.A., Mathematics, 1969

Experience

1980 - Present - Biometeorologist Specialist;University of California, Department of Land, Air and Water Resources, Davis, California

Professional Affiliation

American Meteorological Society
International Society for Horticultural Science
International Society of Biometeorology

Major Research and Teaching Activities

During my employment with the University of California, my main research and teaching activities were related to (1) testing and developing methods for estimating evapotranspiration, (2) irrigation scheduling, and (3) freeze protection of crops. In recent years, my research activities have expanded to include studies on (1) wildfire risk and (2) energy and carbon fluxes over restored wetlands.

For the past few years, we have conducted research to measure evapotranspiration and carbon fluxes from a restored wetland in conjunction with colleagues from the US Geological Survey. This research effort compliments the USGS efforts to monitor carbon balance in restore wetlands. The ultimate goal is to determine if the restored wetland is a source or sink of CO_2 and to determine the evapotranspiration of the wetland. This information is needed to insure drinking water quality for water transfers to Southern California and to make decisions on future management of the Sacramento-San Joaquin River Delta to minimize water losses. The carbon flux information is needed to determine if future Delta management will be beneficial or detrimental to the global carbon balance.

During the past 10 years, I have worked extensively with colleagues to develop the new "Surface Renewal" method for estimating sensible heat flux density using low-cost instrumentation. This has greatly facilitated our estimation of crop evapotranspiration for tomatoes, maize, sunflowers, grapevines, citrus and rice. The goal is to use this information to improve irrigation management and water resource planning in California.

In my early work at the University of California, I was the principal investigator on the California Irrigation Management Information System (CIMIS) research and development project. In this three-year project, a network of 43 electronic weather stations was established to gather data for the calculation of reference evapotranspiration. In addition, field testing of the

ET_o data for use in irrigation scheduling, modeling and improving methods to access irrigation efficiency, analyzing the economic benefits of using CIMIS ET_o for irrigation scheduling, and studies on encouraging the adoption and use of CIMIS were conducted. More than 17 researchers were employed on the three-year project at a cost of approximately $3,500,000. Today there are about 150 electronic weather stations in the network. It is estimated that CIMIS saves California growers about $64 million per year from water savings and increased production. Following on this work, I have more recently been involved in the development of weather simulation application programs for use in long-term water resource planning in California.

As of September 2004, I have authored or co-authored 83 published or in-press refereed scientific papers on a wide variety of topics including frost protection, irrigation scheduling, wetlands ET and carbon fluxes, plant phenology, long-term water resource planning, surface renewal, etc. Reviewed publications that are related to this project are listed below.

Short list of Reviewed Publications (related to this topic)

Drexler, J.Z., Snyder, R.L., Spano, D. and Paw U, K.T. 2003. A Review of Models and Micrometeorological Methods used to Estimate Wetland Evapotranspiration. *Hydrologic Processes*, pp. 54 (in press).

Faber, B.A. and R.L. Snyder. 1988. Extension activities needed to address the limited use of evapotranspiration. J. of Agronomic Education, Vol. 19, No. 1, pp. 7-13.

Paw U, K.T., R.L. Snyder and D. Spano. 2003. Surface renewal. In: Micrometeorology in Agricultural Systems. Hatfield, J.L. and Baker, J.L (Eds.). ASA Monograph No. XX, ASA-CSSA-SSSA, Madison, WI. (in press).

Shaw, R.H. and R.L. Snyder. 2003. Evaporation and eddy covariance. In: *Encyclopedia of Water Science*. Stewart, B.A. and Howell, T. (Eds.). Marcel Dekker Inc., New York. Marcel Dekker Inc., New York. DOI: 10.1081/E-EWS 120010306.

Snyder, R.L. and W.O. Pruitt. 1992. Evapotranspiration data management in California. Irrigation and Drainage Session Proceedings Water Forum 1992, ASCE. August 2-6, 1992, Baltimore, MD., pp.128-133.

Snyder, R.L., D. Spano and K.T. Paw U. 1996. Surface renewal analysis for sensible and latent heat flux density. Boundary Layer Meteorol. 77: 249-266.

Snyder, R.L., M.A. Plas and J.I. Grieshop. 1996. Irrigation methods used in California: a grower survey. J. of Irrig. and Drain. Eng., Vol. 122, No. 4: 259-262.

Spano, D., R.L. Snyder, P. Duce and K.T. Paw U. 1997. Surface renewal analysis for sensible heat flux density using structure functions. Agric. & For. Meteorol. 86 (1997) 259-271.

Spano, D., R.L. Snyder, P. Duce and K.T. Paw U. 2000. Estimating sensible and latent heat flux densities from grapevine canopies using surface renewal. Agric. & For. Meteorol. 104 (2000): 171-183.

Snyder, R.L. 2000. Reference evapotranspiration and crop coefficients. Proceedings of the Agricultural Weather System Workshop. Hubbard, K.G. and M.V.K Sivakumar (eds.), Lincoln, Nebraska, March 6-10, 2000 High Plains Climate Center, Univ. of Nebraska-Lincoln and World Meteorol. Organization, Geneva. p. 149-161.

Ventura, F., B.A. Faber, K. Bali, R.L. Snyder, D. Spano, P. Duce and K.F. Schulbach. 2001. Model for estimating evaporation and transpiration from row crops. J. of Irrig. and Drain. Engng. 127(6): 339-345.

WIM BASTIAANSSEN

Director of Technology, SEBAL North America

Key-qualifications

Dr. Bastiaanssen has more than 15 years experience in energy balance physics applied to agriculture water management. Remote sensing for agricultural water management, basin wide water resources planning, land surface processes, vadose zone hydrology, surface energy balance, irrigation performance diagnosis, crop growth, water rights, spatial variability of hydrological processes, drainage design, soil salinity, rainfall, forest vitality, hydrological information systems.

Career summary (past 5 years)

2003 – present	SEBAL North America (SNA), California / Director of Technology
2000 – present	WaterWatch v.o.f., Wageningen, The Netherlands / Scientific Director
1997 – 2003	International Institute for Aerial Survey and Earth Sciences (ITC), Enschede, The Netherlands / Visiting Professor
1999 – 2000	AgroWater Consultants, Maurik, The Netherlands / President
1996 – 1999	International Water Management Institute (IWMI), Colombo, Sri Lanka / Visiting Scientist

Education

2000 Professor Level Working Skills formally recognized by a commission of peers upon invitation from the International Institute for Aerospace Survey and Earth Observations (ITC), Enschede, The Netherlands

1995 Ph.D. Wageningen Agricultural University, The Netherlands: Regionalization of surface flux densities and moisture indicators in composite terrain, a remote sensing approach under clear skies in Mediterranean climates

1986 B.Sc., Larenstein International College for Land and Water Management, Velp, The Netherlands. Thesis: Computerized Drainage Models for Euroconsult studies in Pakistan

Honors

1995 Tison Award for the best publication of the International Association of Hydrological Sciences (IAHS) written by a promising young scientist.

<u>Publications--Book chapters (Total 12)</u>

Bastiaanssen, W.G.M., 1999. The use of remote sensing to improve irrigation water management in developing countries, in (eds.) G.J.A. Nieuwenhuis, R.A. Vaughan and M. Molenaar, Operational Remote Sensing for Sustainable Development, A.A. Balkema, Rotterdam, The Netherlands, pp. 3-17

Bastiaanssen, W.G.M. and C.J. Perry, 2000. Earth observation demands for improved water resources management, (eds.) M.M. Verstraete et al. Observing land from space: science, customers and technology, Kluwer Academic Publishers, pp. 105-117

Bastiaanssen, W.G.M., M.D. Ahmad and Z. Tahir, 2003. Upscaling water productivity in irrigated agriculture using remote sensing and GIS technologies, in (eds.) J. Kijne, R. Barker and D. Molden, Water productivity in agriculture: limits and opportunities for improvement, CABI Publishing, no. 1, Wallingford, UK, pp. 289-300

Bastiaanssen, W.G.M., R.G. Allen, P. Droogers, G. D'Urso and P. Steduto, 2004. Inserting man's irrigation and drainage wisdom into soil water flow models and bringing it back out: How far have we progressed?, in (eds.) Feddes, de Rooij and van Dam, Unsaturated-zone Modeling, Kluwer Academic Publishers, Wageningen UR Frontis Series: pp. 263-299

Selected Reviewed articles

Bastiaanssen, W.G.M., T. Van der Wal and T.N.M. Visser, 1996. Diagnosis of regional evaporation by remote sensing to support irrigation performance assessments, *Irri. Drain. Syst*., **10**, 1-23

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes and A.A.M. Holtslag, 1998. The Surface Energy Balance Algorithm for Land (SEBAL): Part 1 formulation, *J. Hydrol*. **212**: 198-212

Bastiaanssen, W.G.M., H. Pelgrum, J. Wang, Y. Ma, J. Moreno, G.J. Roerink and T. van der Wal, 1998. The Surface Energy Balance Algorithm for Land (SEBAL): Part 2 validation, *J. Hydrol*. **212**: 213-229

Bastiaanssen, W.G.M., T. Thiruvengadachari, R. Sakthivadivel and D.J. Molden, 1999. Satellite remote sensing for estimating productivities of land and water, *Int. J. Water Resour. Develop*. **15**: 181-196

Bastiaanssen, W.G.M. and M.G. Bos, 1999. Irrigation performance indicators based on remotely sensed data: a review of literature, *Irrig. Drain. Syst*. **13**: 291-311

Bastiaanssen, W.G.M., D.J. Molden and I.W. Makin, 2000. Remote sensing for irrigated agriculture: examples from research of possible applications, *Agric. Water Manage*, **46**: 137-155

Bastiaanssen, W.G.M., R.A.L. Brito, M.G. Bos, R. Souza, E.B. Cavalcanti and M.M. Bakker, 2001. Low cost satellite data applied to monthly irrigation performance monitoring; benchmarks of Nilo Coelho, Brazil, *Irrig. Drain. Syst*. **15**: 53-79

Bastiaanssen, W.G.M. and K.M.P.S. Bandara, 2001. Evaporative depletion assessments for irrigated watersheds in Sri Lanka, *Irrig. Sci*., **21**: 1-15

Bastiaanssen, W.G.M., M.D. Ahmad and Y. Chemin, 2002. Satellite surveillance of evaporative depletion across the Indus Basin, *Water Resour. Res.*, **38**: 1273-1282

Ahmad, M.D., **W.G.M. Bastiaanssen** and R.A. Feddes, 2002. Sustainable use of groundwater for irrigation: a numerical analysis of subsoil water flux, *Irrig. Drain*. **51**: 227-241

Ahmad, M.D., **W.G.M. Bastiaanssen** and R.A. Feddes 2004. A new technique to estimate net groundwater use across large irrigated areas by combing remote sensing and water balance approaches. *Hydrogeology Journal* (accepted).

Bryan P. Thoreson, P.E.
Principal Engineer, Project Manager

Education
Ph.D., Agricultural Engineering, University of Arizona, Tucson, AZ.
M.S., Agricultural Engineering, South Dakota State University, Brookings, SD.
B.S., Agricultural Engineering, South Dakota State University, Brookings, SD.

Professional Registrations
Registered Civil Engineer, California (No. C56194)
Registered Civil Engineer, Washington (No. 36249)

Experience Summary
Mr. Thoreson has more than 10 years of professional experience in water resources and irrigation engineering. He specializes in irrigation water conservation, having skills and experience in the areas of irrigation scheduling, assessing and improving on-farm application efficiency, flow measurement, data management, and irrigation and drainage system operations and maintenance (O&M). Mr. Thoreson has extensive experience in software development and application related to irrigation engineering, including development, deployment and maintenance of customized Oracle SQL databases. Throughout his work, he has consistently demonstrated a unique command of both theoretical principle and practical application. He has authored numerous papers on improved irrigation practice and operations and maintenance procedures. Mr. Thoreson has worked as a principal engineer, project engineer and project manager since he joined Davids Engineering in 1997 and is one of the founders of SEBAL North.

Selected U.S. Experience

- Develop and review technical descriptions of drainwater recycling, tailwater recovery systems, system automation and canal lining water conservation measures with the ultimate goal of specifying technical procedures for verifying water savings.
- Support, through data analyses, the verification of water conservation achieved by projects implemented by IID under its Water Conservation and Transfer Program with Metropolitan Water District of Southern California (MWD).
- Assist the Imperial Irrigation District (IID) efforts to integrate water measurement data collection and quality control functions into a computerized (Oracle) information system. The system is designed to store an inventory of operations and flow measurement structures, history of structure maintenance and time series flow data for the irrigation water distribution system. The system collects and stores all the information necessary for, and computes water savings resulting from 16 water conservation projects.
- Assist the Benton Irrigation District (BID) with the development of a water balance and comprehensive water conservation plan to meet the Yakima River Basin Water Enhancement Project requirements. Water losses identified by the water balance are being aligned with conservation measures with the ultimate objective of formulating a water conservation plan.
- Assist in the development of an integrated canal and drainage network model to assess water quality impacts of on farm conservation activities in the 200,000 ha area served by the Imperial Irrigation District system. The model has over 5,500 demand nodes serving farms

and over 1,000 drain nodes where water quality parameters can be assessed over the anticipated 75 years of output. The model runs on a monthly time step and is based on 12-years of detailed water delivery, cropping and flow data.

- Assist the Turlock Irrigation District (TID) with the data analyses related to the development of an integrated water resource management plan.
- Assist the Merced Irrigation District (MID) with the development of a water balance and water management plan to meet the AB3616 Memorandum of Understanding (MOU) requirements. Water losses identified by the water balance are being aligned with efficient water management practices specified in the MOU.
- Assist the Turlock Irrigation District (TID) with the development of a water balance and water management plan to meet the AB3616 MOU requirements. Water losses identified by the water balance are being aligned with efficient water management practices specified in the MOU.

Mr. Thoreson was an engineer with the Imperial Irrigation District (IID), Imperial, CA from 1994-1997.

Professional Organizations

U.S. Committee on Irrigation and Drainage--Associate Editor of Irrigation and Drainage Managing Water for Sustainable Agriculture
American Society of Civil Engineers
American Society of Agricultural Engineers

Selected Refereed Journal Articles and Proceedings Papers

Thoreson, B. P.; S. Zwart, W. B. Bastiaanssen and G.G. Davids. 2004. Estimating Actual Evapotranspiration Without Land Use Classification. In *Water Rights and Related Water Supply Issues*. Proceedings from the USCID 2004 Water Management, Salt Lake City UT. pp. 355-364.

Bastiaanssen, W.B., E.J.M. Noordman, H. Pelgrum, G. Davids, B.P. Thoreson and R.G. Allen. 2005 (in press). Use of SEBAL model with remotely sensed data to improve water resources management under actual field conditions. *Journal of Irrigation and Drainage Engineering* (upcoming special issue), New York, NY.

Thoreson, B. P.; P. Kosciusko, J. Burns, G. Davids, K. Dimmitt, J. Keller and M. King. 2003. Water Conservation: Savings Determination in Near Real-Time. In *Water for a Sustainable World – Limited Supplies and Expanding Demand*. Proceedings from the USCID Second International Conference on Irrigation and Drainage, Phoenix, AZ. pp. 747-756.

Thoreson, B. P.; C. Villalón, M. Kidwell and K. Dimmitt. 2003. Initial Development of a Decision Support System for Operating a Lateral Interceptor Reservoir System. In *Water for a Sustainable World – Limited Supplies and Expanding Demand*. Proceedings from the USCID Second International Conference on Irrigation and Drainage, Phoenix, AZ. pp. 313-322.

Attachment 6. Table C-1: Project Costs (Budget) in dollars

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share (SNA share) $ (V)	State Share Grant $ (VI)
	Administration[1]					
	Salaries, wages	$95,944	0	$95,944	$0	$95,944
	Fringe benefits	$29,743	0	$29,743	$0	$29,743
	Supplies	$4,000	0	$4,000	$0	$4,000
	Equipment	$4,000	0	$4,000	$0	$4,000
	Consulting services	$181,000	0	$181,000	$90,900	$119,700
	Travel	$4,000	0	$4,000	$0	$4,000
	Other	$40,671	0	$40,671	$0	$40,671
(a)	Total Administration Costs	$298,958		$298,058	$0	$298,058
(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)	$0	0	$0	$0	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0
(m)	Report Preparation	$0	5	$0	$0	$0
(n)	**TOTAL**	$3888,958		$298,058	$90,900	$298,058
(o)	Cost Share -Percentage				0	77%

1- excludes administration O&M.

Attachment 7. Table C-5

Applicant: **Richard L. Snyder**

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Table C-5 Project Annual Physical Benefits (Quantitative and Qualitative Description of Benefits)

	Qualitative Description - Required of all applicants[1]				**Quantitative Benefits - where data are available [2]**
	Description of physical benefits (in-stream flow and timing, water quantity and water quality) for:	Time pattern and Location of Benefit	Project Life: Duration of Benefits	State Why Project Bay Delta benefit is Direct[3] Indirect [4] or Both	Quantified Benefits (in-stream flow and timing, water quantity and water quality)
Bay Delta	This study has the potential to save thousands of acre-feet of water through the development and utilization of improved crop coefficients through irrigation scheduling. Reduced water applications resulting from more accurate crop coefficients are expected to result in reduced irrigation diversions, leading to increased in-stream flows. These in-stream flow increases can be expected statewide.	The time pattern of benefits depends on how the improved crop coefficients compare to the currently used crop coefficients. If the peak of the crop coefficient is reduced, more water would be available in the summer. If storage is available, this water could be held and released in the fall. The location of benefits is expected to be Statewide as all growers and consultants will have access to the improved crop coefficients.	These benefits are expected to initially be small and increase with time as more growers and consultants learn of and adopt the improved crop coefficients.	This project has both indirect and direct Bay-Delta benefits. The indirect benefits are due to reduced water required south of the Delta, thus reducing dependency on the Delta. The direct benefits are the water savings estimated to accrue due to the use of improved crop coefficients and improved confidence in the crop coefficients.	ET from irrigation has been estimated as 21 million acre-feet in a typical year (Burt, et al., 2002). If an average efficiency of 75% is assumed, 28 million acre-feet of applied water results. If improved crop coefficients result in a reduction in applied water of one percent, this is a savings of 280,000 acre-feet. Considering the cost of this study, this is roughly $1 per acre-foot.
Local	The same benefits apply.	The same benefits apply.	The same benefits apply.	**Not applicable.**	The same benefits apply.

[1] The qualitative benefits should be provided in a narrative description. Use additional sheet.

[2] Direct benefits are project outcomes that contribute to a CALFED objective within the Bay-Delta system during the life of the project.

[3] Indirect benefits are project outcomes that help to reduce dependency on the Bay-Delta system. Indirect benefits may be realized over time.

[4] The project benefits that can be quantified (i.e. volume of water saved or mass of constituents reduced) should be provided.