WATER MANAGEMENT ACROSS SCALES IN THE SÃO FRANCISCO BASIN: POLICY OPTIONS AND POVERTY CONSEQUENCES

Preliminary Report of the Basin Focal Project

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Executive Summary

Policymakers at national, state and local levels are charged with the efficient and sustainable use of water resources of the São Francisco River basin, and also to promote economic growth and reduce poverty within the basin. To date, policymakers lack scientific evidence on the consequences for growth, poverty alleviation or environmental sustainability of alternative uses of water resources. To address this key knowledge gap we will develop and use a spatially distributed description of the economic and hydrologic sub-systems, as well as their linkages, and quantify the field to region to basin water and poverty impacts of alternative water policy decisions in the São Francisco Basin. Basin-wide descriptive analysis of water availability and use, agriculture and poverty will set the stage for predictive modeling at the basin, sub-basin and plot levels. At basin level, an aggregate mass balance hydrology model will be developed and linked to município-level economic models to predict the effects of alternative water management strategies and policies on product mix, production technology and area under plow, and the consequences of these agricultural choices for poverty, water productivity, and flows for environmental and other purposes. The model will generate estimates on an annual basis, with the potential to predict agriculture and water use/availability into the future. At sub-basin level an integrated model will be constructed from the field to the watershed scale, consisting of a hydrologic model linked to an agricultural production model. This hydrologic model is a spatially distributed, three-dimensional, variably-saturated flow and transport model, with full reactive salt chemistry capabilities. Given initial conditions on surface water allocation, and soil, surface water, and groundwater quality and quantity, an economic model will predict the types and spatial extent of agricultural activities on an annual basis and produce spatially distributed information on: cropping patterns, water applications, groundwater pumping, irrigation efficiencies, crop yields and revenues from agricultural activities. The output from the economic model is subsequently used by the hydrologic model to simulate the impacts of these management decisions on the natural system including environmental water use. The agricultural production model in turn is updated annually by the hydrologic model to account for changes in soil quality, and groundwater quality and quantity (and hence, water costs). At plot level, land use system (LUS) analysis will assess the impacts on small-scale and other agriculturalists of changes in water availability, water costs and water quality. All models will be used to assess the effects of water management interventions, with special attention paid to effects on poverty and water productivity.

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SECTION 1 – INTRODUCTION

1.1 Background

The São Francisco River (see Map 1) provides about 70% of the surface water in Northeast Brazil and like much of Brazil the basin includes communities characterized by a broad range of incomes and persistent poverty (ANA 2004, Brito and Gichuki 2003). The basin's agricultural systems cover a similar range between capitalized export-focused enterprises and subsistence farms. Major corporations and cottage industries comprise the industrial water use sector while cities and towns tap the basin for municipal supplies. The basin also hosts several important water-dependent ecological zones. Increasingly, the complex web linking water availability, water quality, water productivity, economic growth, poverty alleviation and community and ecosystem health is coming into focus. Conflict for water among various water user communities and sectors is becoming common, often with negative consequences for resource-poor stakeholders. Surface water shortfalls in some areas have increased groundwater utilization which may lead to soil salination.

Map 1 – The São Francisco River Basin in Brazil

Brazil's Federal Law 9.433 (Federal Government of Brazil 1997) was implemented to promote and guide public-sector involvement in water management so as to integrate across the connections defined by the flow of water to improve overall social welfare. More specifically, the Law clearly places hydrological resources in the public domain (Article 1) and charges policymakers with the wise and sustainable management of these resources (Article 3) via the use of water price policy and other policy instruments (Article 5), some of which remain to be developed. However, formidable challenges confront the Law's implementation. Two challenges this research seeks to address in the context of the São Francisco River Basin (SFRB) are:

- incomplete understanding of how water use decisions are taken by important water use groups, and once taken, how these decisions affect the water use options available in other parts of the basin, now and in the future; and

- incomplete information for assessing scale-dependent, freshwater dynamics and using these dynamics to predict the effects of alternative water policies designed to promote the increased water productivity, and livelihood and environmental enhancement.

1.2 Purpose and Organization of the Report

This report sets out the key issues to be examined in the context of this research project and the analytical tools we will develop and use to address them. Section 2 provides an overview of the project's objectives and a sketch of the research methods. Section 3 (divided into four subsections) describes the descriptive and analytical analyses to be undertaken in the SFRB. Subsection 3.1 focuses on basin-wide research involving: assessments of poverty, agricultural and hydrological resources; assessments of water productivity; examinations of the links between water and poverty; and use tools developed to test possible water management interventions and policies on poverty, water productivity and agricultural production. Subsection 3.2 sets out our strategy for examining the same sets of issues, in the same order, but this time for the sub-basin area of the Buriti Vermelho. Subsection 3.3 describes plot-level research to be undertaken *outside* the Buriti Vermelho sub-basin. Section 3.4 discusses institutional analyses and knowledge base development and management. Section 4 focuses concludes the substantive portion of the document with a discussion of issues related to project management. Section 5 contains references and Section 6 contains a series of appendices related to field visits, data needs and the curriculum vitae for the core research team.

SECTION 2 – PROJECT OVERVIEW

With this broad policy mandate and knowledge gaps as a backdrop, our more specific research, outreach and capacity strengthening objectives are:

- identify a broad set of stakeholder views regarding water management and poverty issues;
- locate the rural poor;
- develop a conceptual framework linking water and poverty;
- identify a representative set of ongoing/planned water management interventions, with special emphasis on those aiming to affect poverty outcomes;
- undertake land use system (LUS) analysis to assess the effects of selected water management interventions on farm incomes, with special focus on resource-poor farm households;
- adapt and calibrate scale-dependent agricultural production and hydrologic models;
- use the combined modeling systems to quantify local and regional economic and environmental impacts due to water policy changes, with particular focus on short-term trade-offs among policy objectives;
- derive policy implications from research results and deliver these results to stakeholders;
- suggest relevant biophysical and socioeconomic extrapolation domains for these results and their implications;
- develop research methods and train Brazilian collaborators in their use; and
- generate a prioritized list of future interventions for meeting poverty and sustainable resource management objectives.

2.1 – Need for Policy Guidance

Confusion regarding the term 'policy' is a quite common, in part because users of the term generally fail to identify the focus or foci of concern; policy objectives, policy instrument to be used to achieve those objectives, issues associated with policy action or implementation, or the final impact on stakeholders of policy action undertaken.[1] To be useful, applied research should ideally address all of these aspects of policy (from setting objectives to assessing impacts of policy action), but practically this is not always possible. At a minimum, then, applied research should be quite clear about which aspects of policy will be addressed, and how they will be addressed in the context of modeling activities. The proposed research will to one degree or another address all of the aspects of policy set out above in the context of the SFRB.

Policy objectives will be both inputs into our models and be contained in the results of model simulations. For example, minimum seasonal water flows required to meet (say) environmental objectives will be explicitly included as inputs (constraints) in our models, and the minimum amount

[1] This confusion is often exacerbated by difference across languages, e.g., the Portuguese term 'políticas' is generally used to refer to both of the English words 'policies' and 'politics.'

of surface water required in a particular area to support small-scale agriculture capable of meeting food and livelihood needs will be an 'output' of our modeling efforts.

Policy instruments for managing surface and ground water in the SFRB are currently being discussed and developed in Brazil. In collaboration with stakeholders, we will develop a complete list of policy instruments for managing water at the national, state and sub-state levels, and work with collaborators to ensure that the economic and hydrological models we develop are capable of credibly testing the efficacy and efficiency of alternative policy instruments for achieving stated objectives. Existing models are quite rich in this regard, e.g., models can easily accommodate regulations limiting groundwater extraction, the imposition of taxes or subsidies on water use, etc., and assess their environmental and socioeconomic impacts. One key objective of this project will be to provide guidance regarding which policy instruments ought to be developed and tested, and perhaps codified into laws aimed at managing the SFRB or catchments areas within it.

Policy implementation is never free. Some types of policy action require investments (e.g., construction of dams) and virtually all types of policy action require monitoring. Such costs can be identified, and benefit/cost and related calculations can be generated to guide policy action. In addition, cost recovery policies can be woven into water management strategies (e.g., in the form of user fees); the proposed models can easily accommodate such policy instruments.

Lastly, the project is keenly interested in the impacts on of alternative policy choices (objectives, instruments and means of implementation) on water use, land use, agricultural production and poverty. Hence, the proposed models will generate as outputs measures of all of these important variables.

<u>2.2 – Key Policy Issues in the SFRB</u>

Much is known about the entire SFRB (e.g., ANA 2005, Britto and Gichuki 2003, Federal University of Viçosa 2003), and quite a lot of very detailed information exists for specific sub-regions of the SFRB (e.g., ANA 2005, Embrapa 2001, CODEVAF undated, CNPq undated, SEPLAN undated). In addition, a series of recent priority-setting exercises for the SFRB (e.g., Embrapa and IWMI 2004) have identified issues and knowledge gaps. Building on this knowledge base and supplemented by two focused basin tours, the following set of key policy issues was compiled; this set will guide our research, outreach and training activities. ('And where?' is included in the first entry in the list below to highlight the spatially explicit nature of this issue and all of the policy issues subsequently listed; to avoid redundancy, this 'flag' is not repeated.)

- Regarding the Agricultural Sector
  - How much *surface water* <u>should</u> be diverted for agriculture, and where?
  - How much *groundwater* should be pumped?
  - What is the optimal level of irrigation efficiency?
  - What public policy action (if any) is required to improve overall water use efficiency?
    - E.g., water pricing or water markets; public investments in water infrastructure; or the development/dissemination of water-saving agricultural technologies

        - Who should pay the bill for public policy action?
    - What are the effects of policy action on area under plow, crop patterns and technology choice?

- Regarding Poverty
    - How is water productivity or access to water linked to rural poverty in the SFRB?
    - If linked, how much water should be diverted to poor farmers to reduce poverty?
        - What additional public policy action will be required to reduce poverty?
    - What are the effects of policy action related to water (e.g., water pricing) on poverty?

- Regarding Inter-Sectoral Trade-Offs
    - What are the impacts on agriculture of the diversion of water to generate hydroelectric power?
    - How much water should remain in the river system for environmental benefits?

- Regarding Inter-Basin Trade-Offs
    - What are the agricultural and other costs in the SFRB associated with inter-basin transfers?

2.3 – On Overview of the Research Program

In order to provide policy guidance on these issues, a deeper understanding of both biophysical processes and human behavior, and the interaction between the two, is required. This is particularly important in situations in which some of the important components of the biophysical processes are not 'seen' and hence tend to be overlooked in policymaking.

For this, a joint hydro-economic approach is desirable to better understand the issues of poverty, economic development and sustainability. Two scales will be used to explore this topic. One will be a coarser scale covering the entire SFRB while the other will be a zoom on a selected area of the entire basin to simulate in more detail the interaction between agricultural practices and water resources. Both scales of analysis/modeling will be informed by plot-level research.

From a technical point of view, the different sizes of those two areas pose distinctive problems that have to be addressed in a different manner in order to effectively provide the economic models that partially rely upon hydrologic information with the proper feedback. We will use therefore two linked hydro-economic models to address policy issues (and potential trade-offs among policy objectives) in the São Francisco River Basin. The first is the conceptual/mass balance model MIKE Basin coupled with a município-level economic optimization model and the second is a more detailed physics based model that will be applied to the smaller Buruti Vermelho catchment, which is a selected sub-region of the SFRB.

The Buruti Vermelho basin is the laboratory in which a detailed exploration of the hydrologic processes will be made. The high level of detail reachable for this basin will allow a more exhaustive monitoring of the evolution of the water reserves, giving a deeper insight on the impact that different water practices have on the usable water stock. This detailed approach needs to be simulated with a comprehensive model able to handle the different and complex mechanisms of water transfer within and out of the basin. For this, a state-of-the-art, physics-based, fully coupled distributed surface-subsurface hydrologic model will be used for the task. This model, called MOD-HMS (Panday and Huyakorn, 2004) and developed by HydroGeoLogic Inc, leaves behind part of the technical problems that are derived from semi-coupled-semi-linked approaches in the surface-vadose-groundwater continuum and represents a step further in the hydrologic modeling art.

The entire São Francisco River watershed needs a different tool designed for data-scarce environments. In that case, the objective is not tracking in detail the hydrologic functioning of the basin, but rather providing a reliable evaluation of the water balance and a lumped estimate for the different regions of the usable water reserves. For this task, MIKE-Basin (Danish Hydraulic Institute, 2005), a GIS based conceptual hydrologic model will be used to calculate the water budget of the basin. The strength of this model is that it will provide basin-wide coverage and hence allow us to examine some key policy issues related to (e.g.) the hydrological and economic consequences of removing large amounts of water from one part of the SFRB. The model's weakness is that it depends on a series of technical coefficients that are quite general, independent of one another, and static. These shortcomings create some uncertainty regarding the model's ability to address a broad set of policies, e.g., water pricing policies or groundwater extraction policies.

The choice of this two-scale approach is due to the fact that conceptual (i.e., mass balance) models cannot go into the required to examine some sets of water policy and other policy issues. For example, conceptual models are unable to accurately calculate subsurface flows and hence the transport and transformation (precipitation and dissolution) of salt. Accurate determination of flow improves calculation of root zone water availability to plants (which affects crop productivity and thus revenue) as well as the depth to groundwater that can affect pumping energy and costs. High solute concentrations in the root zone also reduce water availability which is particularly common in more arid irrigated areas of the basin. Changes in soil salinity and groundwater depth and quality have implications for crop yields and hence the profitability of farming operations. Therefore, more detailed and accurate calculations are essential to feed back to the economic model that will respond to changes in salinity and groundwater depth. Those and many other questions (e.g., related to soil erosion) can only be addressed by more sophisticated models such as MOD-HMS.

For the Rio Preto watershed, results from the high-resolution MOD-HMS model and the low-resolution MIKE-Basin models will be compared to assess error due to the combined effects of resolution and of process differences in the models. These errors in the Rio Preto carry into the entire river basin where the low-resolution model will be applied. We will study the effects of upscaling on error for the Rio Preto watershed by increasing cell size to that typical of available data in the entire river basin and to that typical of conceptual hydrologic models. A hope is to motivate more intensive data collection to allow the application of the high resolution system over increasing larger but selected portions of the entire river basin. Moreover, since data needs and data collection activities/costs will become clearer as we progress, we also hope to set estimates of these additional research costs alongside the expected benefits of the improved policy guidance that emerges from MOD-HMS (an admittedly more complicated and expensive research tool); the NPV of developing and implementing MOD-HMS may be quite large, and we will certainly learn much about where and how to deploy such high-resolution, hydro-economic research tools to generate even higher returns in the future.

SECTION 3 – OUTPUTS AND METHODOLOGY FOR THE 2nd PHASE

3.1 – Basin-Wide Research

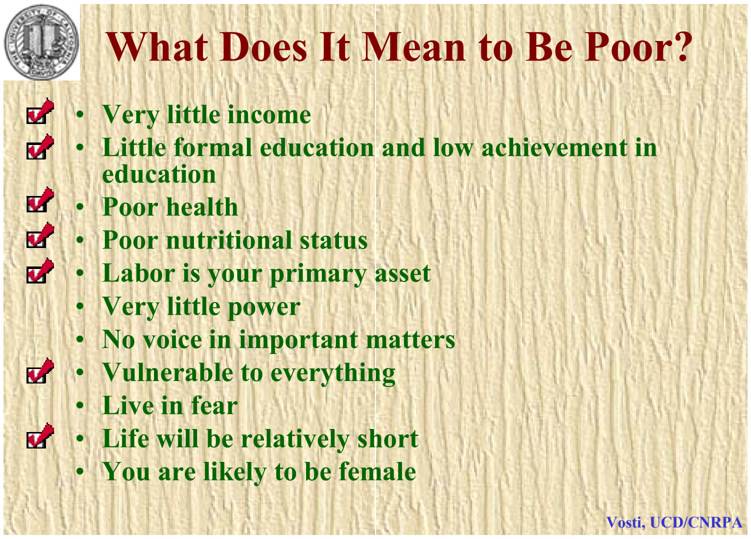
3.1.1 -- Basin-Wide Poverty Assessments

Our descriptive analysis of poverty at basin level begins by addressing the following issues:

- Where Are the Rural Poor?
- What is the Nature of their Poverty?
- What Is the Depth of their Income Poverty?
- What Income-Generating Activities Are Available?
    - Production technology
    - Product mix
    - Area under plow

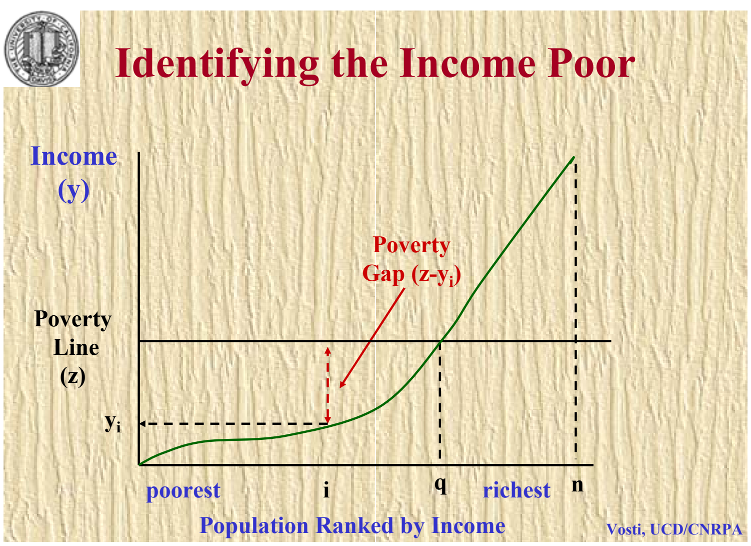
Poverty has several, interrelated dimensions, some of which are more easily quantifiable than others. Figure 1 sets out an array of factors related to poverty; 'checked' factors are those for which some secondary data are available for the SFRB, at one or more points in time, usually at município level.

Figure 1 – Defining poverty



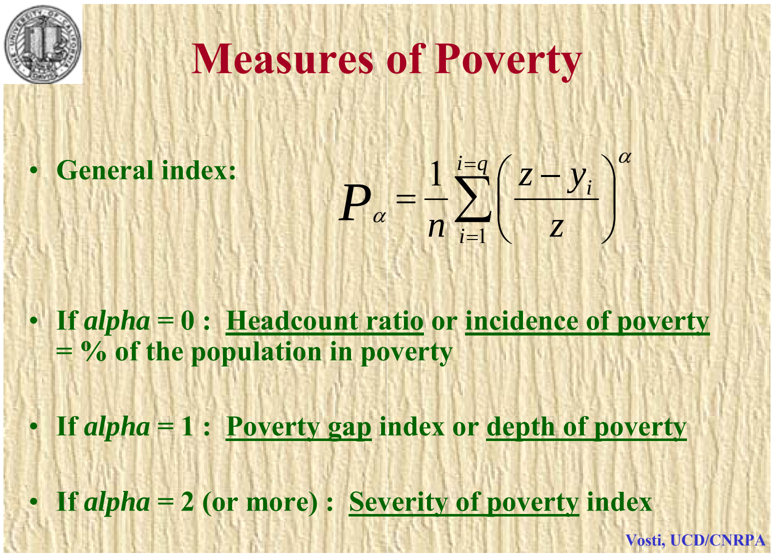
Our initial focus will be on income-based indicators of poverty, two of which are available nationally for Brazil at município, for 1991 and 2001. The first is a headcount measure of the poor, which simply identifies the number of individuals who fall below a specified income threshold and time interval (for Brazil, the income threshold is the *salario mínimo*; the time interval is one month) (IBGE). Figure 2 depicts a typical distribution of income ('y,' green curve) for a developing country and a poverty line (horizontal line Z); combining the two provides a headcount of the poor, in this case 'q' individuals are by definition poor.

Figure 2 – Identifying the number of poor and the 'depth' of poverty



The second measure of poverty relies on identifying the 'gap' between the actual incomes of the poor and the poverty line (Z-y_i in red in Figure 2). These data, too, are available in Brazil at município level (but only for 2001) and will allow us to estimate not only the number of poor in rural areas, but also the depth of their poverty, or the poverty gap at município level.

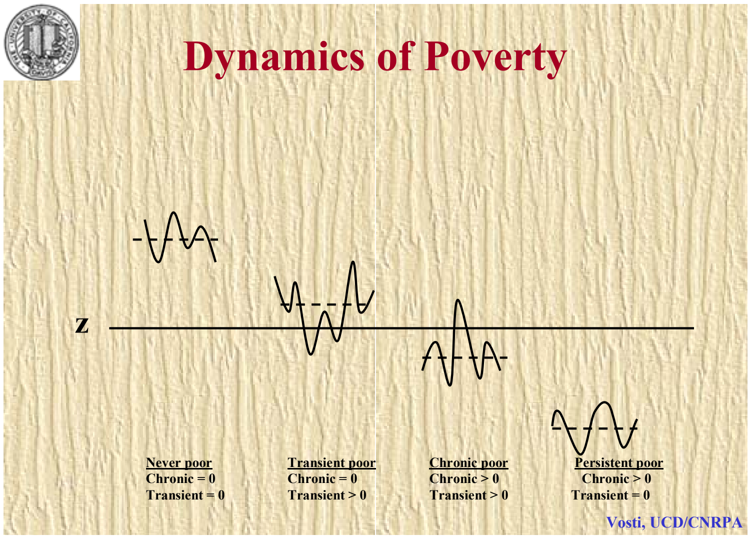
Figure 3 – Poverty ‘weights’ for guiding policy action



Several methods are available for adding up the individual poverty ‘gaps,’ some of which allow policymakers and others to ‘weight’ poverty by its relative severity. Figure 3 provides one such method, with several options for weighting poverty of individuals. If alpha = 0, the measure calculates a head-count of poverty. If alpha = 1, an estimate of the total income required to alleviate all poverty emerges. For any value of alpha greater than two, the poverty of the poorest of the poor receives above-average ‘weight’ in the summation of poverty. With estimates of the depth of poverty in hand, we can then proceed to generate indices that weight poverty.

Temporal variations in the incidence of depth of poverty can be important, especially in the context of rural areas where income derived directly (via crop production) or indirectly (via wage labor) represents a large proportion of total income. Agricultural incomes are known to suffer from large seasonal and inter-annual swings. Some of these income swings can lead to transient or chronic poverty; the non-poor never dip below the poverty line during such swings, and the persistently poor never rise above it (Figure 4). If the agricultural practices of the poor can be defined, município-level data on agricultural output and yields may allow us to estimate temporal fluctuations in income derived from such activities; income derived from off-farm activities (especially off-farm, non-agricultural activities) will complicate the linking of fluctuations in crop-derived income and poverty, but the potential for changes in water management to reduce seasonal and other swings in income make this an empirical exercise worth pursuing.

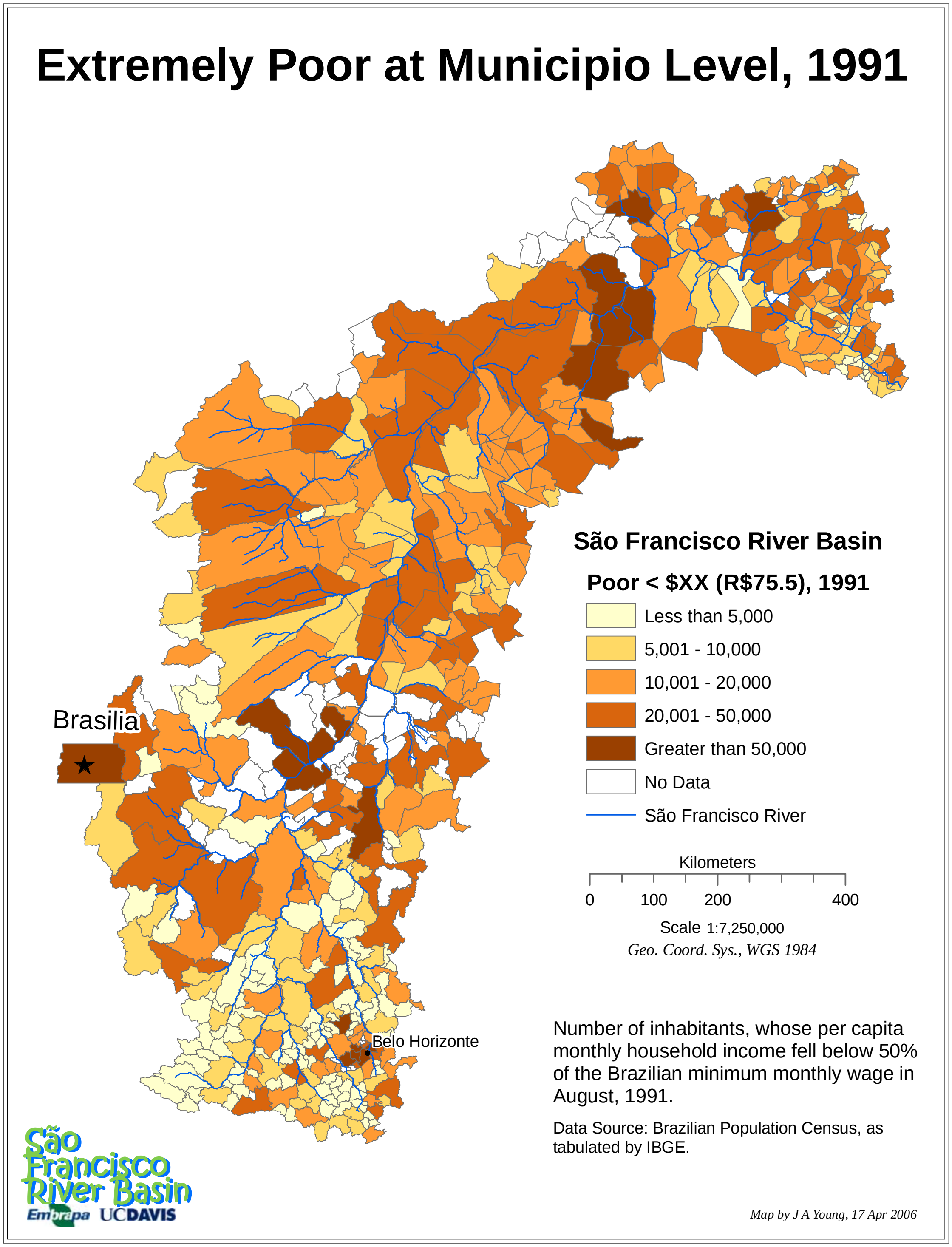
Figure 4 – Temporal variations in poverty



Secondary data will be relied upon exclusively for the basin-level poverty assessments. Município-level data on poverty (head counts and poverty depth) for 1991 and 2001 are available, additional sources may be identified and included in the analyses.

Outputs from poverty assessment exercises include rural poverty maps for 1991 and 2001 (for head counts and poverty depth), and for changes in both measures of poverty over that 10-year period. An example of such an output appears below in Map 2, which depicts the incidence of extreme poverty (the number of individuals in a given município who earn less that ½ of a minimum salary per month). Note that while extreme poverty is not pervasive in the SFRB, there are pockets of such poverty, some of which lie along major tributaries to the SFR.

Map 2 – Extreme poverty in the São Francisco River basin, 1991



The statistics package STATA will be used manage the data and calculate poverty indices; ArcGIS will be used to produce poverty maps.

3.1.2 – Basin-wide Characterization of Agriculture

The characterization of agriculture will be undertaken at the município level; over 500 municipios from seven states comprise the SFRB. Characteristics will include product mix, input mix, area under plow, the value of agricultural production. Several ‘snapshots’ of agriculture will be generated, most recently for the 2004/05 cropping year, for the 1995/96 cropping year, and perhaps for several other years in order to identify trends in key characteristics.

Secondary data at município level will be used to characterize agriculture. Unfortunately, the most recent agricultural census is over a decade old. Nonetheless, we will rely on it to identify input mix and to estimate applied water. A more up-to-date, annual series is available for area (by crop) and output. Price data for agricultural inputs and outputs are available annually since the 1970s.

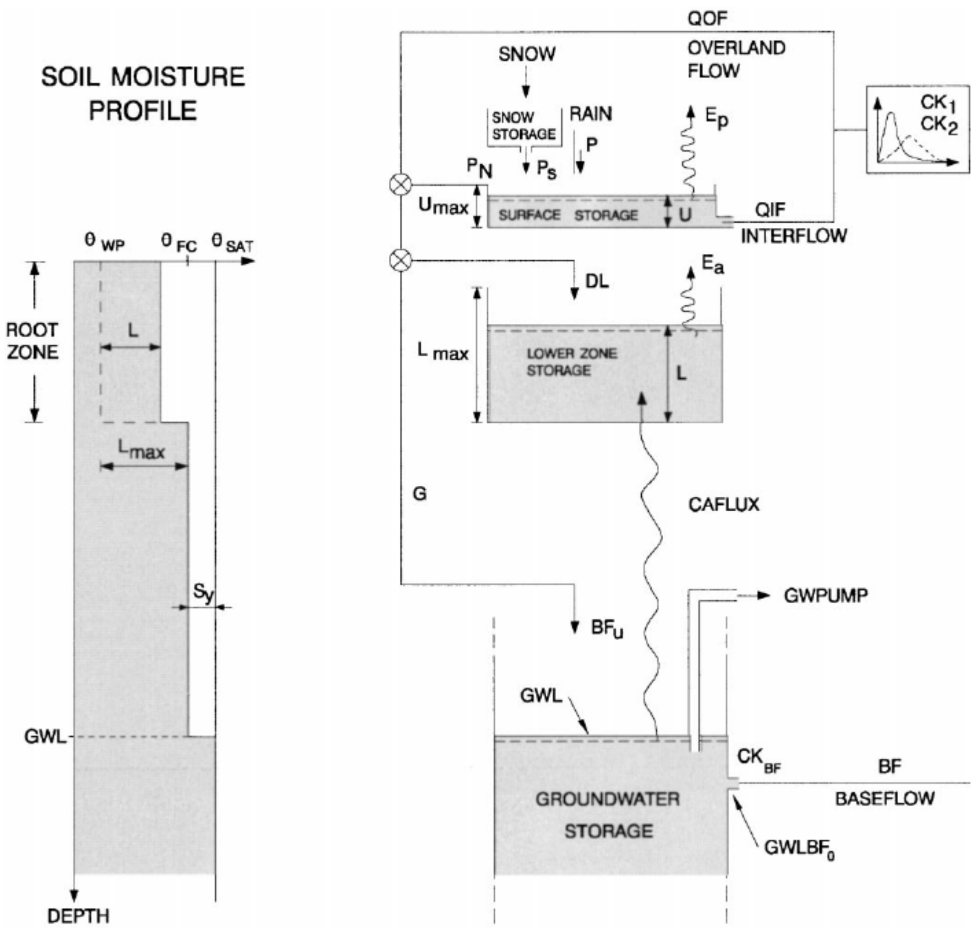
Outputs include basin-wide maps of agricultural land use and the value of agricultural production, annually, for several years, by município.

Data will be stored/managed using STATA; maps will be generated using ArcGIS.

3.1.3 – Basin-wide Characterization of Hydrology – MIKE Basin

MIKE basin is a simple model used to quickly calculate water budgets for large watersheds where hydrology data are scarce. The data needed to run the model are minimal, but the information it provides is limited. This information is aggregated to the level of user-defined sub-basins within the main watershed. The core of MIKE Basin is a rainfall-runoff model (NAM model) based on a multiple-tanks concept that simulates the release of water from the different storage units in each sub-basin (Figure 5). The produced runoff is routed down the river network using the Muskingum method; stage-discharge and rule curves are used to operate the reservoirs.

Figure 5 -- Structure of the rainfall runoff model embedded in MIKE BASIN (after Madsen, 2000)



To begin, one must delineate the watershed boundaries and the river network so MIKE Basin can calculate the watershed areas and the river/reservoir topology. The user must supply precipitation, reference evapotranspiration, vegetation/crop properties to calculate actual transpiration, and water management data from groundwater and reservoirs (pumped water from groundwater and water withdrawals from reservoirs and rivers). To characterize the soil wilting point (θ_{wp}), field capacity (θ_{fc}) and saturation volumetric soil water contents (θ_{sat}) are required.

All other information needed is imbedded in the conceptual parameters (which emerge from model calibration), including maximum water content in the surface storage (U_{max}, mm), maximum water content in the lower zone storage (L_{max}, mm), an overland flow runoff coefficient (CQOF, -), the threshold value for overland flow (TOF, -), the threshold value for interflow (TIF, -), the threshold value for recharge (TG, -), the time constant for interflow from the surface storage (CK_{if}, hours), the time constants for overland (CK_1) and interflow (CK_2) routing and the base flow time constant (CK_{bf}, hours) used to generate base flow from the groundwater storage. Those are all values aggregated for each of the sub-basins.

Initial conditions for the model include the initial groundwater depth (GWL, mm), the initial soil storage (L, mm), and the initial surface storage (U, mm). The information provided to link with the economic model is basically comprised of the water stocks in the each of the three types of storage.

Typically, calibration of conceptual models involves many coefficients and parameters, but the model run times are much shorter than those for physics-based models, so a more exhaustive search of the solution space is possible. The built-in Shuffled Complex Evolution optimization algorithm (Duan *et al.* 1992) has proven to be very efficient in finding the global solution in highly dimensional optimization problems and will be used to calibrate MIKE-Basin.

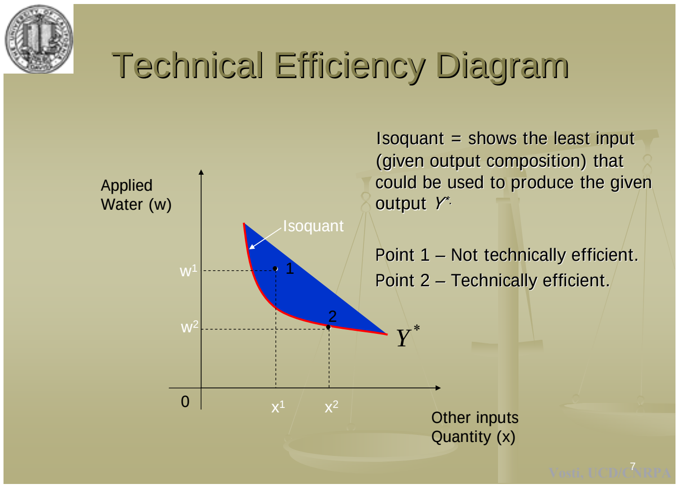
Outputs emerging from this analysis include basin-wide maps of water availability; spatial resolution will be municipios or clusters of (agroecologically) similar municipios.

One issue related to assessing the hydrology of the SFRB (or any sub-region of it) merits mention here. At any spatial or temporal scale, it is very important for policy researchers to clearly distinguish between water 'availability' and 'access' to water. With the possible exception of rainfed agriculture, access to water will imply costs (e.g., costs of pumping water from a stream to a field, or costs of establishing a gravity-flow conveyance system to carry available water to your field) and these costs can drive a 'wedge' between the water access and water availability. This issue will be especially relevant for the rural poor who may lack the financial (or other) resources to gain access to available water.

3.1.4 – Basin-wide Assessments of Water Productivity

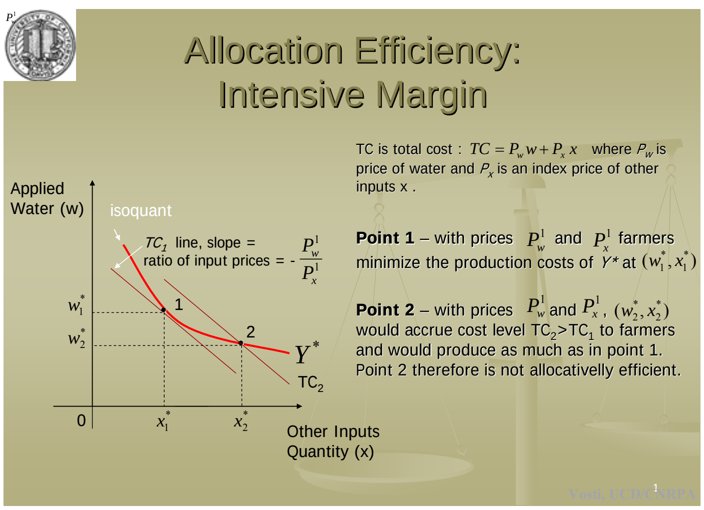
Our efforts to estimate water productivity at basin level will begin by examining the economic notion of input use efficiency in the context agriculture. All farmers adjust (continuously, if they can) to changes in incentives, among them the farmgate costs of applied water. Farmers first seek to be technically efficient, i.e., to produce as much as they can with the inputs available. Figure 6 captures this notion.

Figure 6 – Technical efficiency in agriculture



Next, farmers seek the precise place on the technically efficient production frontier by choosing input combinations that minimize the costs of producing a particular quantity of output. At this point (depicted as w_1,x_1 in Figure 7) the value of the marginal products of each input is exactly equal to its cost.

Figure 7 – Allocative efficiency in agriculture at the intensive margin



Finally, in terms of presentational sequence, farmers identify the efficient extent of their crop-specific agricultural 'frontier.' Figure 8 captures this farm-level adjustment in the context of the allocation of water to crops with very different technical water use efficiencies.

Figure 8 – Allocative efficiency in agriculture at the extensive margin

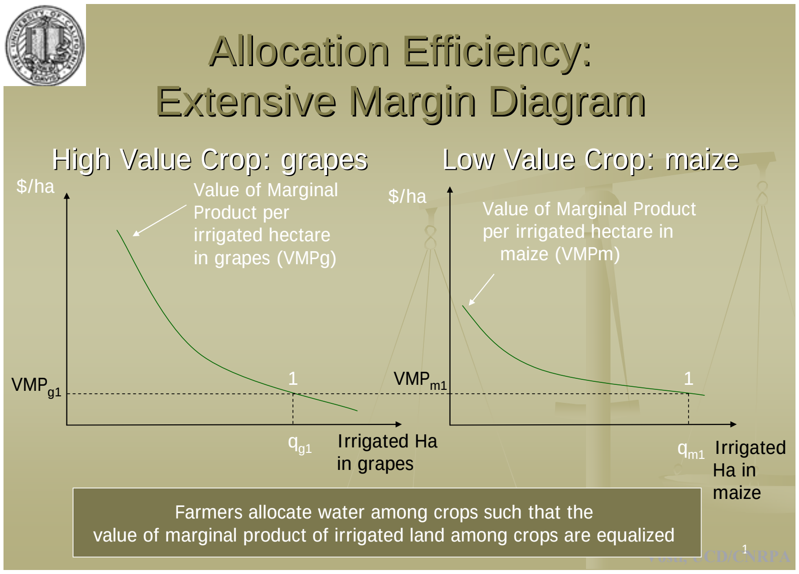
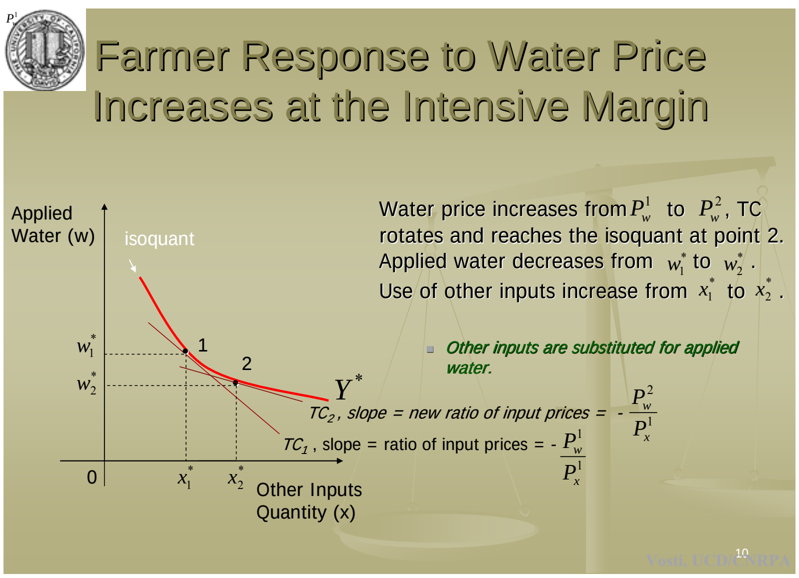
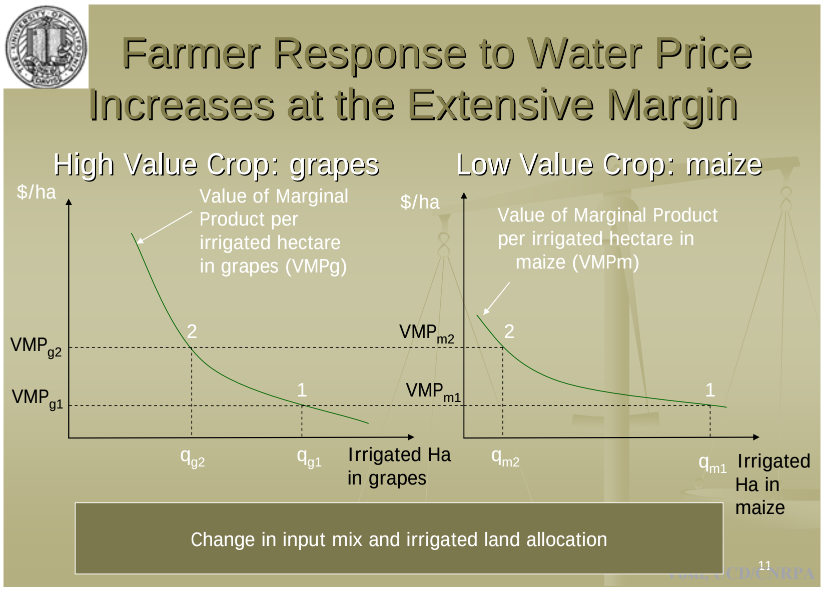


Figure 9 – Responses to water price changes at the intensive margin



Combining all three notions of efficiency (technical, allocative efficiency at the intensive and extensive margins), it become clear that farmer can and do react to changes in input and product prices in several ways; Figures 9 and 10 depict the effects of an increase in water prices on area dedicated to different products and on input mix. Measures of water productivity need to reflect these potential farm-level adjustments. Perhaps more important, policymakers need to bear these adjustments in mind when contemplating changes in water prices, for example, increases in water prices may lead to only a shift in the allocation of water across crops and not to a reduction in overall water use.   All of the economic optimization models developed for the SFRB will explicitly include all of these possible farm-level adjustments.

Figure 10 -- Responses to water price changes at the extensive margin



Once the issues associated with input productivity in general, and water productivity in particular, are sorted out, we will move forward with estimates of water productivity in agriculture at basin level. We will combine information from the characterization of agriculture in the SFRB (see above) with that derived from the hydrological characterization of the basin to generate estimates (at município level, for the 2003/2004 cropping year, at least) of water productivity.

Outputs will include basin-wide maps of water productivity (again, the spatial resolution will be at município level). Specific productivity measures will include tons of grain (perhaps expressed in terms of cereal equivalents) per unit of applied water, and the value of agricultural output per unit of applied water.

STATA and MIKE Basin will be used to generate and manage data; ArcGIS will be used to produce maps.

3.1.5 – Basin-wide Links between Water and Poverty – A Conceptual Framework

Key issues that can only be addressed once water and poverty links are determined include:

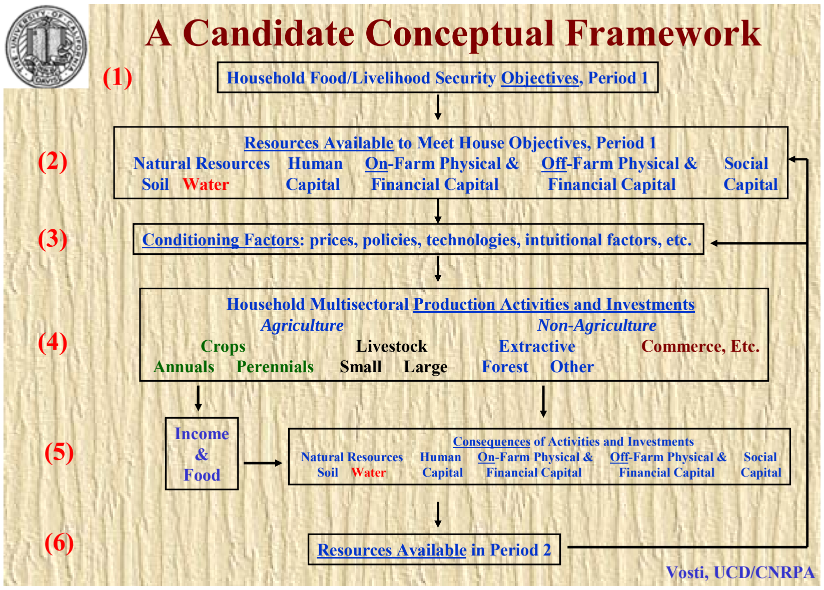
- How and To What Extent Might Changes in Access to Water Alter these Income-Generating Activities?
- By How Much Will Such Changes Reduce Poverty?

- What, if any, Is the Role of Public Policy in Changing Access to Water to Reduce Poverty?
- What Policy Instruments Should Be Used?
- Where Should Policy Action Be Focused?
- What, If Any, Supporting Policies Need to Be in Place Before Moving Forward?
  - To target or protect the poor
  - To responsibly manage ecosystem services

To date, no comprehensive conceptual or analytical framework exists for establishing water and poverty interrelationships. Indices based on access to water and other water- and income-related variables (e.g., Sullivan 2002) can be useful in understanding some water-poverty links, but because these indices use essentially arbitrary weights and do not address cause-effect relationships, their usefulness for policy guidance is limited. Based on the literature on poverty (e.g., Decaluwe et al. 1999, Ravallion 1998 and Behrman and Srinivasan 1995) and the literature on poverty environment links (e.g., Carpentier et al. 2005, Tomich et al. 2005, Scherr 2000, Vosti and Reardon 1997, and Reardon and Vosti 1995) we will develop conceptual and analytical frameworks that allow us to link changes in access to, costs of, and quality of water to poverty, in rural and urban settings. With these frameworks in hand, we will develop practical ways to measure water/poverty links and use these tools to assess the effects of changes in water policy on rural poverty.

A candidate framework is presented in Figure 11. Households begin each decision time period by identifying their objectives. They then move on (down) to identifying the vector of water and other resources available to meet established objectives. In step four, households choose collections of activities (on and off the farm) and investments they feel will most likely generate sufficient food and income to meet their objectives. The selection of activities and investments is conditioned by available technologies, relative prices, etc. (step 3 of Figure 11). The food and income generated by selected activities and investments help meet household objectives, but also alter the water and other resources available to meet future food/income needs. Policy action can ‘intervene’ in many places in this conceptual framework, most notably in step 3. All of the economic models developed in the context of this project will roughly follow this conceptual framework.

Figure 11 – A conceptual framework for poverty/water links



Any framework that aims to address water-poverty issues must also address the issue of uncertainty, vulnerability and risk. Moreover, the framework should suggest ways of measuring exposure to shocks (e.g., the yield and income consequences of shortfalls in precipitation) susceptibility to shocks, the ability to cope with the effects of shocks, and from all this, distill messages for policymakers regarding public policy interventions to reduce exposure or susceptibility to shocks, or enhance the ability of the rural poor to cope with shocks.

We expect to prepare a working paper that sets out a conceptual framework examining water/poverty links in rural areas; this working paper will guide our data collection and modeling efforts, and the latter activities will lead to improvements in the conceptual framework.

3.1.6 – Basin-wide Links between Water and Poverty: Spatial Econometrics

It may be possible to establish statistical links between one or more of our município-level measures of poverty and an array of agricultural variables known to provide income to and employment for the rural poor, controlling for the effects of hydrological variables on agriculture.

The estimate equation may take the form:

$$\text{Poverty}_{i,t} = \alpha + \beta_1 \text{water}_{i,t} + \beta_2 \text{characteristic of agriculture}_{i,t} + \beta_3 \text{hydrology variables}_{i,t}$$

Annual data series are available at município level for area and production (and hence, yield), product and input prices, and for some hydrological variables (e.g., rainfall). Detailed agricultural data are available only for 1995/96. Poverty data are available for 1991 and 2001.

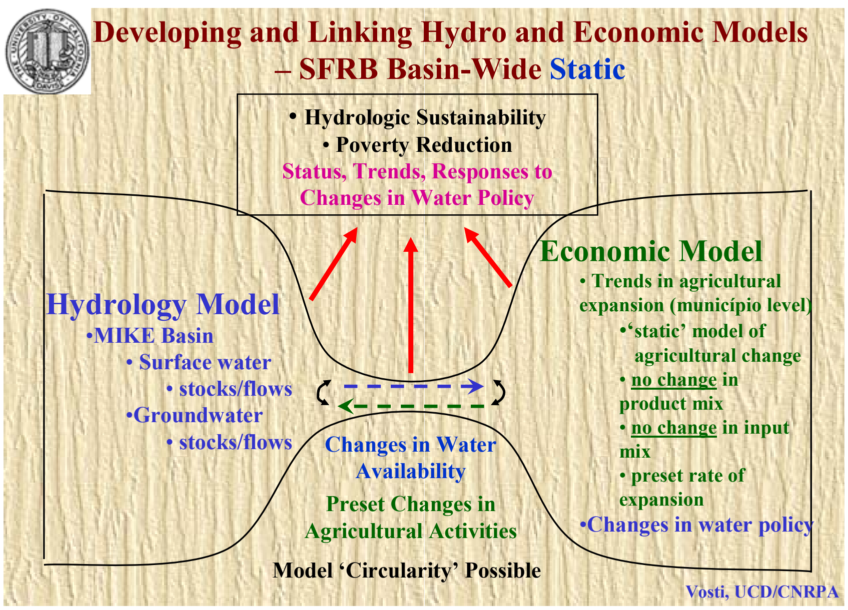
STATA will be used to estimate the equations; ArcGIS will be used to display any spatial patterns that emerge.

Outputs include quantitative estimates of the links between selected water-related variables and poverty.

3.1.7 – Basin-wide Links between Water and Poverty – A Static Hydro-Economic Model

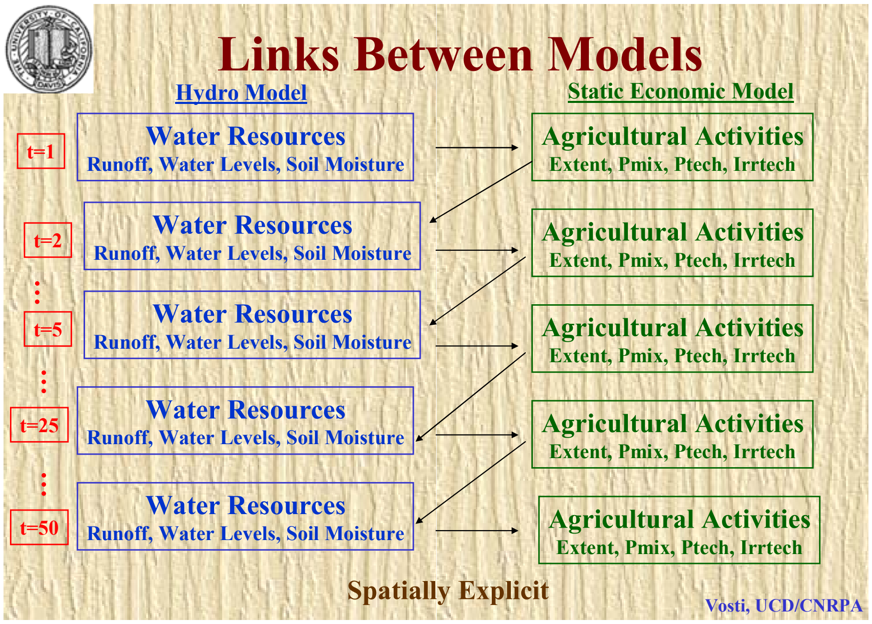
Building on the longitudinal characterization of agriculture based on município-level data, we will identify trends in agricultural change (product mix, input use, spatial extent of agricultural activities) and use these trends to predict these same characteristics over the next decade or so for agricultural activities in each of the 500+ municipios that comprise the SFRB. The right-hand side of Figure 12 identifies the types of information that will be contained in the 'static' economic model; note that no changes in product mix or input mix will be introduced, beyond those that are identified in historical trends in secondary data. The left-hand side of Figure 12 lists the types of hydrological information that will 'feed into' the economic model.

Figure 12 – Ingredients of a static, basin-wide hydro-economic model



The results of these static predictions of future agricultural activities will then be 'fed into' the MIKE Basin model to: a) assess the hydrological feasibility of these predictions, and b) if feasible, to assess the hydrological implications of predicted trends. Figure 13 characterizes the nature of the information to be exchanged across models, the flow of at information, and the timing of information exchanges.

Figure 13 – Information exchanges between hydrology and economic models



We will use STATA to generate estimate the characteristics of future agricultural activities, MIKE Basin to assess the hydrological consequences of these trends, and ArcGIS to produce maps.

Outputs from this component of the research will include basin-wide maps of predicted future agricultural land use and predicted water availability.

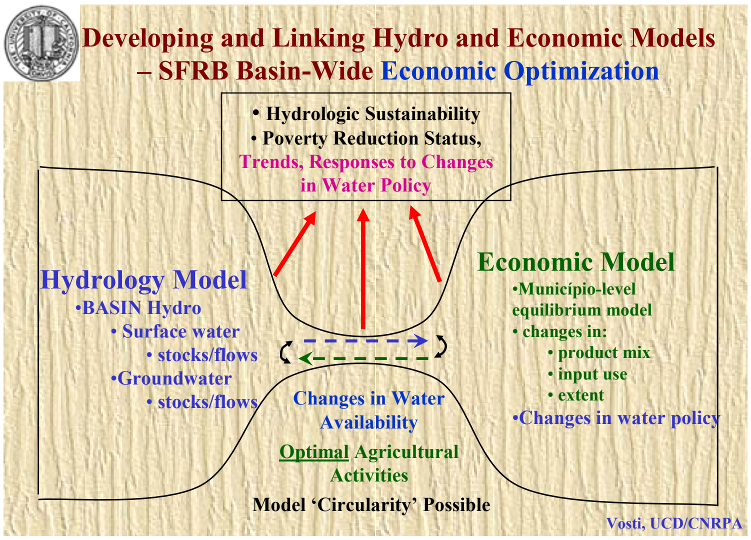
3.1.8 – Basin-wide Links between Water and Poverty – A Hydro-Economic Optimization Model

A second type of economic model will be developed to predict future agricultural activities at the basin scale, once again, at the spatial resolution of municípios. This model will simulate optimal land management "behavior," and link annual agricultural outcomes associated with this behavior to a conceptual hydrologic model (MIKE Basin) to assess the hydrological implications of these outcomes.

More specifically, production functions in the model define crop yield as a function of crop type, soil type, applied water, variable inputs (e.g., fertilizers), and irrigation technology, all of which are considered to be endogenous (or choice) variables, and soil salinity in the root and vadose zones (which are taken to be exogenous).

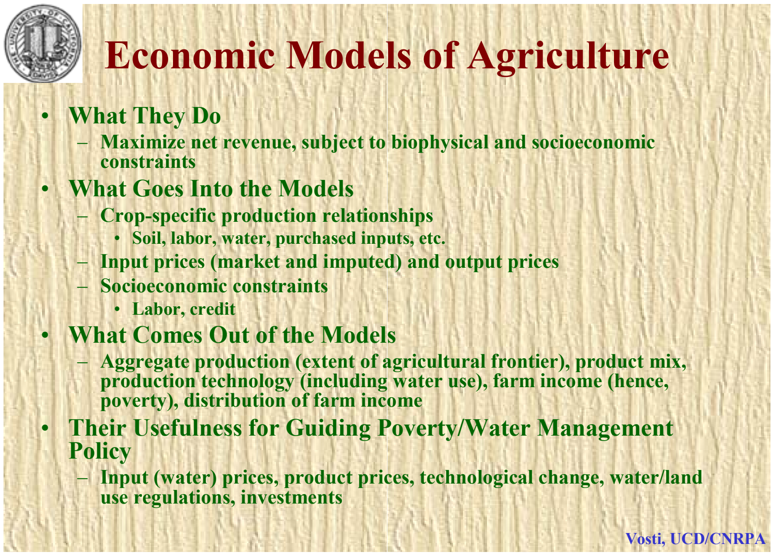
The connections between the production function and the hydrologic components flow in both directions. (See Figure 14.) The feedbacks are evapotranspiration (produced by different crops, locations and cropping practices) and groundwater pumping (a field-level decision variable the influences production costs). The applied water can be composed of melded surface and ground water supplies. Surface water supplies will be determined by the mass balance model. Thus we will be able to model the yield responses to alternative natural- and policy-based fluctuations in surface water supply.

Figure 14 – Ingredients of an economic optimization, basin-wide hydro-economic model



The approach used will be to calibrate crop-specific production functions using primary data on the crop yield, salinity levels, soil types, applied water and other inputs. The production function used will be of the constant elasticity of substitution class (CES) that allows adjustment and substitution of the fixed and variable inputs. The elasticities of substitution needed to calibrate the function will be obtained from statistical analysis performed on plot-level data provided by Embrapa. Data on soils, salinity and applied water will be obtained from municipal records and from survey data. The quantities of variable inputs used such as pesticides, labor and fertilizer will be obtained from farm surveys and from Embrapa and IBGE. Field-level data on crop yields pose a challenge. Two sources of data are envisaged, the first is annual data from IBGE on output and area dedicated to specific crops (from which we can calculate yields), and the second source is remotely sensed data in the form of a vegetative index that will form the basis for estimating município-level yield data. Figure 15 summarizes the objectives, data needs and outputs produced by the economic model, and to what use these outputs might be put in the policy arena.

Figure 15 – Economic models of agriculture: objectives, data needs, products and policy uses



Changes in access to and the costs of surface water and groundwater can affect the profitability of alternative product mixes and production technology choices, and their consequences for food security and poverty. This is especially true for resource-poor farmers who may not have the technical knowledge, access to capital markets or the 'agility' to make all of the profit-maximizing/loss-minimizing substitutions among inputs that (e.g.) sudden changes in water availability might require. Since not all farmers in the SFRB are resource poor, we will develop two types of archetypical farms that will be contained in each of the município-level 'decisionmaking units' in the basin-wide model – the relative importance of each type of farm as regards the amount of farmland they manage can vary across municípios and over time for a given município. The first farm type will capture the 'reality' of the *un*constrained farm situation, e.g., farms operating large-scale pivot irrigation schemes. For this case, the field-level profit functions will have a constant linear specification in output and input prices; all prices are assumed to be exogenous to all farmers in this region because of inter-regional trade. The second type of farm will be developed to capture the 'reality' of the *resource-poor* farmer. Capital constraints and limitations on factor substitutions will be introduced, especially for expensive investments in on-farm irrigation infrastructure. In both cases, the profit function is linked to the production functions and to the basin-wide hydrologic model. For example, the cost of pumping ground water be estimated using information provided by MIKE Basin.

The hydro-economic model (the economic optimization version explained here, and the static version outlined above) can also be used to determine on-farm employment associated with crop production. Município-level crop-specific production information will be utilized to determine on-farm labor demand. Adjustments in product mix and production technology in response to (say) changes in water availability or cost within the same area will then generate corresponding changes in labor needs.

To do this, we will rely on published labor demand coefficients for Brazilian agriculture from sources such as the IBGE, especially the most recent agricultural census. The data is sufficiently precise to allow specification of both regular and seasonally employed labor for each major task. Knowledge of the production acreage for each crop in the specified geographic area and the corresponding labor demand coefficients makes it possible to determine labor needs for each crop. By summing the results for all crops, agricultural labor demand for the entire area may be computed. Earned income of agricultural employees can also be computed. Only prevailing wage rates and labor demand for each task are needed.

Outputs of from this basin-wide, hydro-economic model will include maps of optimal future agricultural land use and their predicted hydrological consequences, including water availability.

STATA will be used to manage data and to do the necessary preliminary statistical work to estimate and calibrate the economic model, GAMS will be used to run the economic model, MIKE Basin will provide hydrological information and ArcGIS will be used to produce maps.

3.1.9 – Identifying and Testing Water Management Interventions at Basin Level

Water allocation and water use decisions are influenced by public policy and other factors both within and beyond the basin. Within the basin, public policy action can take the form of investments in water conveyance infrastructure (e.g., canal systems), the establishment of water user associations, the establishment (and enforcement) of water or land use regulations, the establishment of water pricing schemes, etc. Outside the basin, such policies as national-level tax policies relating to irrigation development, operations, and maintenance; agricultural input and output pricing policies; and inter-basin water transfer schemes can act to either reinforce or mitigate effects of policies at the basin-level and sub-basin levels. In identifying the effects of alternative water management options, we aim to use the available to estimate the effects of proposed and contemplated agricultural and water policies on water use, agriculture and poverty. Particular attention will be paid to policies that regulate surface and groundwater use, and those that establish basin-wide and sub-basin water prices, and how such policies might independently and jointly effect agricultural productivity and profitability, water use efficiency and environmental quality in the basin.

We will begin by using the *static* hydro-economic model (described above) to assess the economic and hydrological effects of selected interventions; recall that the 'baseline' (or counterfactual) for these comparisons will be the extrapolation of historical trends in product mix, production technology and area under plow.

The more suitable hydro-economic model that incorporates the *optimizing behavior* of agricultural decisionmakers will then be used to assess the effects of particular interventions on the same set of outcomes, taking into consideration the ability of farmers to respond to changes in economic incentives, among them changes in the cost of applied water.

Comparisons of the results of the two models (static and economic optimization, both linked with MIKE Basin) for given interventions will provide insights into the value-added *for policy* *purposes* associated with incorporating economic optimization algorithms into hydro-economic models.

Outputs from this element of research will include maps depicting the responses to specific interventions of (using the static and economic optimization versions of the model) future agricultural land use and predicted water availability, and the consequences of both for rural poverty.

3.2 – Research in the Buriti Vermelho Sub-Basin

3.2.1 – Poverty Assessments in the Buriti Vermelho Sub-Basin

Secondary data will be relied upon exclusively for the basin-level poverty assessments. Município-level data on poverty (head counts and poverty depth) for 1991 and 2001 are available, additional sources may be identified and included in the analyses.

Outputs from poverty assessment exercises include rural poverty maps for 1991 and 2001 (for head counts and poverty depth), and for changes in both measures of poverty over that 10-year period.

The statistics package STATA will be used manage the data and calculate poverty indices; ArcGIS will be used to produce poverty maps.

3.2.2 – Characterizing Agriculture in the Buriti Vermelho Sub-Basin

Agricultural characterization at the sub-basin level will be done in two ways. The first will rely on a time series of secondary data for the municípios that comprise the Buriti Vermelho catchment area. Characteristics will include product mix, input mix, area under plow, the value of agricultural production. Several 'snapshots' of agriculture will be generated, most recently for the 2004/05 cropping year, for the 1995/96 cropping year, and perhaps for several other years in order to identify trends in key characteristics. Unfortunately, the most recent agricultural census is over a decade old. Nonetheless, we will rely on it to identify input mix and to estimate applied water. A more up-to-date, annual series is available for area (by crop) and output. Price data for agricultural inputs and outputs are available annually since the 1970s.

The second will make use of detailed field surveys to identify agricultural production practices and relative prices of inputs and outputs at farm gate. Specific information on input use (purchased and owner-supplied, including labor) and crop management practices (including irrigation technology and management) will be collected. Sample design will be influenced by hydrological (e.g., location in watershed) and socioeconomic variables (e.g., access to market) and sample size will be influenced by the numbers and characteristics of farms in the area (e.g., smallholders versus large-scale farming operations, or subsistence farming versus commercial agriculture).

Outputs from the characterization based on secondary data will include basin-wide maps of agricultural land use and the value of agricultural production, annually, for several years, by município. Outputs from the field-based characterizations will include the identification of farm types and the characteristics of these farm types. Field data will also be used to undertake LUS analyses (see below) and to parameterize the sub-basin economic optimization model (see below).

Survey data will be managed using MS Access; primary and secondary data will be stored/managed using STATA; maps will be generated using ArcGIS.

3.2.3 – Characterizing Hydrology in the Buriti Vermelho Sub-Basin– MOD-HMS

The purpose of the hydrologic model is to assess in a spatially and temporally explicit manner the impact of agricultural management decisions on soil and groundwater resources at relatively high resolution with a region. In particular, the hydrologic model simulates surface flows as well as water flow and solute transport through the vadose (unsaturated) and groundwater zones as it is influenced by agricultural management decisions (applied water rates, groundwater pumping, cropping patterns). As such, it provides a powerful tool for the assessment of management alternatives in the complex irrigated ecosystem.

We will use the high-resolution hydrologic models MOD-HMS (*HydroGeologic* 2001).[2] MOD-HMS is a Modflow-based distributed watershed model. It simulates three-dimensional variably-saturated subsurface flow and solute transport. Subsurface flow is simulated with the three-dimensional Richards equation while accounting for the following hydrologic stresses:

- application of water at the surface;
- precipitation;
- soil evaporation and crop transpiration, as a function of soil moisture and salinity; and
- agricultural pumping.

Subsurface multi-species reactive salt transport is simulated with the three-dimensional advection-dispersion equation (MOD-HMS). We recently completed coupling MOD-HMS flow and transport code to an existing salt reaction model (Simunek et al. 1996) using an operator-splitting approach. The resulting reactive transport model accounts for the following processes:

- three-dimensional advective-dispersive transport of 8 mobile species (Ca, Mg, Na, K, HCO3, SO4, Cl, tracer);
- ion complexation reactions in soil solution;
- cation exchange reactions with 4 sorbed species (Ca, Mg, Na, K); and

[2] As part of our successful experience using MOD-HMS, our group has collaborated with the *Hydrogeologic* to incorporate an optimization algorithm which has lead to consistent forecasts of spatially distributed drainage data during the calibration and validation periods as well as unbiased prediction of measured groundwater table depths not included in the calibration (Vrugt et al. 2004 and Schoups et al. 2005). These robust optimization methods, applied to MOD-HMS are the break-through technology to successfully calibrate, validate and apply spatially distributed models, and hence provide comprehensive guidance on water management strategies.

• precipitation-dissolution reactions of calcite and gypsum.

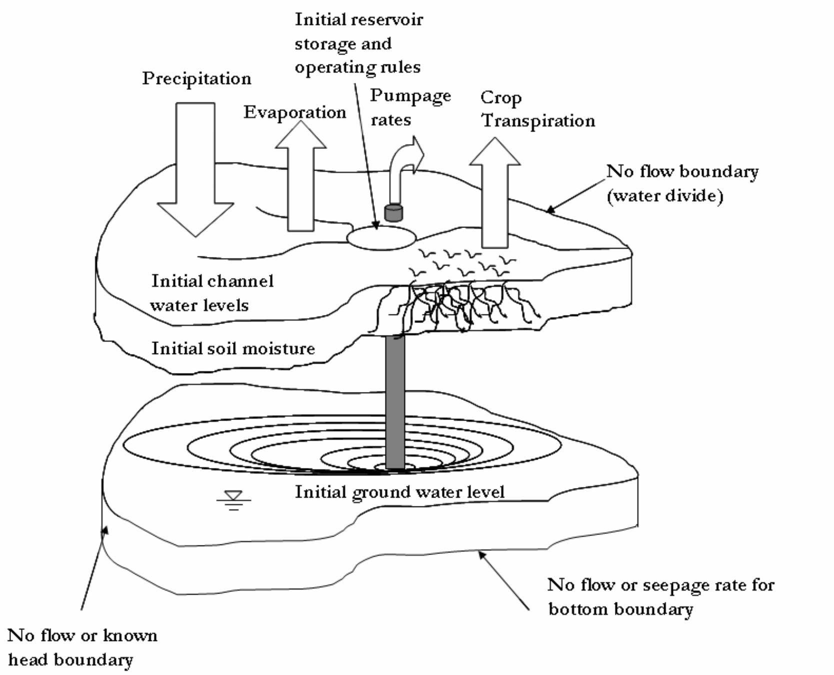
The hydrologic models distinguish themselves from other modeling systems on three levels in that they consider: (1) variably-saturated flow; (2) both flow and salt transport; and (3) salt chemistry.

The models are discretized into field-scale grid cells. In the vertical, variable discretizations are used, ranging from submeter near the surface to tens of meters at greater depth. The model uses monthly boundary conditions for irrigation, rain, evapotranspiration, and pumping. Aquifer and soil hydraulic properties are assigned based on a combination of soil survey and well log texture data, if available. We will study the effects of upscaling on error for the Buriti Vermelho watershed by increasing cell size to that typical of available data in the entire river basin and to that typical of conceptual hydrologic models. (We are cooperating with the team working on the Challenge Program Small Reservoirs Project.)

The simulation domain is defined by the limits of the watershed extracted from a DEM and the depth to the bottom limit of the aquifer. Vertically, the model can be discretized from the submeter near the surface to tens of meters at greater depth. The model uses user-based time-step boundary conditions for irrigation, rain, evapotranspiration, and pumping. Aquifer and soil hydraulic properties are assigned based on a combination of soil survey and well log texture data; many of these data are available for the Buriti Vermelho area.

A scheme of the boundary and initial conditions that have to be supplied to MODHMS are depicted in Figure 16. Some of the boundary conditions are the 'links' between the hydrology and economic models.

Figure 16 – Boundary and initial conditions for MOD-HMS



A sophisticated model such as MODHMS is able to describe the effects of the water use on all elements of the hydrological system. Some of the basic information needed to construct the model is contained in the DEM of the basin. This DEM will define the planar geometric properties of the domain including its limits, slope and topology. Usually, more detailed data on reservoir and channel geometries have to be collected. The geometry of the subsurface is given by the hydrogeologic information that will define the lower limit of the 3D basin and the structure of the aquifer, i.e. whether it is a simple water table aquifer or a complex multi-layer aquifer separated by semi-impervious layers.

Beyond the definition of the domain, the hydrologic properties of the basin have to be provided and the state variables have to be determined. For the surface, hydrologic properties basically include the hydraulic resistance to flow and parameters that permit the calculation of detention storage. Land use and standard crop coefficients will provide information on the hydrologic effect of the vegetation. For the subsurface information, hydrogeologic properties are crucial. These include the structure of the aquifer and information on the storage, yield and saturated hydraulic conductivity to simulated saturated flow in each hydrogeologic unit, and the soil retention curves (pF curves) and hydraulic conductivity functions to simulate unsaturated flows. The baseline of the system will typically include giving the initial surface and channel water depths or flows, the initial reservoir storages, the initial soil moisture content and the initial groundwater heads.

The primary boundary conditions of the model include flow conditions at the bottom and border limits of the watershed, precipitation, reference evapotranspiration, groundwater pumpage rates and operating/extraction rules for the reservoirs; the final two are provided by the economic model and are subject to policy action.

All of this information will be provided to the model in a spatially distributed way. In most cases, data modeling (e.g., interpolation between data points) will provide spatial dimensions to the data gathered at the point scale. To further refine the values of the most sensitive parameters and to re-scale the most sensitive hydrologic properties from the point to the pixel scale, an automatic calibration strategy will be used. Innovative data sources providing richer information to the calibration algorithm will be employed to improve the robustness of the calibrated model and the reliability of the predictions.

The hydrologic models will be calibrated, using PEST (optimal search algorithm), to historical observed changes of the hydrologic system, which include surface flows, observed water table elevations, and soil and groundwater quality. Calibration parameters are hydraulic parameters and solute dispersivities. Historical data on cropping patterns, surface water deliveries and groundwater pumping are collected for this purpose.

Remote sensing will support several components of the proposed water management program and allow both within-field comparisons as well as larger-area assessments (mentioned below). Remote sensing images will be used for spatially and temporally distributed model inputs, especially an evapotranspiration model (SEBAL), and provide a mechanism for evaluation of model predictions. Specifically, we will obtain the following information; spatial distribution of soil variability before crop emergence; spatial distribution of crop types and a classified map of crop distributions; spatial distribution of canopy cover and development over the growing season; spatial distribution of areas of poor crop growth and yield; and some semi-quantitative estimates of relative crop yield.

As indicated above, the DHI conceptual hydrologic model MIKE Basin will be applied over the entire river basin for the low resolution analysis. For the Buriti Vermelho watershed, results from the high resolution MODHMS and the low resolution MIKE Basin models will be compared to assess error due to the combined effects of resolution and of process differences in the models. These errors in the Buriti Vermelho carry into the entire river basin where the low-resolution model will be applied. A hope is to motivate more intensive data collection to allow the application of the high resolution system over increasing larger portions of the entire river basin.

Outputs from the sub-basin hydrological assessment will include detailed maps of surface (including surface storage, by depth from the surface) and subsurface water availability.

3.2.4 – Estimating Water Productivity in the Buriti Vermelho Sub-Basin – LUS Analysis

Land use system (LUS) analysis will be used to address several issues at the sub-basin level; we introduce the tool here.

The LUS framework is used here to evaluate alternative land use systems based on their ability to address environmental concerns, agronomic sustainability issues, farmer adoption problems and poverty. The framework (presented in Figure 17) differs from others presented previously (e.g. NRC (1993) and Tomich *et al*. (1998a)) in that it: (1) specifies land use system trajectories, including technology, land area, and the timeline associated with each system (matrix rows); (2) defines indicators corresponding to interests of various stakeholders (matrix columns); (3) presents measurements for each land use system selected (matrix cells); and (4) defines the socioeconomic and geographic setting for the analysis.

For discussions of water-poverty links, this matrix can provide a useful first characterization of potential systems, and make transparent some consequences of different water management strategies on water use efficiency and on income derived from farming activities. The systems identified here (column 1 of Figure 18) are examples of LUS that broadly represent the systems currently prevalent on the landscape, and can be evaluated against one another and against other systems capable of potentially improving LUS performance. These systems are compared using indicators on alternative development outcomes of interest (columns 2 through 7 of Figure 18), among them poverty and water productivity. These measures allow assessment of whether each technological change: (1) leads to improvements in water productivity (using value-based productivity measures); (2) is adoptable by smallholders (taking into account household livelihood security constraints and the broader institutional context); and (3) complements biophysical processes (measured in terms of agronomic sustainability and impacts on particular ecological services).

Figure 17 – An overview of LUS analysis

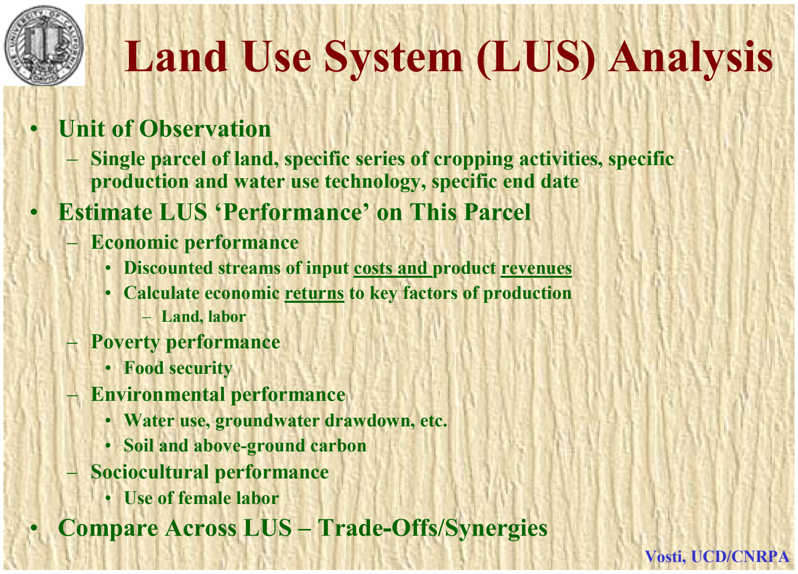
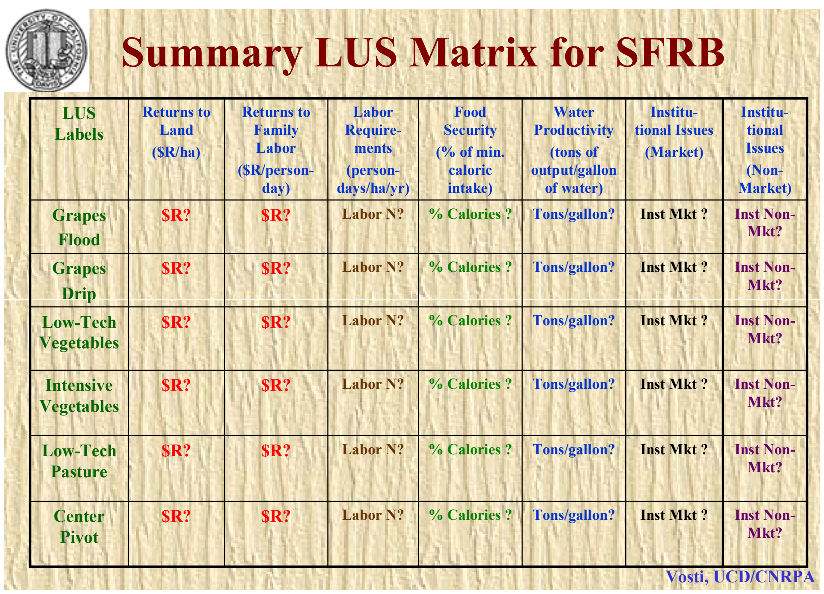


Figure 18 – Candidate LUS and measurements for the Buriti Vermelho sub-basin



Summary LUS Matrix for SFRB

LUS Labels	Returns to Land ($R/ha)	Returns to Family Labor ($R/person-day)	Labor Require-ments (person-days/ha/yr)	Food Security (% of min. caloric intake)	Water Productivity (tons of output/gallon of water)	Institu-tional Issues (Market)	Institu-tional Issues (Non-Market)
Grapes Flood	$R?	$R?	Labor N?	% Calories ?	Tons/gallon?	Inst Mkt ?	Inst Non-Mkt?
Grapes Drip	$R?	$R?	Labor N?	% Calories ?	Tons/gallon?	Inst Mkt ?	Inst Non-Mkt?
Low-Tech Vegetables	$R?	$R?	Labor N?	% Calories ?	Tons/gallon?	Inst Mkt ?	Inst Non-Mkt?
Intensive Vegetables	$R?	$R?	Labor N?	% Calories ?	Tons/gallon?	Inst Mkt ?	Inst Non-Mkt?
Low-Tech Pasture	$R?	$R?	Labor N?	% Calories ?	Tons/gallon?	Inst Mkt ?	Inst Non-Mkt?
Center Pivot	$R?	$R?	Labor N?	% Calories ?	Tons/gallon?	Inst Mkt ?	Inst Non-Mkt?

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Rapid rural appraisals will be used to identify LUS that will be the foci of analysis. Plot-level data will be collected to completely characterize each LUS, and to generate estimates of water productivity associated with each one.

Outputs include measurements of water productivity (output/unit of applied water and value of output/unit of applied water) at the LUS level. (Other products associated with LUS are noted below.)

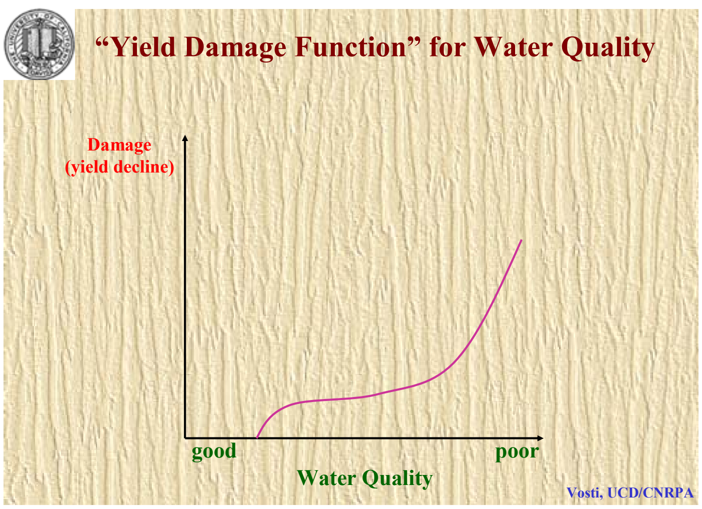
MS Access will be used to input field data; STATA and Excel will be used to manage micro data and to perform analyses.

3.2.5 – Understanding Water-Poverty Interrelationships in the Buriti Vermelho Sub-Basin

Two analytical approaches will be used to explore and better understand water-poverty links at the spatial scale of the Buriti Vermelho sub-basin.

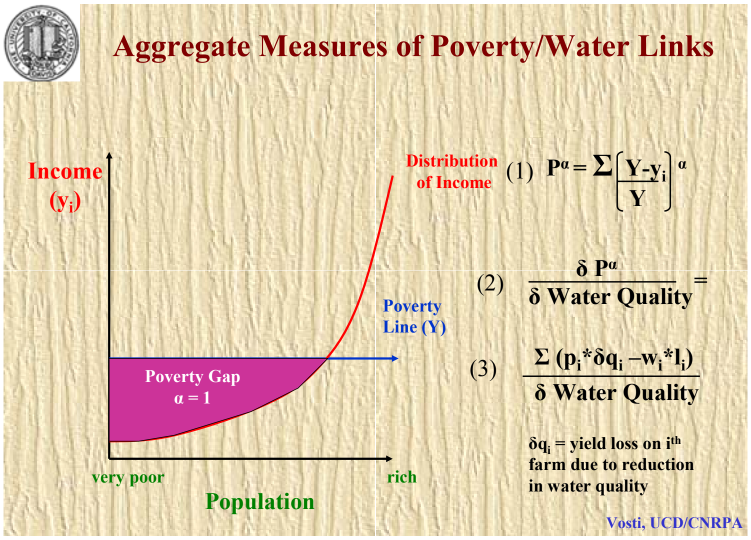
The first relies on LUS analysis and using this tool to examine the effects on income associated with the strategic technical/management alterations to existing farmer practices or changes in water quality. Figure 19 captures this notion in the context of 'damage functions' (where damage is understood to be the implications for plot-level economic performance) linking changes in water quality and poverty (via yield, and hence, income declines); poorer water quality (e.g., increased salinity) lead to yield declines which translate into large (and negative) effects on income. The same type of analysis can be done to examine the effects of changes in the cost of applied water on the economic performance of a given LUS.

Figure 19 – Example of a water quality damage function



If one knows the local poverty line and total household income (and hence the household-level poverty gap; see Figure 20), then one can assess the effects of changes in (say) the cost of applied water or a change in irrigation practices on poverty. Equations 1-3 in sketch out a method (and the data required) to do so. LUS can provide the plot-level information needed on changes in income associated with changes in management practices; survey data may be able to provide the require income and poverty line information.

Figure 20 – Measuring the poverty effects of changes in water quality



Outputs from this aspect of research will include detailed information on the effects of policy and technology changes on the economic performance (net present value, establishment costs, seasonality of income flows, etc.) of selected LUS.

The second analytical approach used to understand water-poverty links will be an Economic optimization model of agriculture linked to a detailed hydrology (MOD-HMS) of the sub-basin. The hydrology model was described above; what follows is a description of the economic optimization model (which is very similar to that of the basin-wide economic optimization model set out above).

The first step is to collect detailed field data on the inputs used in production processes (and their respective costs, if they are purchased) and the outputs generated by these processes (and their respective value). The input/output information combined with market prices for purchase inputs and outputs are used to estimate shadow values for those inputs that are *not* purchased (including, importantly, applied water). With these shadow values in hand, the complete set of inputs/outputs and relative prices are used to estimate an model of farmer behavior which has at it's core the objective of maximizing profits, but which explicitly includes the market-related and other constraints that farmers face in determining what products to produce, how much area to dedicate to each, and which set of inputs to use in producing them. The model is calibrated to 'replicate' the field-level 'reality' captured by the data collection process.

The economic model then 'interacts' with the hydrology model. Given initial conditions on surface water allocation, and soil, surface water, and groundwater quality, the agricultural production model generates optimal cropping patterns, water applications, irrigation efficiency, and crop yields for soil quality zones in a region. The output from the agricultural production model is subsequently used by the hydrologic model to simulate the impacts of these management decisions on the natural water system. In particular, the hydrologic model computes soil quality as well as groundwater quality and quantity, and their changes throughout the year, for every cell of the model grid (field scale and up). The condition of the natural system at the end of the first year (soil and groundwater salinities, water table depths) as calculated by the hydrologic model serves as initial condition for the agricultural production model in the second year, and so on.

An important consideration in coupling the economic and hydrologic models is their difference in scale, both in space and time. First, the agricultural production model makes predictions at the watershed scale, whereas the hydrologic model uses field size grid cells. Since there are several hydrologic grid cells within each economic zone, spatial up and downscaling operations are needed to pass information between the agricultural production model and the hydrologic model. Downscaling is done by randomly assigning crops to hydrologic grid cells within an economic zone, such that the crop area for that zone, as predicted by the agricultural production model, is preserved. Upscaling from the hydrologic grid cells to the economic zones of the agricultural production model, on the other hand, is readily achieved by arithmetic averaging grid cell soil quality over each zone. Second, the agricultural production model predicts annual irrigation amounts for each crop in each zone. These annual values are distributed over the months for input into the hydrologic model by assuming constant irrigation efficiency during the year, i.e. monthly applied water is computed from monthly crop water demand.

Moving up to the regional scale, the region-resolution model mentioned above will be used to calculate flow across regions within the watershed, again to capture the regional variation. As an example detailed information on which crops are being grown and their changing stages of development might be approximated using remote sensing technology from which lower resolution vegetation water use formulations will emerge. The challenge will be to explore whether these simplifications preserve the important distinctions between plant development and plant water use that are occurring at higher resolution.

Outputs from this aspect of the research will include maps at sub-basin level of optimal agricultural land use and water surface and sub-surface availability.

3.2.6 – Identifying and Testing Water Management Interventions in the Buriti Vermelho Sub-Basin

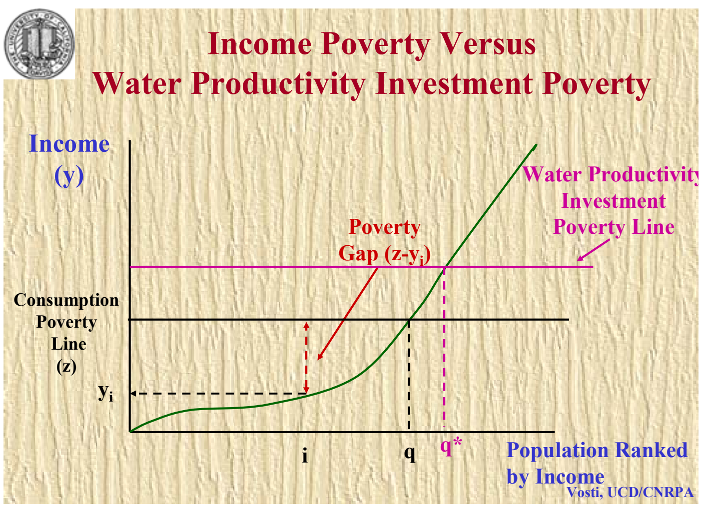
Using the methods described above, we will adopt two approaches to assessing the effects of water management interventions in the Buriti Vermelho sub-basin.

The first is LUS analysis. As discussed earlier, this tool is capable of measuring the effects of policy (e.g., water price policy) on the economic performance of LUS. It should be noted that LUS is a static analysis (in the sense that farmers are not 'allowed' to alter input mix associated with, eg., a change in water pricing) and hence may overestimate the effects of changes in water prices on key economic indicators. However, the ability of resource-poor smallholders to alter product mix or input use may be extremely limited (especially in the short term); if this is the case, then the results of LUS analysis can be quite robust.

Outputs from this research will include (static) estimates of the effects of alternative interventions (public investments, technologies, policy-induced changes in incentives, other) on water productivity and on the returns to farmer land and farm household labor dedicated to specific agricultural activities.

LUS analysis will also be used to examine the effects of establishment costs and especially management costs associate with changes in water management on poverty via their effects on the *level* of income required to escape poverty. Figure 21 captures this notion by identifying a new poverty line which lies above the consumption-based poverty line by the amount of cash required to establish and maintain the water-productivity-enhancing investment.

Figure 21 – Consumption poverty versus water productivity investment poverty



The second approach to examining water-poverty links at the sub-basin level will employ the linked hydro-economic model described above – economic optimization model and MOD-HMS. The effects of a broad array of interventions can be tested using this approach (e.g., public investments, production or irrigation technologies, policy-induced changes in relative prices) and farmer behavior is ‘free’ to adjust in ways that profit-maximization suggest are reasonable. Policy-induced and other interventions in the model take the form of changes in initial conditions (e.g., changes in relative prices of inputs, among them water) or changes in technical relationships among inputs (e.g., the introduction of drought-resistant varieties of crops).

Outputs from this research activity will include detailed maps depicting the responses to specific interventions of predicted optimal future agricultural land use and predicted water availability.

<u>3.3 – Research at the Sub-Basin Level *Outside* Buriti Vermelho</u>

Water-poverty analyses will also be undertaken outside the Buriti Vermelho sub-basin. Whenever possible, secondary data will be used (in ways described above) to assess the amount and depth of poverty and to characterize agriculture in specific areas within the SFRB. MIKE-Basin (described above) will provide basin-wide information on hydrological conditions; this information can be re-scaled to meet the spatial resolution of sub-basin analyses (rescaling will require important assumptions regarding key model parameters, especially boundary conditions).

At selected sites, LUS analysis (also described above) will be performed to characterize agriculture and to assess the effects of interventions on water productivity and poverty.

Selection of sites for intensive LUS analysis within the basin will be done in collaboration with stakeholders, but will be guided by agricultural and hydrological variables, the spatial distribution of poverty, and especially the potential for interventions in water management to reduce poverty; basin-wide research and that undertaken within the Buriti Vermelho sub-basin is expected to provide insights into which interventions are most likely to reduce poverty and to what extent.

Outputs associated with this site-specific research include estimates of the returns to farmer land and farm household labor dedicated to specific agricultural activities, estimates of water productivity, and changes to these in response to alternative water management and other interventions (e.g., public investments, technologies, or policy-induced changes in incentives).

<u>3.4 – Institutional Analyses and Knowledge Base Development</u>

3.4.1 – Institutional Analyses

As part of the basin-wide and sub-basin characterization activities, we will identify and examine the policies, legal frameworks and institutional arrangements that may affect access to or use of water in agriculture. This analysis will be done at the national, basin, state, município and 'local' levels, where 'local' could be as narrow as water user organizations. We expect our assessment of these levels of the policy and institutional 'landscapes' to cover the period from 1995 to present.

Outputs from this analysis should include time lines, by level of spatial resolution, of policies, etc., detailed descriptions of these, and path diagrams suggesting possible effects of selected policies, laws and intuitions on the cost of applied water and water use.

3.4.2 – Knowledge Base Development

This aspect of the research project has already begun. We are in the process of compiling existing (primarily secondary) data for preliminary analyses, and are developing a strategy to collect and process the needed primary data (both biophysical and economic). Data and data collection instruments will be shared with BFP partners.

We will also prepare working papers (most of which evolve into published papers/book chapters), policy briefs, Power Point presentations, and training materials that document and convey to stakeholders the research methods we develop, our research results, and the policy implications of our results.

We have also begun to develop a strategy for delivering key research results to stakeholders. We envision this process as a 'full circle' – decisionmakers and other stakeholders who early on in the project provided guidance regarding key water and poverty policy issues to be address, and who were the recipients of and reviewers of preliminary research results, will be convened at the end of the project to comment on the final research results and to assist us in distilling and policy messages from these results and identifying recipients for these messages.

The immediate beneficiaries of this research will be the stakeholders in the São Francisco River Basin, especially the rural poor within the SFRB. Other beneficiaries include sub-regional, regional and national professional managers, engineers and scientists. Furthermore, the academic community, outreach, consulting companies in the Basin and more broadly nationally and internationally will have access to the information and approach to water and land management. Of particular importance will be our colleagues in other CP Basin Focal Projects who will be the recipients of the refined methodologies and other intermediate projects we develop and test, and collaborators in examining cross-basin research and policy issues.

As noted above, we are cooperating closely with the team working on the Challenge Program Small Reservoirs Project in the Buriti Vermelho sub-basin. Some of the issues they set out to address, among them the effects on groundwater availability and quality of small-scale water storage, will be addressed using the high-resolution and process-based MOD HMS model.

One key object of the Basin Focal Projects is to develop, test and deliver research methods that can be used across all CP basins. To meet this challenge in the SFRB, we will: a) develop a conceptual framework linking poverty and water; b) based on this framework and on advances in measuring water productivity, suggest a common set of indicators for cross-basin synthesis work; c) develop a set of LUS analysis tools and test their usefulness in a variety of agroecological and socioeconomic settings; d) develop and use MIKE-Basin to assess the general effects of alternative water management strategies at basin level; and e) develop, test and use a detailed hydro-economic model (MOD-HMS) to assess the long-term effects at the sub-basin level of alternative water management strategies and water policies on surface and groundwater availability and quality, and on product mix, production technology, farm profits and farm employment. In collaboration with and with support from BFP Central, selected components of this research tool kit will be delivered to collaborators working in other CP basins.

SECTION 4 – PROJECT MANAGEMENT

4.1 – Implementation Plan

The Gantt chart (Table 1) sets out the implementation plan for this collaborative research effort. The basin tour has been completed and we will shortly convene a planning workshop on the UC Davis campus. Preliminary field visits have been made by all members of the research team, and data collection activities will begin shortly after the planning workshop is concluded.

Table 1 – Implementation Plan

	2005	2006				2007				2008	
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
ACTIVITIES											
Stakeholder/Issues Document											
Activity 1.1 -- Literature Review											
Activity 1.2 -- Data Review											
Activity 1.3 -- Focused Basin Visit/Stakeholder Interaction											
Activity 1.4 -- Prepare Draft Document											
Activity 1.5 -- Prepare Final Document											
Time-Bound Plan of Work											
Activity 2.1 -- Planning Workshop											
Activity 2.2 -- Prepare Draft POW											
Activity 2.3 -- Prepare Final POW											
Water/Poverty Conceptual Framework											
Activity 3.1 -- Literature Review											
Activity 3.2 -- Data Review											
Activity 3.3 -- Prepare Draft Document											
Activity 3.4 -- Circulate Draft Document for Comments											
Activity 3.5 -- Prepare Final Document											

Basin-Wide Poverty Assessment											
Activity 4.1 -- Literature Review											
Activity 4.2 -- Data Review											
Activity 4.3 -- Data Analysis											
Activity 4.4 -- Prepare Draft Document											
Activity 4.5 -- Circulate Draft Document for Comments											
Activity 4.6 -- Prepare Final Documents											
Land Use System Analyses											
Activity 5.1 -- Literature Review											
Activity 5.2 -- Site Selection											
Activity 5.3 -- Data Collection											
Activity 5.4 -- Data Analysis											
Activity 5.5 -- Prepare Draft Document											
Activity 5.6 -- Circulate Draft Document for Comments											
Activity 5.7 -- Prepare Final Document											
Basin-Wide Model of Water Productivity/Poverty											
Activity 6.1 -- Literature Review											
Activity 6.2 -- Data Review											
Activity 6.3 -- Data Preparation and Analysis											
Activity 6.4 -- Model Calibration and Testing											
Activity 6.5 -- Policy Simulations											
Activity 6.6 -- Prepare Draft Document											
Activity 6.7 -- Circulate Draft Document for											

Comments											
Activity 6.8 -- Prepare Final Documents											
Sub-Basin Model of Water Productivity/Poverty											
Activity 7.1 -- Literature Review											
Activity 7.2 -- Data Review											
Activity 7.3 -- Data Preparation and Analysis											
Activity 7.4 -- Model Calibration and Testing											
Activity 7.5 -- Policy Simulations											
Activity 7.6 -- Prepare Draft Document											
Activity 7.7 -- Circulate Draft Document for Comments											
Activity 7.8 -- Prepare Final Documents											
Final Report											
Activity 8.1 -- Compile/Synthesize Products from Outputs 1-7											
Activity 8.2 -- Prepare Draft Report											
Activity 8.3 -- Circulate Draft Report for Comments											
Activity 8.4 -- Prepare Final Report											
CPWF Products											
Suggested TOR for other BFPs											
High-Potential Interventions in the SFRB											
Other Activities											
Training											
Outreach											

4.2 – Research Team, allocation of tasks and coordination

The core UC Davis research team is comprised of Wes Wallender (hydrologist/engineer), Steve Vosti (economist), Marco Maneta (hydrologist) and Marcelo Torres (agricultural economist). Brazil-based collaborators include Luis Bassoi (agronomist/soil physics) and Lineu Rodrigues (agricultural engineer). UC Davis will coordinate all research activities. We will be collaborating closely with Richard Howitt (agricultural economist, UC Davis) and with Carolina Balazs (social scientist, UC Berkeley). We envision hiring two research assistants in Brazil (one economist and one hydrologist). We also envision establishing an institutional link with the Instituto Internacional de Educação do Brasil (IEB), located in Brasilia, and working closely with them to distill and disseminate research findings.

4.3 – Project Budget

Table 2 sets out the project budget. Note that this budget does not account for the contributions by UC Davis or by Embrapa; both organizations will be contributing substantial amounts of researcher time and will cover some field research costs.

Table 2 – SFRB Project Budget

UCD Budget

	Year One (12 Months)	Year Two (12 Months)	Year Three (6 Months)
UCD Salary & Benefits			
Researcher Salary	$22,133	$34,196	$35,192
Researcher Benefits @ 36%	$11,940	$12,298	$12,656
Postgraduate Scholar @ 100% Academic Yr & 100% Summer	$45,500	$46,865	$24,135
Postgraduate Scholar Benefits (AY + Sum)	$13,650	$14,060	$7,241
Postdoctoral Scholar @ 100% Fiscal Year (FY)	$45,500	$46,865	$24,135
Postdoctoral Scholar Benefits (FY)	$13,650	$14,060	$7,241
Subtotal	**$152,373**	**$168,343**	**$110,601**
UCD Travel			
National Travel (3 Trips @ ($700+150*5/days)/trip)	$4,350	$4,350	$4,350
International Travel ($1500+$150*10days/trip)	$15,000	$15,000	$9,000
Domestic Travel in Brazil	$11,500	$7,000	$2,000
Travel Insurance, Visas, etc.	$1,000	$1,000	$527
Subtotal	**$30,850**	**$27,350**	**$15,877**
Other Costs			

Workshops				
Planning Workshop	$5,000			
Final Policy Workshop	$0		$5,000	
Field Research Costs	$24,166	$10,936	$2,377	
Office Supplies				
2 Desktop and 2 Laptop Computers	$10,000			
Assorted Research Supplies	$1,000	$1,000	$1,000	
Subcontract (Facilitator in Brazil)				
Salary/Benefits -- Brazil-based Staff				
Two, Full-Time Research Assistants (RA) @ 100% FY	$23,424	$24,127	$12,425	
Benefits for Research Assistants	$7,027	$7,238	$3,728	
4% Indirect Costs	$1,218	$1,255	$646	
Subtotal	**$71,835**	**$44,555**	**$25,176**	
Direct Cost	$255,059	$240,249	$151,654	
Modified Total Direct Cost	$183,223	$195,693	$126,478	
10% Indirect Cost Rate (plus 10% on first 25k pass-through)	$20,822	$19,569	$12,648	
				Total Request
TOTAL	**$275,881**	**$259,818**	**$164,301**	**$700,000**

4.4 – Intellectual Assets Audit

The following is a formal letter from DHI authorizing the use of their hydrology modeling packages in the context of this project.

DHI
WATER & ENVIRONMENT

April 12, 2006

To:
Wesley W. Wallender
Professor, Departments of Land, Air and Water Resources (Hydrology)
and Biological and Agricultural Engineering
221 Veihmeyer Hall
One Shields Avenue
University of California
Davis, CA 95616-8628

Dear Dr. Wallender,

This letter confirms that DHI Water & Environment is that selected DHI Software products are being used by the University of California for research sponsored by the International Water Management Institute in Sri Lanka. DHI Water & Environment is proud to support this program and we look forward to seeing the results of this research.

Yours truly,

Pat Delaney

Patrick Delaney
Vice President
DHI, Inc.

SECTION 5 – REFERENCES

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SECTION 6 – APPENDICES

6.1 – Basin Tour

The UC Davis-Embrapa research team undertook a focused basin tour over the period 12/7-16, 2005. Below is a brief list of sites and individuals visited. The tour ended with a two-day workshop in Petrolina sponsored by Embrapa.

12/09 - Within the Federal District (Brasília)

Buriti Vermelho and Vicinity

- Senor Antônio das Cobras; 2 hectares near the reservoir, vegetable production system
- Senor Azira, the “gaúcho”; +/- 60 hectares planted with vegetables and corn, with hog production as the main source of income
- Caretaker for property at the headwater of the Rio Preto; large-scale farm with center pivot irrigation system; grain production system. Water is brought into a reservoir by a +/- 1 kilometer pipeline.

Jardins Region, Land Reform Project

- 4-hectare property with annuals and perennials (vegetables and lime). Use of two systems of irrigation (drip and flood) supplied by a nearby reservoir.

12/10 – Unaí, Minas Gerais

Paraíso Region, Land Reform Project

- Older farmer whose wife and children had left the farm. He is the manager of the farmers’ association. Milk production is the main activity in the area, and the 70 farmers in the region produce 60000 liters/month from +/- 2000 cows. Some beef cattle production was noticed; some subsistence agriculture was evident, too. One deep water well supplies plenty of water for the area.

12/14 – Petrolina, Pernambuco

Vermelhos Region

- Senor Agil. 15 hectares of rented land planted to vegetables. Pumped water directly from the SF River via an underground pipeline. Two family members employed on the farm plus 10 hired laborers.

Bebedouro Irrigation District

- Senor Francisco (Chicão). 11 hectares near the river – 60% mango, 40% table grapes. 15 workers total; 4 family members. Water payment scheme split into two components: K1 (fixed cost), and K2 (variable cost).

Near Piauí state

- Senor José. 53 hectares, but only two are irrigated -- annuals and perennials (banana, passion fruit, papaya, etc). Some livestock activities, mainly goats and sheep. Constructed a private reservoir, with potential negative consequences for down-stream water users. Employed 2 hired laborers.

Piauí state

- Senor Maécio. 80 hectares, 5 made use of a rainfed irrigation system. Some livestock activities (goats and sheep) and some basic grain production.
- Senor Matias. 36 hectares of rainfed agriculture; an earthen reservoir was being built to retain and manage runoff.

12/15-16 Petrolina Workshop

	Workshop on Water Productivity - December 15th
8:00 - 8:30	Opening and Welcome Geraldo Eugênio / Director of Embrapa Pedro Gama / Head of Embrapa Tropical Semi-Arid
8:30 - 9:00	Challenge Program on Water and Food Frank Rijsberman / Director of IWMI and Chair of CPWF
9:00 - 9:30	Irrigation performance Rien Bos / ITC
9:30 -10:00	Water productivity concept Frank Rijsberman / Director of IWMI and Chair of CPWF
10:00 - 10:30	Coffee Break
10:30 -11:00	Soil water balance: study cases in Brazilian Semi-Arid Luís Henrique Bassoi / Embrapa Tropical Semi-Arid
11:00 -11:30	Physiological responses of intercropping in the Brazilian Semi-Arid José Moacir Pinheiro Lima Filho / Embrapa Tropical Semi-Arid
11:30 -12:00	Software Irriga Fácil - A simple and precise strategy to increase water productivity Morethson Resende / Embrapa Corn and Sorghum
12:00-14:00	Lunch
14:00 -14:30	SWAP model Jos van Dam / Wageningen University and Research Centre
14:30 -15:00	Soil moisture estimation by remote sensing in Cerrados Edson Sano / Embrapa Cerrados
15:00 -15:30	Energy balance applications in the Brazilian Semi-Arid Antonio Heriberto de Castro Teixeira / Embrapa Tropical Semi-Arid
15:30 -16:00	Coffee Break
16:00 -16:30	Improving the water use on irrigated areas with micrometeorology and remote sensing techniques Bernardo Barbosa da Silva / Campina Grande Federal University
16:30 -17:00	SEBAL applications in South Asia Mobin-ud-Din Ahmad / IWMI
17:00 -17:30	Sediment sources in São Francico River: an approach by orbital remote sensing techniques Iedo Bezerra Sá / Embrapa Tropical Semi-Arid
17:30 -18:00	Discussion

	Workshop on Water Productivity - December 16th
8:00 - 8:30	Water productivity in an irrigation district at Low São Francisco Basin Ronaldo Souza Resende / Embrapa Coastal Tablelands
8:30 - 9:00	Irrigation efficiency and water productivity in irrigation districts of Ceara State Adunias Teixeira – Ceará State University
9:00 - 9:30	Use of additional sprinkler to eliminate "dry spots" in water distribution of Itaparica Project Rodrigo Ribeiro Franco Vieira / Codevasf
9:30 -10:00	Small Resevoir Project Lineu Neiva Rodrigues / Embrapa Cerrados
10:00 - 10:30	Coffee Break
10:30 -11:00	Knowledge Sharing Project Sanjini de Silva / IWMI and CPWF
11:30 -12:00	Discussion
12:00-14:00	Lunch
14:00 -14:30	Strategic Action Program for the Integrated Management of the São Francisco River Basin and its Coastal Zone José Luiz de Souza / GEF São Francisco Project
14:30 -15:00	São Francisco Basin Focal Project – Hydrologic Model Wesley Wallender / University of California, Davis
15:00 -15:30	São Francisco Basin Focal Project – Economic Components of Models Marcelo Torres / University of California, Davis
15:30 -16:00	São Francisco Basin Focal Project - Land Use System analysis Stephen Vosti / University of California, Davis
16:00 -16:30	Coffee Break
16:30 -18:00	Discussion and Closing

6.2 – Data Sources and Needs

The following data and sources at município and state levels have been identified from the 1995/96 Brazilian Agricultural Census.

At município level

- **Outputs, Area and Value**
  - Area harvested per crop (tb21, 22 in the website)
  - Quantity produced per crop (tb 21, 22 in the website)
  - Value of production per crop (tb 21,22 in the website)
  - Area in natural pasture (tb 67 in CDRom)
  - Area in planted pasture (tb 67 in CDRom)
  - Resting area (tb 67 in CDRom)
  - Unutilized but productive land area (tb 67 in CDRom)
  - Value of total animal production (tb 10Mn in the website or tb 76 in the CDRom)
  - Livestock (bovines and suines) (tb 8Mn in the website or tb 26, 30 in the CDRom)
  - # of farmers per main crop, (tb 16 in the website)
  - # of farmers and area per size group (tb 17 in the website)
  - Irrigated area and type of irrigation used (tb 18 in the website)

- **Inputs and costs (not divided by crop)**
  - Labor quantity divided in familiar and off farm (permanent and temporary) (tb 68 in the CDRom)
  - Storage capacity (tons) for grains and other outputs (tb 71 in CDRom)
  - Total # tractors (tb 7Mn in the website or tb 72 in the CDRom)
  - Total # of machines (tb 7Mn in the website or tb 73 in the CDRom)
  - Total # of plows (tb 73 in the CDRom)
  - Total # of trucks and vehicles (caminhoes + utilitarios + reboque) (tb 7Mn in the website or tb 74 in the CDRom)
  - Total value of investments (tb 11Mn in the website or tb 75 in the CDRom)
  - Total financing expenses (11Mn in the website or tb 75 in the CDRom)
  - Expenses, (all in tb24 in the website)
    - Electricity
    - Labor
    - Fuel
    - Land Renting and Sharing
    - Fertilizers
    - Seeds
    - Pesticides
    - Animal feeding
    - Transport of production
    - Interest rate and banking services
    - Renting of machines and other equipments

- **Types of farmers**

  - # of farmers who own the land and total land area under ownership (tb 2Mn in the website or tb 65 in the CDRom)
  - # of farmers who rent the land and total land area under renting (tb 2Mn in the website or tb 65 in the CDRom)
  - # of farmers who share the land and total land area under sharing (tb 2Mn in the website or tb 65in the CDRom)

At the State Level

- **Outputs, Area and Value**
  - Area harvested per crop (tb 8, 9 in the website or tb 53-60 in the CDRom)
  - Quantity produced per crop (tb 8, 9 in the website or 53-60 in the CDRom)
  - Value of production per crop (tb 8, 9 in the website or 53-60 in the CDRom)
  - Area in natural and planted pasture (tb13 in the website or tb9 in the CDRom)
  - Resting area (tb13 in the website or tb9 in the CDRom)
  - Unutilized but productive land area (tb13 in the website or tb9 in the CDRom)
  - Irrigated area and method of irrigation per crop, (tb 2 in the website)
  - Livestock (cattle, suines, equines etc) per crop (tb 6 in the website)
  - # of bovines (matrizes+outros fins) bought and sold, and revenue (matrizes + outros fins) (tb 36 in CDRom)
  - # of suines (equines and etc) bought and sold, and revenue (tb 38 - in CDRom)

- **Inputs, costs, investment and financing**
  - Input Quantities and Characteristics
    - # of Familiar labor per crop, (tb5 in the website)
    - # of Off farm labor (permanents + temporary) per crop, (tb5 in the website)
    - Storage Capacity (sum of tons of capacity for granel, acondicionado e outros) (tb 15 in the CDRom)
    - Total # of tractors per crop, (tb7 in the website)
    - # of machines (sum colheita and plantio) - PGEA (tb 17 in the CDRom)
    - # of plows (arados), (sum mechanic and animal) - PGEA (tb 17 in the CDRom)
    - # of trucks and vehicles (caminhoes + utilitarios+reboque) - PGEA (tb 17 in the CDRom)

  - Expenses (all in tb 11 in the website)
    - Electricity per crop
    - Labor per crop
    - Fuel per crop
    - Land Renting and Sharing per crop
    - Fertilizers per crop
    - Seeds per crop
    - Pesticides per crop
    - Animal feeding per crop
    - Transport of production per crop
    - Interest rate and banking services per crop

        - Renting of machines and other equipments per crop

    - Investment Value
        - Buildings and other facilities - PGEA (tb 21 in the CDRom)
        - New vehicles - PGEA (tb 21 in the CDRom)
        - Crop planting investments - PGEA (tb 21 in the CDRom)
        - Machines new + used - PGEA (tb 21 in the CDRom)
        - Land - PGEA (tb 21 in the CDRom)
        - Total Animals Acquisition (for reproduction, raise etc) – PGEA (tb 21 in the CDRom)

    - Loans for
        - Land preparation and crop planting (custeio)- PGEA (tb22 in the CDRom)
        - General investments - PGEA (tb 22 in the CDRom)
        - Commercialization - PGEA (tb 22 in the CDRom)

- **Types of farmers (PGEA)**
    - # of farmers who own the land and total land area under ownership PGEA (tb 3 in the CDRom)
    - # of farmers who rent the land and total land area under renting- PGEA (tb 3 in the CDRom)
    - # of farmers who share the land and total land area under sharing- PGEA (tb 3 in the CDRom)

6.3 – Curriculum Vitae of Research Team Members

Luís Henrique Bassoi

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Education

1985 B.Sc. Agronomy, University of São Paulo, College of Agriculture "Luiz de Queiroz", Brazil.
1990 M.Sc. Agronomy / Irrigation and Drainage, São Paulo State University, College of Agricultural Sciences, Brazil.
1994 PhD: Science / Nuclear Energy in Agriculture, University of São Paulo, Center for Nuclear Energy in Agriculture, Soil Physics Section, Brazil.
2000 Pos Doc: University of California, Department of Land, Air, and Water Resources, Hydrology Program, USA.

Positions Held

1994 to date Researcher, Embrapa Semi-Arid, Brazil.
1999 – 2000 Visiting scholar, University of California, Davis, USA.
1994 CNPq researcher fellow, University of São Paulo, College of Agriculture "Luiz de Queiroz", Brazil.
1991 – 1994 PhD student, University of São Paulo, Brazil.
1988 – 1990 M.Sc. Student, São Paulo State University, Brazil.

Selected Publications

Bassoi, L.H.; Carvalho, A.M.. Leaching of macronutrients in a soil cultivated with corn with and without supplemental irrigation. Revista Brasileira de Ciência do Solo, Campinas, v.16, n.3, p.283-287, 1992 *[in portuguese]*.

Bassoi, L.H.; Fante Júnior, L.; Jorge, L.A.C.; Crestana, S.; Reichardt, K. Distribution of maize root system in a Kanduidalfic Eutrudox soil: II. Comparison between irrigated and fertirrigated crop. Scientia Agricola, Piracicaba, v.51, n.3, p.541-548, 1994 *[in portuguese]*.

Bassoi, L.H.; Reichardt, K. Nitrate leaching in a Kanduidalfic Eutrudox cultivated with fertirrigated corn. Revista Brasileira de Ciência do Solo, Campinas, v.19, n.3, p.329-335, 1995 *[in portuguese]*.

Bassoi, L.H.; Reichardt, K. Dry matter and nitrogen accumulation by corn cultivated during winter season with sidedressing and irrigation water apllication. Pesquisa Agropecuária Brasileira, Brasília, v.30, n.12, p.1361-1373, 1995 *[in portuguese]*.

Souza, M.D.; Bassoi, L.H.; Bacchi, O.O.S.; Reichardt, K.; Hermes, L.C.; Abakerli, R.B.; Pilotto, J.E. Atrazine movement in a dark red latosol of the tropics. Scientia Agricola, Piracicaba, v.54, p.116-120, 1997.

Bassoi, L.H.; Flori, J.E.; Silva, J.A.M.; Alencar, C.M.; Ramos, C.M.C. Spatial root distribution of peach palm in irrigated soils, São Francicsco Valley, Brazil. Engenharia Agrícola, Jaboticabal, v. 19, n. 2, p. 163-176, 1999 *[in portuguese]*.

Macedo, A.; Vaz, C.M.P.; Naime, J.M.; Cruvinel, P.E.; Bassoi, L.H.; Bacchi, O.O.S.; Fante Júnior, L.; Oliveira, J.C.M. The use of tomography to evaluate soil compaction in a red yellow podzolic area of the Brazilian Northeast. In: Paulo E. Cruvinel; Luiz A. Colnago (ed.) Advances in Agricultural Tomography. Barretos:, Country, 2000, v.1, p. 105-109.

Fante Júnior, L.; Oliveira, J.C.M.; Bassoi, L.H.; Vaz, C.M.P.; Macedo, A.; Bacchi, O.O.S.; Reichardt, K. Evaluation of a soil compaction as concerned to land use. In: Paulo E. Cruvinel; Luiz A. Colnago Advances in Agricultural Tomography. 1 ed., Barretos:, Country, 2000, v. 1, p. 125-130.

Serrarens, D.; Macintyre, J.; Hopmans, J.W.; Bassoi, L.H. Soil moisture calibration of TDR multilevel probes. Scientia Agricola, Piracicaba, v. 57, n. 2, p. 349-354, 2000.

Bassoi, L.H.; Resende, G.M.; Flori, J.E.; Silva, J.A.M.; Alencar, C.M. Root distribution of two asparagus cultivars in irrigated areas of Petrolina, Brazil. Horticultura Brasileira, Brasília, v. 19, n. 1, p. 17-24, 2001 *[in portuguese]*.

Vaz, C.M.P.; Bassoi, L.H.; Hopmans, J.W. Contribution of water content and bulk density to field soil penetration resistance as measured by a combined cone penetrometer-TDR probe. Soil And Tillage Research, Amsterdan, v. 60, n. 1-2, p. 35-42, 2001.

Reichardt, K.; Silva, J.C.A.; Bassoi, L.H.; Timm, L.C.; Oliveira, J.C.M.; Bacchi, O.O.S.; Pilloto, J.E. Soil spatial variability and the estimation of the irrigation water depth. Scientia Agricola, Piracicaba, v. 58, n. 3, p. 549-553, 2001.

Silva, V.P.R.; Azevedo, P.V.; Silva, B.B.; Bassoi, L.H.; Teixeira, A.H.C.; Soares, J.M.; Silva, J.A.M. Evapotranspiration estimation in mango orchard using soil water balance. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v.5, n.3, p.456-462, 2001 *[in portuguese]*.

Fante Júnior, L.; Oliveira, J. C. M.; Bassoi, L. H.; Vaz, C. M. P.; Macedo, A.; Bacchi, O. O. S.; Reichardt, K. Computed tomography for the soil density evaluation of samples of semi-arid brazilian soil. Revista Brasileira de Ciência do Solo, Viçosa, v.26, n.4, p.835-842, 2002 *[in portuguese]*.

Bassoi, L.H.; Grangeiro, L.C.; Silva, J.A.M.; Silva, E.E.G. Root distribution of irrigated grapevine rootstocks in a coarse texture soil of the São Francisco Valley, Brazil. Revista Brasileira de Fruticultura, Jaboticabal, v. 24, n. 1, p. 35-38, 2002.

Teixeira, A.H.C.; Bassoi, L.H.; Costa, W.P.L.B.; Silva, J.A.M.; Silva, E.E.G. Water consumption of a banana crop in São Francisco Valley, Brazil, estimated by the Bowen ratio method. Revista Brasileira de Agrometeorologia, Santa Maria, v.10, n.1, 2002. *[in portuguese]*.

Vaz, C.M.P.; Hopmans, J.W.; Macedo, A.; Bassoi, L.H.; Wildenschild, D. Soil water retention measurements using a combined tensiometer-coiled TDR probe. Soil Science Society of America Journal, Madison, v.66. n.6, p.1752-1759, 2002.

Coelho, E.F.; Oliveira, A.S.; Neto, A.O.A.; Teixeira, A.H.C.; Araújo, E.C.E.; Bassoi, L.H. Irrigation. In: The mango crop, ed. P.J.C. Genu, A.C.Q. Pinto. Brasília: Embrapa, 2002, p.166-189 *[in portuguese]*.

Bassoi, L.H.; Hopmams, J.W.; Jorge, L.A.C.; Alencar, C.M.; Silva, J.A.M. Grapevine root distribution for drip and microsprinkler irrigation. Scientia Agricola, Piracicaba, v.60, n.2, p.377-387, 2003.

Teixeira, A.H.C.; Bassoi, L.H.; Reis, V.C.S.; Silva, T.G.F.; Ferreira, M.N.L.; Maia, J.L.T. Estimativa do consumo hídrico da goiabeira utilizando estações agrometeorológicas automática e convencional. Revista Brasileira de Fruticultura, Jaboticabal, v.25, n.3, p.457-460, 2003. [*in portuguese]*.

Bassoi, L.H.; Flori, J.E.; Silva, E.E.G.; Silva, J.A.M. Guidelines for irrigation scheduling of peach palm for heart-of-palm production in the São Francisco Valley, Brazil. Horticultura Brasileira, Brasília, v.21, n.4, p.681-685, 2003

Pires, R.C.M.; Sakai, E.; Bassoi, L.H.; Fugiwara, M. Irrigation. In: Grape: cropping system, post-harvest, market, ed. C.V. Pommer, Porto Alegre: Cinco Continentes, 2003, p. 477-523 *[in portuguese]*.

Bassoi, L.H.; Silva, J.A. M.; Silva, E.E.G.; Ramos, C.M.C.; Sediyama, G.C. Guidelines for irrigation scheduling of banana crop in São Francisco Valley, Brazil. I- Root distribution and activity. Revista Brasileira de Fruticultura, Jaboticabal, v.26, n.3, 2004.

Bassoi, L.H.; Teixeira, A. H.C.; Lima Filho, J.M.P.; Silva, J.A. M.; Silva, E.E.G.; Ramos, C.M.C.; Sediyama, G.C. Guidelines for irrigation scheduling of banana crop in São Francisco Valley, Brazil. II- Water consumption, crop coefficient, and physiologycal behavior. Revista Brasileira de Fruticultura, Jaboticabal, v.26, n.3, 2004.

MARCO PABLO MANETA-LÓPEZ

Biographic data

- Marital Status: Single
- Nationality: Spanish
- Birth date: April, 4th 1977
- Birth Place: Badajoz (Spain)

Education

Ph.D. University of Extremadura (Spain). Degree expected in May 2006. Dissertation: *Modelización de los procesos hidrológicos en una cuenca de dehesa*. *Hydrologic processes modelling in a small semiarid watershed*. Advisor: Prof. Dra Susanne Schnabel & Dr Victor Jetten

DEA (similar to Msc in the USA). University of Extremadura (Spain), 2003. Dissertation*: LUCIE 1.0alpha, a semi-distributed, conceptual hydrologic model. Concepts and applications*. Advisor: Susanne Schnabel

Degree in Geography. University of Extremadura (Spain), 2001.

Diploma in European Studies. University of Kent, Canterbury (UK). 1999

Degree in Humanities. University of Extremadura (Spain), 1995-1999

Memberships

Member of the European Geosciences Union (EGU)

Member of the International Association of Hydrological Sciences (IAHS)

Teaching experience

Assistant professor. *University of Extremadura (Spain)*. Full time position started September, 15th 2006. Teaching duties were carried out at the area of Physical Geography, dpt of Geography and Land Planning and included lecturing on soil hydrology and field techniques for hydrologic research.

Research experience and areas of specialization

Ph.D. research. *University of Extremadura (Spain)*. Research on hydrologic processes and modelling of semi-arid environments. Field work techniques and process approach to hydrology. *University of Utrecht (The Netherlands)* Code development in C++ of a parameter efficient fully distributed physically-based quasi-3D model to simulate the whole land phase of the hydrologic cycle in semi-arid lands. This model is integrated in the GIS PCRaster giving full GIS functionality for data pre- and post-processing. *University of California, Davis*. Calibration of parameters and uncertainty assessment using a Marquardt-Levenberg algorithm (PEST)

Master research. *University of Extremadura (Spain)*. Code development and application of a semi-distributed conceptual hydrologic model in semi-arid lands. Development of artificial neural network software and application of this tool to forecast the distribution of near-surface soil moisture

Distinctions and Honors

Outstanding Graduate Student Award, University of Extremadura. 2001

Publications

Maneta, M. and Schnabel, S., 2003. "Aplicación de redes neuronales artificiales para determinar la distribución espacial de la humedad del suelo en una pequeña cuenca de drenaje. Estudios preliminares". En: J. Álvarez-Benedí y P. Marinero (Editores), VI Jornadas sobre Investigación en la Zona no Saturada del Suelo. ITA, Valladolid, pp. 296-304

Schnabel, S. and Maneta, M., 2005. Modelling suspended sediment time-series produced by runoff peaks in small semiarid catchments: A neural network approach. In: R. Batalla (Editor), River/Catchment Dynamics. IAHS Red Books, Solsona, pp. 91-100.

Maneta, M, Pasternack, G, Wallender, W and Schnabel, S (submitted). Temporal instability of parameters in an event-based distributed hydrologic model for semi-arid basins. Journal of Hydrology

Rovira, A. and Maneta, M (under review). Application of ARIMA and artificial neural network models for streamflow prediction. Hydrological Processes

Lavado, F, Maneta, M and Schnabel, S (accepted). Prediction of near-surface soil moisture at large scale by digital terrain modeling and neural networks. Environmental Monitoring and Assessment

Current papers in preparation related to the PhD:

Maneta, M, Jetten, V and Schnabel, S. A simple distributed, physically-based 3-D model for semi-arid lands. To be submitted to Hydrological Processes Journal

Abstracts and Presentations

-Maneta, M and Schnabel, S (2003). *Aplicación de redes neuronales artificiales para determinar la distribución espacial de la humedad del suelo en una pequeña cuenca de drenaje. Estudios preliminares*. VI Jornadas sobre Investigación en la Zona no Saturada. Valladolid (Spain), 5-7 nov 2003 (In Spanish)

-Maneta, M (2004). *Determining Near-Surface Soil Moisture Using Artificial Neural Networks.* Invited talk at the Department of Physical Geography of the University of Utrecht. March, 24th 2004.

-Van Schaik, L Jetten, V de Jong, SM Ritsema, C van Dam JC, Maneta, M (2004). Influence of Preferential Flow on the water balance at catchment scale. EGU 1st General Assembly. Nice, France. April, 25-30th 2004. Poster Presentation

- Schnabel, S and Maneta, M (2004). *Modelling suspended sediment time-series produced by runoff peaks in small semiarid catchments: a neural network approach*. International Conferences on River/Catchment Dynamics: Natural Processes and Human Impacts. Solsona, Cataluña (Spain), 15-20 May, 2004

- Maneta, M Schnabel, S Lavado, F (2005*). Influence of event characteristics on the dynamics and on the identifiably of parameters in an overland flow model*. EGU General Assembly, Vienna, Austria 24-29th April, 2005. Poster presentation

Participation in Research Projects

Sâo Francisco River Basin Focal Project within the CGIAR Water for Food Challenge Program. Water management accross scales in the Sâo Francisco basin: policy options and poverty consecuences. Funded by the CGIAR and the International Water Management Institute (IWMI). From 2006 to 2008

Caracterización y modelización de procesos y regímenes hidrológicos en Cuencas Aforadas para la predicción en cuencas NO Aforadas (CANOA) [*Characterization and modeling of processes and hydrologic regimes of gauged basins for prediction in ungauged basins (CANOA)]* (CGL2004-04919-C02-02/HID) Funded by the Spanish Ministery of Science and Technology from 2004 to 2007.

Procesos hidrológicos en áreas seminaturales mediterráneas. Estudio de las variaciones espacio-temporales en sistemas adehesados [*Hydrologic processes in semi-natural mediterranean lands. Studies of the spatio-temporal variations in dehesa systems*] (REN-2001-2268-C02-02). Funded by the Spansih Ministery of Science and Technology from 2001 to 2004. Funded € 100966. Principle Investigator: Dra. Susanne Schnabel.

Participation in the experimental implementation of the UN program for sustainable development, Agenda-21, at the local scale in Extremadura through the assessment and evaluation of the hydrologic resources in two regions of Extremadura (Castuera and Los Santos de Maimona). Coordinator: José Luis Gurría Gascón.

Contribución española al desarrollo del Convenio Mundial para prevenir la desertificación: I.- Red de Cuencas y Parcelas Experimentales de Seguimiento y Evaluación de la Erosión y Desertificación (RESEL) [*Spanish Contribution to the Development of the World Convention to Prevent Desertification: I. Experimental Plot and Watershed Network to Monitor and to Evaluate Erosion and Desertification (RESEL).* Spanish Ministery of Environment. 2002-2004. Funded € 37262. Principle Investigator: Dra. Susanne Schnabel.

Grants and Scholarships

2002-2006. Ph.D. Research Fellowship by the Ministry of Science and Technology.

2002. European Union Studentship to travel and attend the *Advanced Study Course on River Basin Modelling* held in Birmingham (UK). November, 2002

2000-2001. Seneca grant of the Spanish Ministry of Education and Science for undergraduate exchange to the Universitat Autònoma de Barcelona, Spain

1998-1999. Erasmus grant of the European Union for undergraduate exchange to the University of Kent at Canterbury.

Other Studies and research exchanges Abroad

Faculty of Geosciences, Dpt of Physical Geography. University of Utrecht (The Netherlands). 2005. Objectives: Calibration and sensitivity analysis of the previously developed model in long term simulations involving the full hydrologic cycle. Length of the stay: 4 months.

Department of Land, Air and Water Resources. University of California, Davis (USA). 2004. Objectives: Work on parameter optimization, uncertainty assessment and predictability limits of the model previously developed in Utrecht (the Netherlands) using a Gauss-Marquardt-Levenberg algorithm implemented in PEST parameter estimation package. Length of the stay: 3.5 months.

Faculty of Geosciences, Dpt of Physical Geography. University of Utrecht (The Netherlands). 2004. Objectives: Development and programming of a distributed model able to simulate the whole land phase of the hydrologic cycle coupling overland flow, vadose zone hydrology and groundwater. Length of the stay: 5 months.

Faculty of Civil Engineering, University of Birmingham, UK. 2002. Advanced Study Course on River Basin Modelling. Length of the stay: 2 weeks.

Department of Geography, Universitat Autònoma de Barcelona. Barcelona, Spain. 2000 -2001 Undergraduate exchange. Length of the stay: 12 months.

Languages and technical skills

Spanish. Native language.

English. Correctly spoken, written and read.

Portuguese. Correctly spoken and read.

Computer skills:

Programming experience in C++

GIS experience both with raster and vector formats (Idrisi, Arc-view/Arc-GIS, MapInfo, PCRaster)

Experience interfacing GIS software and custom code using the Advanced Programmers Interface (API) included in the GIS software IDRISI and PCRaster.

Experience using other analysis and graphical packages such as Surfer, Sigma Plot and Statistica and R

Advanced use of the MS Office Suite and LaTeX2e text processing

Other skills:

Experience using remote sensing images. Experience mapping soil cover from satellite images and processing an interpreting aerial photograph.

Experience setting and programming Campbell, Unidata and Datataker field data-loggers.

Field experience monitoring experimental watersheds and using fieldwork tools such as infiltrometers, TDR, etc.

March 27, 2006

LINEU NEIVA RODRIGUES

Year of Birth	: 1968
Nationality	: Brazilian

Education

1999	Ph.D. Federal University of Viçosa – Agricultural Engineering
1995	M.S. Federal University of Viçosa – Agricultural Engineering
1993	B.S. Federal University of Lavras – Agricultural Engineering

Professional Experience

2002 to present	***Senior Researcher,*** Embrapa Cerrados. Perform research on water resources, irrigation, hydrology, and system modeling. Research program development, funding, preparation of proposals and tenders, maintenance and development of Institute linkages with governmental agencies and international organizations, foundations, and partner institutions. Participate of various research programs of the Institute.
2002 to 2002	***Visiting research,*** Conducted a series of research projects and assignments in the water sector jointly with Federal University of Viçosa. Led the Precision Irrigation project.
2001 to 2002	***Consulting,*** Organization of American States. Conducted a sub-project in the scope of the **Integrated Management of Land-Based Activities in the San Francisco Basin project**. In this project were conducted environmental, economic and hydrological assessments.
1999 to 2001	***Researcher.*** University of Nebraska-Lincoln. Performed research on water resources and system modeling. Research program development, funding, preparation of proposals and tenders. Participated of various research programs of the Institute.
1995 to 1999	***Agricultural Engineer,*** Research group in water resource. Developed and evaluated Hydrologic modelling in order to understand the hydrologic process. Participated of various research programs of the research group in water resource.
1994 to1995	***Professor,*** Gurupi State University.

Selected Project Experience

2002-2004 Brazil	*Decision Support System for Center Pivot Design and Management in Precision Irrigation conditions*. **Principal Investigator and Project Manager**. Decision support system (DSS) tool to be used in evaluation of precision irrigation feasibility and in irrigation management zones definition.
2003-2005 Brazil	*Development and test of models to estimate soil physical properties in the Cerrado.* **Activity leader**.
2003-2005 *Brazil*	*Development and Adaptation of water management techniques to the west of Bahia's State.* **Activity leader**.
2001-2002 *Brazil*	Quantification and Analysis of the water use in the São Francisco Basin. **OAS Consultant.** Surveyed available data and inventory water uses in the basin, as well as evaluated the basin water use efficiency.
1999 - 2001 *United States*	*A Center pivot site specific water balance model*. **Principal investigator.** Development of a center pivot site specific water balance model to be used in precision irrigation conditions.
1996 – 1999 Brazil	*Hidros - Integrated planning and management of the water resources*. Development of a system (Hidros) to help planners to evaluate options for planning and managing the water resources in Brazil. **Hydrologic Model Developer**. Developed the Hydrologic model and evaluated its application in field.

Selected Publications

2004 SILVA, E.M., LIMA, J.E.F.W., RODRIGUES, L.N., AZEVEDO, J.A. Comparação de modelos matemáticos para o traçado de curvas granulométricas. Pesquisa Agropecuária Brasileira, v. 39, n. 4, p. 363-370, 2004.

2004 GUERRA, A.F., LIMA, J.E.F.W., RODRIGUES, L. N. Água e Irrigação. Agroanalysis, v. 24, n. 4, p. E-12-E-13, 2004.

2004 SILVA, E.M., LIMA, J.E.F.W., AZEVEDO, J.A., RODRIGUES, L.N. Proposição de um modelo matemático para a avaliação do desempenho de sistemas de irrigação. Pesquisa Agropecuária Brasileira, v. 39, n. 8, p. 741-748, 2004.

2004 RAMOS, M.M., PRUSKI, F.F., RODRIGUES, L.N., FREITAS, W.S., SANTANA, G.S., RIBEIRO, R.A. Quantificação do uso e da eficiência da irrigação na bacia do São Francisco. Item: Integração e Tecnologia Moderna, n. 60, p. 22-33, 2003.

2001 RODRIGUES, L. N., PRUSKI, F. F., SILVA, D. D., MARTINEZ, M. A. GEOPIVO: Model to simulate center pivot irrigation system performance. (Portuguese). Revista Brasileira de Engenharia Agrícola e Ambiental. Campina Grande, v.5, p.397 - 402, 2001.

2001 PRUSKI, F. F., SILVA, J. M. A., SILVA, D. D., RODRIGUES, L. N. Surface runoff simulation in areas under conventional tillage and no-till. Agricultural Mechanization in Asia Africa and Latin America. Tokyo: , v.32, n.3, p.27 - 30, 2001

2001 PRUSKI, F. F., RODRIGUES, L. N., SILVA, D. D. Methodology to estimate runoff on agricultural lands **In:** Competitive use and conservation strategies for water and natural resources. Ed.Brasília : ABID, 2001.

1999 RODRIGUES, L. N., MANTOVANI, E. C., SEDIYAMA, G. C., RAMOS, M. M. Estudio de caso para evaluaciòn del modelo de Ritchie: Estudio de caso para la determinaciòn de la evapotranspiraciòn del frijol (Phaseolus vulgaris L.) en condiciones de regadio (Spanish). Revista Agro-Ciência. Chillan: , v.15, n.1, p.100 - 110, 1999.

1999 PRUSKI, F. F., SILVA, J. M. A., RODRIGUES, L. N., SILVA, D. D. A model to obtain the hydrograph of surface runoff in terraced areas **In:** Water and the environment: Innovation issues in Irrigation and drainage.1 ed.London : E&FN Spon, 1998

1998 RODRIGUES, L. N., SEDYIAMA, G. C., SOCCOL, O. J., MANTOVANI, E. C. The Ritchie model for determining dry bean crop (Phaseolus vulgaris L.) transpiration and soil water evaporation In: 23RD Conference on agricultural and forest meteorology, 1998, Albuquerque. American Meteorological Society, 1998. p.208 – 211.

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Education

Ph.D. Department of Agricultural and Resource Economics, University of California, Davis, December 2004.

Title: "Production and Distribution Cost Economies in Water Firms: A Multiproduct Cost Model Incorporating Input Rigidities and Spatial Variables."

M.A. Economics, University of São Paulo, USP, 1997, Brazil.
B.A. Economics, University of Brasília, UnB, 1993, Brazil.

Research Interests

Water Production/Distribution Management, Cost Economies, Natural Resources Economics, Productivity Analysis.

Professional Experience

Researcher Associate. Development and conceptualization of agricultural production models coupled with hydrological and biophysical models and their application in the context of São Francisco River Basin, Brazil. University of California-Davis, São Francisco River Basin Focal Project, 2006 - 2008.

Junior Specialist. Conducted research based on the econometric estimation of transformation functions and productivity analysis in the context of the Alaskan pollock fisheries. In collaboration with Professor Catherine Morrison Paul, University of California, Davis, 2004 - 2005.

Teaching Assistant: Department of Agricultural and Resource Economics, University of California-Davis, Fall 2001 - Spring 2003. Courses included: Intermediate Microeconomics, Corporate Finance, and Econometrics

Research Assistant: Provided research assistance and policy analysis in the areas of urban economics and regulation, poverty and environment. Institute for Applied Economic Research – IPEA; Urban Policy Division, 1995-1998. (IPEA, the Brazilian governmental institution for applied economic research, is based in Brasília, Brazil.)

Publications

Torres, Marcelo and Catherine Morrison Paul. 2006. Driving Forces for Consolidation or Fragmentation of the U.S. Water Utility Industry: A Cost Function Approach with Endogenous Output, *Journal of Urban Economics* 59 (2006) 104-120.

Torres, Marcelo, C. C. Mueller and D. Motta. 2001. "A Dimensão Urbana do Desenvolvimento Econômico-Espacial Brasileiro" (Urban and Spatial Aspects of the Brazilian Economic Development,) with Discussion Paper Series, # 530. IPEA, Brasília, December, 32p, 2001.

Distinctions

- Brazilian Government Ph.D. Scholarship, CNPq, 1998-2002.
- Brazilian National Program for Economic Research - PNPE – Fellowship, 1995-1998.

Research Grants

Co-authored proposal for Giannini Foundation. Funded $20,000. (Principal Investigator: Catherine Morrison Paul, Ph.D.)

Languages

Portuguese – Native Speaker.
English – Fluent.
French – Excellent reading, good fluency.

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Education
Ph.D. in Economics 1984 -- University of Pennsylvania
M.Sc. in Economics -- 1981 -- University of Pennsylvania
B.A. -- 1977 -- Whitman College, Washington
-- 1975-76 -- Institute of European Studies, Madrid

Professional Experience

2003 to present:	Associate Director, Center for Natural Resources Policy Analysis, John Muir Institute of the Environment, University of California, Davis
2002 to present:	Assistant Adjunct Professor, Department of Agricultural and Resource Economics
1999 to 2001:	Visiting Professor, Department of Agricultural and Resource Economics, University of California, Davis
1987 to 1998:	Research Fellow, International Food Policy Research Institute, Environment and Production Technology Division
1985 to 1987:	Rockefeller Foundation, Population Sciences Postdoctoral Research Fellow, visiting CEDEPLAR (Centro de Desenvolvimento e Planejamento Regional), Department of Economics, Federal University of Minas Gerais, Brazil

Teaching Experience
- Assistant Adjunct Professor, Department of Agricultural and Resource Economics, University of California, Davis
- Visiting Professor at CEDEPLAR (Centro de Desenvolvimento e Planejamento Regional), Department of Economics, Federal University of Minas Gerais, Brazil
- Senior Fellow, German Institute for Development Studies (ZEF), Univ. of Bonn, Germany -- 2002 to present

Awards
- Science Award for Outstanding Partnership for 2005, awarded by the CGIAR to the Alternatives to Slash-and-Burn Agriculture (ASB) Program
- Dean's Award for Excellence in Instruction, University of Pennsylvania, Philadelphia, PA – 1984

- Elected to the Phi Beta Kappa Society, Whitman College, Walla Walla, Washington – 1977
- Honors in Foreign Study, Institute of European Studies, Madrid, Spain – 1977
- Paul Garrett Scholarship, Whitman College, Walla Walla, Washington -- 1973-1977

Grants and Contracts

Over $4 million in research, outreach and capacity strengthening grants raised over the past 20 years.

Selected Publications

Books

Palm, Cheryl A., Vosti, Stephen A., Sanchez, Pedro A., and Ericksen, Polly J. (eds.). 2005. Slash and Burn Agriculture: The Search for Alternatives, Columbia University Press, New York, NY

Pardey, P. G., J. M. Alston, C. Chang-Kang, E. C. Magalhães and S. A. Vosti. 2004. *Assessing and attributing the benefits from varietal improvement research: evidence from Embrapa, Brazil*. Research Report 136. International Food Policy Research Institute, Washington, DC. Published in collaboration with the Empresa Brasileira de Pesquisa Agropecuaria (*Embrapa*), Brasilia, Brazil

Pardey, P. G., S. A. Vosti, J. M. Alston, C. Chang-Kang, and E. C. Magalhães. 2004. Calculando e atribuindo os benefícios da pesquisa de melhoramento de variedades: O caso da Embrapa. Empresa Brasileira de Pesquisa Agropecuaria (*Embrapa*), Brasília, DF, Brazil (Technical editors: Eliseu R. de A. Alves, M. C. Magalhães and P. P. Guedes)

Vosti, S. A., J. Witcover and C. L. Carpentier. 2002. Agricultural Intensification by Smallholders in the Western Brazilian Amazon: From Deforestation to Sustainable Land Use. Research Report 130. International Food Policy Research Institute, Washington, DC

Vosti, S. A., and T. Reardon, eds. 1997. Agricultural sustainability, growth, and poverty alleviation: A policy and agroecological perspective. Baltimore, MD: Johns Hopkins University Press

Vosti, Stephen A., Chantal Line Carpentier, Julie Witcover, and Judson F. Valentim. 2001. Intensified small-scale livestock systems in the western Brazilian Amazon. In Agricultural Technologies and Tropical Deforestation. Arild Angelsen and David Kaimowitz (eds.). CAB International, Wallingford, UK

Book Chapters

Vosti, Stephen A., et al. 2001. Intensifying Small-Scale Agriculture in the Western Brazilian Amazon: Issues, Implications and Implementation. In Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment. David Lee and Chris Barrett (eds.). Wallingford, UK: CAB International.

Sydenstricker, John M. and Stephen A. Vosti. 1999. Hogares y uso del suelo en las selvas tropicales húmedas: el Proyecto Machadinho de Colonización, Rondônia, Brasil. In Población y medio ambiente: descifrando el rompecabezas. Edited by Haydea Izazola, coordinator. Zinacantepec, Estado de México: El Colegio Mexiquense: Sociedad Mexicana de Demografía.

Journal Articles

Alston, Julian M., Daniel A. Sumner, and Stephen A. Vosti. 2006. Are Agricultural Policies Making Us Fat? Likely Links between Agricultural Policies and Human Nutrition and Obesity, and Their Policy Implications. *Review of Agricultural Economics*, Fall, 2006. Forthcoming.

Pardey, Phillip, J. Alston, C. Chan-Kang, E. Magalhaes and S. Vosti. 2006. International and Institutional R&D Spillovers: Attribution of Benefits Among Sources of Brazil's New Crop Varieties. *American Journal of Agricultural Economics. Vol. 88 Issue 1, Pages 104-123, February 2006.*

J. Witcover, S. A. Vosti, C. L. Carpentier and T. C. de Araujo Gomes. 2006. Impacts of Soil Quality Differences on Deforestation, Use of Cleared Land, and Farm Income. *Environment and Development Economics* 11: 1-28 2006.

Palm, C. A., T. Tomich, M. van Noordwijk, S. Vosti, J. Gockowski, J. Alegre, L. Verchot. 2004. Mitigating GHG emissions in the humid tropics: Case studies from the Alternatives to Slash and Burn Program (ASB). *Environment, Development and Sustainability* 6: 145-162.

Vosti, Stephen A., E. M. Braz, C. L. Carpentier, M. N. d'Oliveira and J. Witcover. 2003. Rights to Forest Products, Deforestation and Smallholder Income: Evidence from the Western Brazilian Amazon, *World Development:* Volume 31, Issue 11, November 2003, pp 1889-1901.

Carpentier, C. Line, S. Vosti and J. Witcover. 2000. Intensified production systems on western Brazilian Amazon settlement farms: could they save the forest? *Agriculture, Ecosystems and Environment*: 1635 (2000) 1-16.

Vosti, S. A., J. Witcover, S. Oliveira, and M. D. Faminow. 1998. Policy issues in agroforestry: Technology adoption and regional integration in the western Brazilian Amazon. *Agroforestry Systems* 38: 195-222.

Tomich, T., M. van Noordwijk, S. A. Vosti, and J. Witcover. 1998. Agricultural development *with* rainforest conservation: Methods for seeking *best bet* alternatives to slash-and-burn, with applications to Brazil and Indonesia. *Agricultural Economics* 1315 (1998).

Vosti, S. A., and J. Witcover. 1996. Slash-and-burn agriculture: Household perspectives. *Agriculture Ecosystems & Environment* 58(1996): 23-38.

de Bartolome, C. A. M., and S. A. Vosti. 1995. Choosing between public and private health-care: A case study of malaria treatment in Brazil. *Journal of Health Economics* 14: 191-205.

Reardon, Thomas A. and S. A. Vosti. 1995. Links between rural poverty and environment in developing countries: Asset categories and 'investment poverty.' *World Development* 23 (9): 1495-1506.

Alderman, H., L. Haddad, J. Hoddinott, and S. A. Vosti. 1994. Strengthening agricultural and natural resource policy through intrahousehold analysis: An introduction. *American Journal of Agricultural Economics* 76: 1208-1212. December.

Contini, E., Y. Sugai, and S. A. Vosti. 1994. Alimentos básicos para a população brasileira segundo suas exigências nutricionais. Ministério da Agricultura, do Abastecimento e da Reforma Agrária. *Revista de Política Agrícola B Ano II - No. 5.*

Vosti, S. A. 1990. Malaria among goldminers in Southern Pará: Preliminary estimates of determinants and individual costs. *Social Science and Medicine* 30 (10).

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EDUCATION AND REGISTRATION

Ph.D. Utah State University, Engineering, June 1982.
M.S. University of California Davis, Water Science, June 1978
B.S. Utah State University, Agricultural and Irrigation Engineering, September 1981
B.S. Oregon State University, Agricultural Engineering Technology, June 1976
EIT Engineer-in-Training Exam, May 1979
PE Professional Engineer, California, 1987

WORK EXPERIENCE

1982-present. Assistant-82-88, Associate-88-92 and Full-Professor-92-present, University of California Davis. Research includes modeling and measurement of precipitation- and irrigation-driven watersheds from submeter to kilometer scales. Specific subject matter interest includes water, energy and chemical transport for sustainable agroecosystems. Teach undergraduate courses in fluid mechanics, GIS and spatial analysis, and irrigation system design and graduate courses in continuum mechanics as well as surface irrigation hydraulics. Funding in excess of $7 million supporting the completion of 40 graduate student theses. More than 110 refereed journal articles and book chapters.

1992-3. Director, University of California Salinity/Drainage Research Program. Administered the development, interpretation, and dissemination of research knowledge addressing critical environmental problems on salinity, drainage, selenium, and other toxic elements in the San Joaquin Valley. Initiated a long term study on the sustainability of irrigated agroecosystems within environmental constraints.

1980-2. Consultant to Keller Engineering, Logan, UT. Measured and analyzed mine wastewater disposal. Conducted infiltration tests to design pressurized irrigation systems.

1987-present. Registered Profession Engineering Consultant. Advise watershed entities in California. Advice and consulting to governments of France, Egypt, Oman, Mexico, Morocco, China, Brazil, and India and to the International Rice Research Institute (Philippines) and the International Water Management Institute (Sri Lanka).

PROFESSIONAL, SCIENTIFIC, HONORARY SOCIETIES AND AWARDS

American Geophysical Union, American Society of Agricultural Engineers, American Society of Civil Engineers
Who's Who Among Students in American Universities and Colleges, Phi Kappa Phi, Sigma Xi, Alpha Zeta, Tau Beta Pi, Blue Key
Who's Who in California, 1998
Who's Who in Engineering Education, 2002

External Reviewer (4, Ph.D. Dissertation, Indian Institute of Technology
American Society of Civil Engineers, Best Practices Paper Award, 2002.
American Society of Civil Engineers, Best Research Paper Award, 2003.
American Society of Agricultural Engineers, Technical Reviewer Special Recognition, 2001, 2002
Distinguished Alumnus Award, Utah State University, College of Engineering (BIE), 2004

MEMBERSHIP ON COMMITTEES AND EDITORIAL BOARDS

Editor, Soil and Water Division, American Society of Agricultural Engineers, 2004-present
Associate Editor, Soil and Water Division, American Society of Agricultural Engineers, Developed and implemented procedures for an electronic journal, 1991-present
Member, Advisory Board, International Journal of Water Resources Engineering, 1991-present
Member, Editorial Board, Irrigation Science, 1994-present
Member, Editorial Board, Brazilian Journal of Irrigation and Drainage, 2002-present
Member, Technical Advisory Committee on Forest Geology, State of California Mining and Geology Board, 2002-present
Member, Challenge Program Consortium, Global Challenge Program on Food and Water, Consultative Group on International Agricultural Research, 2001-2
Member, Integrated Basin Water Management Systems (Research) Workgroup, Global Challenge Program on Food and Water, Consultative Group on International Agricultural Research, 2001-2

RECENT REFEREED PUBLICATIONS

Burke S.M., R.M. Adams, and W. W. Wallender. 2004. Water banks and environmental water demand: case of the Klamath basin. Water Resources Research 40, W09S02, Doi:10.1029/2003WR002832.
Zalom, F.G., I. Werner, M.N. Oliver, L.A. Deanovic, T.S. Kimball, B.W. Wilson, J.D. Henderson, and W.W. Wallender. 2004. Organophosphate dormant spray pest control efficacy, pesticide concentration and toxicity in storm runoff. Bulletin of Environmental Contamination and Toxicology 73:299-305.
Tarboton, K.C., W.W. Wallender and N.S. Raghuwanshi. 2004. Salinity appraisal with water reuse. Irrigation and Drainage Systems 18:255-273.
Buyuktas, D. W.W. Wallender, R. W. Soppe and J.E. Ayars. 2004 Calibration and validation of a three-dimensional subsurface irrigation hydrology model. Irrigation and Drainage Systems18:211-225.
Sivakumar, B. and W.W. Wallender. 2004. Deriving high-resolution sediment load data using a nonlinear deterministic model. Water Resources Research. 40, doi:10,1029/2004WR003152.
Ito, H, W. W. Wallender and N.S. Raghuwanshi. Optimal sample size for furrow irrigation design. Biosystems Engineering 91(2):229-237. doi:10.1016/j.biosystemseng.2005.02.009.
Islam, MD, W.W. Wallender, J Mitchell, S. Wicks, R.E. Howitt. 2005. A comprehensive experimental study with mathematical modeling to investigate the affects of cropping practices on water balance variables. Agriculture Water Management.
Mitchell, J.P., W.R. Horwath, T.K. Hartz, K.K. Klonsky, B.R. Hanson, E.M. Miyao, D.M. May, and W. W. Wallender. 2005. Recent advances in tomato production systems management in California. 6th World Congress on the Processing Tomato and the 9th International Society for Horticultural Science's Symposium o the Processing Tomato. Melbourne 15-18 November 2004.

Mitchell, J.P., K.K. Klonsky, J.B. Baker, R.L. DeMoura, W.R. Horwath, R.J. Southard, D.S. Munk, J.F. Wroble, K.J. Kembree, J.J. Veenstra, W. W. Wallender. Transitioning cotton and tomato production to conservation tillage. California Agriculture.

Buyuktas, D., W.W. Wallender and B. Sivakumar. 2005. Sensitivity analysis of an enhanced subsurface-surface irrigation hydrology model. Irrigation and Drainage Systems.

Sivakuma, B., W.W. Wallender, W.R. Horwath, J.P. Mitchell, S.E. Prentice, B.A. Joyce. 2005. Rainfall dynamics at the sustainable agriculture farming systems (SAFS) project site in California's Sacramento Valley. Hydrologic Processes.

Gao. P, G. Pasternack, K. M. Bali, and W. W. Wallender. 2005. Impact of Agricultural Practices on Soil Erosion at the Field Scale in the Salton Sea Watershed. Proceedings of the Third International Conference on Irrigation and Drainage. Water District Management and Governance. San Diego, CA. March 30-April 2, 2005. USCID. pp:571-580.

Schoups, G., J.W. Hopmans, C.A. Young, J.A. Vrugt, and W.W. Wallender. 2005. Multi-criteria optimization of a regional spatially-distributed subsurface flow model. Journal of Hydrology. Doi: 10.1016/j.hydrol.2005.01.001