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

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&
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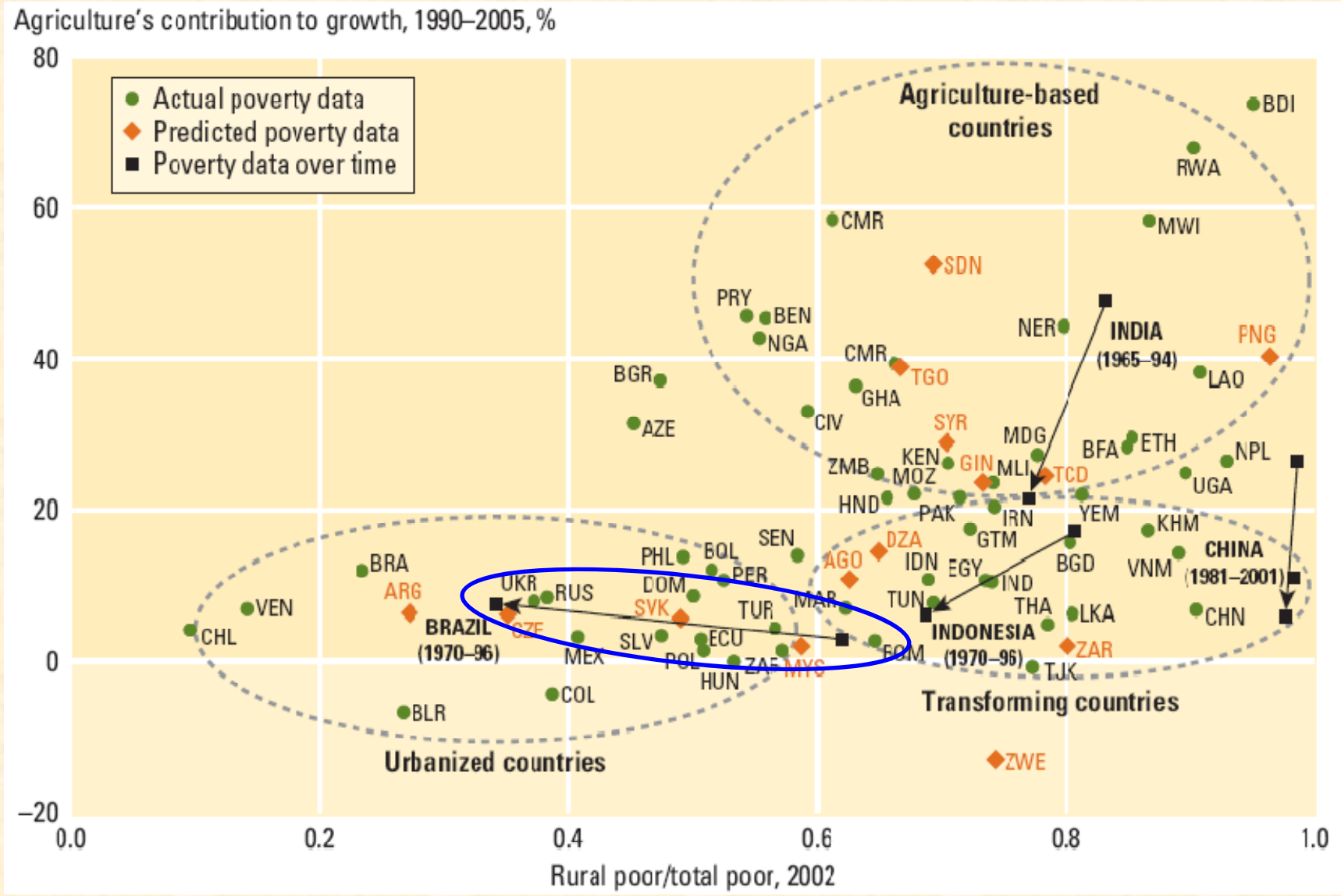
Presentation Overview

- Trends, Current Conditions and Driving Forces
  - Population, Poverty, Agriculture, Market Structure
- Key Policy Issues
- Fundamental Gaps in Knowledge
  - Participant Action
- Research Undertaken in the SFRB to Fill these Gaps
- Possible Contributions of the SFRB in Phase II
  - Participant Action
- Concluding Remarks (Our Personal Stories)

Three Worlds of the WDR 2008



Source: World Development Report 2008

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Changing Market Structure

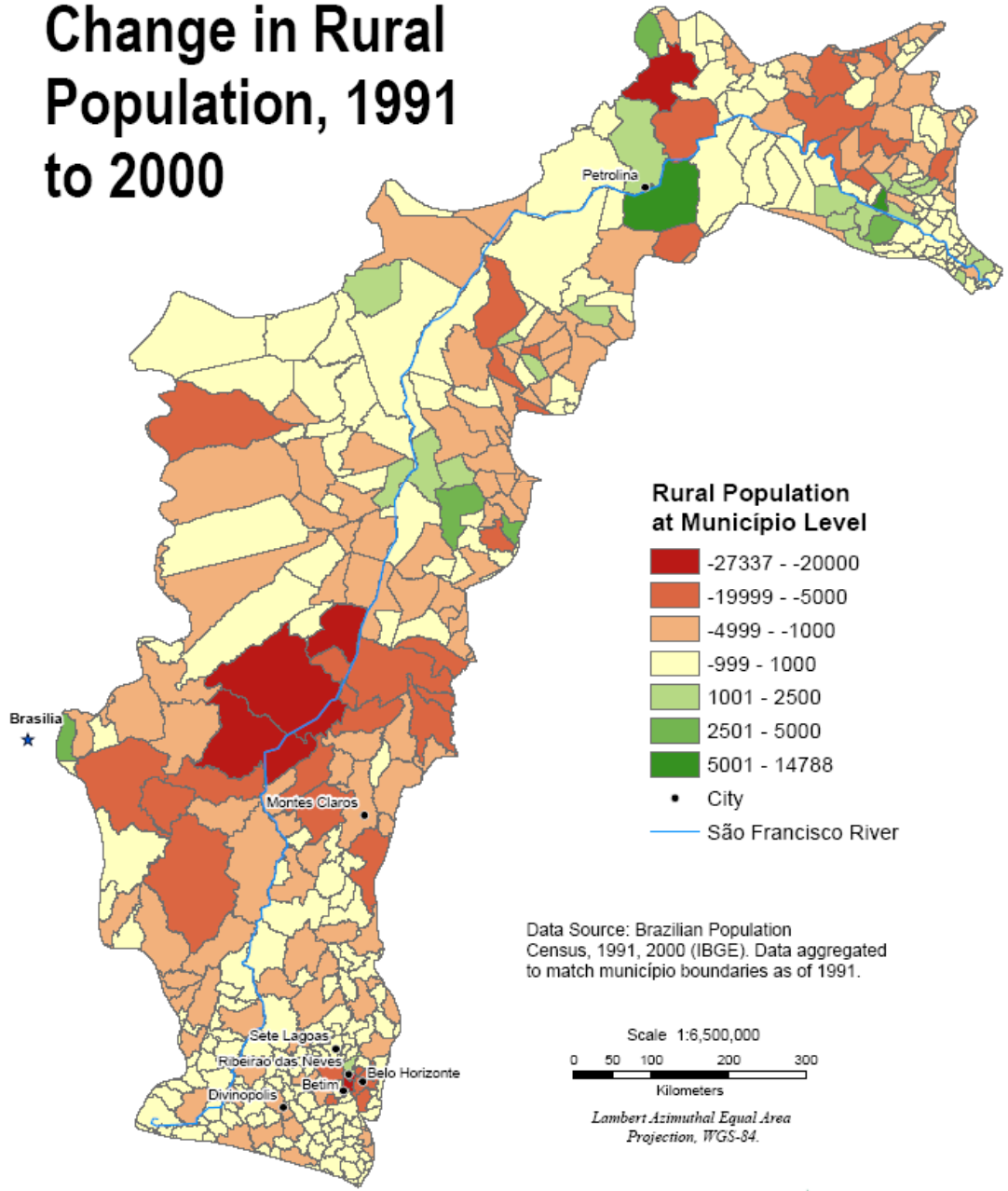
Table 1: Supermarket shares in food retail and numbers of stores: selected Latin American countries circa 2000, arranged by per capita income

	Population in millions	Per capita income in thousands	Supermarkets' % of country's food retail	Number of supermarkets (per million population in brackets) [a]	Number of supermarkets OR share of food retail a decade earlier (year)
Argentina	37	7.5	57[b]	1306 (35)	35% (in 1990)
Mexico	98	5.1	45[c]	1026 (10)[d]	544
Chile	15	4.6	50[e]	654 (44)	
Costa Rica	4	3.8	50	221 (55)	113 (in 1990) 85 (in 1984)
Brazil	170	3.6	75	5258 (31) 24000 (141)[f]	14000 (in 1990)
Panama	3	3.3	54	110 (37)	n.a.
El Salvador	6	2.0	37	138 (23)	n.a.
Colombia	42	2.0	38[g]	1200 (29)	n.a.
Guatemala	11	1.7	35	128 (12)	66 (in 1994) 15% (in 1994)
Ecuador	13	1.2	n.a.	120	n.a.
Honduras	6	0.9	42	37 (6)	n.a.
Nicaragua	5	0.4	n.a.	40 (8)	5 (in 1993)

Population Change in the SFRB

São Francisco River Basin

Change in Rural Population, 1991 to 2000



Map by J.A Young, 4 September 2007

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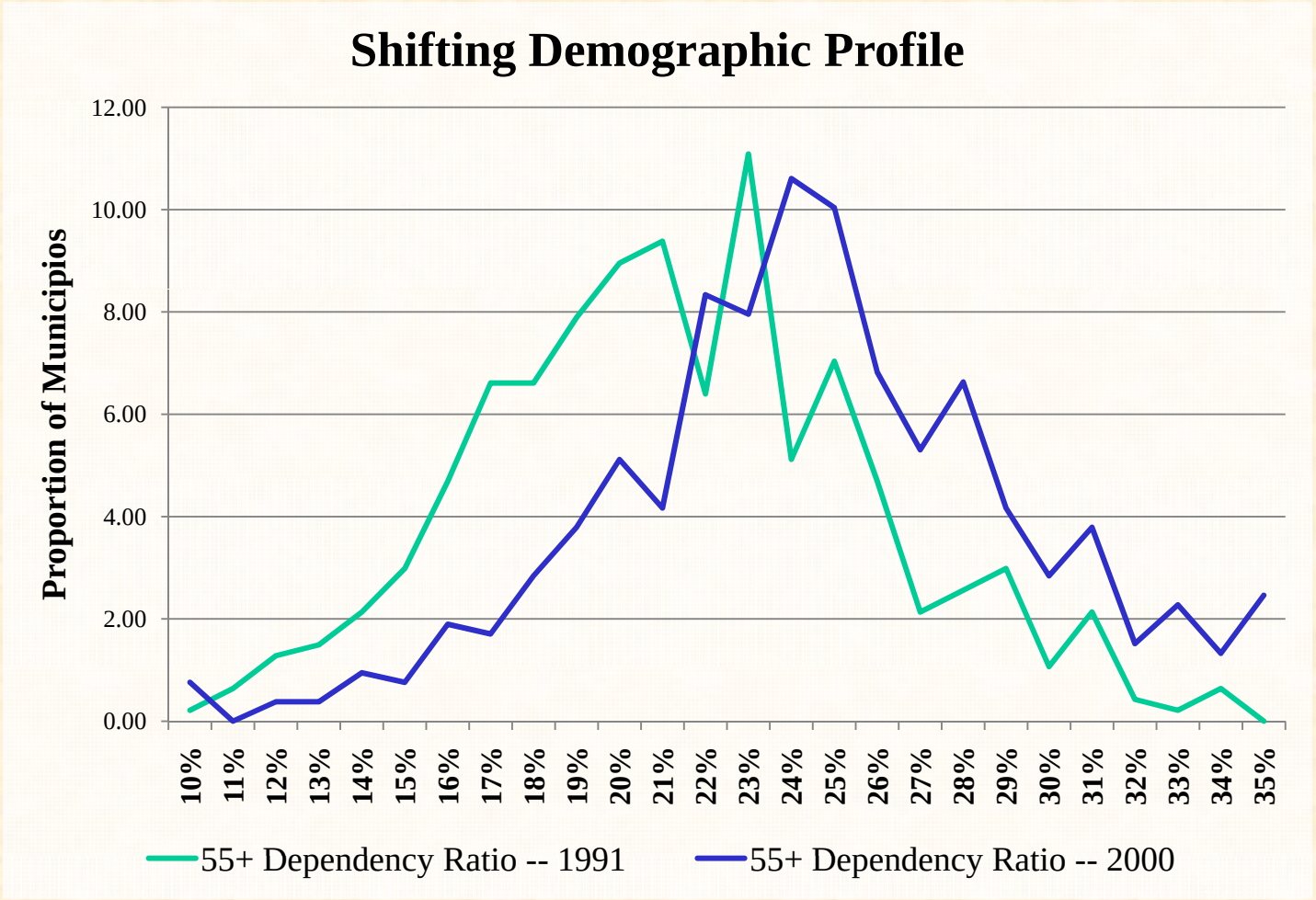
Total Popula
Total for SFI
Alagoas
Bahía
Distrito Fede
Goiás
Minas Gerai
Pernambuco
Sergipe

Rural Populatio
Total for SFI
Alagoas
Bahía
Distrito Fede
Goiás
Minas Gerai
Pernambuco
Sergipe

Aging of the Rural SFRB Population



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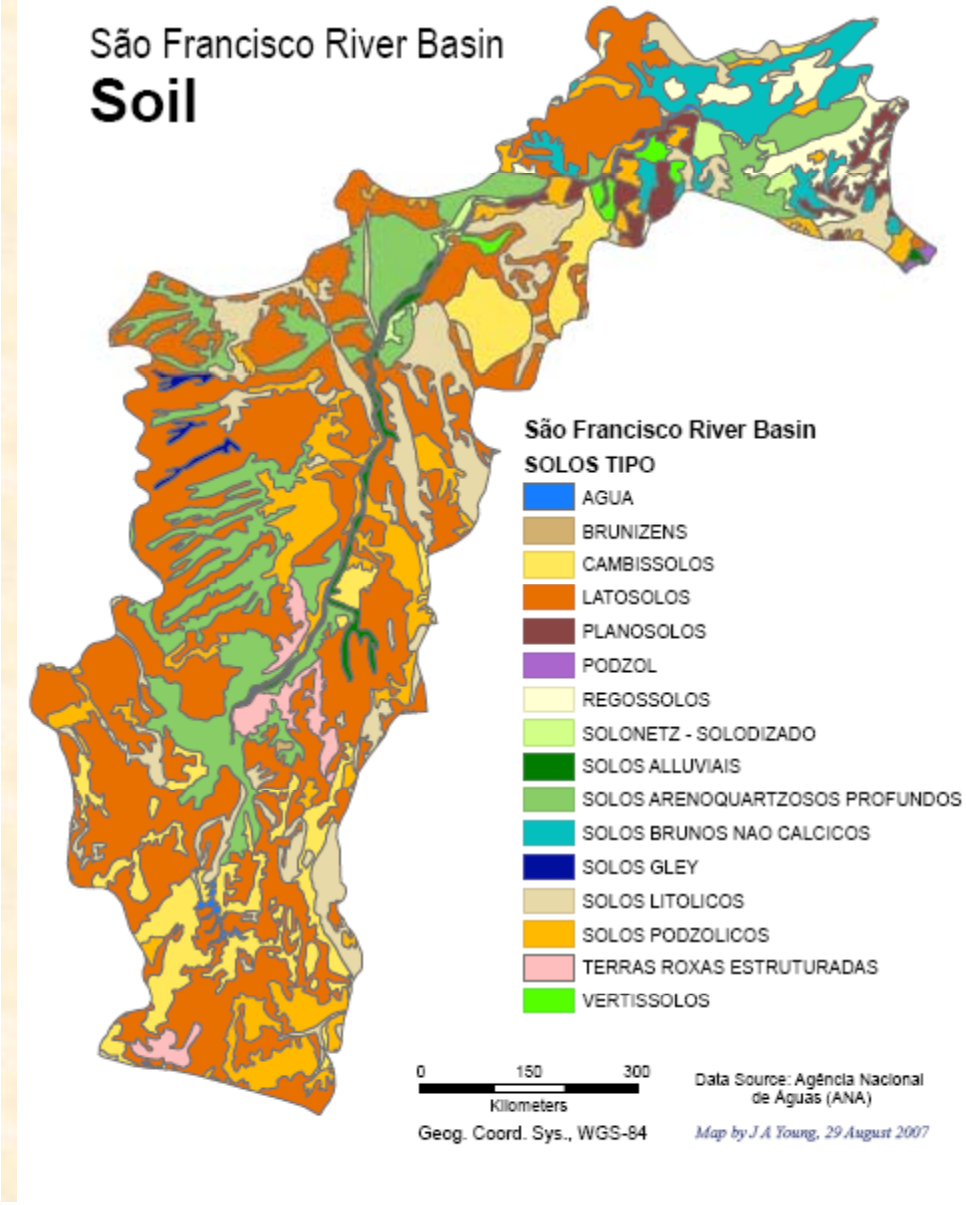
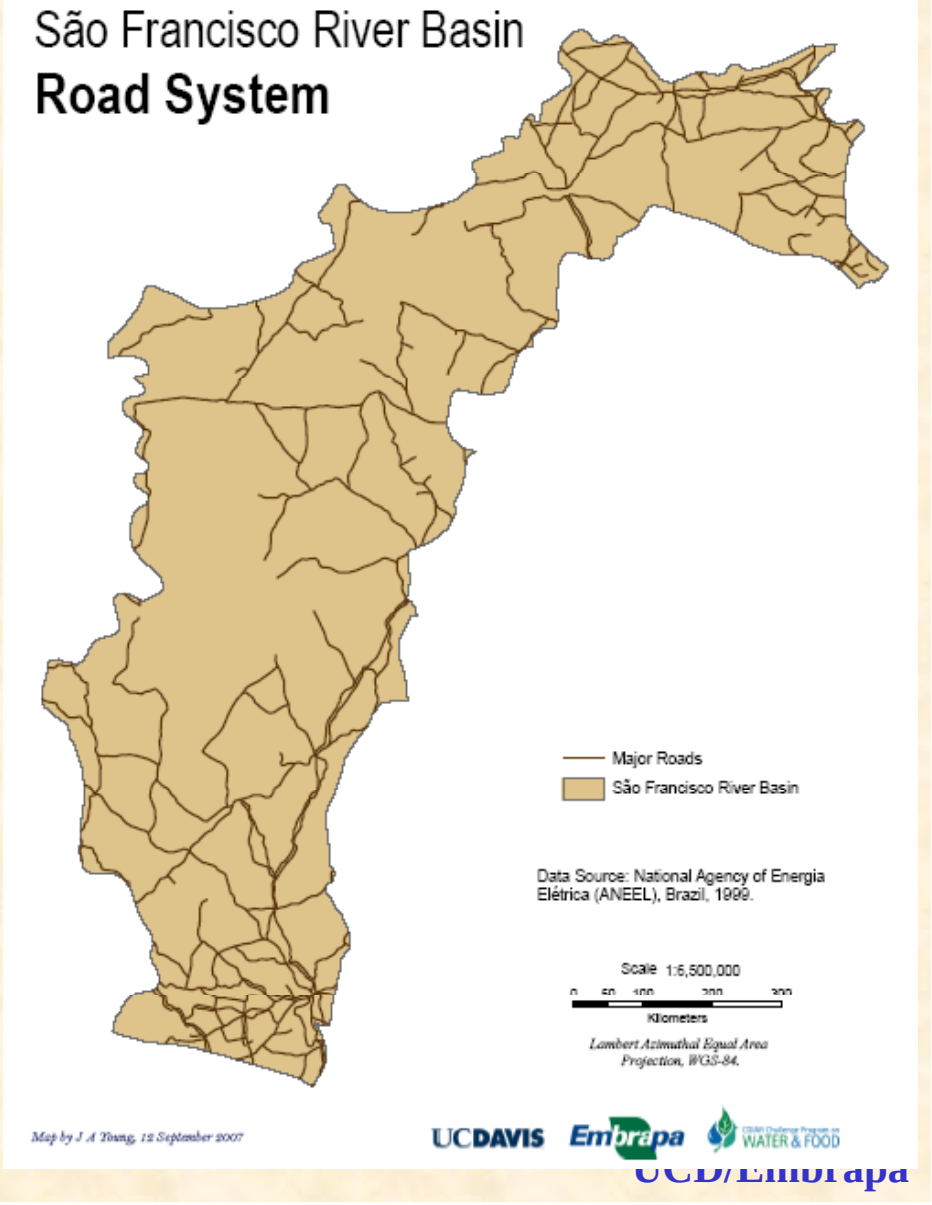
Soil Types and Distance to Market





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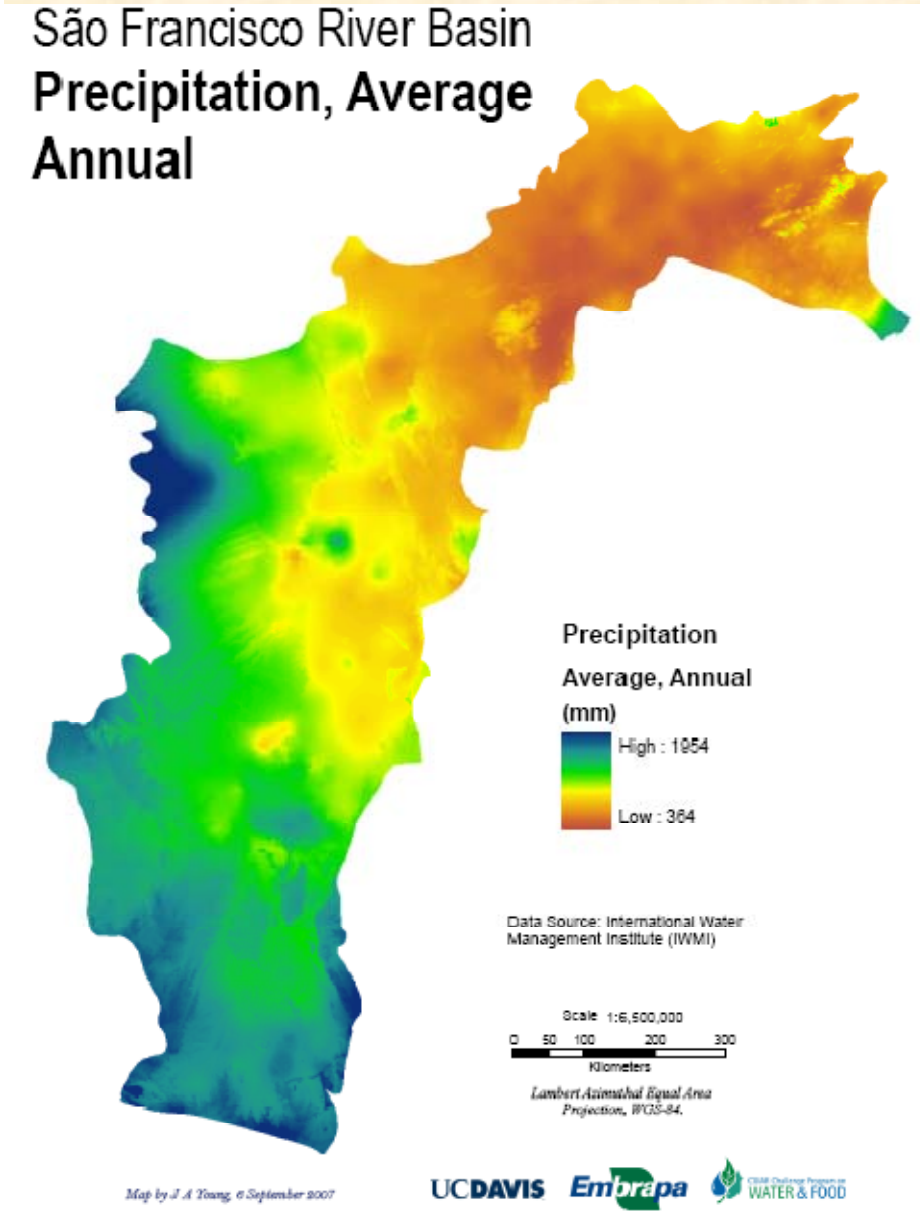
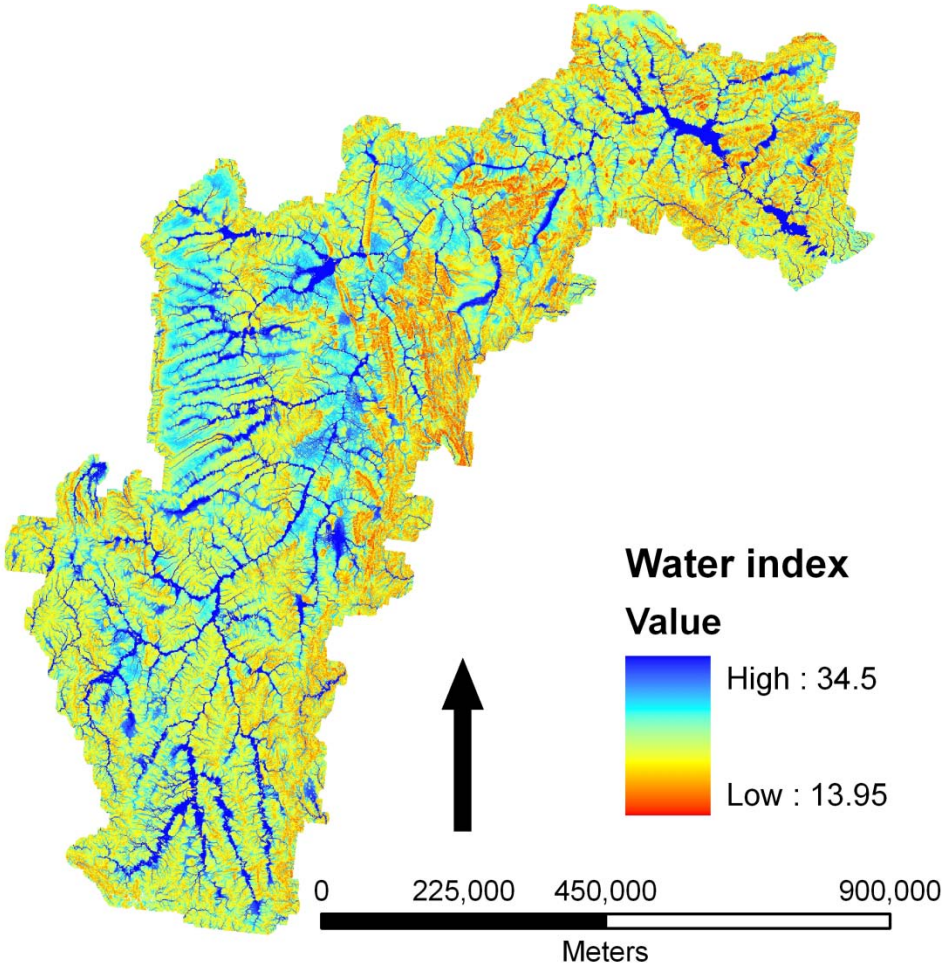
Water Availability





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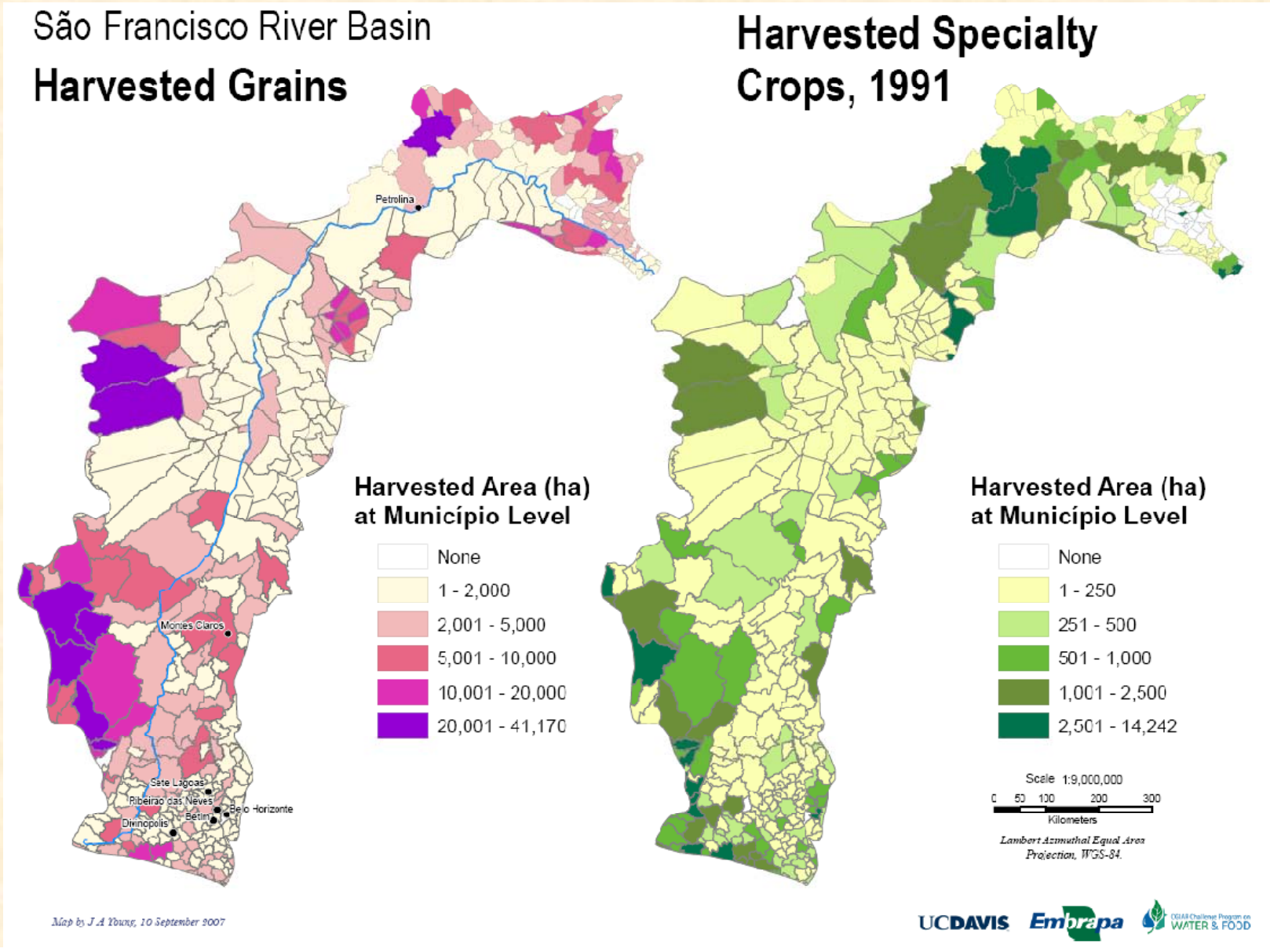
Agriculture in the SFRB -- 1991



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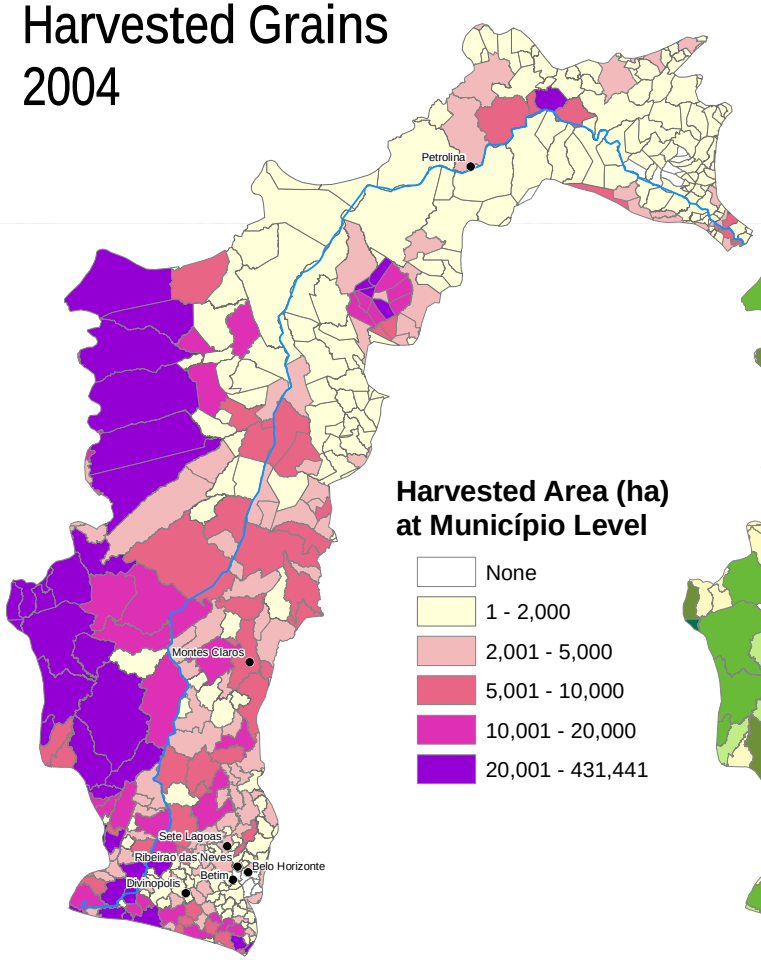
Agriculture in the SFRB -- 2004

São Francisco River Basin

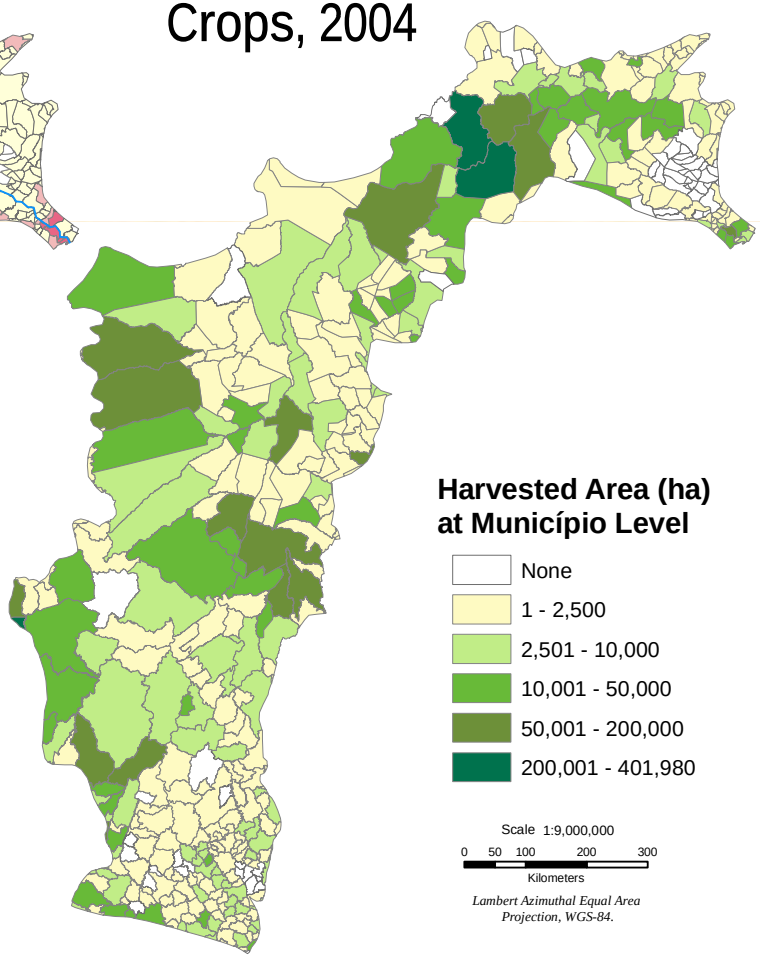
Harvested Grains 2004



Harvested Area (ha) at Município Level

- None
- 1 - 2,000
- 2,001 - 5,000
- 5,001 - 10,000
- 10,001 - 20,000
- 20,001 - 431,441

Harvested Specialty Crops, 2004



Harvested Area (ha) at Município Level

- None
- 1 - 2,500
- 2,501 - 10,000
- 10,001 - 50,000
- 50,001 - 200,000
- 200,001 - 401,980

Scale 1:9,000,000

0 50 100 200 300

Kilometers

Lambert Azimuthal Equal Area Projection, WGS-84.

Map by J A Young, 12 September 2007

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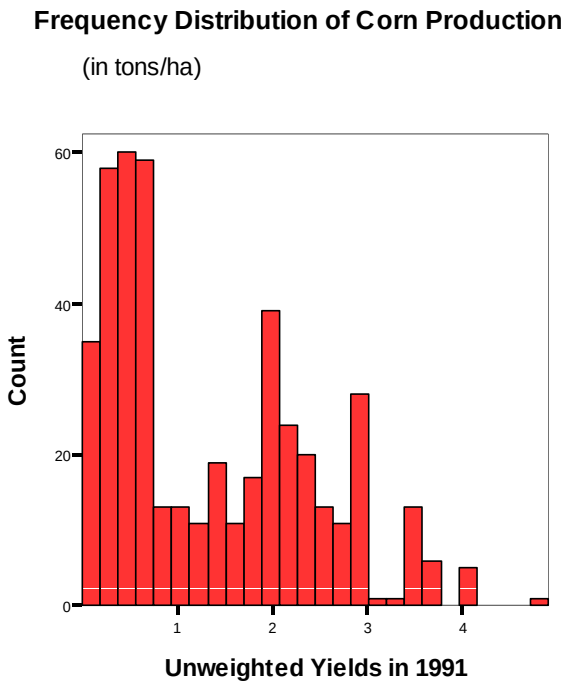
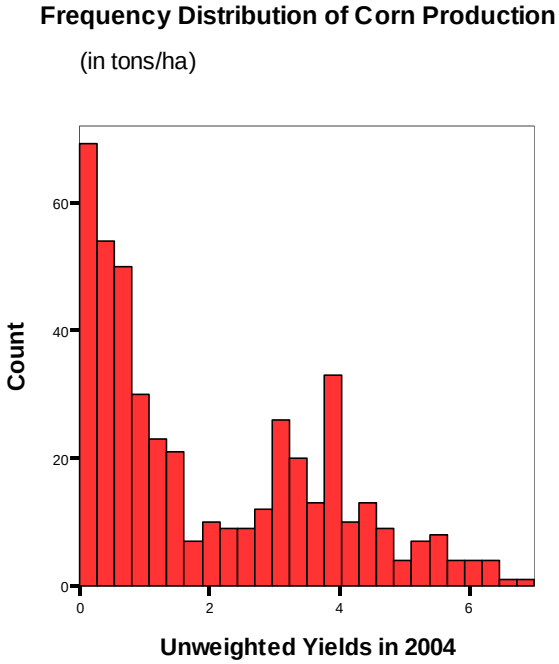
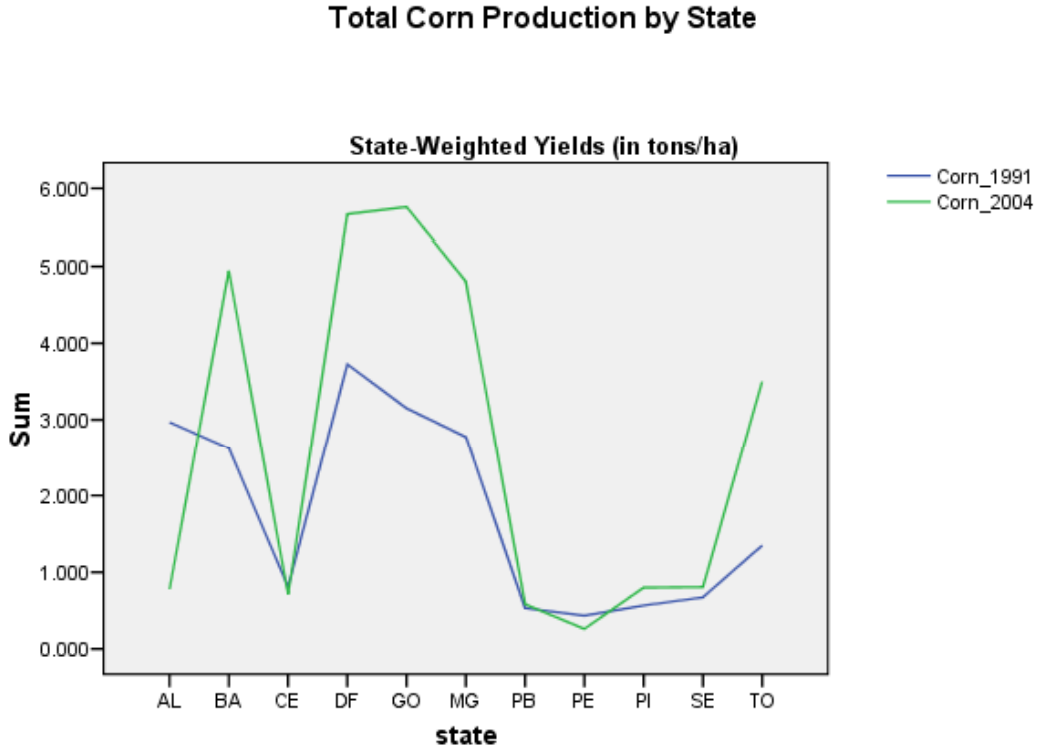
Changes in Land Productivity







Scale of Farming is Changing Rapidly

- **Vast Majority of Area Expansion is by Large-Scale Enterprises**

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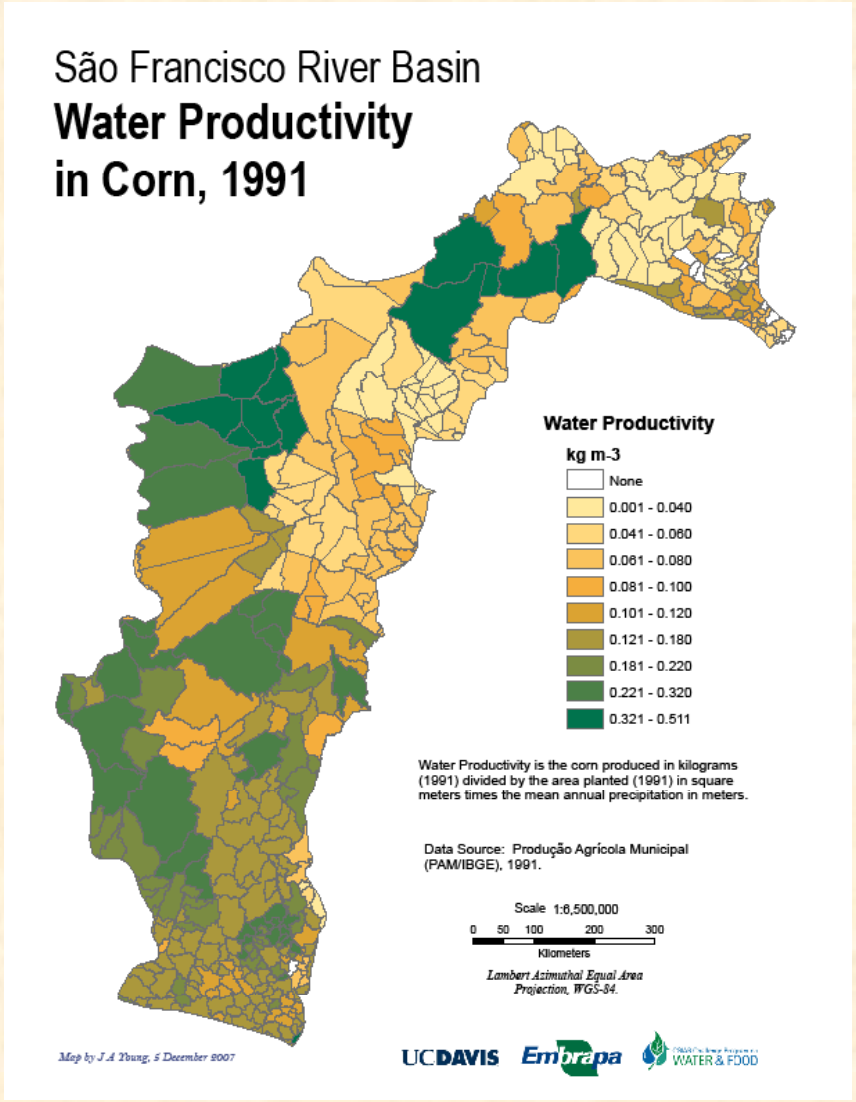
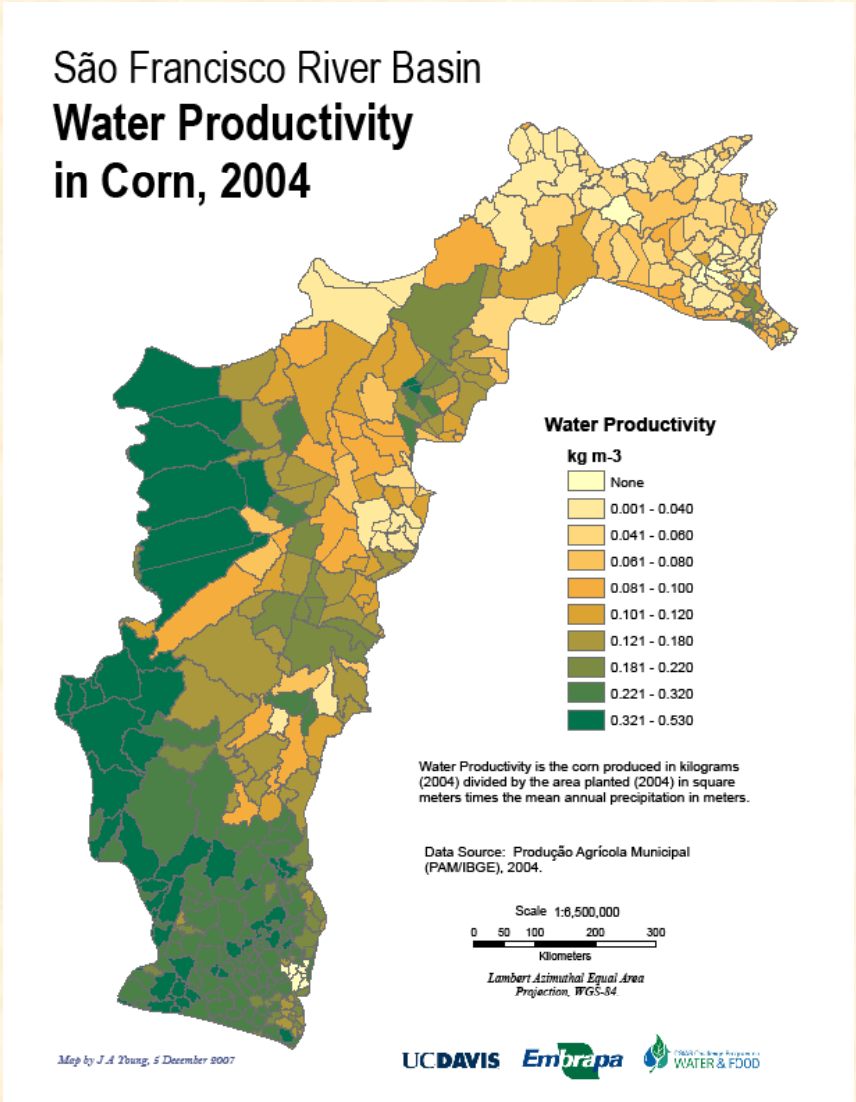
Water Productivity in Corn





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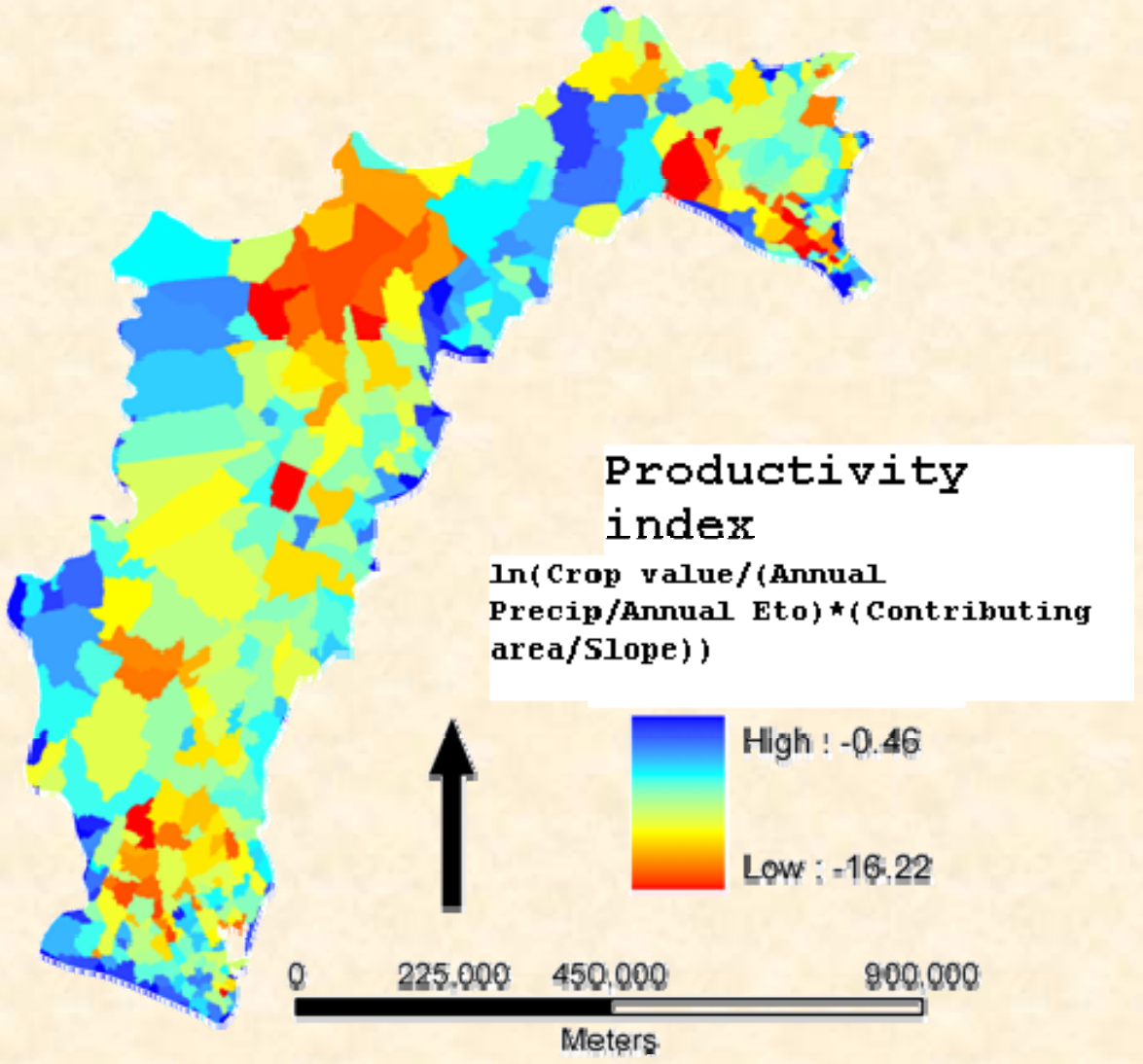
Water Productivity



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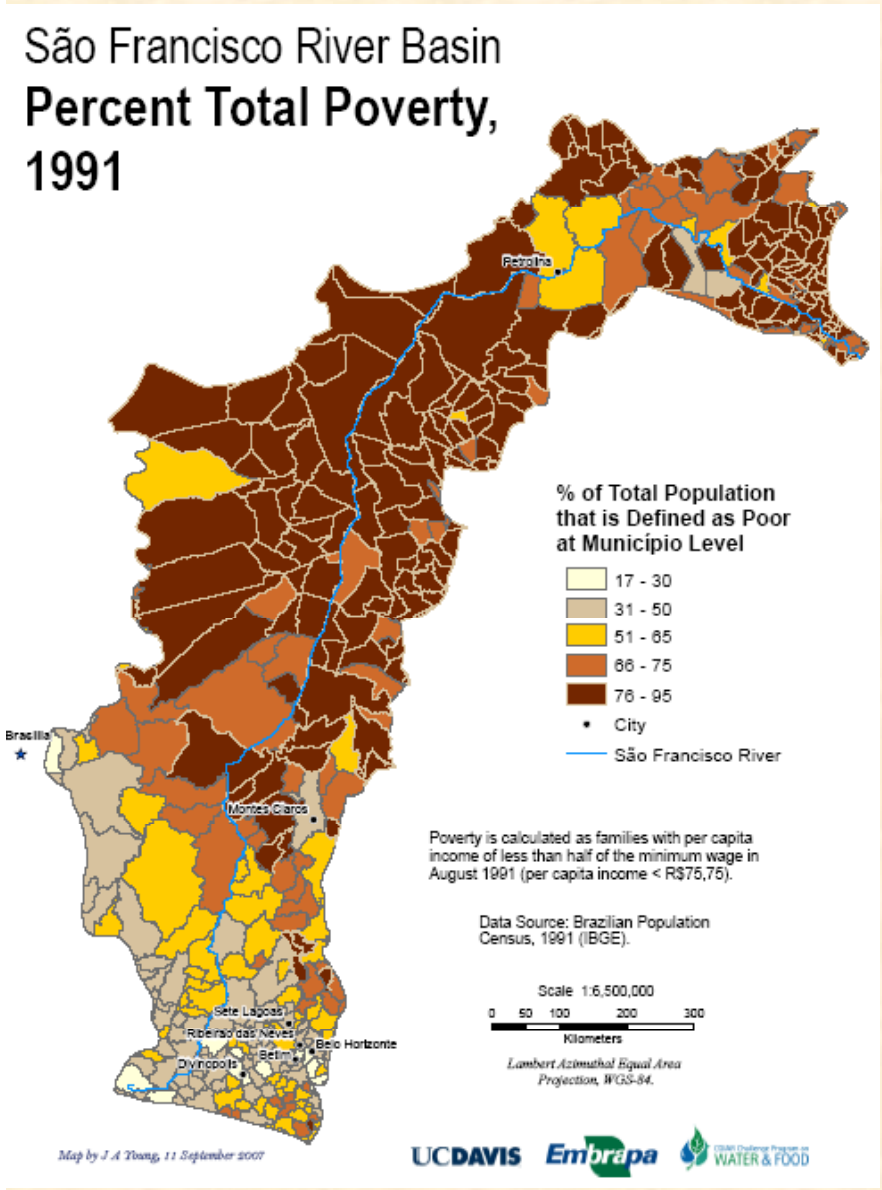
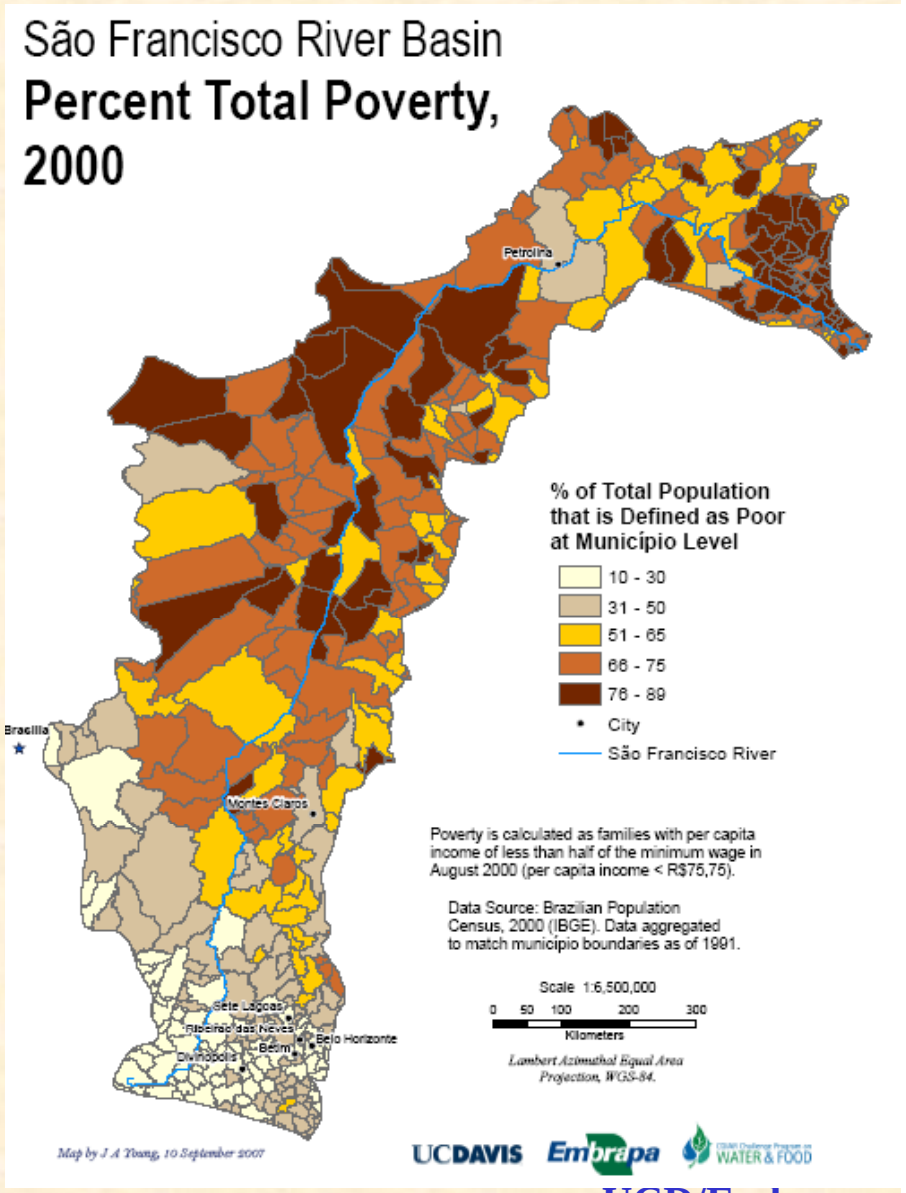
Poverty in the SFRB





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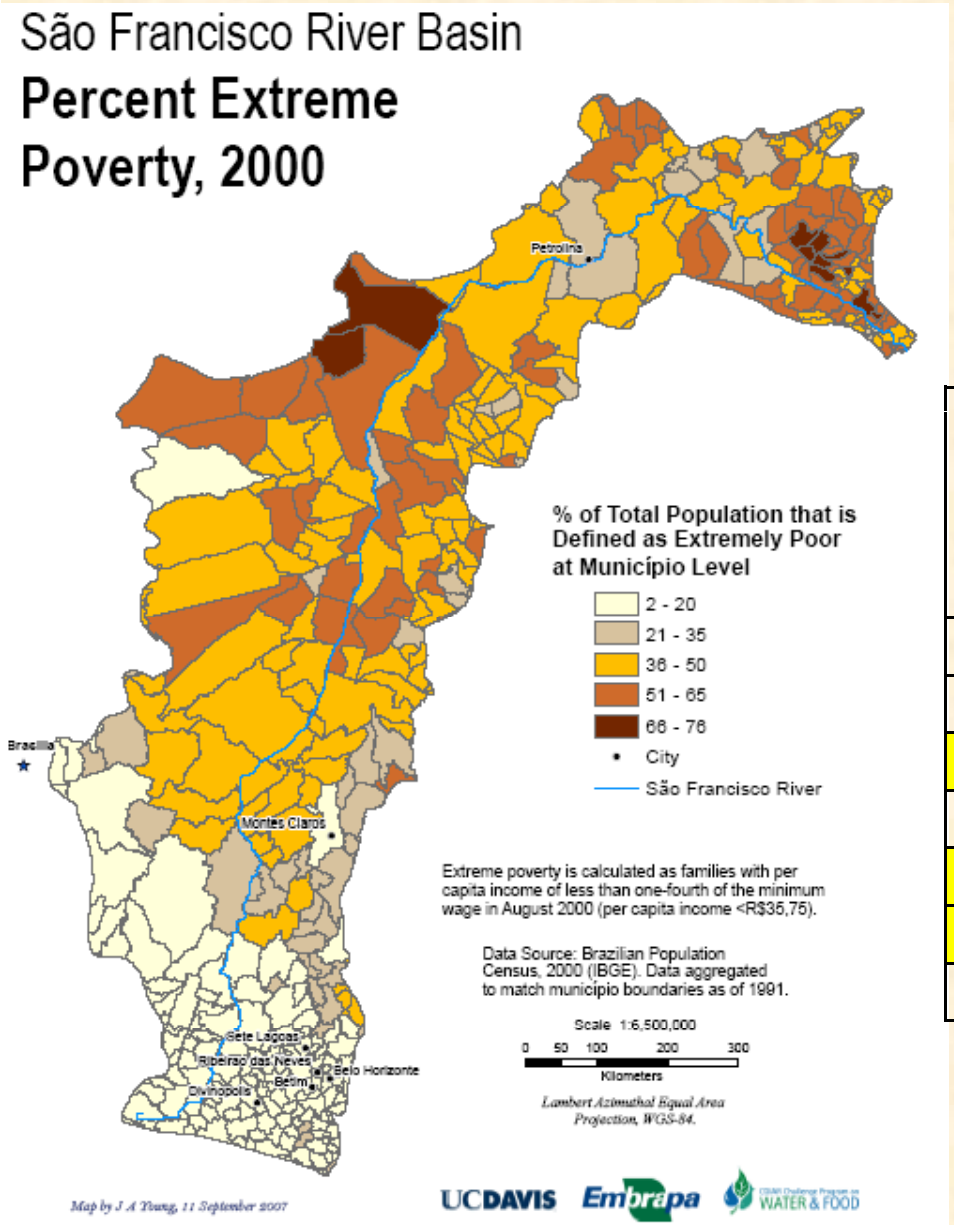
Extreme Poverty in the SFRB



2003 Rural Poverty	Rural Poverty		Extreme Poverty-Rural	
	Absolute	% of Rural Pop	Absolute	% of Rural Pop
Total for SFRB	1,012,095	28%	345,677	9%
Alagoas	163,307	41%	70,400	2.6%
Bahía	328,313	23%	139,941	9.7%
Goiás	7,792	21%	2,846	7.5%
Minas Gerais	178,006	22%	43,214	5.3%
Pernambuco	258,004	37%	53,484	7.6%
Sergipe	48,635	37%	19,603	14.9%

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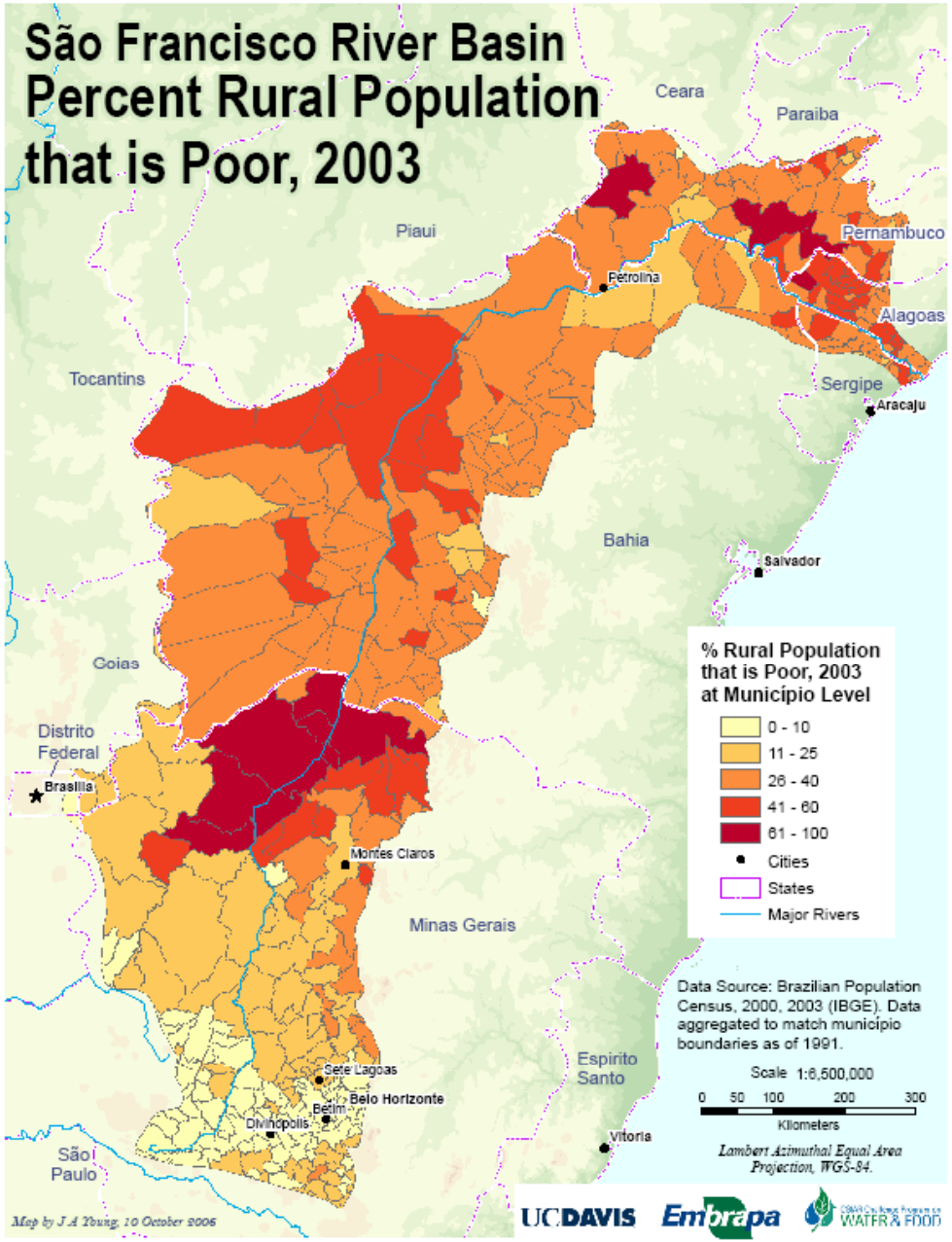

Spatial Distribution of Rural Poverty

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Key Policy Issues

- **Agricultural Sector**
  - How much *surface water* should 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 better manage water resources?
    - What are the effects of water management policies on the poor?

- **Poverty**
  - How is water productivity or access to water linked to 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?

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

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

* 'and where' applies to all issues

Fundamental Gaps in Knowledge

- **Farmer Responses to Policy and Other Changes**
  - Water policies (e.g., water prices, regulations, etc.)
  - Market conditions (e.g., input and output prices)
  - Weather conditions (e.g., drought)
- **Effects of Farmer Behavior on Water Resources**
  - Surface water
  - Groundwater

Pause for Discussion

- **Do These Situations or Trends 'Ring True' for your Basins?**
- **Do the Fundamental Gaps in Knowledge Reflect those in your Basins?**

SFRB Team Activities

- **Research at Three Spatial Extents – Basin-Wide, Buriti Vermelho Sub-Catchment, Plot Levels**
  - **Characterization**
    - **Poverty**
    - **Hydrology**
    - **Agriculture**
      - **Water use in agriculture**
    - **Water productivity**
  - **Modeling**
    - **Hydro inter-relationships**
    - **Human behavior in agricultural**
    - **Linking models**
  - **Use Models to Assess the Effect of Selected Interventions and Policy Changes**
- **Training and Capacity Strengthening**
- **Outreach**

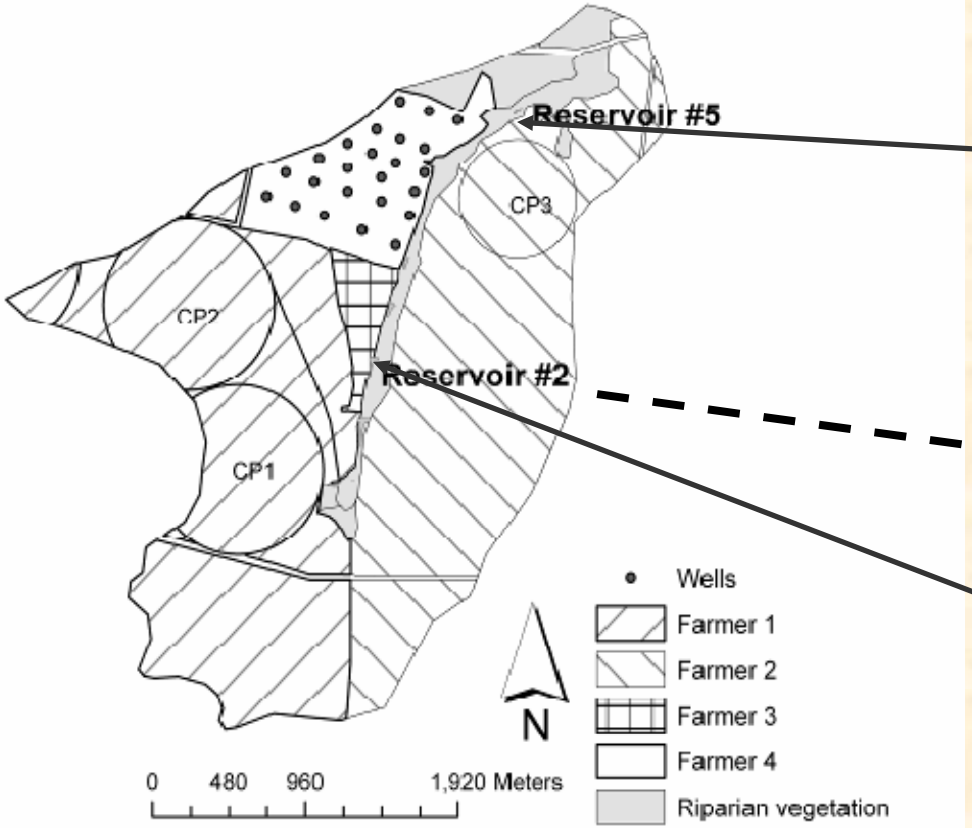
Key Objectives of Hydro-Economic Models

- **Understand Farmer Behavior and Outcomes**
  - **Cropping patterns, input mix, employment, water use**
  - **Income and poverty**
  - **Surface water and groundwater availability**
- **Predict the Effects of Proposed Policy and other Changes on Farmer Behavior/Outcomes**
- **Inform Policy**
- **Modeling at Three Spatial Extents**
  - **Plot-Level LUS Models**
  - **Buriti Vermelho Models**
  - **Basin-Wide Models**

Basic Components of Hydro-Economic Models

- **Hydrologic Models**
  - **Water flows/stocks, in space/time**
- **Economic Models of Agriculture**
  - **Farming decisions**
    - **Crop mix, production technology, water use**
- **Linking the Models**

Burití Vermelho



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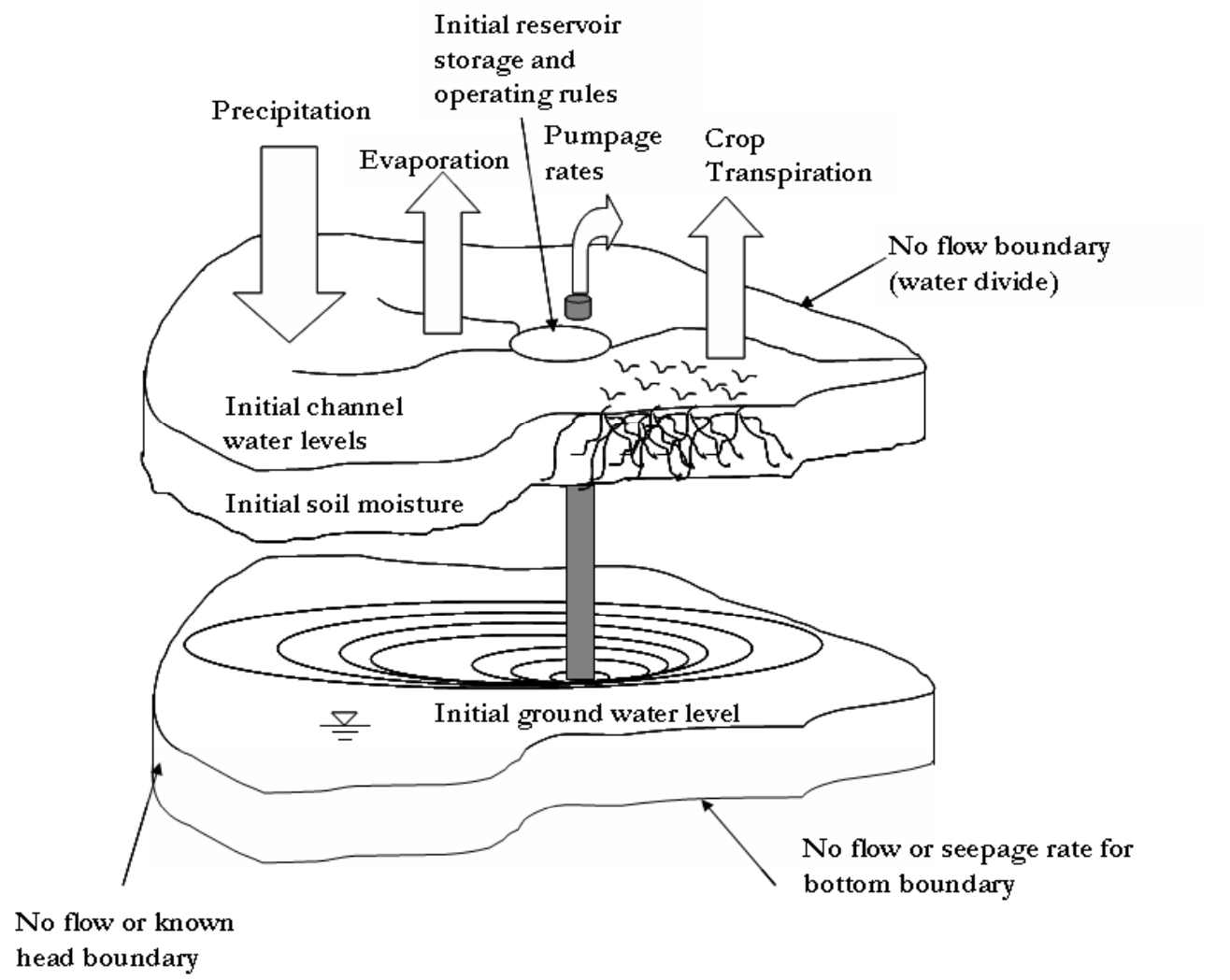
A Spatially Distributed Hydrologic Model for Buriti Vermelho



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Hydrologic Model (MOD-HMS)

Overland flow

$$\frac{\partial h_O}{\partial t} - \frac{\partial}{\partial x}\left(dk_x \frac{\partial h_O}{\partial x} \right) + \frac{\partial}{\partial y}\left(dk_y \frac{\partial h_O}{\partial y} \right) - dq_{og} - dq_{oc} = 0$$

Channel flow

$$B\frac{\partial h_C}{\partial t} - \frac{\partial}{\partial \ell}\left(\kappa_l \frac{\partial h_C}{\partial \ell} \right) - Aq_{co} - Aq_{cg} = 0$$

$$\frac{\partial}{\partial x}\left(K_{xx} k_{rw} \frac{\partial h_G}{\partial x} \right) + \frac{\partial}{\partial y}\left(K_{yy} k_{rw} \frac{\partial h_G}{\partial y} \right) + \frac{\partial}{\partial z}\left(K_{zz} k_{rw} \frac{\partial h_G}{\partial z} \right) - W + q_{go} + q_{gc} = \phi \frac{\partial S_w}{\partial t} + S_w S_s \frac{\partial h_G}{\partial t}$$

Flow in porous media with variable degrees of saturation

Simulation

Panday & Huyakorn (2005). Adv. Wat. Res.

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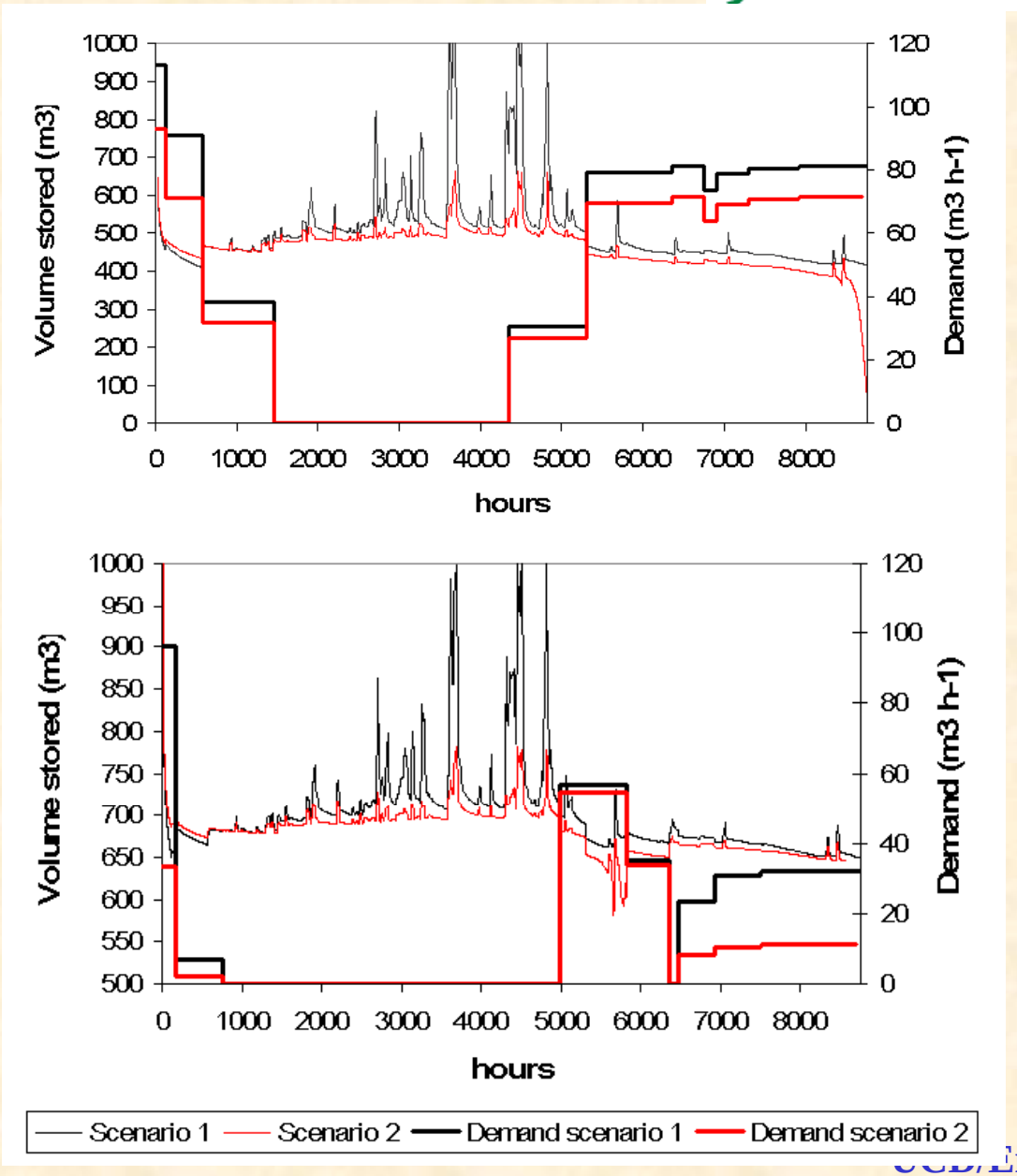
Changes in Reservoir Demand

Reservoir #2

Reservoir #5



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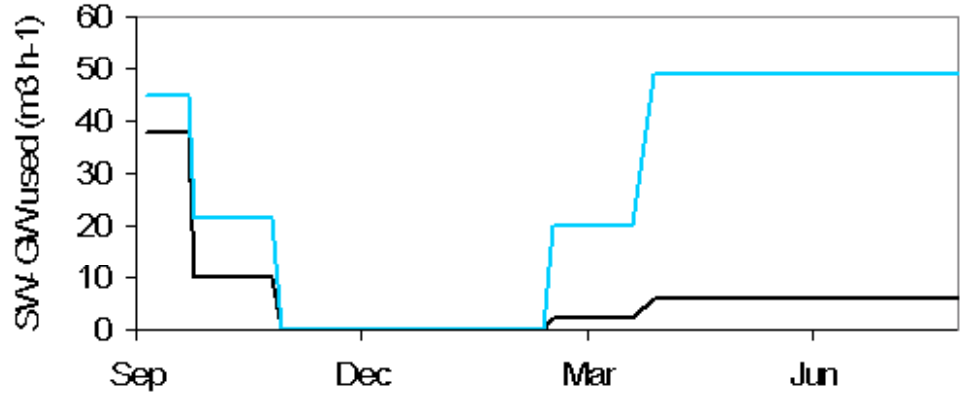
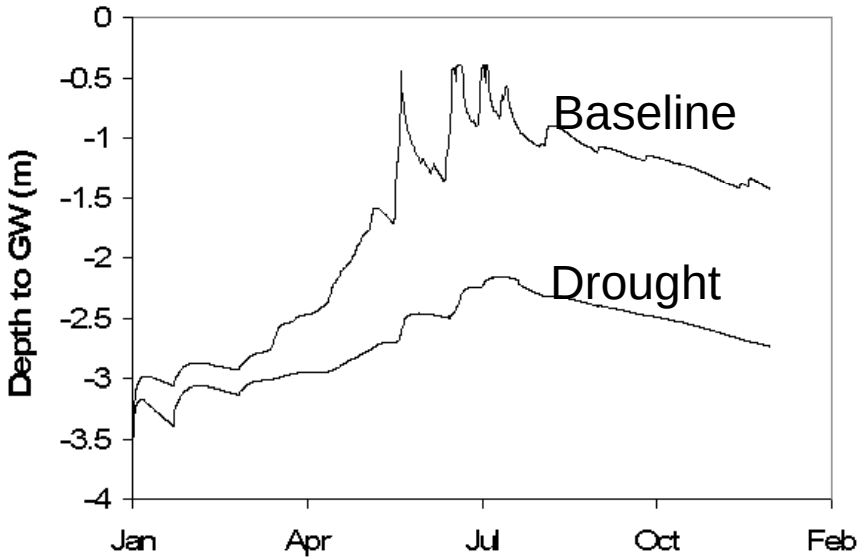
Groundwater & Surface Water Use (Farmer 4)

Applied Water By Source



Depth to Water Table



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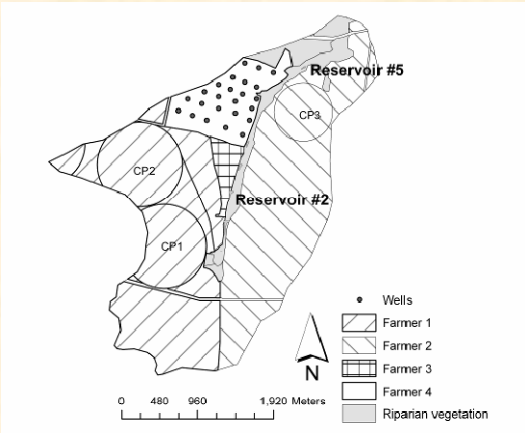
Basin-Wide Hydrology Model

Upscale



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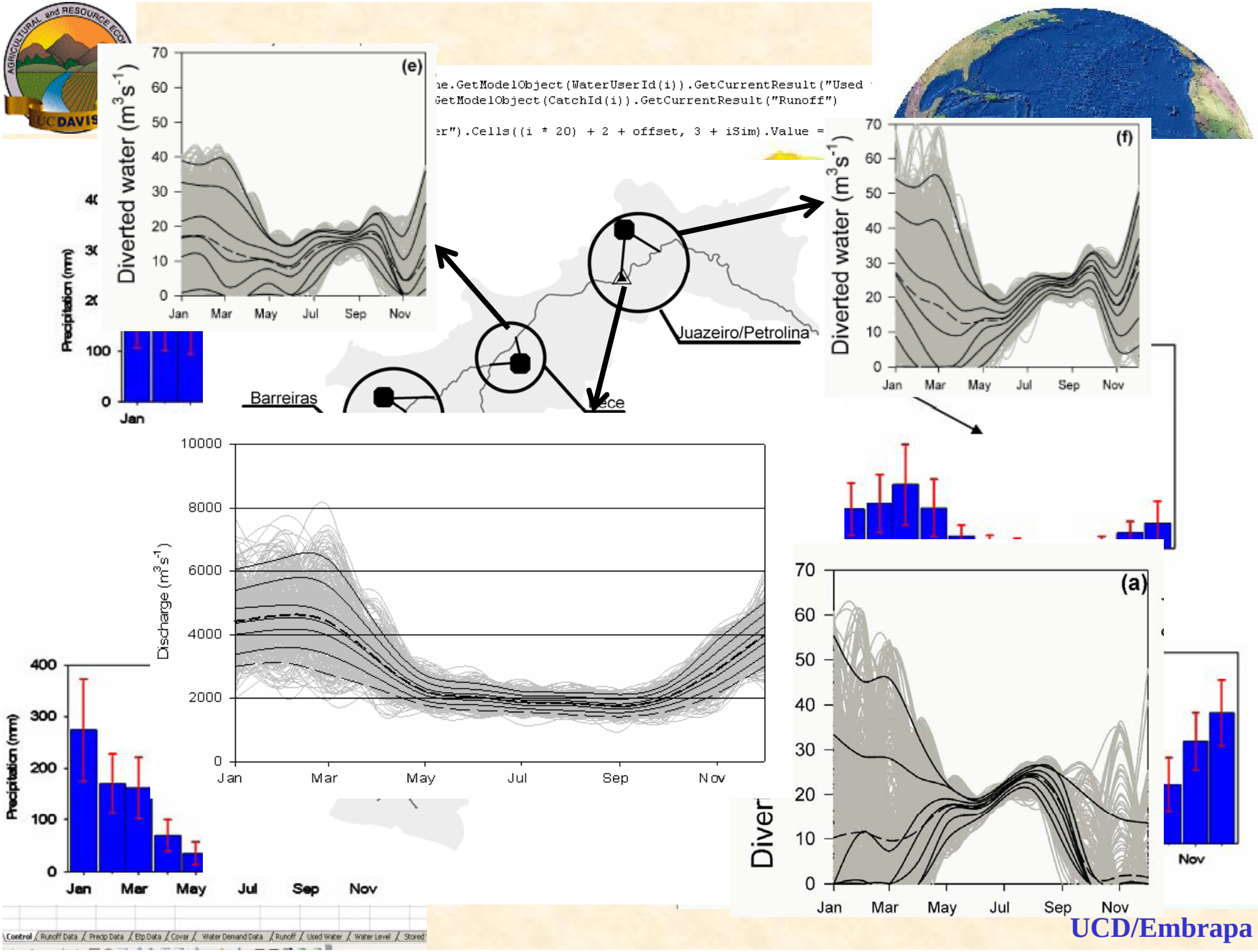
(e)
Diverted water (m^3s^{-1})
Jan Mar May Jul Sep Nov
Precipitation (mm)
Jan
Barreiras
Juazeiro/Petrolina
(f)
Diverted water (m^3s^{-1})
Jan Mar May Jul Sep Nov
Discharge (m^3s^{-1})
Jan Mar May Jul Sep Nov
Precipitation (mm)
Jan Mar May Jul Sep Nov
(a)
Jan Mar May Jul Sep Nov
Nov
Control Runoff Data Precip Data Etp Data Cover Water Demand Data Runoff Used Water Water Level Stored

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Hydrologic Modeling Conclusions

- Physics-based models capture spatial and temporal impacts of economic activity on the hydrologic system
- Give insights and enhance understanding of the biophysical system
- For the larger scale, stochastic techniques can calculate water availability in terms of frequency and permits quantification of risk
- Dynamic models have predictive capability and therefore allow for policy testing

Core of the Economic Models of Agriculture: Farmer Objective Function

- **Maximize Profits**
  - **Choose product mix and production technology**
    - **Including the amount and sources of water, and how it is applied**
- **Subject to an Array of Constraints**
  - **Socioeconomic**
    - **Feed the family**
    - **Access to markets and credit, etc.**
  - **Biophysical**
    - **Soils, weather, etc.**
  - **Access to water**
    - **Surface water, groundwater**

Core of the Economic Model of Agriculture: Farmer Objective Function

$$\max \sum_i p_{it} q_{it}(\mathbf{x}_{nirrt}, ew_{it}(\mathbf{x}_{irrt})) - \sum_i w_{jt} x_{ijt} - \sum_i c_{ew_{it}}(\mathbf{p}_{irrt}, \mathbf{x}_{irrt}; z)$$

Crop Prices

Agricultural Production Function

- Vector of Non-Irrigation Inputs (x_{nirr}):
  - Fertilizers, seeds, land, pesticides, machinery etc
- Effective Water – *ew*
- Function of Irrigation Inputs (x_{irr}):
  - Applied water
  - Irrigation Capital
  - Irrigation Labor
  - Irrigation Energy

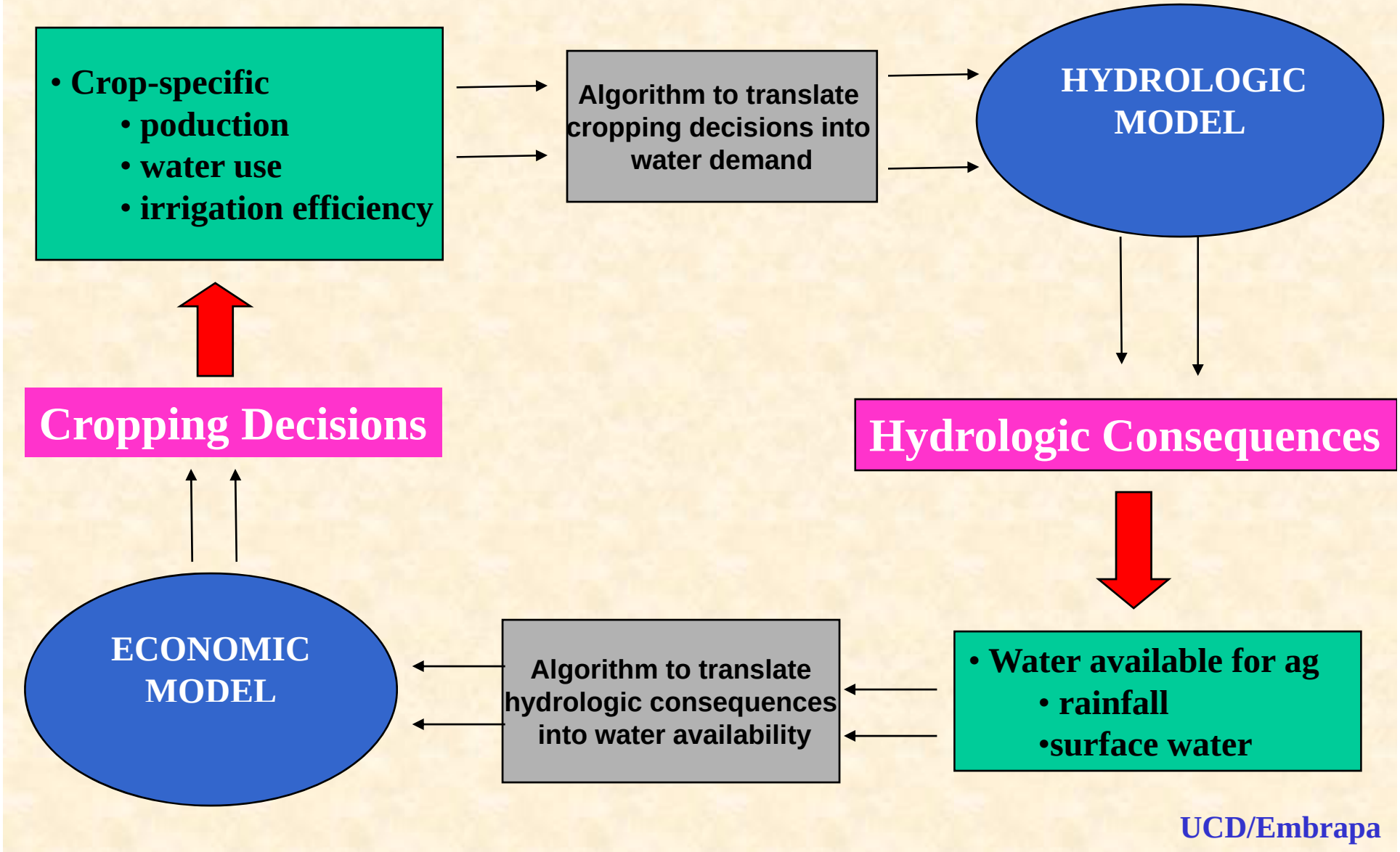
Non-Irrigation Input Cost

- Price - w_{sj}
- Quantity - x_{sij}

Effective Water Cost

- Irrigation Input Prices – p_{irr}
- Irrigation Input Quantities - x_{irr}
- z – Vector of factors that may affect irrigation costs (e.g. distance to river)

Hydrologic & Economic Model Links



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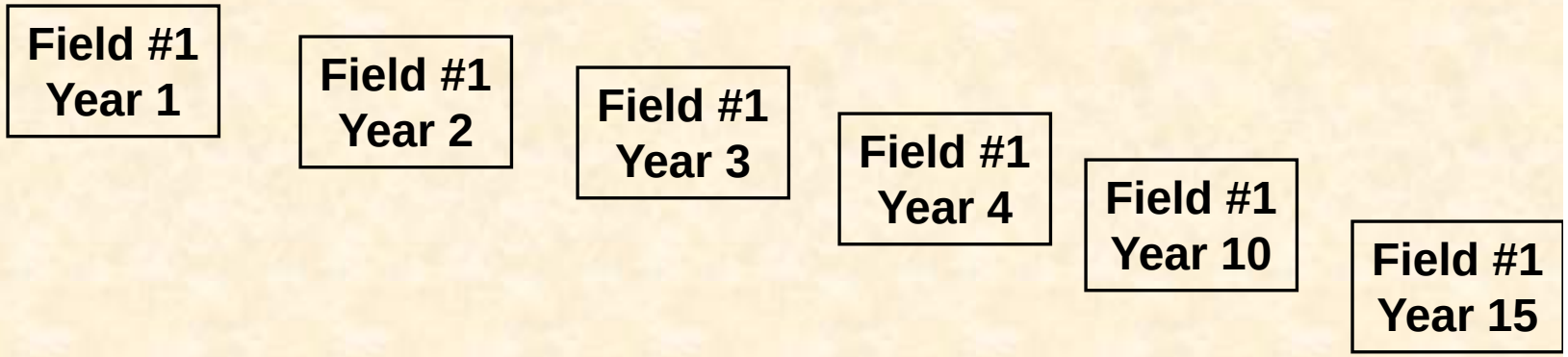
Land Use System Analysis (LUS)

- **Space**
  - Single parcel of land
- **Time**
  - Multi-year duration, specific end date, seasonal time steps
- **Economic Model of Agriculture**
  - Specific series of cropping activities, specific production and water use technologies
- **Hydrology Model**
  - Farmer's assessments of water availability
- **All Data Collected at Farm Level**



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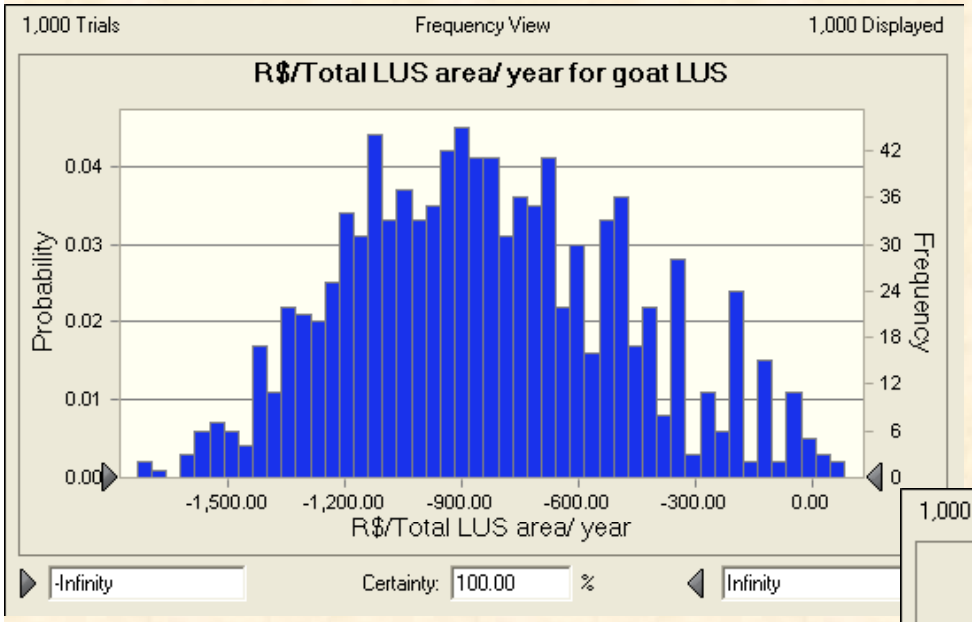
LUS Results for Alternative Production Systems in Petrolina

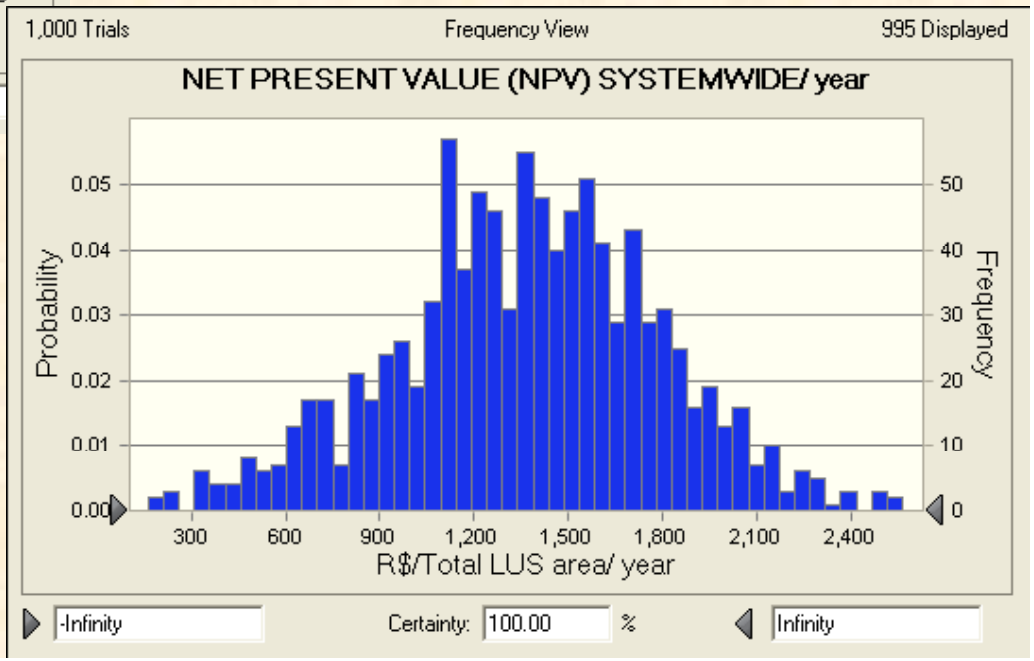
LUS	Economic Performance				Labor Requirements		Water for Irrigation					Employment
	NPV	NPV per hectare	Excess Returns to Family Labor	Returns to Land	Establishment	Total Family Labor Used	Establishment Cost -- Property	Establishment Cost -- Plot (per hectare)	Operational Costs	Water Use	Water Productivity (NPV/ 1000m³)	Operational Phase
	$R	$R/ha	$R/ person-day	$R/ha /year	Person-days /ha	Person-days/ ha/ year	$R	$R/ ha	$R/ha/ year	1000M³/ ha/year	$R/ 1000m³	person-days/ha/ year
Goats and Sheep	-12	0	0	0	1.5	6.3	0	0	6	4	0.00	0
Melon -Onion	43,963	21,981	11	1,099	28	102	50	25	2,466	21	53.26	229
Manga -- flood irrigation	3,087	772	1	39	35	45	553	138	1,177	12	3.12	93
Mango -- micro sprinkler	11,057	2,764	4	138	44	32	4,212	1,053	973	10	14	69
Table grapes with seeds	778,074	129,679	31.14	6,484	151	208	96,600	16,100	3,157	18	368	524
Table grapes seedless	1,369,349	228,225	54.81	11,411	151	208	96,600	16,100	3,157	18	648	438

Effects of Uncertainty

Effects of Goat Mortality Uncertainty on NPV per Year



Effect of Uncertainty in Mango Prices on NPV per year



Policy Experiments Using LUS

Intercropped Limes in Buriti Vermelho, Brazil; Micro-sprinkler Irrigation

Final Matrix with Policy Experiments

Policy Settings	Baseline Values	Policy Experiment #1	Policy Experiment #2	Policy Experiment #3	Policy Experiment #4	Policy Experiment #5	Policy Experiment #6	Policy Experiment #7
Input Prices								
Water Price (R$/m^3)	0	0.25	0	0	0	0	0	0
Electricity Price (R$/kwh)	0.21	0.21	0.4	0.21	0.21	0.21	0.21	0.21
Minimum Wage (R$/person-day, unskilled)	18	18	18	25	18	18	18	18
Agricutlural Research								
Yield Response to Applied Water (kg/m^3)	2.841	2.841	2.841	2.841	3.2	2.841	2.841	5
Regulations								
Available Water for Irrigation (m^3/season)	3200	3200	3200	3200	3200	1600	660	1600

Baseline LUS & Policy Experiments	Economic Performance			Water for Irrigation				
	NPV of the LUS	Returns to Land	Returns to Family Labor	Cost of Establishing Irrigation System on the Property	Cost of Establishing Irrigation System on the LUS Plot	Operational Costs	Amount of Applied Water	Water Productivity
								NPV/m^3
	$R	$R/ha/year	$R/person-day	$R	$R/2 ha	$R/ha/year	M^3/ha/year	$R
Irrigated Limes -- Baseline	42,079	1,753	74	5,330	7,636	19,356	3,168	1.11
Policy Experiment #1	30,898	1,287	54	5,330	7,636	19,356	3,168	0.81
Policy Experiment #2	21,897	912	38	5,330	7,636	36,511	3,168	0.58
Policy Experiment #3	38,439	1,602	67	5,470	7,650	19,510	3,168	1.01
Policy Experiment #4	55,508	2,313	97	5,330	7,636	19,356	3,168	1.46
Policy Experiment #5	15,768	657	28	5,330	7,636	9,776	1,600	0.82
Policy Experiment #6	7	0	0	5,330	7,636	4,033	660	0.00
Policy Experiment #7	36,155	1,506	63	5,330	7,636	9,776	1,600	1.88

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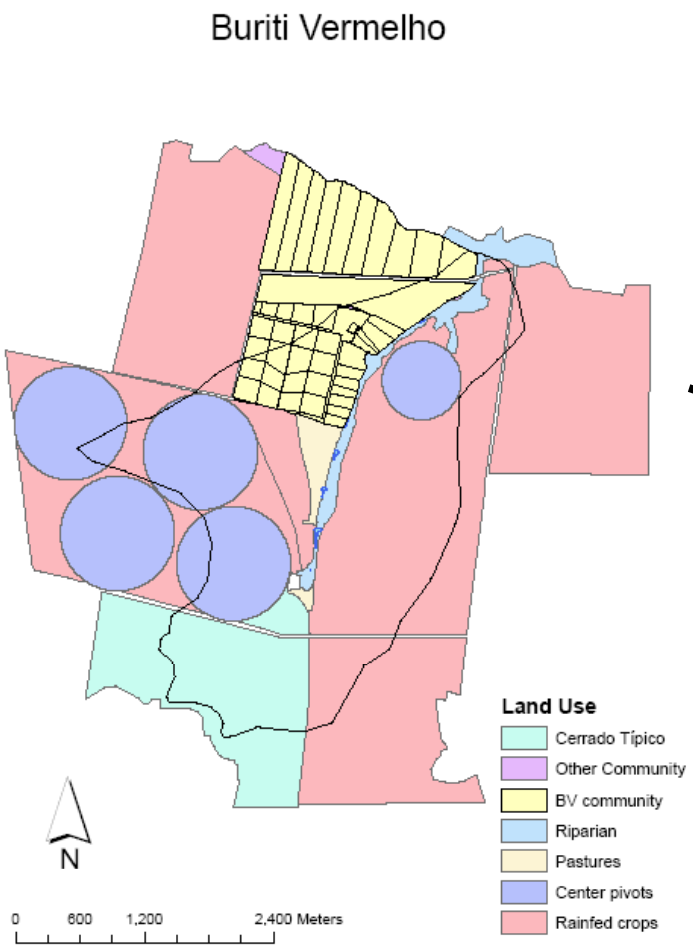
Modeling the Buriti Vermelho Sub-Catchment

Benefits of Co-Location of Research Sites



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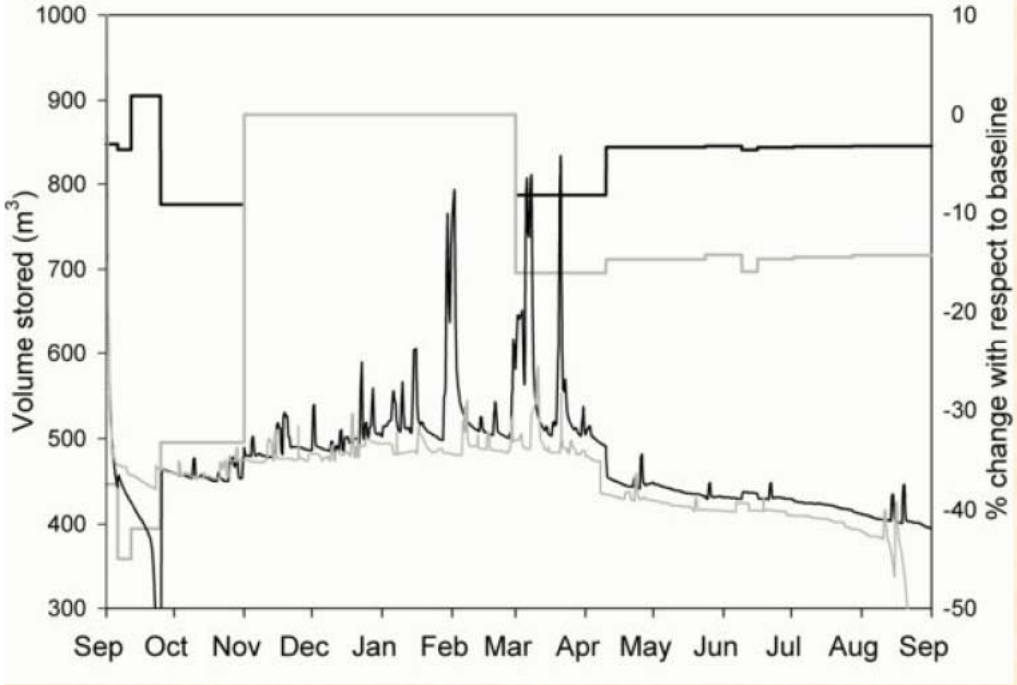
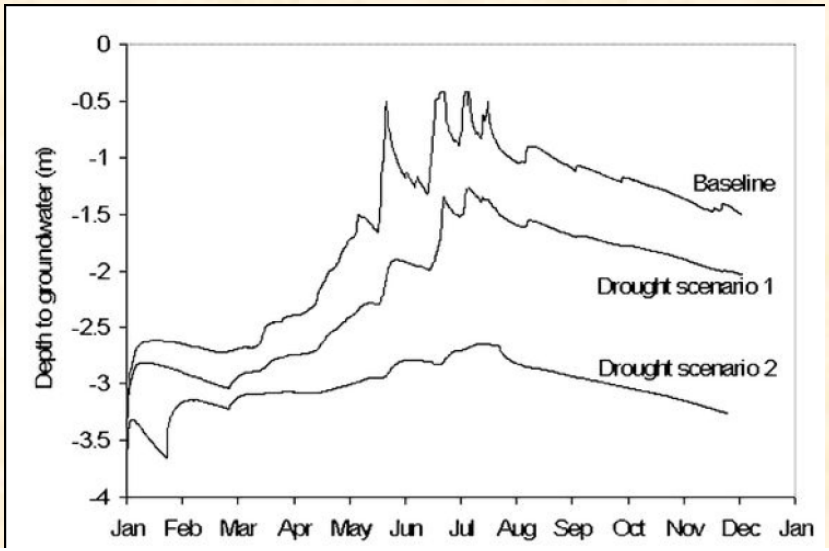
Water Availability and Use in BV

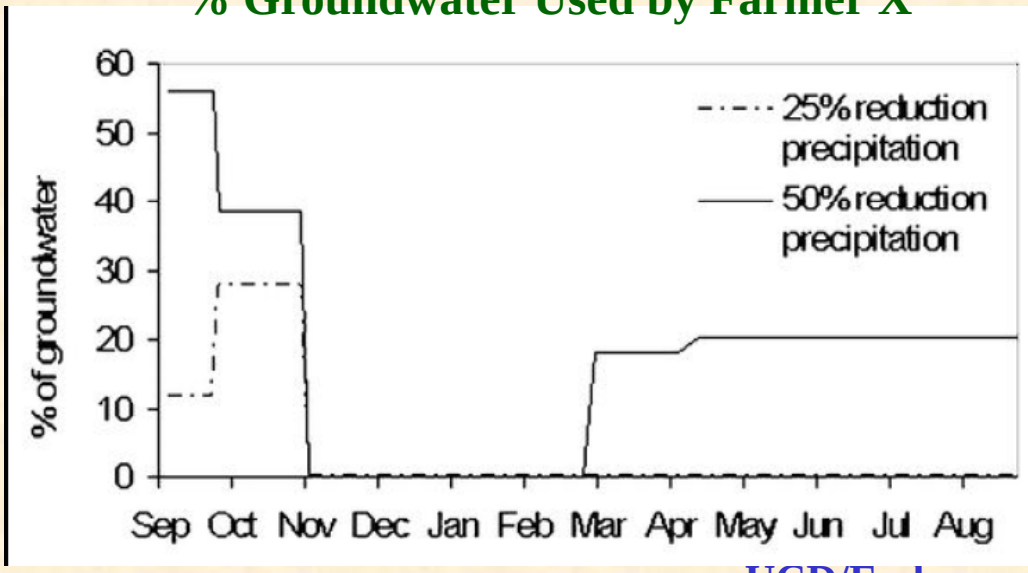
Water Stored and Withdrawn from Reservoir #2



Depth of Groundwater in Well Field



% Groundwater Used by Farmer X



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Economic Effects of Drought

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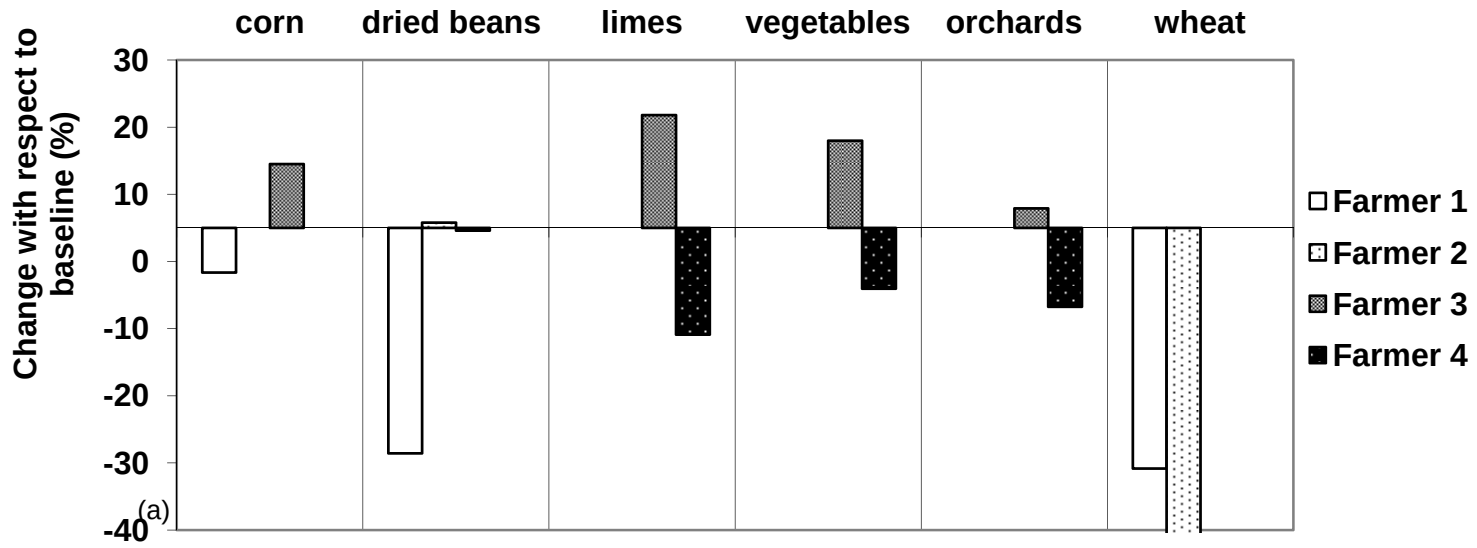
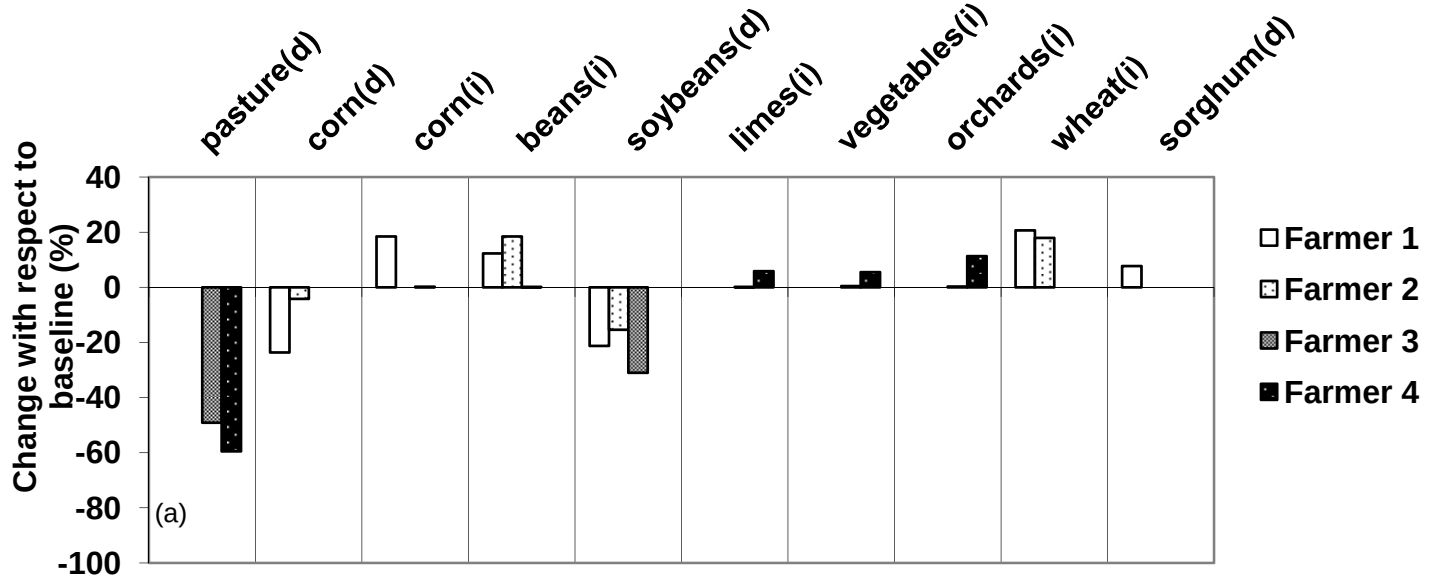


Changes in Applied Water



Changes in Land Allocation

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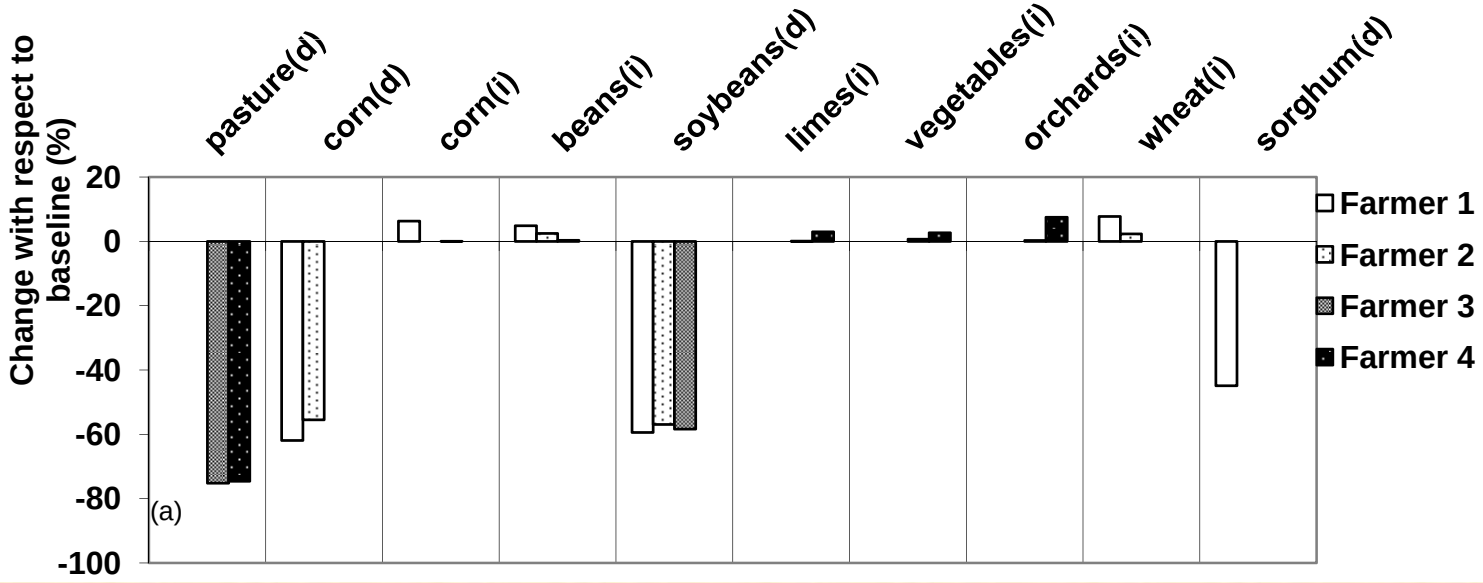
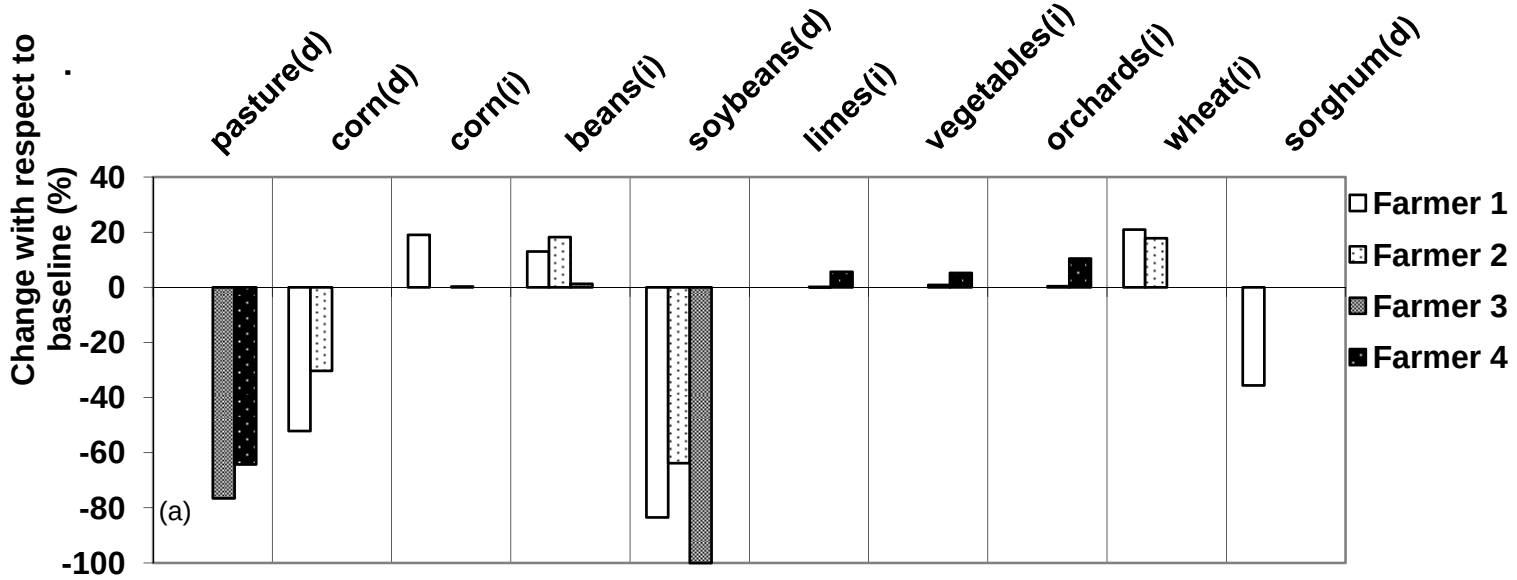
Economic Effects of Drought



Changes in Profits



Changes in Hired Labor Use

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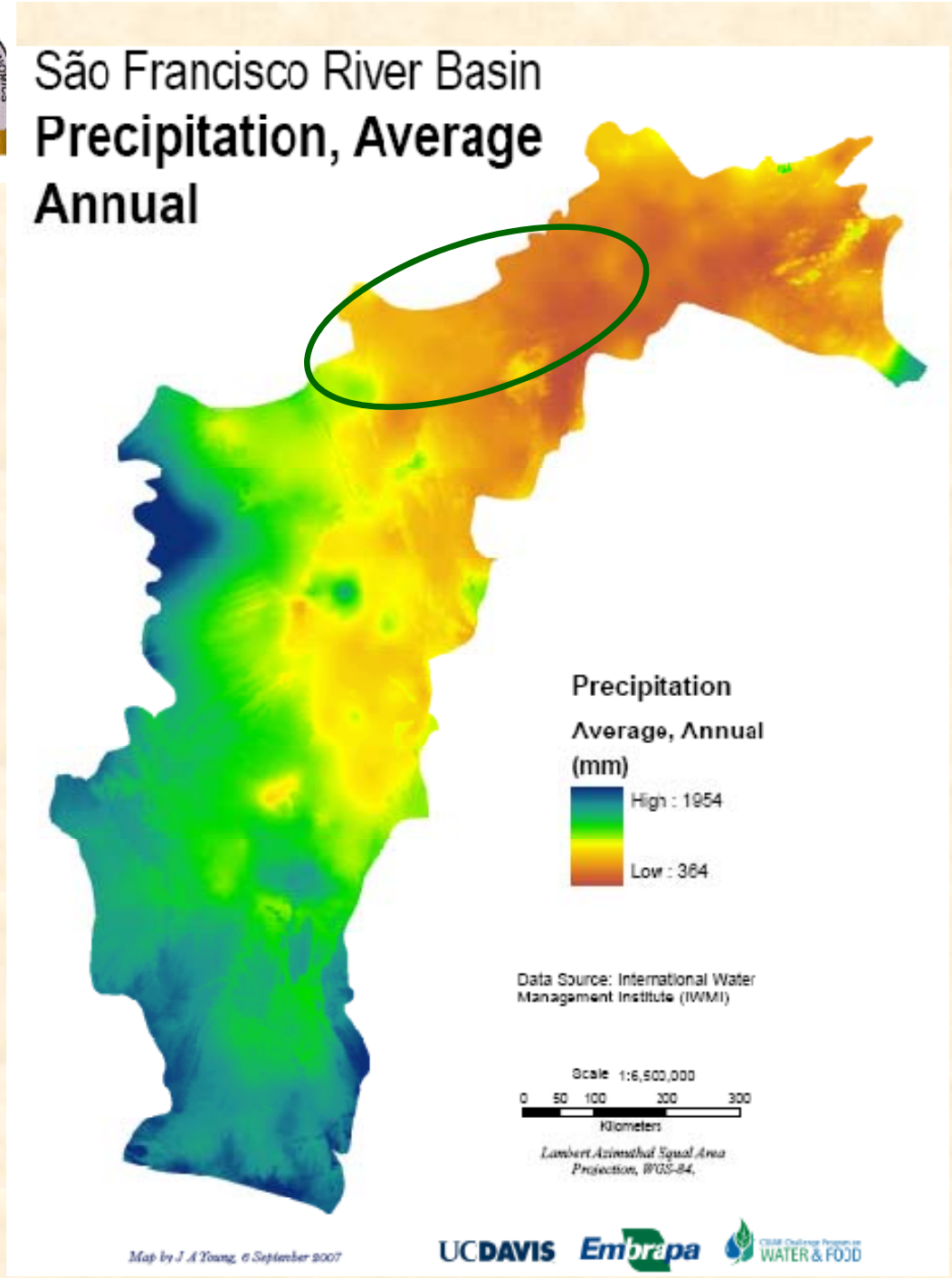
Basin-Wide Setting

- **Variable Weather Conditions**
  - **Wet year and drought**
  - **Rainfall and evapotranspiration**
- **Water Policy Setting**
  - **Application of the ANA guidelines**
- **Price Shock**
  - **Large increase in sugarcane prices**
- **Use Hydro-Econ Models to Predict:**
  - **Cropping patterns, water use, employment, income**
  - **Water availability in river system**



Precipitation in the SFRB and Focus of the Basin-Wide Policy Experiment

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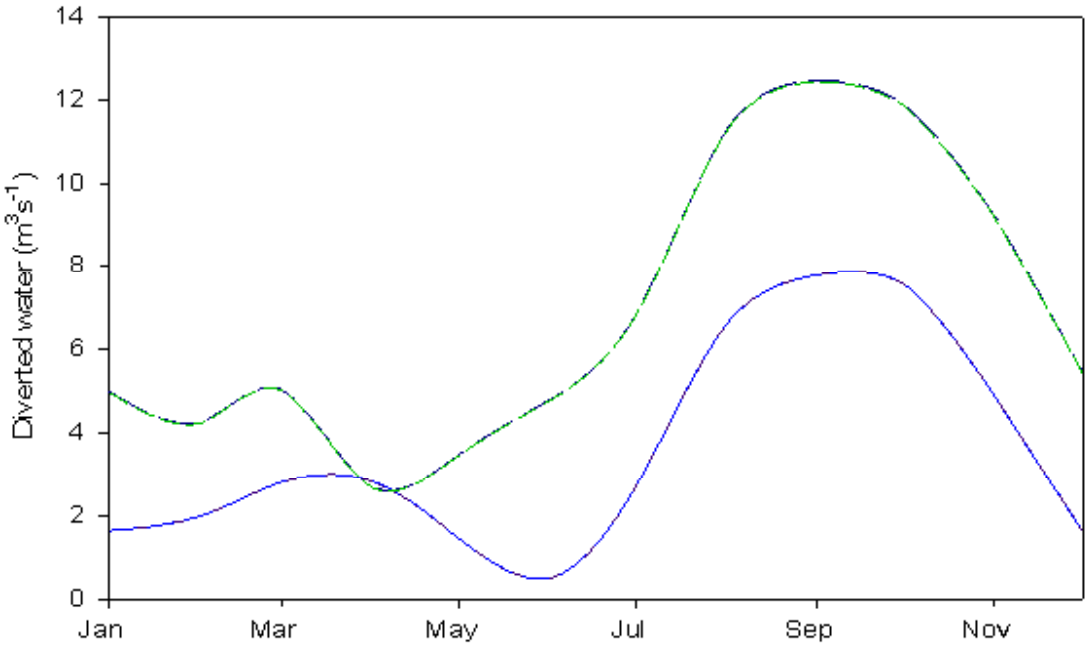
Upstream Water Demand

Upstream Water Demand for Boqueirão (sample município)

Blue = baseline

Green = Sugarcane Price Increase



Total Demand of all Simulated Upstream Responses to Sugarcane Price Increases (m^3s^{-1})

January	39.5
February	33.4
March	40.1
April	22.3
May	27.1
June	37.8
July	54.4
August	89.5
September	99.4
October	92.5
November	74.6
December	43.1

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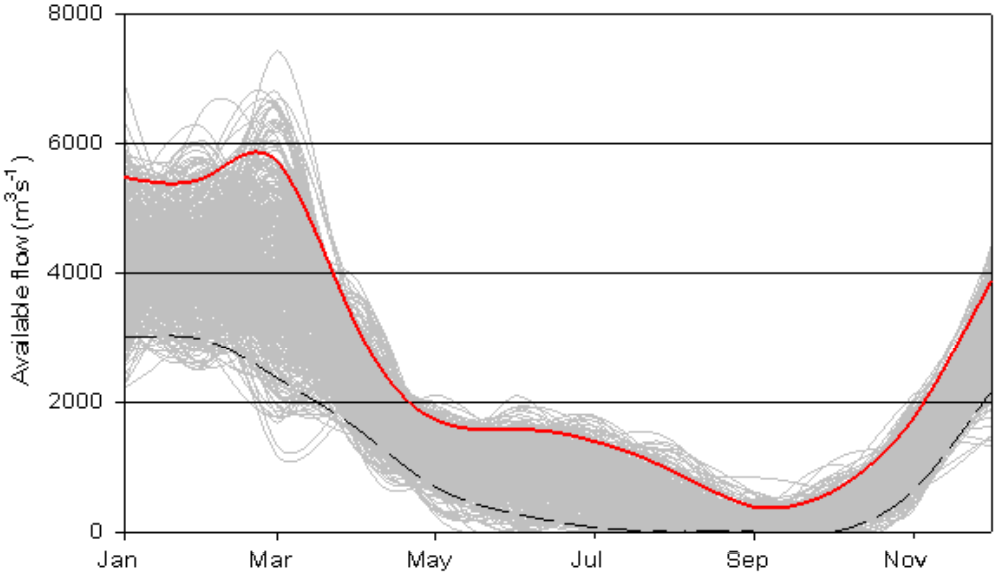
Water Available at Sobradinho Dam -- Before Price Shock



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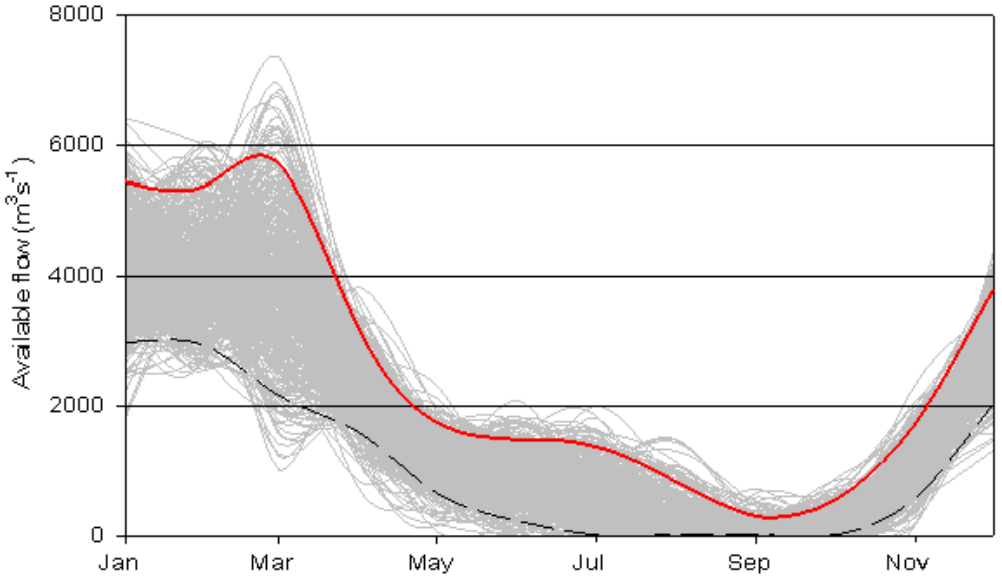
Water Available for Agriculture

Water Available at Sobradinho Dam -- After Price Shock



"Available" for Ag = River Flow Entering Sobradinho Dam Minus 2000 m^3s^{-1} for Environmental Flows
(following Braga and Lotufo 2008)

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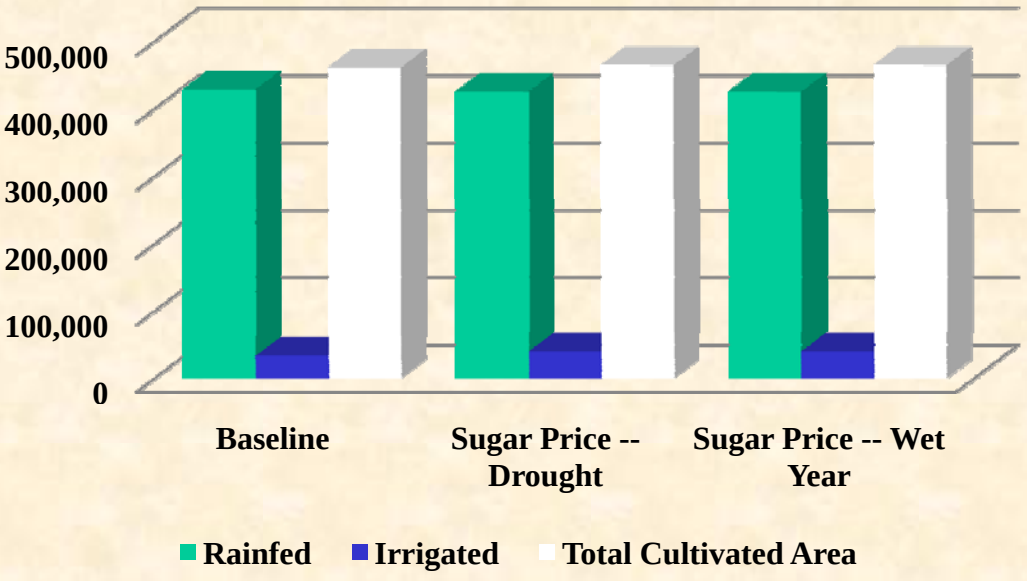
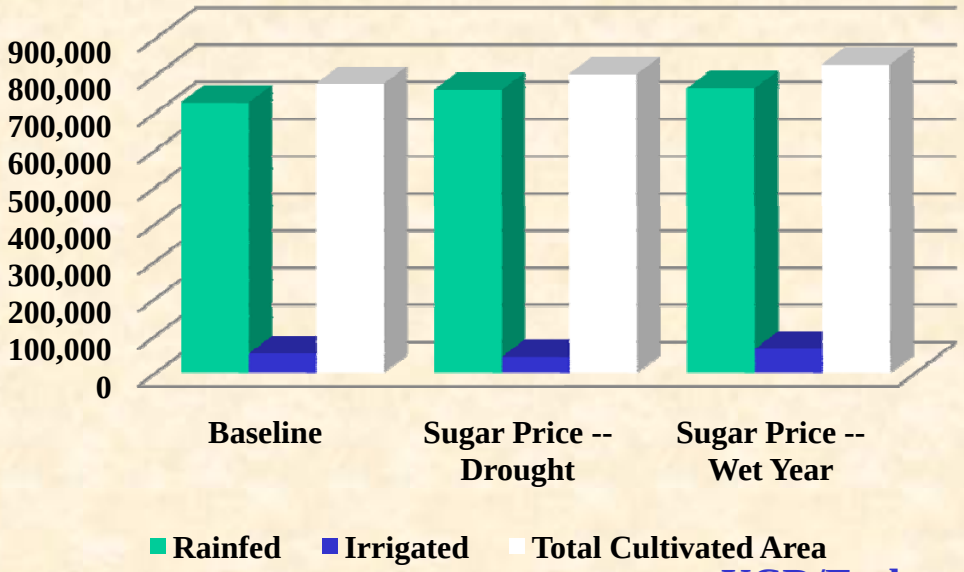
Agricultural Land Use

Upstream Cultivated Areas (by scenario, irrigation)



Downstream Cultivated Areas (by scenario, irrigation)



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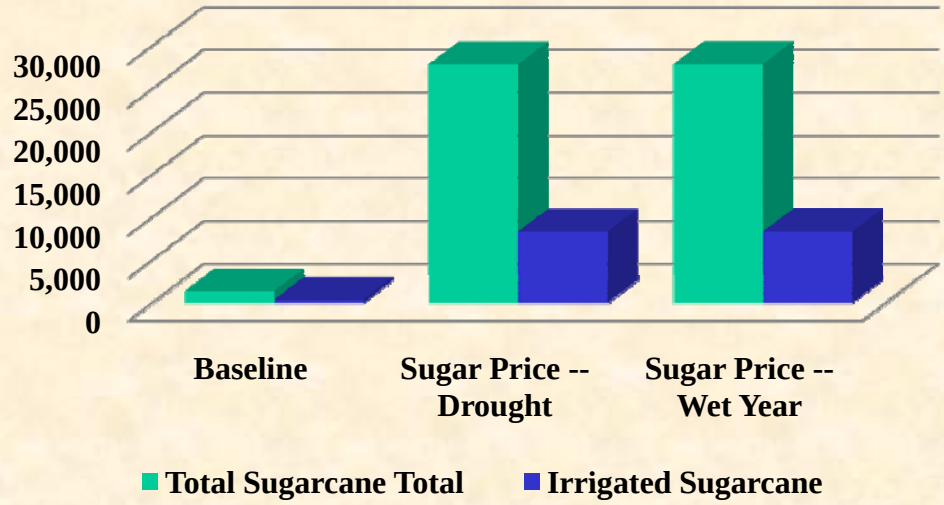
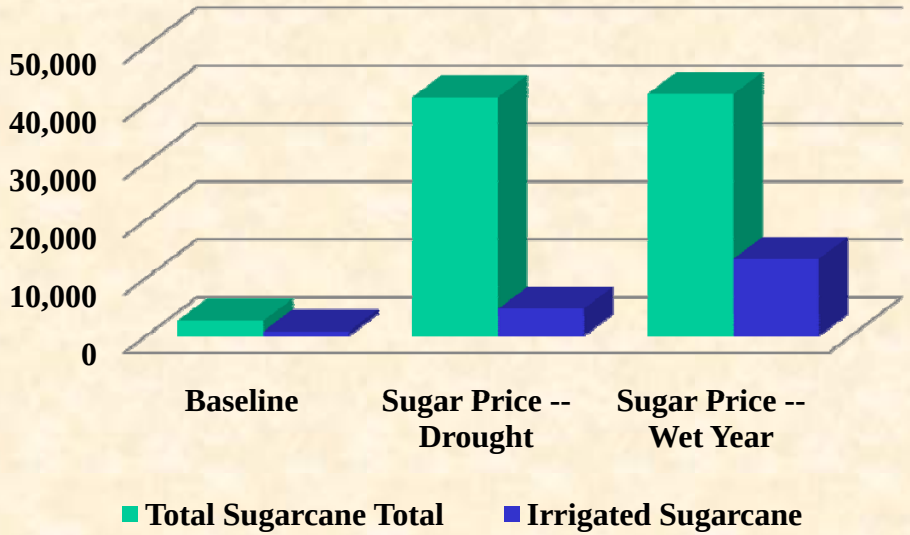
Area in Sugarcane

Upstream Sugarcane Areas (by scenario, irrigation)



Downstream Sugarcane Areas (by scenario, irrigation)



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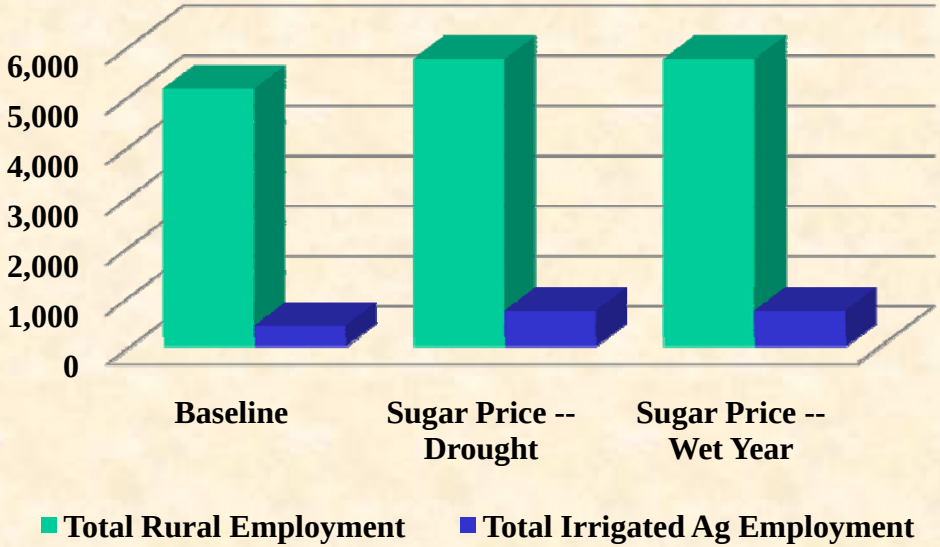
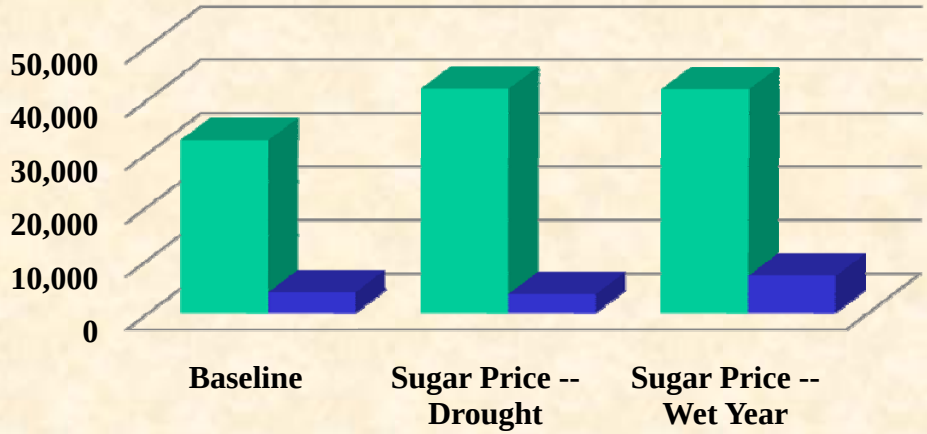
Rural Employment

Upstream Agricultural Employment (by scenario, irrigation)



Downstream Agricultural Employment (by scenario, irrigation)



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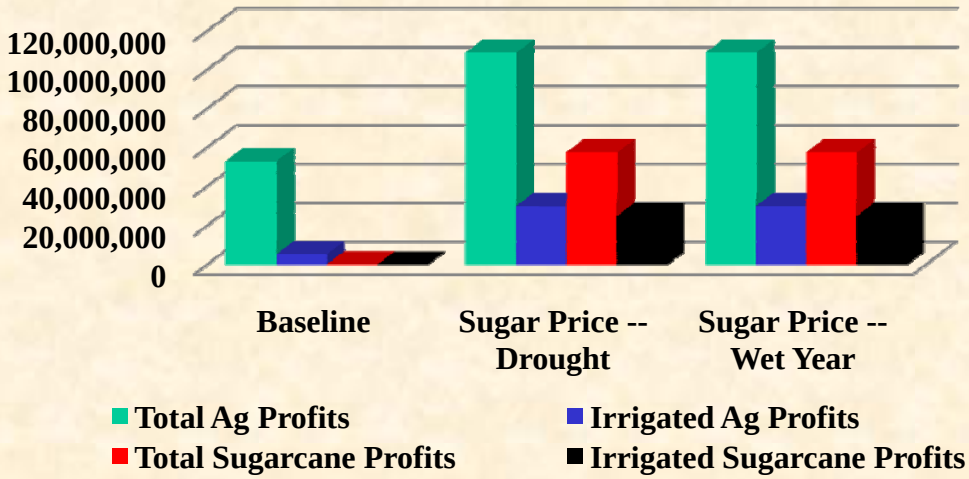
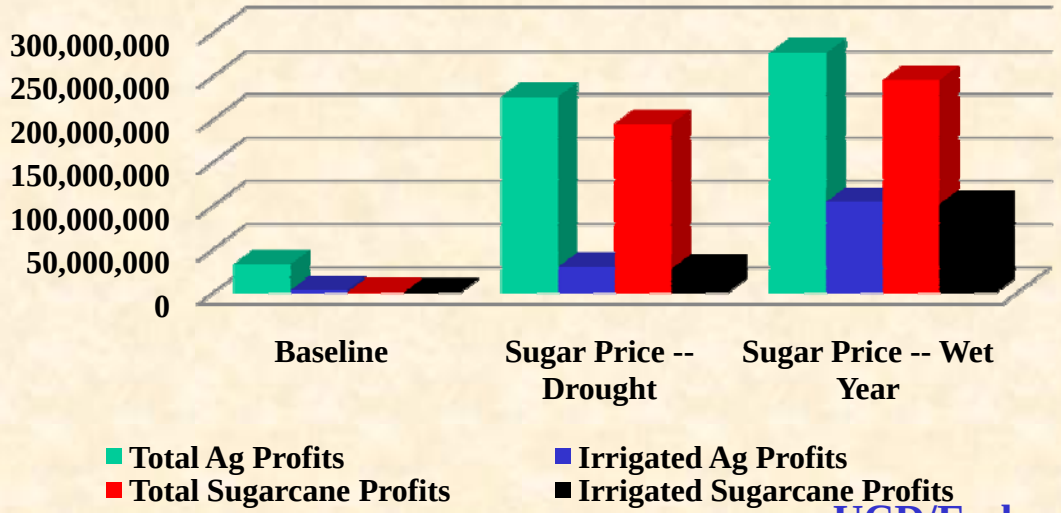
Agricultural Profits

Upstream Sugarcane and Total Ag Profits (by scenario, irrigation)



Downstream Sugarcane and Total Ag Profits (by scenario, irrigation)



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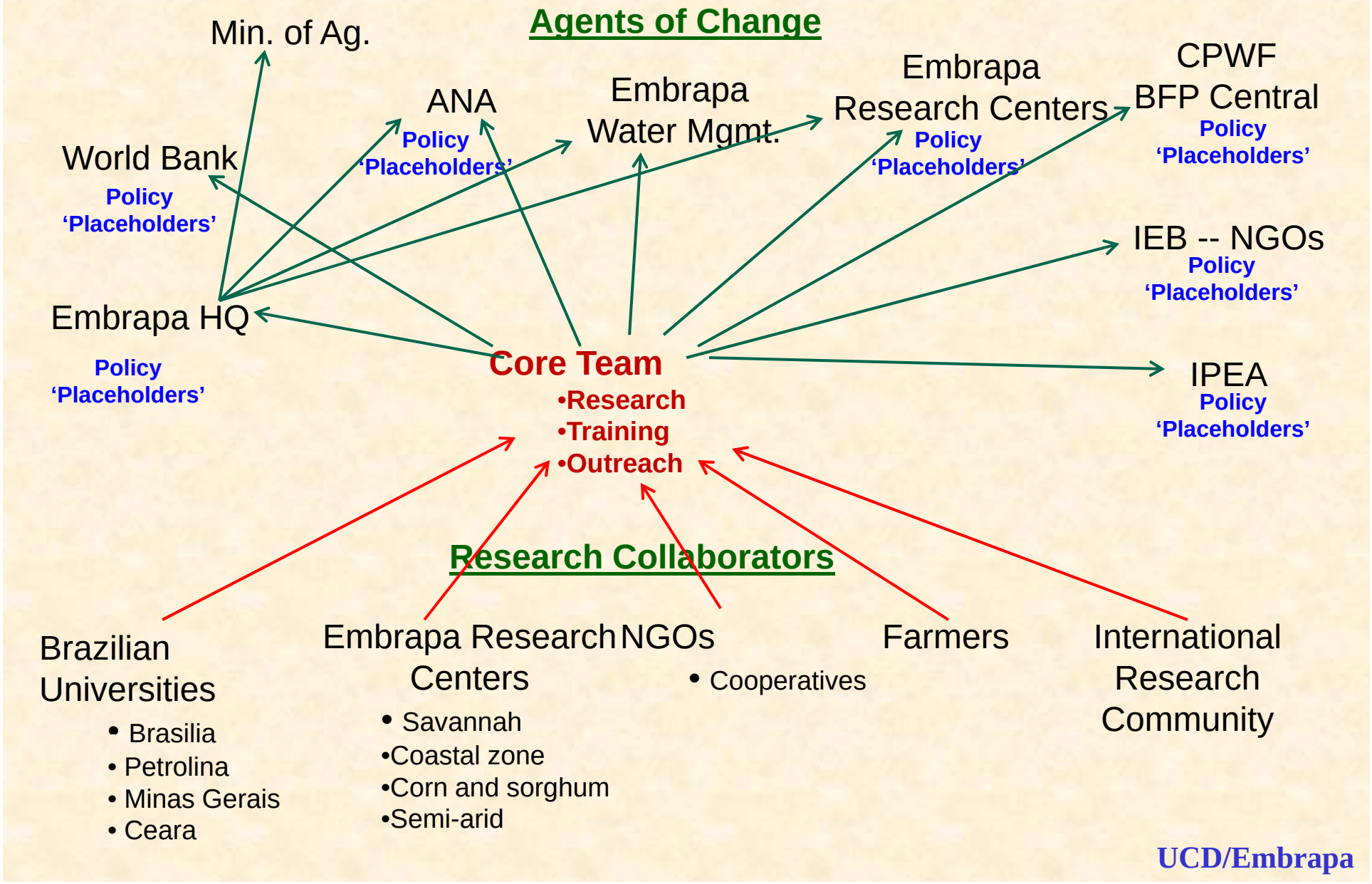
Behavioral Modeling

- **Value Added**
  - **Insight into farming and farm household decisions**
  - **These decisions can affect water use**
  - **Insights into water-poverty links**
- **Practicality**
  - **Array of tools available**
    - **Static models (LUS)**
    - **Equilibrium models (PMP)**
    - **Agent-based models**
    - **Others**
  - **Linking hydro and behavioral models can be challenging**
    - **Depending on circumstances, it can be worth the effort**

Knowledge Pathways and Impact Pathways



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Research Outputs

- **Written Output**
  - **Journal papers, conference papers, working papers, posters, etc.**
  - **Policy Briefs (Portuguese and English)**
- **Methodologies**
  - **Linked, hydro-economic models**
  - **LUS models**
- **Human Capital**
  - **Embrapa, UC Davis, U. of Brasilia**
- **Data Sets**
  - **Agriculture, water resources, poverty**

Next Steps for the SFRB Research Team

- **Refine and Use the Models to Address Pressing Water-Ag-Poverty Issues in Brazil**
- **Deliver these Messages to Decision Makers**
- **Contribute to CPWF Research/Training Efforts**
- **Convey Models and Data to Collaborators**
- **Publish our Findings**
  - **Journal papers**
  - **Book on our multi-scale effort in the SFRB**

SFRB Potential Contributions to Phase II Basin Challenges

- **Benefit Sharing Mechanisms**
  - Sharing water versus sharing the benefits of water
- **Adaptive Management**
  - Objectives? – rural poverty alleviation, managing environmental flows, etc.
  - What are we reacting to? – weather, climate change, market conditions
- **Improved Livelihoods**
  - Which stakeholders, by how much?
  - Uncertainty and risk
- **The Integrated Management of Production Systems Based on Groundwater**
  - Surface water/groundwater interactions
- **Improved Planning and Management of Hydroelectric Facilities**
  - Long-term management with variable rainfall
  - Effects of agricultural change
- **Developing and Maintaining Sustainable Small Reservoirs**
  - Volume, placement and management

Pause for Discussion

- **How Have We Done?**
- **What Have We Missed?**
- **What Would YOU Like to See the SFRB Team Contribute to the CPWF?**

Concluding Remarks

- **Our Stories**
  - **Steve Vosti and Marcelo Torres**
  - **Marco Maneta**
- **Your Views**

Muito Obrigado!