

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

## **A Basin Focal Project Proposal**

University of California, Davis  
Empresa Brasileira de Pesquisa Agropecuária -- Embrapa  
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### **INTRODUCTION**

The São Francisco River 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 (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 leading to soil salination.

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.

Acknowledging the need for a more realistic, spatially distributed description of the economic and hydrologic sub-systems, as well as their linkages, we will quantify the field to region to basin water and poverty impacts of water policy decisions in the São Francisco Basin.

Basin-wide descriptive analysis of water use, agriculture and poverty will set the stage for predictive modeling at the farm, sub-basin and basin levels. At farm 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. At sub-basin level, a layered, integrated model will be constructed from the field to the watershed scale, consisting of a hydrologic model linked to an agricultural production and farm model. The hydrologic model is a 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, the agricultural production model simulates agricultural production on an annual basis and produces spatially distributed information on: cropping patterns, water applications, groundwater pumping, irrigation efficiencies, crop yields and revenues from agricultural activities. 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 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). Outputs of the integrated modeling system include farm profits, crop yields, and spatially and temporally distributed values of soil quality, groundwater quality and quantity as well as instream flows. Agricultural activities will be aggregated to the archetypical farm level to assess the effects of water policy on resource-poor farm households. Lastly, at basin level, a more aggregate hydro-economic model will be used to predict the effects on water productivity and poverty of alternative water policies.

## OBJECTIVES

More specifically, our research, outreach and capacity strengthening objectives are:

- identify a broad set of stakeholder views regarding water management and poverty issues;
- locate the rural and urban 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 planned/ongoing 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 system 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;
- suggest relevant biophysical and socioeconomic extrapolation domains for these results and their implications;
- develop research methods for use in other CP basins; and

- identify gaps in knowledge and generate a prioritized list of future CP projects that might fill such gaps.

## **APPROACH AND METHODS**

### ***Identifying Key Issues***

Much is known in general about the entire SFRB (e.g., 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. Building upon recent priority-setting exercises for the SFRB (e.g., Embrapa and IWMI 2004) one of our first activities will be to canvas the formal and gray literatures (e.g., OAS 2005, Embrapa 2001, CODEVAF undated, CNPq undated, SEPLAN undated) to generate as complete a set of key issues as possible from those sources, and then to undertake a focused basin visit to interact with existing and new stakeholders to ensure our slate of priority research issues is complete and properly ordered.

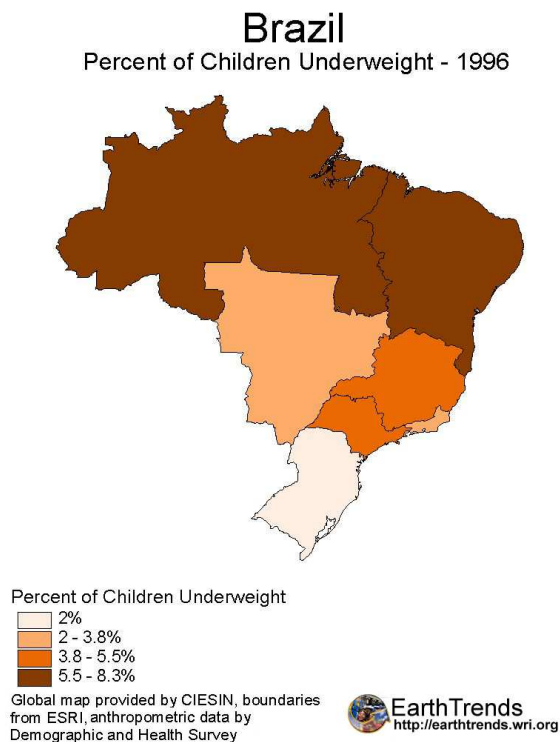
### ***Project Planning***

Once the focused basin visit is completed, a planning workshop will be convened to establish a time-bound plan of work for all research, capacity strengthening and outreach activities.

### ***Poverty Assessments***

Although some information and data on poverty are available at national and sub-national levels (e.g., as reported in Brito and Gichiki 2003, ECLAC 2002), these data are usually aggregated to the level of macroregions, regions or states within Brazil. Moreover, most poverty measures are based on anthropometric data, which, while reliable for international and longitudinal comparisons and relatively easy to disaggregated to (say) município level, are not likely to easily reveal the relationships between poverty and water. Figure 1 makes these points very clearly. Weight-for-height Z-scores are used to measure poverty which is judged to be uniform for the entire SFRB; we know poverty is not uniform within the SFRB. We also know that weight-for-height Z-scores are affected by many policy-relevant factors in Brazil, among them access to water (e.g. Merrick 1989), but only a few are related to water. The same sorts of shortcomings are true of most poverty maps (e.g., see those currently available at [povertymaps.net](http://povertymaps.net)).

**Figure 1 – ‘Poverty’ in Brazil, by macroregions**



An important departure from reliance on anthropometric data and on state or higher levels of aggregation is a recent study of the World Bank (2001) of poverty in Brazil. This study uses nationally representative household survey data (PNAD) and other data to locate and measure poverty, to identify its determinants, and to assess the possible effects of policy action on poverty. While the results are often presented in terms of more aggregate spatial units, it may be possible to rely on such data to identify a more refined picture of poverty in the SFRB, perhaps down to the município level (over 500 of which comprise the SFRB).

Therefore, poverty assessments undertaken in the context of this project will make use of existing secondary data, with special focus on município-level data that may allow us to generate ‘maps’ of poverty based on income and other indicators.

### ***Water Productivity and Hydro-Economic Modeling***

Some background data on precipitation, surface water, and surface water movements have been collected and analyzed for the São Francisco River Basin (e.g., Federal University of Viçosa 2003), and these studies will be the point of departure for both data collection and analyses that will generate basin-level and sub-basin-level measures of water productivity. An important new focus of data collection and processing (and analysis, see below) will be the addition of groundwater availability and quality, both as factors that directly influence agricultural productivity and as factors and are influenced by surface water availability.

Although the SFRB is clearly not a 'closed' basin, focus on water productivity is still essential; sub-basin areas and poor inhabitants within them may benefit from increases in water productivity, and a basin-wide assessment of water productivity that includes groundwater/surface water interactions will be needed to avoid repeating water management mistakes that have generated millions of hectares of salinated or waterlogged area in Asia and elsewhere that no longer support agriculture.

Therefore, this project will generate measures water productivity at basin level and for selected sub-basin areas based on existing data, and assess the effects of alternative water management strategies for water productivity. But we propose to do much more.

Plant science, soil science, ecology, hydrology, engineering, and economic disciplines will be combined to provide an overarching framework for modeling that is designed to guide water management decisions. We begin by representing the flow of water and its constituents within and between layers of the landscape (Figure 2, layers a-f). The hydrologic system modeling includes surface flows (not depicted) as well as unsaturated and saturated (groundwater) layers. Lateral surface and groundwater flows link the fields, farms and regions within the basin. Changes in policy affect these flows. Field, farm, and local and regional economic layers G-J are supported by hydrology layers where outputs from one layer are inputs to the next layers (Figure 2). This approach fits nicely into a Geographic Information System (GIS) which organizes, pre- and post-processes, and displays the inputs and outputs as well as parameters. The GIS system is a tool to organize the efforts of our team made up of physical, biological and quantitative social scientists and, most importantly, to communicate our findings to policymakers and other stakeholders.

Hydrologic Model (layers a-f). 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.

Candidate high-resolution hydrologic models used in this study are the Danish Hydrologic Institute product MIKE SHE, licensed for use by the Challenge Program, and the MOD-HMS (*HydroGeologic* 2001). MIKE 11 is the preferred model for surface flows and is an important tool to calculate in-stream benefits of environmental water. 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 either MIKE SHE or 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.

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, HCO<sub>3</sub>, SO<sub>4</sub>, Cl, tracer);
- ion complexation reactions in soil solution;
- cation exchange reactions with 4 sorbed species (Ca, Mg, Na, K); and
- 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 Rio Preto watershed (We are cooperating with the team working on the Challenge Program Small Reservoirs Project.) by increasing cell size to that typical of available data in the entire river basin and to that typical of conceptual hydrologic models.

The DHI conceptual hydrologic model BASIN will be applied over the entire river basin for the low resolution analysis. For the Rio Preto watershed, results from the high resolution (MIKE SHE or MODHMS) and the low resolution (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. 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.

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.

Field Production (layer g). Layer G shows how the field-level disaggregation of the root zone hydrologic model maps directly into the agricultural production model. The production function defines 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 at the field level, and soil salinity in the root and vadose zones (which are taken to be exogenous at the field level).

The connections between the production function and the hydrologic components flow in both directions. The root and vadose zone model will feed forward a proportional yield reduction parameter that links the salinity level to the crop yield potential. Feedback loops from the production model layer are shown in Figure 2. The feedbacks are evapotranspiration (produced by different crops, locations and cropping practices) and groundwater pumping (a field-level decision variable that 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.

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 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 additional sources of data are envisaged, the first will be a survey of farmers in the selected areas of the SFRB, the second approach will use remotely sensed data in the form of a vegetative index that will form the basis for a field-level desegregation of municipal-level yield data. This

layer will likely be separated into one region that focuses on an archetypical constrained smallholder and another archetypical unconstrained large farm enterprise region.

Economics and Field-Level Profit (layer h). Changes in access to and the costs of surface water and groundwater can affect the profitability of alternative product mixes and production technology choices. 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 field-level models. The first will capture the ‘reality’ of the unconstrained farm situation. 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. A second model 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 hydrologic models. For example, the cost of pumping ground water is a feed-forward function of the water levels in the confined (A) and semi-confined layers (C). The feed back from the field-level profit layer to the root and vadose zone layers (E & D) occurs through the incentives for investments in and use of irrigation technology that changes in the relative costs of inputs will generate.

Poverty persists in the SFRB, especially in marginal lands in rural areas. Meeting livelihood security needs will be trivial for large farm enterprises, but not so for resource-poor households that may suffer (at least seasonally) from food insecurity. To address this issue, the results of field-level profitability models will be aggregated to the archetypical farm/household level to estimate total farm income and seasonal fluctuations in income, which in turn will be used to assess the extent to which collections of agricultural activities being practiced under alternative relative price and water scarcity/cost scenarios are sufficient to meet food and livelihood needs.

Regional Economy (layer j). Determination of on-farm employment associated with crop production relies on the notion that labor demand for a specific crop, measured in hours, is proportional to the number of hectares dedicated to that crop. Crop-specific production information (measured in hectares) referring to a defined geographic area will be utilized to determine on-farm labor demand (measured in hours of 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 yield corresponding changes in labor needs. Separate determinations will be made of post-harvest processing labor requirements and indirect community impacts.

To do this, we will rely on published labor demand coefficients for Brazilian agriculture from sources such as the IBGE. The data is sufficiently precise to allow specification of both regular (R) and seasonally (S) 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.

Integrating the Hydro-Economic Model and Addressing Scale Issues. The formal linkages extend from the agro-economic models into the detailed hydrologic balance between the different layers that characterize the area. The use of spatially differentiated tiles to link and scale the models will enable the project to utilize the substantial Geographic Information System knowledge embodied in the team members. The ability to differentiate the physical and economic impacts by location will enable the fixed aspects such as soil type and salinity to be distinguished from those aspects that can be changed by human behavior (cropping activities or investments) and that may be the subject of policy action. The detailed spatial resolution planned for the project will enable policies to be spatially differentiated, and thus more cost effective for a heterogeneous environment. 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 (layer I, Figure 2), 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 (layer j, Figure 2), the region-resolution model mentioned above will be used to calculate flow across regions within the watershed (layer h, Figure 2), 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. Similarly an aggregated economic and a conceptual hydrologic model such as DHI's BASIN will simulate aggregate water and land management "behavior" and the annual physical and biological sub-basin response within the basin and national policy framework.

At the river basin scale, agricultural water use needs to be balanced against demands from other sectors (ANA). Typically this balancing occurs on a monthly or annual basis and by lumping variable agricultural water use patterns into extensive patches of uniform vegetation water demand. Our research will explore whether the aggregation of processes that occur on a daily or sub-daily scale and which vary dramatically from vegetation to vegetation (e.g. crop ET) can be reasonably aggregated. Again the economic model will simulate behavior and the system models will calculate the physical and biological response.

### ***Linking Poverty and Water***

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 poverty. This will be done for selected stakeholder groups in selected sites at a disaggregate level (at or below farm level) and also at a more aggregate levels (at the sub-basin and basin levels).

To assess water/poverty links at a disaggregate level in rural areas, we will modify existing land use system (LUS) analysis tools (see Tomich et al. 1998 or Vosti et al. 2001 for examples of LUS applications) to capture the effects on income and other socioeconomic factors of changes in water availability, cost and quality. Effects in rural areas are usually via changes in crop yields or production costs, but can also be via changes in the returns to time dedicated by particularly vulnerable groups (e.g., females) to cultivation, processing or marketing. This analytical tool can also be applied to large-scale farming operations; water/poverty links in such cases can emerge via effects on farm employment or via externality effects that large farm enterprises may have on (say) availability of groundwater or surface water.

At a more aggregate level (sub-basin or basin level) water/poverty links will be determined primarily by the effects of alternative water management options on product mix, production technology and profits. In areas where detailed surface/groundwater hydroeconomic modeling is done, these interrelationships will be made explicit. In other areas, the WEAP Basin model, coupled with insights gleaned from LUS analyses and detailed hydroeconomic modeling, may be used to assess the effects of alternative water management options on poverty via changes in the value of aggregate agricultural output and employment.

Identifying water/poverty links in urban setting will be challenging. We will rely on selected case studies in major metropolitan areas (home to most of the poor in Brazil) to help identify water/poverty links, perhaps relying on sets of poverty indicators that go beyond access to clean water and modern sanitation facilities.

### ***Identifying and Addressing Water Policy Issues***

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. (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.’) 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 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 growth, environmental damage and poverty. Hence, the proposed models will generate as outputs measures of all of these important variables.

### ***Identifying and Testing Alternative Water Management Options***

Water allocation and water use decisions are influenced by factors beyond the basin to the national level, namely national-level tax policies relating to irrigation development, operations, and maintenance; agricultural input and output pricing policies; and trends in public expenditures for irrigation and water resources, that can act to either reinforce or mitigate effects of policies at basin-level. In identifying the effects of alternative water management options, we aim to integrate these two levels of analysis 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.

### ***Delivering Research Results to Key Stakeholders***

At this point, the research project comes ‘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, are now convened 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.

### ***Identification of Cross-Basin Opportunities***

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 WEAP-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 to assess the long-term effects 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.

### ***Impact Assessment and the Returns to Investments in Water Management Research***

One important objective is to link with IFPRI/CIAT colleagues to undertake an ex ante impact assessment of the CP Small Reservoirs Project in the SFRB. Contacts with IFPRI and with CIAT have already been established, and preliminary discussions regarding how best to measure expected future hydrological and socioeconomic impacts are underway. The SFRB research team is also quite keen to measure the ‘value added’ of our interdisciplinary research approach in terms of new and more refined hydrological and other information it will provide, and, to the extent possible, to ‘value’ this new information in terms of poverty reduction and

other social objectives. We expect to develop new methods for ex ante assessments of water management interventions and for estimating the benefits of improved hydro-economic models; these methods will also be available for use in other CP basins.

### **BENEFICIARIES**

The immediate beneficiaries of this research will be the stakeholders in the São Francisco River Basin. The research will target the poor in these basins in particular, in finding ways to build capacity and enhance their livelihoods - including access to water, adequate food and improved health. In order for these elements to be sustainable, the surrounding ecosystem itself must be sustained, thus this element will be introduced into the planning process. 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. Impacts to improve the livelihoods of stakeholders include:

- increased productivity of water used for agriculture and environment;
- decreased soil salination;
- enhanced the economic returns to water;
- a cadre of trained water policy modelers in Brazil;
- a validated set of analytical tools suitable for the river basin analysis; and
- sets of water policy objectives and policy instruments for achieving these objectives.

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**Figure 2 -- Typical agro-economic and hydrologic system**

