Overview of

Doctoral Research

by

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in cooperation with

CIAT Hillsides Program

under supervision of

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Rationale - *what happens with the water? (1)*

- **WATER**. The decreasing production capacity of water has been identified as one of the major problems in the Rio Cabuyal watershed. This has caused conflicts between communities and their members.

  As human population and food demand will further grow, pressures on the water resources and competition for water to meet agricultural, industrial and domestic water demand will increase further.

- **SCALE**. Focus on the different communities within a watershed. A watershed is a useful scale on which to address multiple stakeholder issues.

  Watersheds and the streams provide a vehicle to consider the critical linkages between upstream and downstream effects and on-farm and off-farm effects.

Rationale - *what happens with the water? (2)*

- **INFORMATION**. Experience with stakeholders in the Rio Cabuyal watershed demonstrated the need for accurate data on the state of water resources, and how they are changing over space and time as land use and water demand change. This allows decision-makers to systematically analyze options for future resource use and alternate paths of development.

- Specifically, assess the implications of spatial and temporal changes in
    - land cover/land use
    - increasing water demand
    - demographic shifts within the watershed
    - climate characteristics, in particular extremes
    - alternate water extraction and allocation schemes
    - location and daily operation of dams, if any.

MODELING OF WATERSHED HYDROLOGY

Requirements to a watershed model

- Technical model characterization: Continuous simulation (*vs*. storm event), distributed parameter (*vs*. lumped parameter) and watershed scale (*vs*. field scale). The model must work properly for steep topography.

- Focus on estimating stream water balance and water availability over space and time, rather than on the model's ability to describe flow of water and nutrient in the soil (infiltration, percolation, leaching) in detail.

- Although the focus is on water resources, the model must account for the land use in hillside watershed and include relevant water-land interactions.

- Model should have relatively low (biophysical) data requirements so that it can easily be applied to agricultural hillside watershed in Latin and Central America, for which few spatially-variable data may be available.

Spatial Water Budget Model (SWBM)

No existing distributed parameter, watershed-scale model (AnnAGNPS, SWAT and ANSWERS 2000) meets these requirements, so I developed a new model.

This model…..

simulates water supply and water use over space and time,

as a function of basic soil, land use, climate and water demand data,

on a daily basis and on a watershed scale (area: 500 - 100,000 ha),

using raster GIS data structures (ArcView GIS Spatial Analyst).

Major processes that are simulated:

(a) land unit water balance

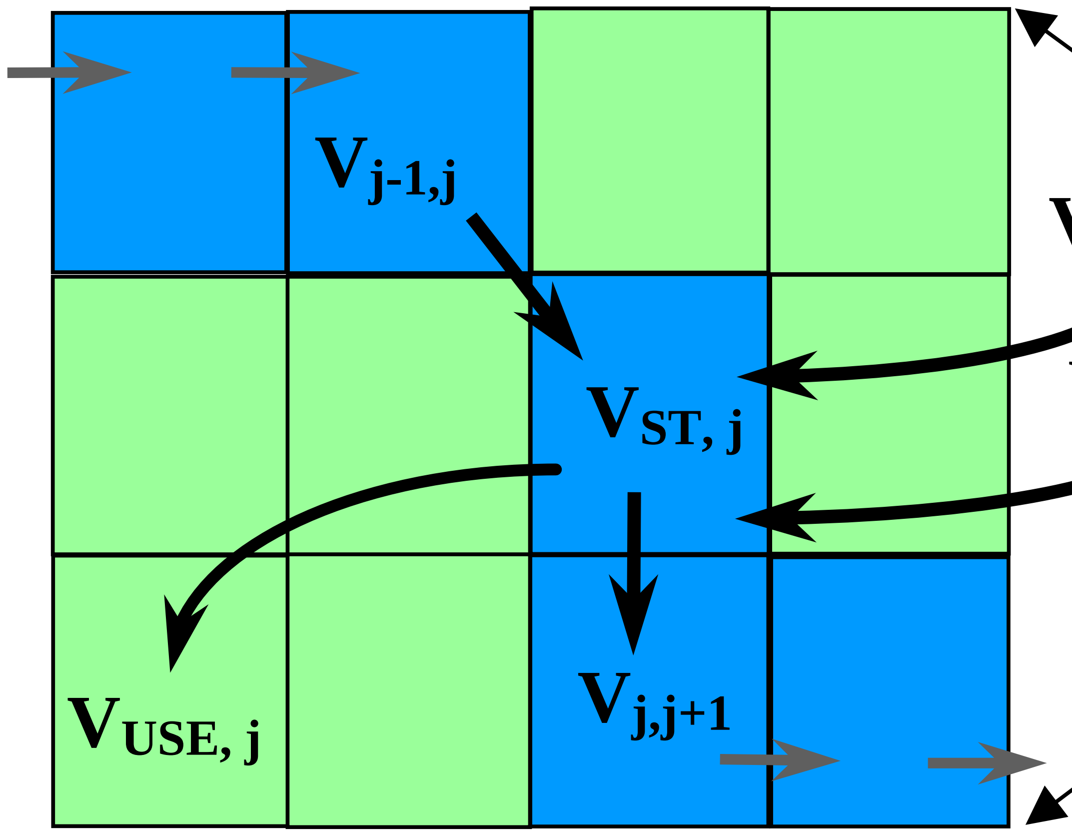
(b) water flow to streams

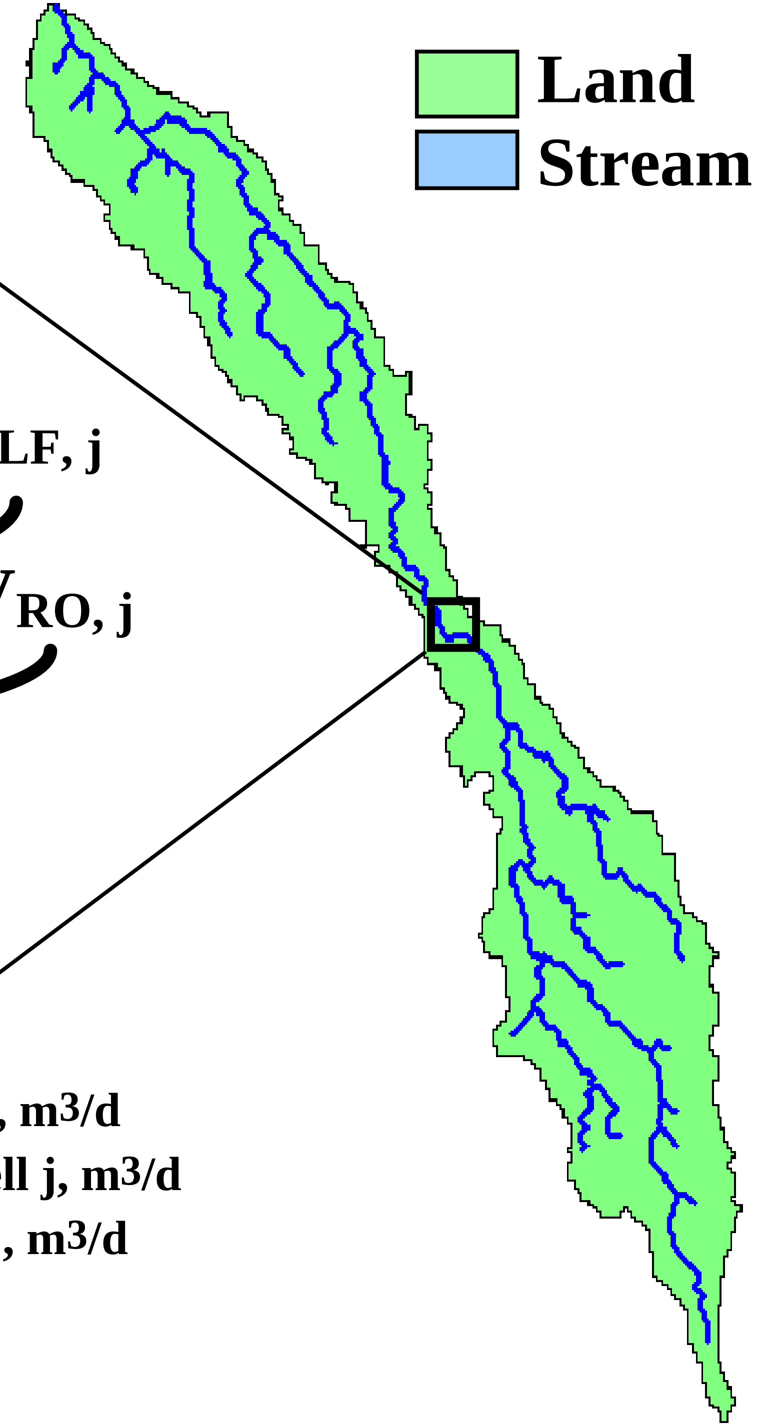
(c) stream water balance

(d) water storage in dams

(e) water extraction from streams (agricultural, industrial and domestic use)

Water Balance for stream cell *j*





$V_{j,j+1}$ = daily flow volume from stream cell j to j+1, m3/d

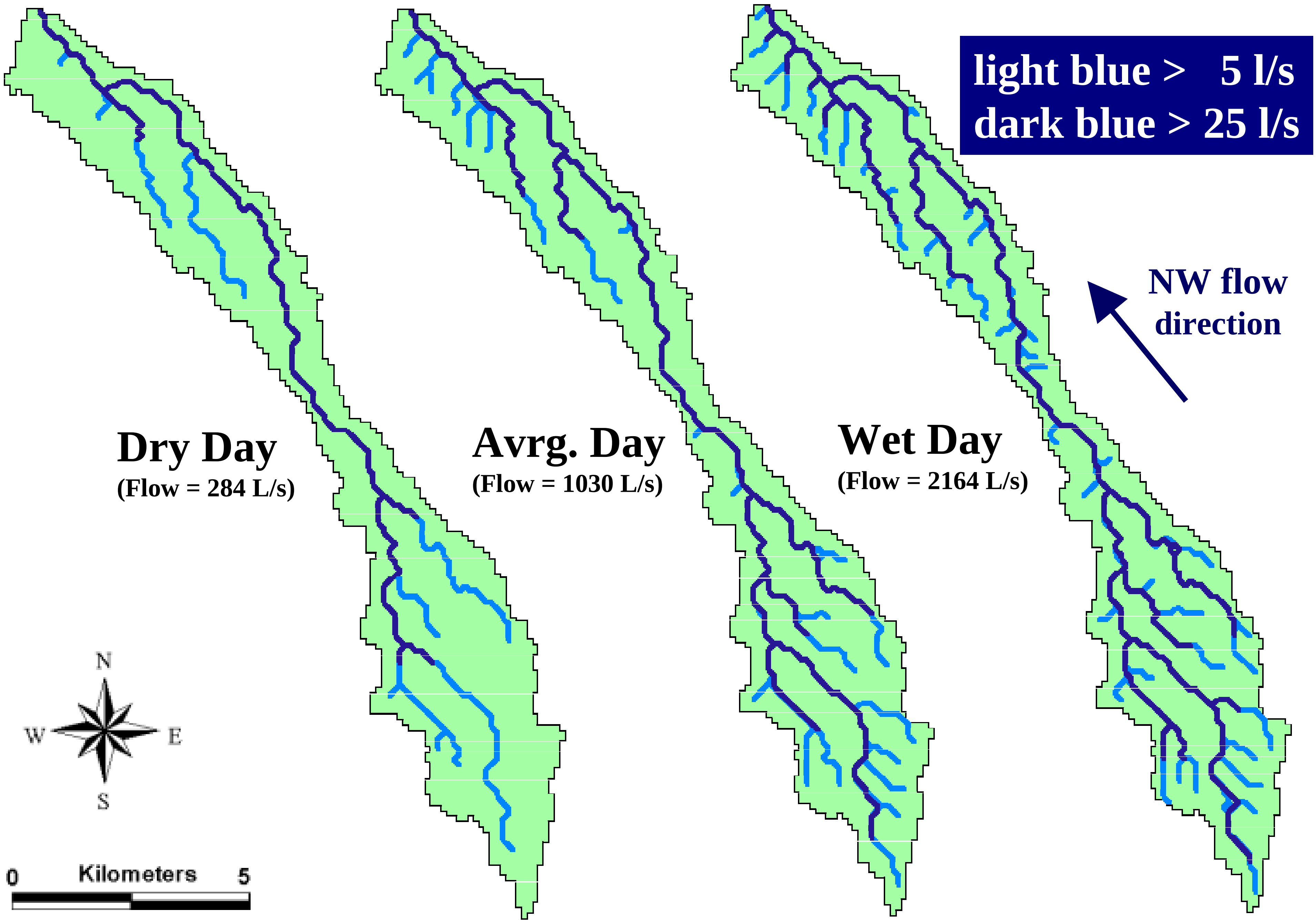
$V_{RO,j}$ = accumulated surface runoff into stream cell j, m3/d

$V_{LF,j}$ = accumulated lateral flow into stream cell j, m3/d

$V_{USE,j}$ = water extracted from stream cell j, m3/d

$V_{ST,j}$ = water stored in stream cell j, m3

Simulated flow rates in Rio Cabuyal Watershed

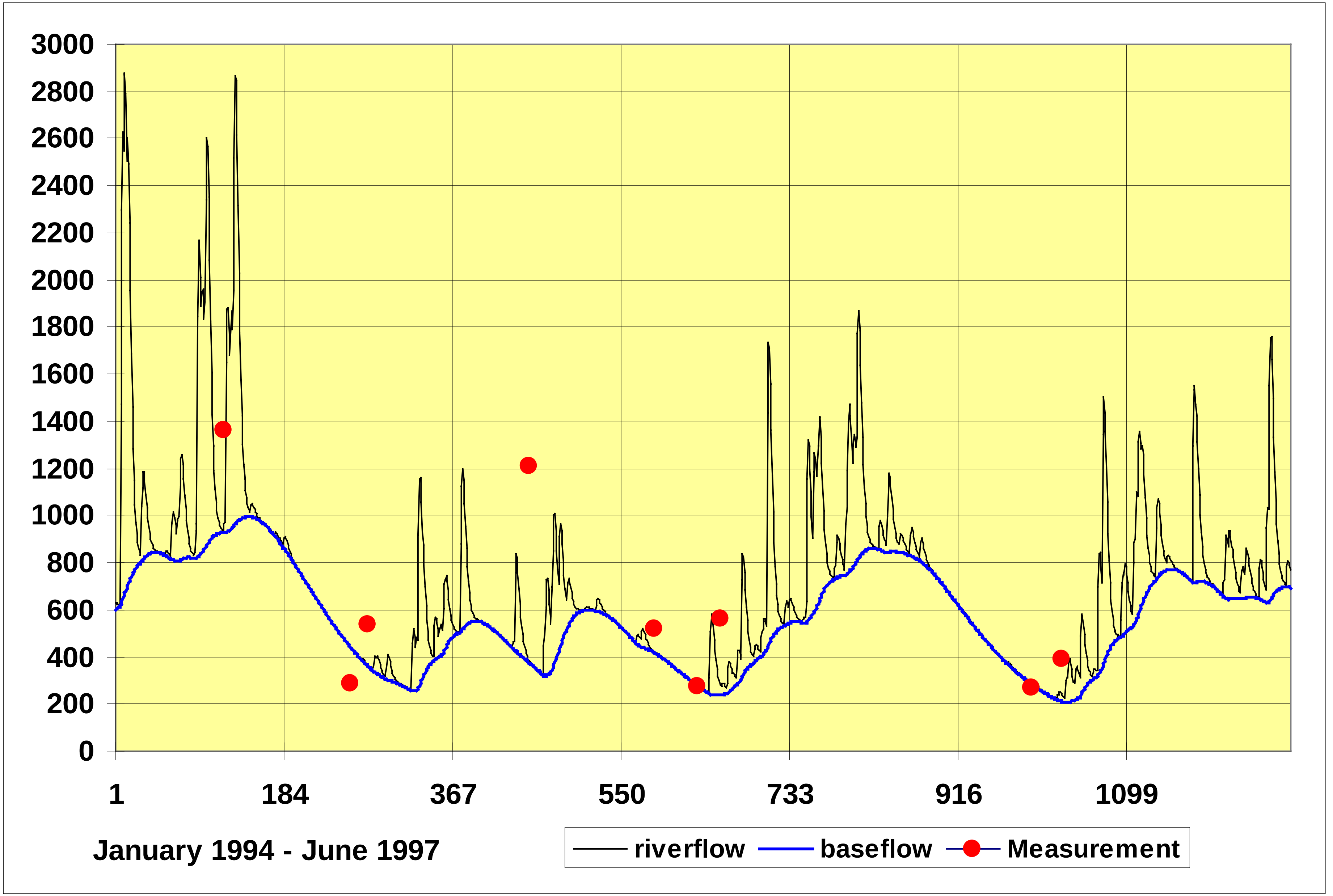


Day	River flow (l/s)	BFI	Length Streams (km)	Stream Density (m/ha)	Avrg. Dist. to stream (m)
## Threshold 5 l/s					
Wet, 2 May 1994	2164	0.45	73.1	22.5	169
Avrg, 17 Jun 1994	1030	1.00	55.9	17.2	244
Dry, 9 Nov 1994	284	1.00	39.2	12.3	370
## Threshold 25 l/s					
Wet, 2 May 1994	2164	0.45	43.8	15.5	323
Avrg., 17 Jun 1994	1030	1.00	34.3	10.6	487
Dry, 9 Nov 1994	284	1.00	20.2	6.2	1382

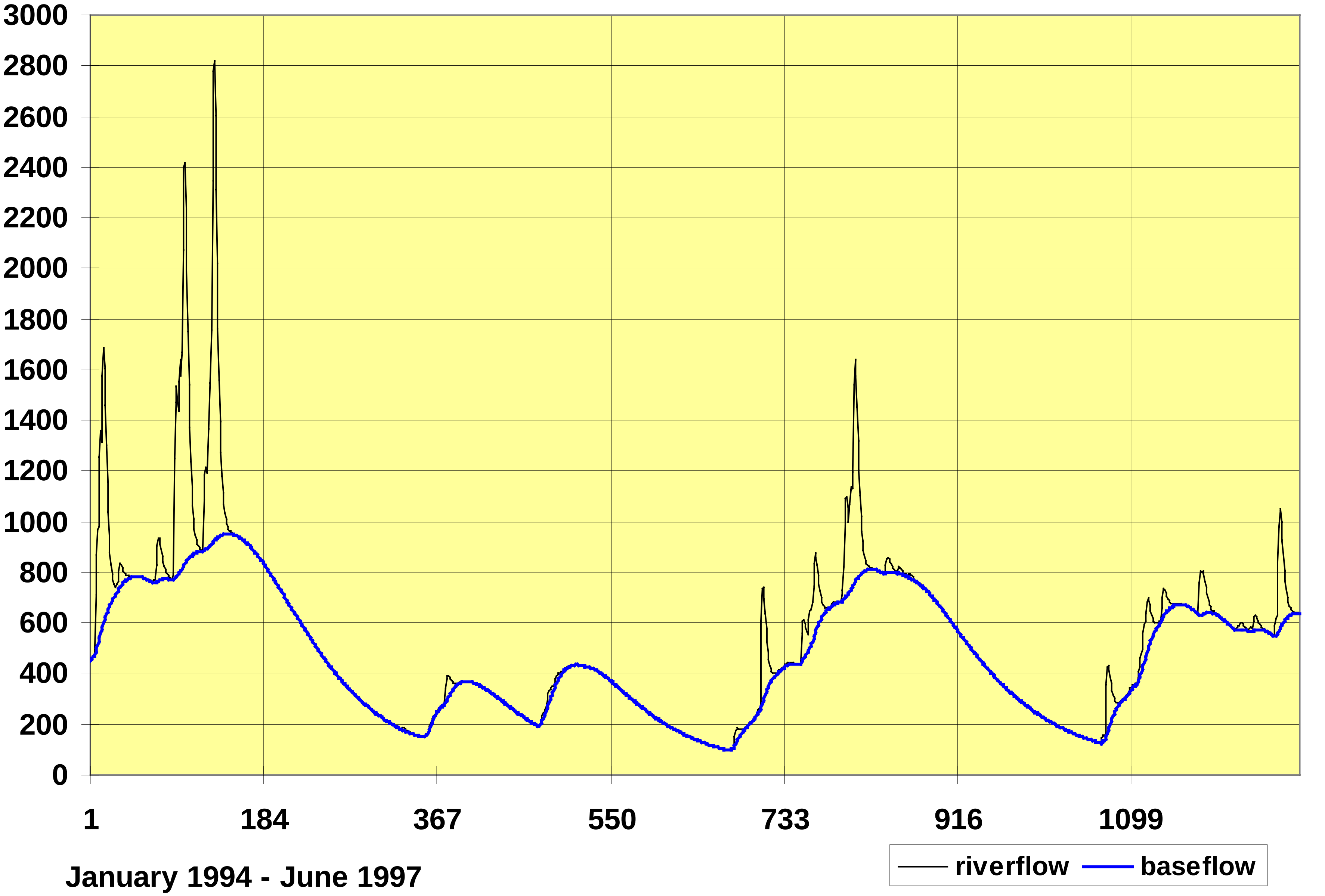
Some statistics on the stream network for a rainy day in a wet period (2 May 1994), a dry day in a wet period (17 June 1994), and a dry day in a dry period (9 November 1994). Results are based on simulations with actual weather data, and are shown for a 5 l/s and a 25 l/s stream flow threshold. The 5 l/s threshold is best for the Rio Cabuyal watershed.

BFI = Base Flow Index, ratio of base flow to stream flow.

Simulated Flow in Rio Cabuyal (l/s), ACTUAL LAND USE

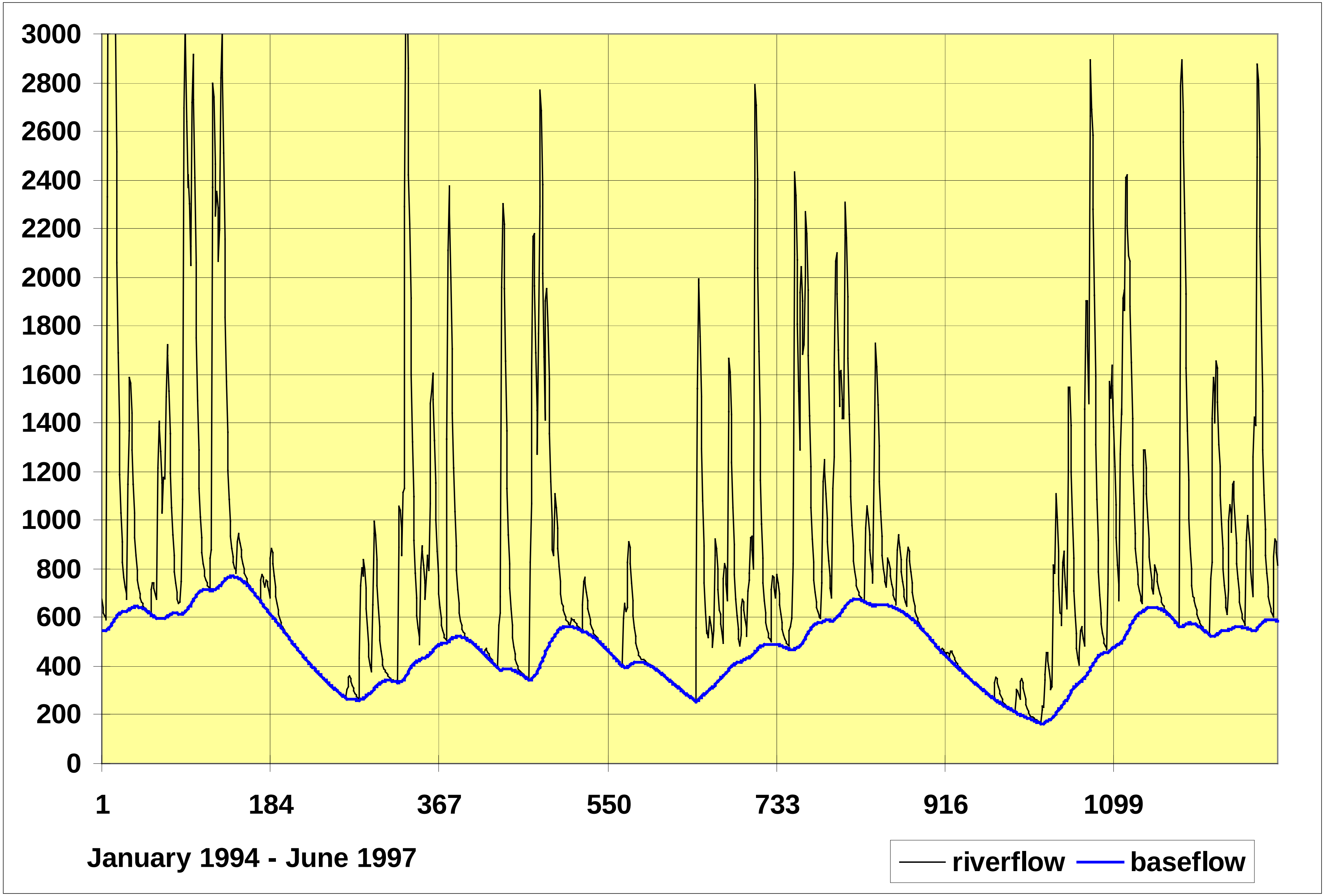


Simulated Flow in Rio Cabuyal (l/s), ONLY FOREST



January 1994 - June 1997

Simulated Flow in Rio Cabuyal (l/s), ONLY BARE SOIL



SCENARIO	Average ET (mm/yr)	Average BFI	Minimum Baseflow (l/s)	Maximum Baseflow (l/s)	Surface runoff (l/s)	Average River flow (l/s)
Actual land use	1070	0.78	206	994	157	724
Only cropped land	997	0.75	204	1032	198	804
Only dense forest	1254	0.89	98	953	58	529
Only bare soil	929	0.55	165	769	387	865
Actual, -20% rain	1025	0.85	110	749	62	409
Actual, +20% rain	1096	0.70	297	1119	320	1061

Simulated water flows for actual land use data, 3 hypothetical land uses, and 2 different precipitation regimes. Data apply to potential supply of water, i.e. before any water is extracted from streams to meet water demand.

Simulation was done using measured weather for the period January 1994 - June 1997 from the Jose Domingo farm. It should be noted that rainfall during this period was considerably lower than the long-term average in the region. The *actual, +20% rain* scenario may therefore describe the average situation better.

Base flow = slow groundwater flow that contributes to stream flow.
BFI = Base Flow Index, ratio of base flow to stream flow.

Strengths of the model (1)

- SWBM was designed for analyzing temporal and spatial variation in the overall water balance and in stream water availability in a multiple-community watershed.

- Specifically, assess the implications of spatial and temporal changes of environmental and institutional conditions.
  - land cover/land use
  - increasing water demand
  - demographic shifts within the watershed
  - climate characteristics, in particular extremes
  - alternate water extraction and allocation schemes
  - location and daily operation of dams, if any.

- <u>Key question</u>: What changes are the watershed and the water resource base sensitive to, and how is that information useful to decision makers?

Strengths of the model (2)

- All data are georeferenced and the GIS allows to easily visualize landscape responses to water and land management interventions. This make it easy for local stakeholders to relate to what's really happening in the landscape around them.

- Can provide information to help (decision makers)….

  determine critical points in watershed behavior and the state of water resources.

  develop risk indicators.

  develop water resource use and monitoring strategies.

  stimulate community discussions.

  negotiate compromises to resolve conflicts of interest about resource use.

  assess implications of alternate paths of development.

  improve the capacity of multi-institutional alliances.

Limitations of the model (1)

- The model simulates water flows…...NOT sediment loading, soil erosion, nutrients flows and vegetation growth (however, crop development stages and other land cover characteristics are available from monthly lookup tables).

- The model cannot adequately be used to estimate peak flow rates and perform storm hydrograph analysis that require analysis on a time scale < 1 day.

- Location of streams is based on topography and are the only landscape elements from which water can be extracted. Wells or separate drinking water systems are not directly considered (although they can indirectly be accounted for).

- Because of the GIS-embedded model design and its relatively slow execution, the model is unsuitable for Monte-Carlo simulations (e.g. with stochastic weather).

Limitations of the model (2)

- The model does not contain socioeconomic components. Relevant socioeconomic drivers must be “translated” into appropriate biophysical data sets that can actually be used. Likewise, output data must be “translated” into qualitative cause-effect relations that are understandable to stakeholders and policy makers.

2 examples:

Driver: The demographic trend is that population increases with 3% annually, and increasing sugarcane production/processing in the lower areas drives people to higher elevations.

For model: Need to determine likely locations of water extraction in the future, and how much water will be demanded at each location/sub-region within the watershed.

Driver: Analysis of air photos indicated that forest changed to scrub and scrub changed to pasture (J. Rubiano). If this trend continues, what is the impact on water flows by 2020?

For model: Need to determine a plausible land use pattern for the year 2020, using (cellular automata?) rule sets that describe how land conversions are likely to occur.

Use of SWBM to build common knowledge bases (1)

- Despite its user-friendly user-interface, SWBM remains a complex research model that requires special software (ArcView) and a good computer. It is not intended for large-scale distribution or for use by non-researchers.

- Because of its GIS-embedded design, linking the model to other applications (for example, in Habanero) is difficult.

- Rather, the model should be used as a stand-alone program, and results should be incorporated in the common knowledge base as lookup tables/graphs.

Use of SWBM to build common knowledge bases (2)

- **Approach**: Analysis of a limited number of plausible, explorative scenarios. The results of these analysis can be incorporated in the knowledge base.

  "Corporate Farming Scenario"

  "Rural Fortress Scenario"

  "Managed Watershed Scenario"

  "Future Desired Conditions scenario" ??

- **Challenge**: define and verify rules of change to create plausible data sets to simulate the scenarios.

  Based on historical patterns of change; vision of local people; long-term national policies??? BENEFIT from other projects.

Deliverables

- Doctoral Dissertation, main sections:
    1. "A Systems Approach to Community-based Watershed Management"
    2. "Development and Evaluation of a GIS-based, Watershed-scale, Water Balance Model"
    3. "Quantifying Current and Future Domestic, Industrial and Agricultural Water Demand in the Rio Cabuyal Watershed"
    4. "Implications of Various Paths of Development on Availability and Distribution of Water in the Rio Cabuyal Watershed"

- Watershed Simulation Model. It has a generic design so that it can potentially be used for others watersheds. Data and lookup tables that can contribute to our common knowledge base.

- **The road ahead…...what is our vision about future applicability and actual use of this and other comprehensive simulation models?**