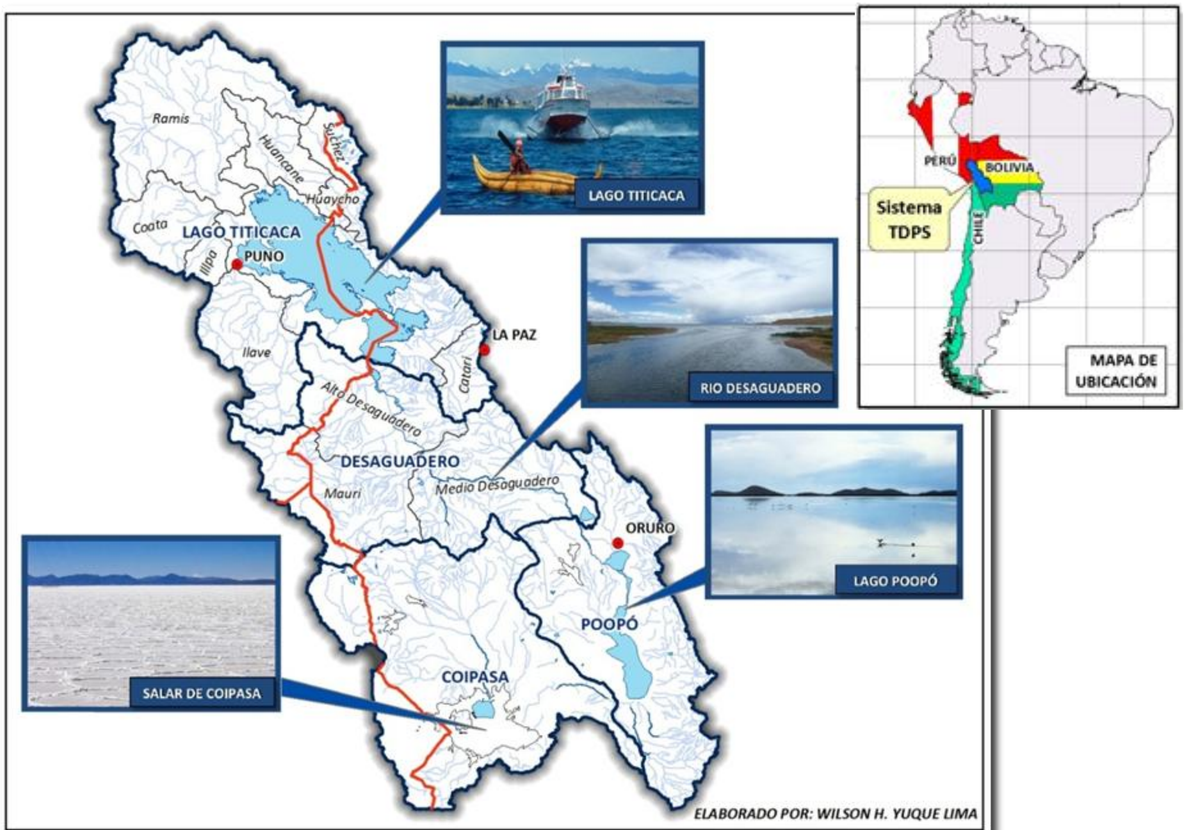
# Water resources management under climate change scenarios: Case studies in Bolivia

J. Molina Carpio, D. Espinoza, B. Gutiérrez, R. Cruz, P. Pacheco, W. Yuque, A. Uría, C. Cornejo, D. Hernández, C. Carrasco, A. Castel

CORDEX Central America and South America Training Workshop on Downscaling Techniques 2018
La Paz – Bolivia

# ADAPTING TO CLIMATE CHANGE IN COMMUNITIES FROM THE BOLIVIAN CENTRAL ALTIPLANO (2012-13)




**The TDPS system**

The northern and central parts of the endorheic South American Altiplano region are known as the TDPS system (Titicaca lake, Desaguadero River, Poopó lake and Coipasa salt pan).

The TDPS system (144 000 km²) is located between 14°- 20° S and 66.3°-71.1° W, above 3700 masl (3700-6550 masl).

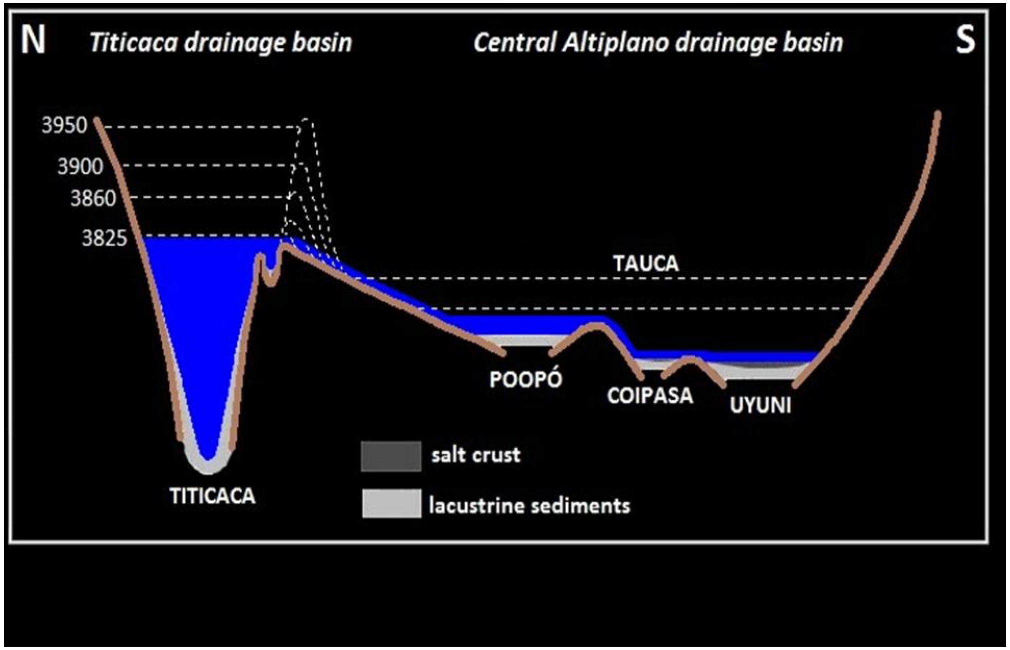
3.7 million inhabitants

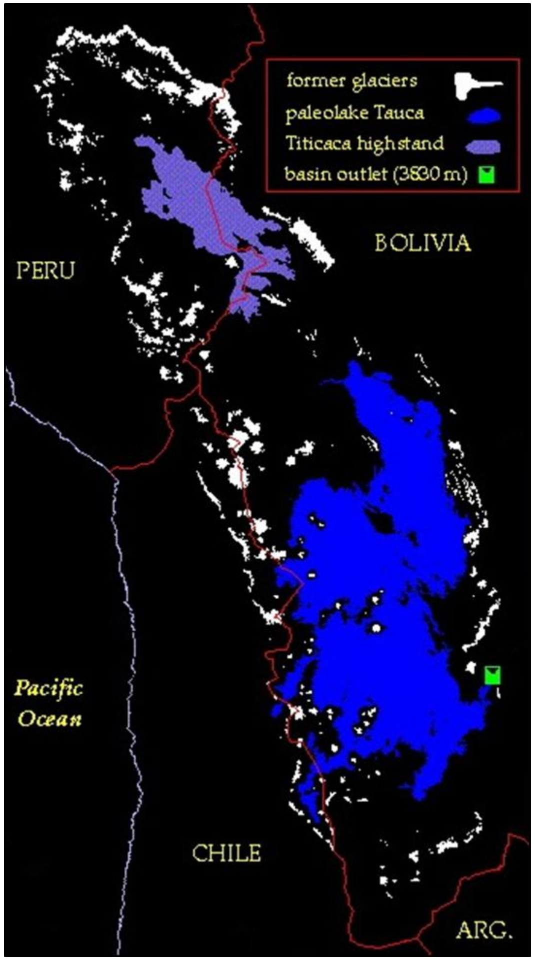
Unique ecosystem with significant endemism

Regional context

**Context:** The Altiplano is a cold semiarid region very sensitive and naturally vulnerable to climatic change. In fact, the ancient Tiwanaku civilization vanished at the end of the 12th century as a consequence of a dry period several decades long. It is considered that extensive agriculture could develop in the Altiplano only 3500 years ago at the end of the dry Holocene.

During the Quaternary period, the Altiplano alternated from a small and low level Titicaca Lake as the only water body, to a situation when most of its surface was covered by water (Tauca Lake).

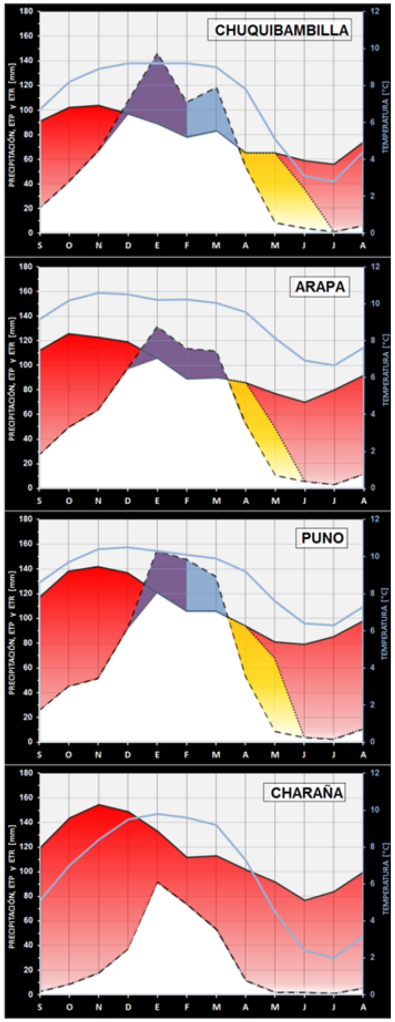


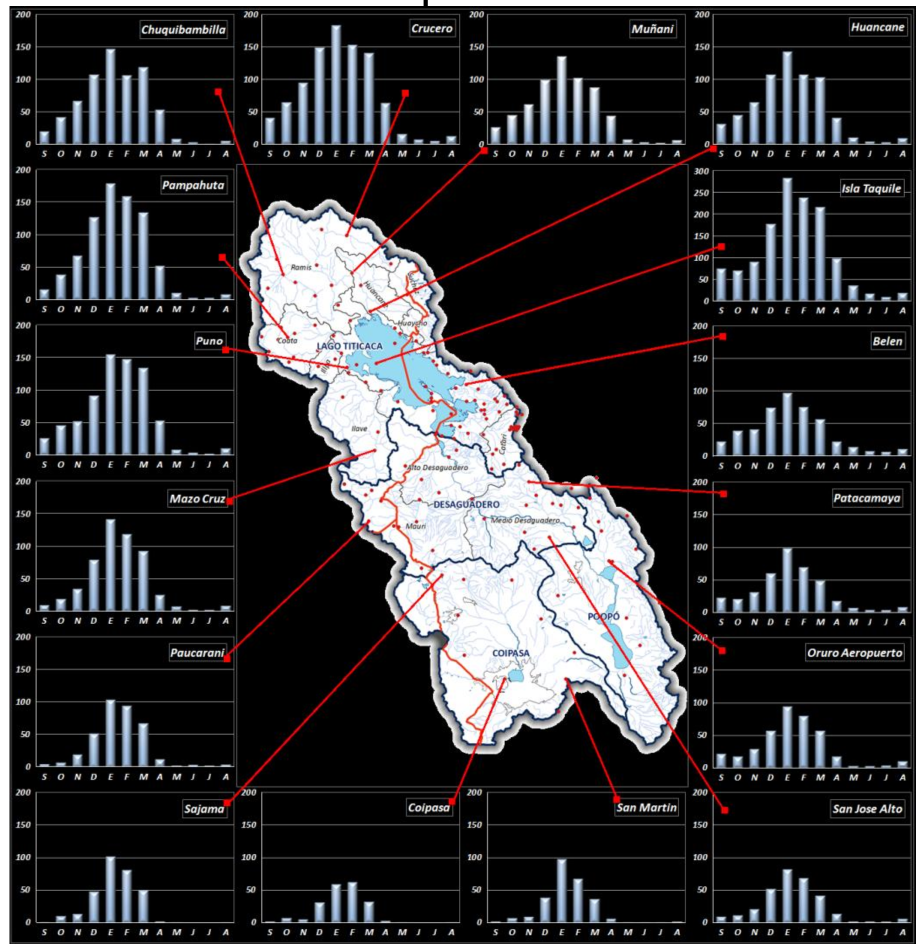
**Regional context**

The TDPS system is characterized by a south tropical rainfall regime, with a marked dry season during the austral winter and a wet season during the austral summer

PET>P 9-12 months per year




Precipitation



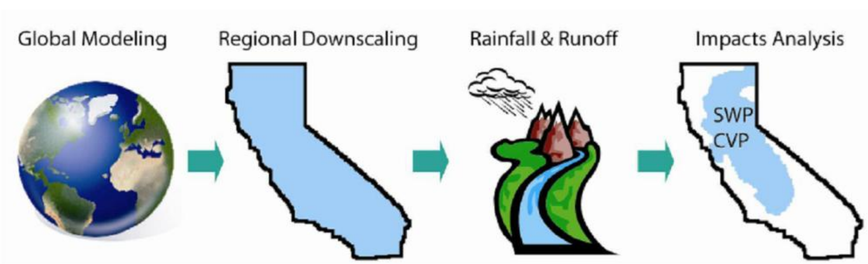

A temperature increase of 0.2-0.3° C per decade has been detected for the Altiplano (Hunziker et al. 2018) since 1980

Objectives

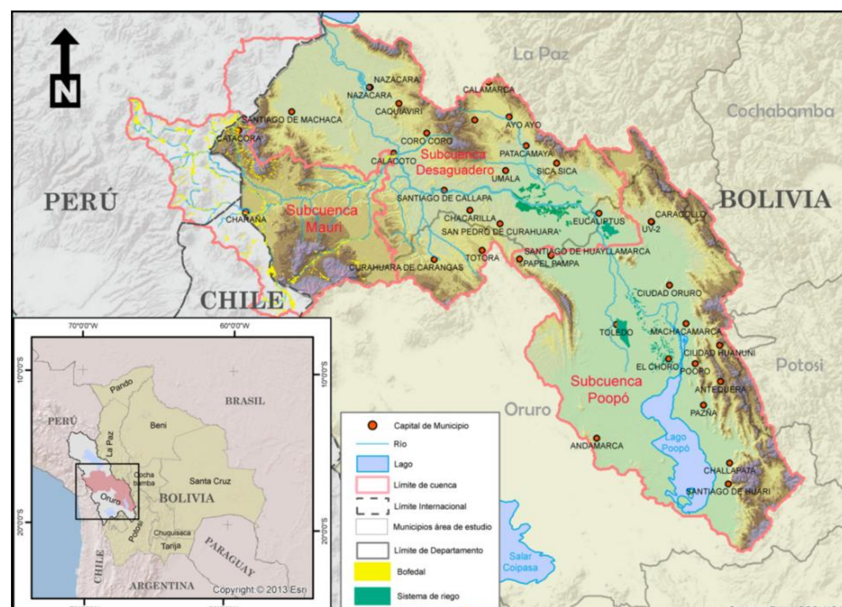
## Objective

**For the project:** To propose a regional climate change adaptation plan from a basin perspective, through previous research on natural and social issues and the participative construction of adaptation strategies on a local scale (rural communities).  This would allow public investment to be more efficient and, therefore, have better results in terms of reducing rural communities vulnerability to climate change.

**From a water resources and modelling perspective:** To establish water resources availability and water demand in the study area for different climate change and water management scenarios. Both a rainfall-runoff model (Temez) and a water resources model (Mike Basin) were used to simulate the behaviour of the water resource system under those scenarios.

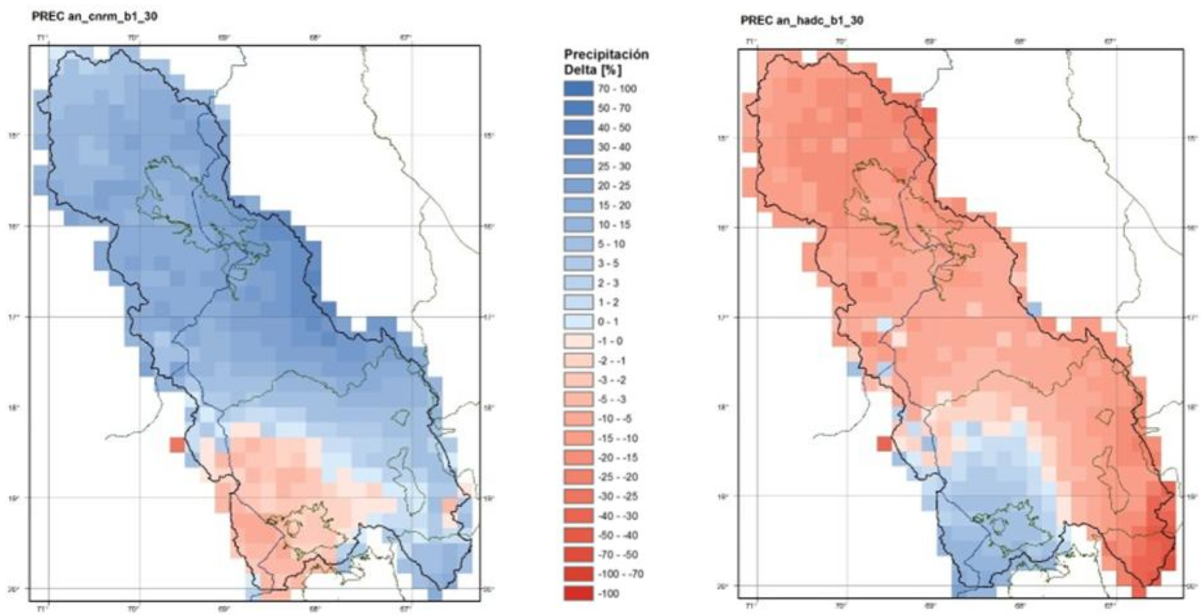



The water resources study area was restricted to the Mauri-Desaguadero River basin (31 000 km2), but climate and hydrological studies were carried out for the entire TDPS system



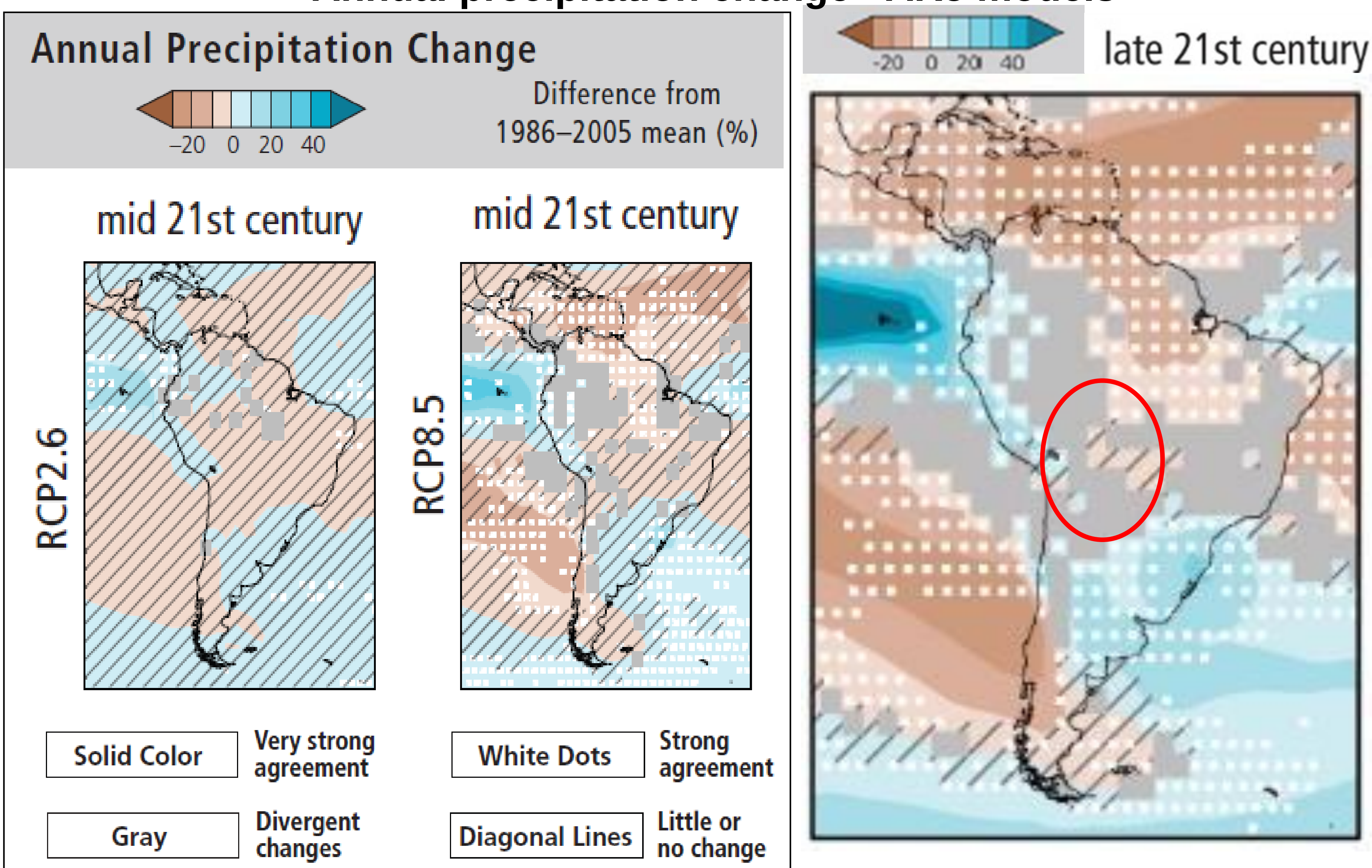
**Challenges**

- Most (>95%) of the water demand comes from **agriculture**.
- There is not water resources planning and management at the basin level, in spite of the existence of the Binational Water Authority (ALT) for the TDPS system. River flow is not regulated.
- **Data** had to be gathered from government agencies of three countries. Data collection periods and the number of working gauging stations vary a lot.
- Data provided by the National Weather Services and Government agencies is not usually checked for consistency and are not quality-controlled.
- As there were no climate modelling capabilities in Bolivia, CCAFS AR4 statistically downscaled datasets were used (http://www.ccafs-climate.org/data)
- GCM AR4 models gave **divergent** results (precipitation) for the region.



# GCM divergence and uncertainty

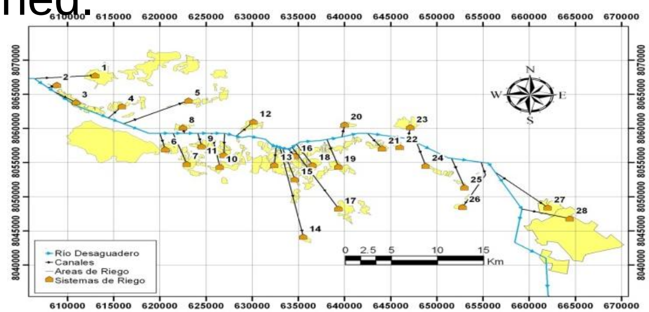
## Annual precipitation change - AR5 models



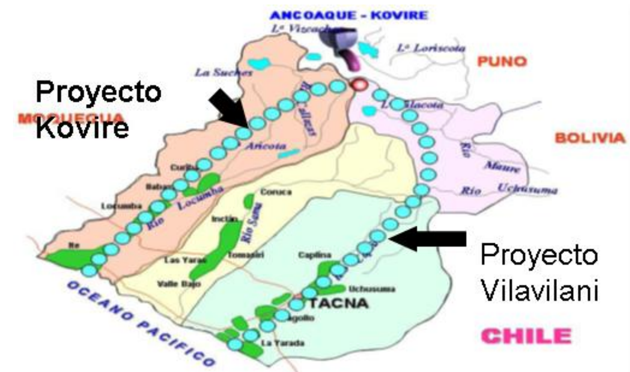
## Challenges (cont.)

Additional pressures are put on the Mauri-Desaguadero water resources:

- Several irrigation projects are under construction or planned along the Desaguadero River, thus increasing competition on water resources.
- A significant amount of water from the upper Mauri River and some of its tributaries is diverted and transferred to the Pacific coast in Peru. Water diversion has already caused serious impacts on water users and valuable ecosystems (wetlands) in Bolivia and Peru. Additional water transfer projects are under construction or planned.




Irrigation projects upstream of Chuquiña




## Dealing with challenges

- The 1960-2012 period was established as the working period for the study. Data quality was assessed with the help of multiple tools and methods. Someway reduced but more consistent hydroclimatic databases resulted from this.
- Time and effort were dedicated to describe and understand both the spatial and the temporal climate variability within the TDPS system
- It was decided to not use model ensembles, but outputs from models selected by using some “filters” (Espinoza et al. 2009) and previous studies. Six IPCC models were selected first and then two: ECHAM 5 and MIROC 3.2

Scenarios

# Scenarios

## Water use

1. Current irrigation projects along Desaguadero River in Bolivia and current water transfer to the Pacific coast in Peru
2. New irrigation projects (planned) in Bolivia
3. Additional water transfer from Mauri River basin in Peru

## Climate change

| | |
|---|---|
| -Baseline 1961-00 | -Baseline 1961-00 |
| *Miroc 3.2* | *Echam 5* |
| -A2 2030 | -A2 2030 |
| -A2 2050 | -A2 2050 |
| -B1 2030 | -B1 2030 |
| -B1 2030 | -B1 2030 |

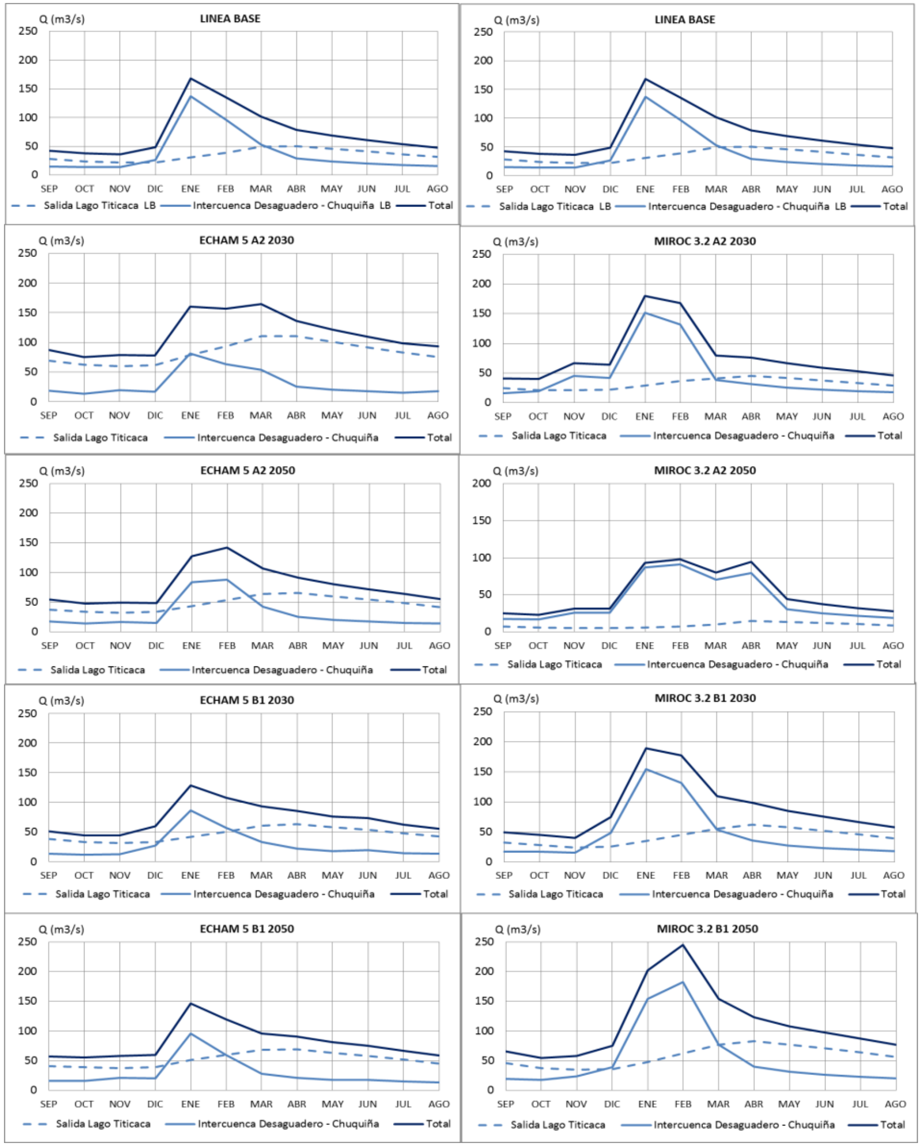
## Adaptation scenarios

1. Improved irrigation efficiency
2. Water management at the basin level

## Performance indexes

| | | | | |
|---|---|---|---|---|
| Water users: water deficit (mean, largest and duration) | Hydrology: flow duration | Ecosystems: impact on wetlands, Lake Poopo | | Food safety, health |

# Results: Runoff




Annual runoff (Desaguadero River mean discharge) increases for six out of eight CC scenarios, as related to the BL.

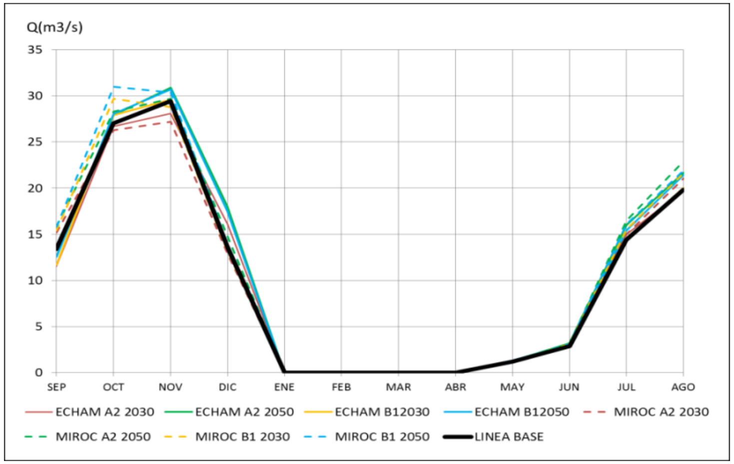
Mean annual hydrographs would be modified as a consequence of predicted seasonal precipitation changes.

A significant runoff decrease occurs for the MIROC A2 2050 scenario, mainly because of diminished Lake Titicaca water supply to the Desaguadero River.

Mean annual hydrographs Desaguadero River for BL and CC scenarios.

Carrasco & Molina (2014), Gutiérrez & Molina (2014)

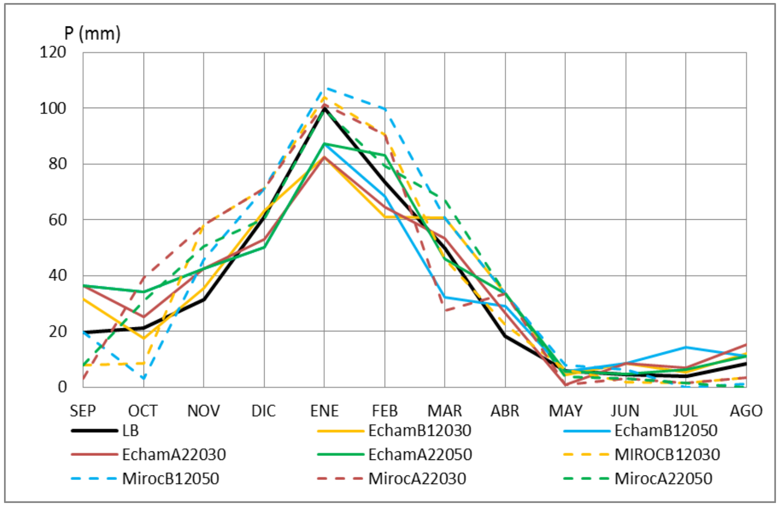
# Water demand

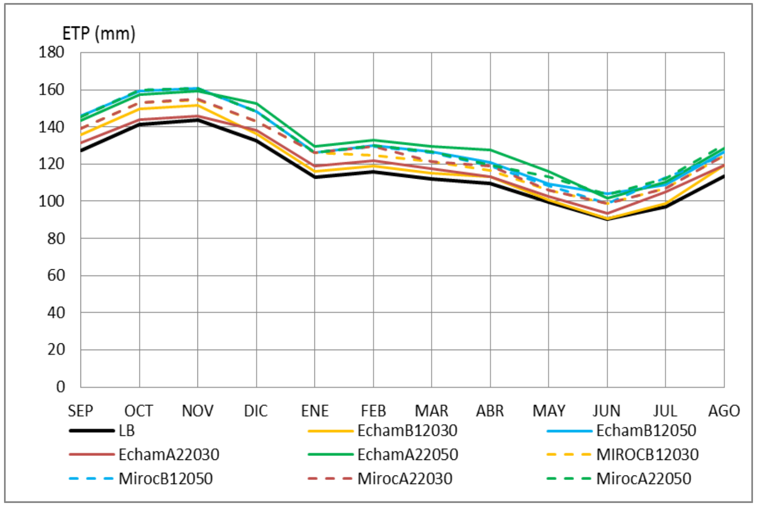



Global water demand (m3/s) of the Desaguadero River irrigation systems

Water demand of irrigation projects sligtly increases (related to BL) for 6 out of 8 scenarios. This is related to increased evapotranspiration (PET) associated to temperature increase and changes in the seasonality of precipitation.

Water demand peaks at October-November and is almost zero from January to May.



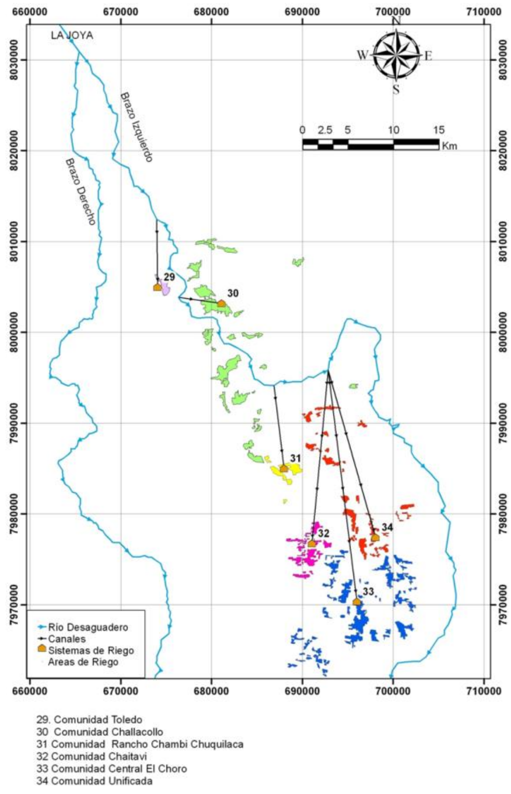

P(mm) and PET(mm) – Patacamaya station: Baseline LB, Echam 5 y Miroc 3.2 scenarios

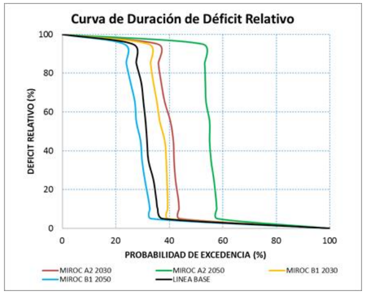
Results

- Mean **water deficit** for irrigation projects situated on the left branch of the Desaguadero River (downstream end of the system) increases for 6 out of 8 CC scenarios
- In most cases this is related with the predicted shifts/dislocations of the annual hydrograph and the increase of the water demand peak in October and November.

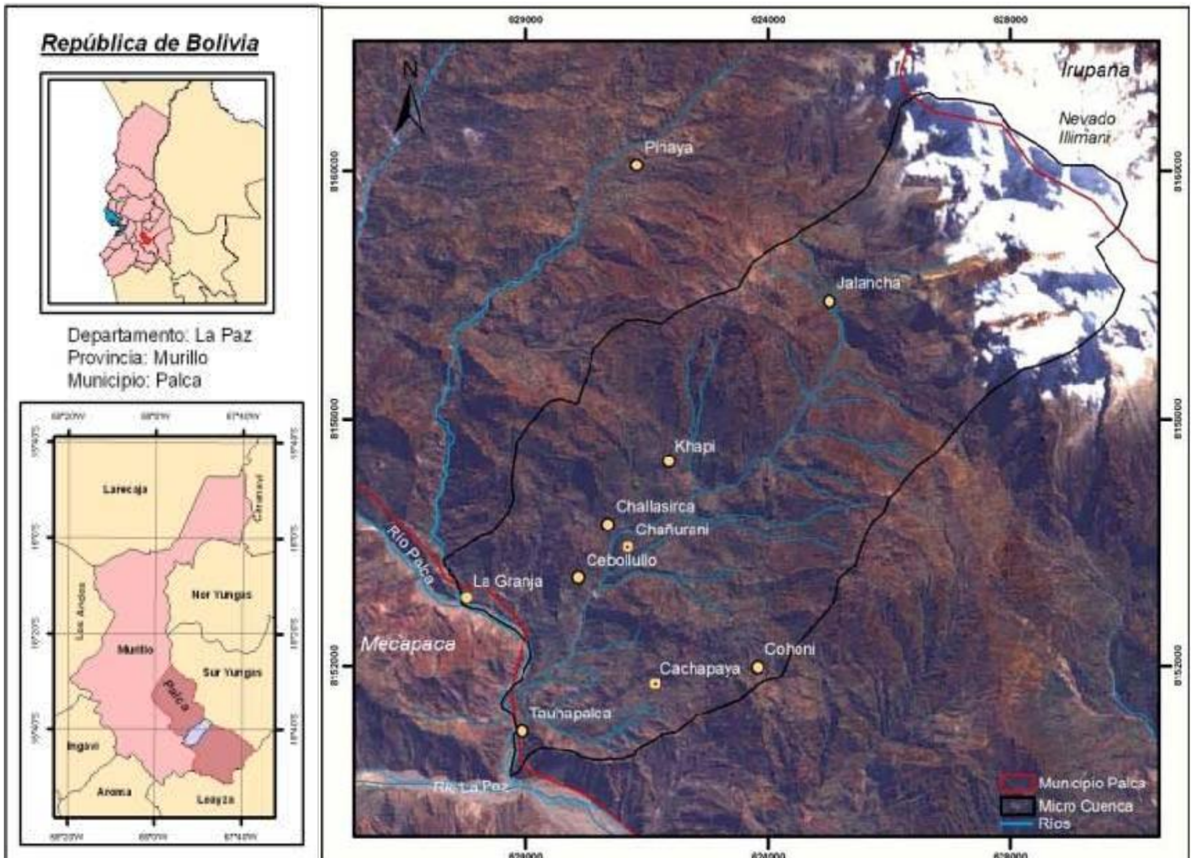
Mean water deficit (WDF) and relative RWDF (%) of Desaguadero River left branch irrigation systems

| Scenario | Water demand (m3/s) | WDF (m3/s) | RWDF (%) |
|---|---|---|---|
| **Baseline** | 5.36 | 1.92 | **35.8** |
| **Echam A2 2030** | 5.32 | 1.20 | 22.5 |
| **Echam A2 2050** | 5.74 | 2.69 | 46.9 |
| **Echam B1 2030** | 5.23 | 2.31 | 44.1 |
| **Echam B1 2050** | 5.64 | 2.30 | 40.7 |
| **Miroc A2 2030** | 5.20 | 2.51 | 48.2 |
| **Miroc A2 2050** | 5.70 | 3.78 | 66.4 |
| **Miroc B1 2030** | 5.60 | 2.47 | 44.2 |
| **Miroc B1 2050** | 5.76 | 1.95 | 33.9 |



# DEVELOPING ADAPTATION STRATEGIES TO CLIMATE CHANGE IN COMMUNITIES FROM THE CORDILLERA REAL – CENTRAL ANDES (2010-11)




**Study area**

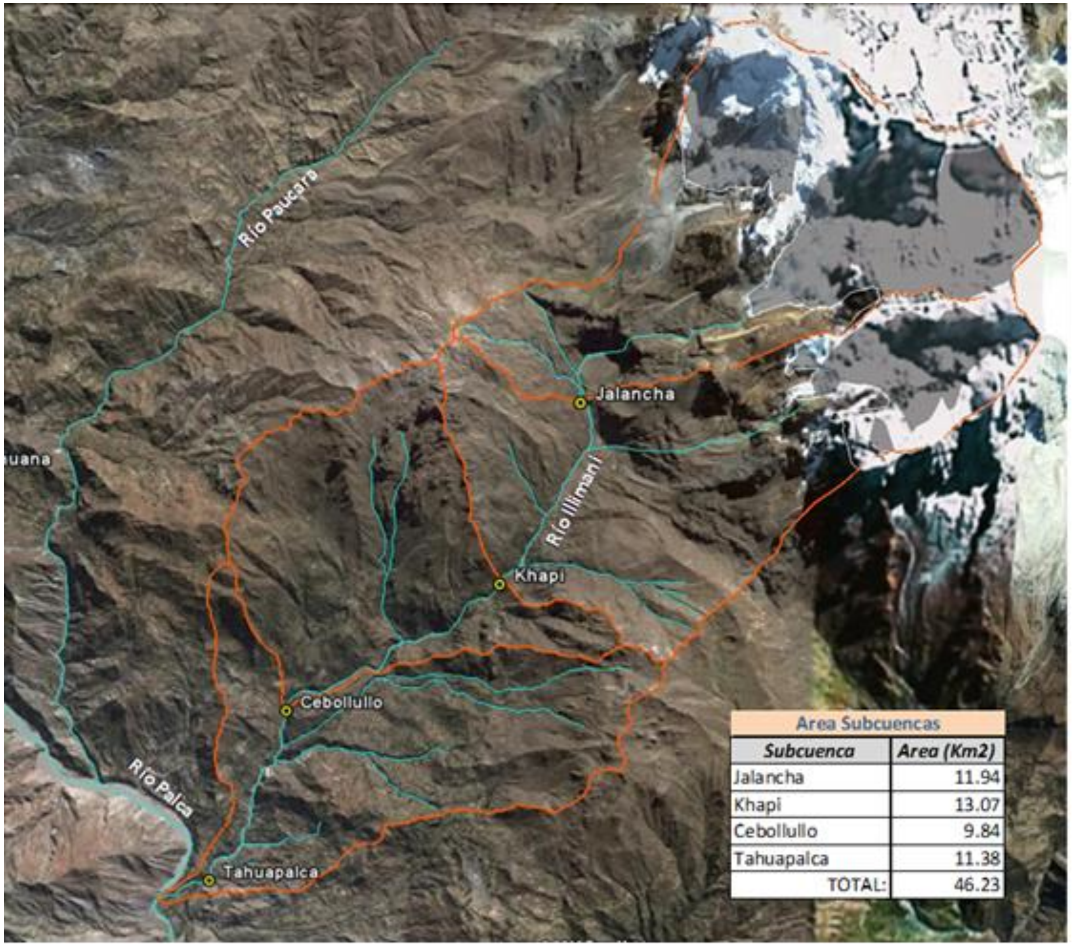
The small (59 km2 including its influence area) Sajhuaya River basin is located on the western flank of the Illimani mountain, around 16.7° S and 67.8° W, between 2500-6350 masl.

Mean temperature: 17.5 °C to -7 °C (above 6000 masl)

Precipitation: 400-800 mm/year

# Context

The presence of glaciers (8.56 km2) and numerous springs allow agriculture all the year round below 3500 masl. The area provides a significant part of the fruit (plum) and vegetables (lettuce, chard...) consumed by La Paz citizens




| Area Subcuencas | |
|---|---|
| **Subcuenca** | **Area (Km2)** |
| Jalancha | 11.94 |
| Khapi | 13.07 |
| Cebollullo | 9.84 |
| Tahuapalca | 11.38 |
| TOTAL: | 46.23 |

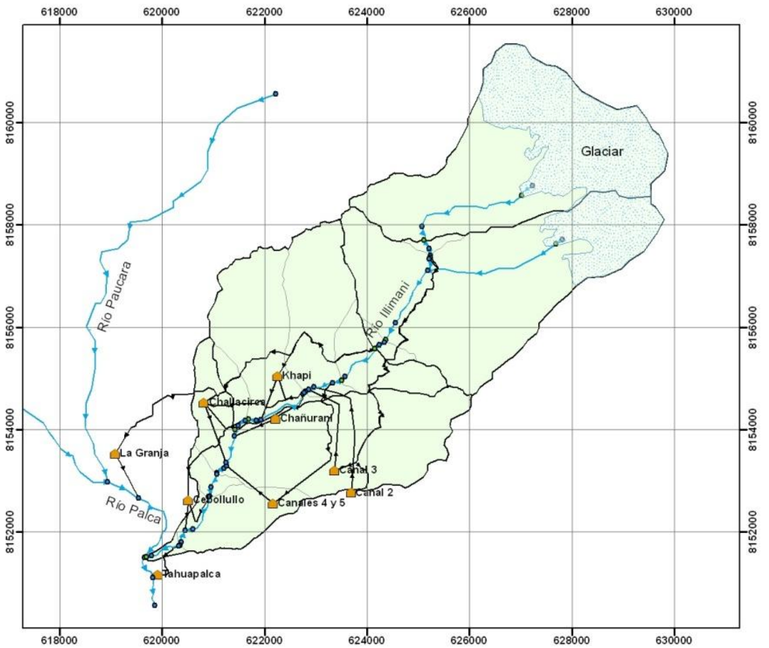
- Both river runoff and crop area are increasing because of climate change.
- Steep slopes restrict plots size: less than 2 ha of irrigated area per farmer.
- Very low irrigation efficiency
- Headwater priority for water allocation, but agreements between communities are common.
- Potential water conflicts arise from existing water rights structure and future river flow reduction.

**Project aim**

To strengthen capacity and develop a strategy for adaptation to the effects of climate change in the Sajhuaya/Illimani River basin area, promoting sustainability of agriculture and ecology systems, and adequate provision of drinking water

**From a scientific perspective:** To develop methods and tools that enable their replicability in conditions of scarce information in Andean basins.

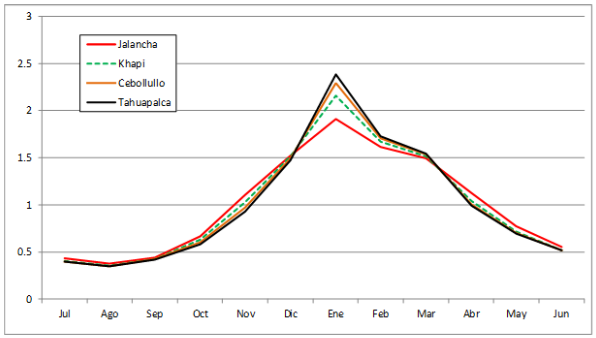
A degree-day model for the glaciated sub-watershed, a rainfall-runoff model (CHAC) for the rest and a water resources model (Mike Basin) were used to simulate the behaviour of the hydro system under future climate scenarios.

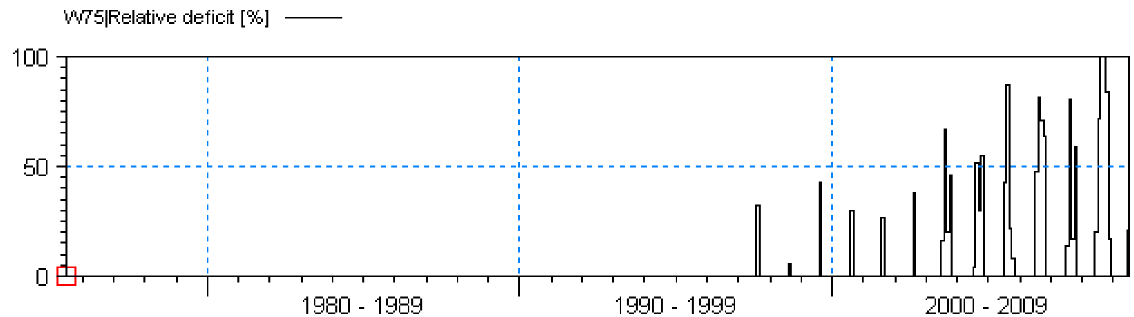



Scheme of the water system.
Water users = communities

## Baseline scenario 1979-2009

Glaciers reduce annual hydrograph amplitude and shifts minimum flow to August. Increasing river diversion translated in increasing water deficit for downstream users since the 90s




Relative deficit for Canal 3 water users, 1979-2009

## Climate change scenarios

- Most GCM AR4 models predicted a slight increase in precipitation and significant temperature changes by 2050: from +1.9 °C (B1) to +2.8 °C (A1)
- Several CC scenarios resulted from GCM models selected (CNRM) and trend analyses of climate data.

## Climate change (cont.)

But the critical scenario (RGE) arised from a likely runoff decrease as a consequence of glacier shrinking and the related loss of “reservoir effect”.

http://www.tandfonline.com/loi/thsj20

**Avenir des ressources en eau glaciaire de la Cordillère Blanche / On the future of the water resources from glacier melting in the Cordillera Blanca, Peru**

Bernard Pouyaud, Marco Zapata, Jorge Yerren, Jesus Gomez, Gabriela Rosas, Wilson Suarez & Pierre Ribstein

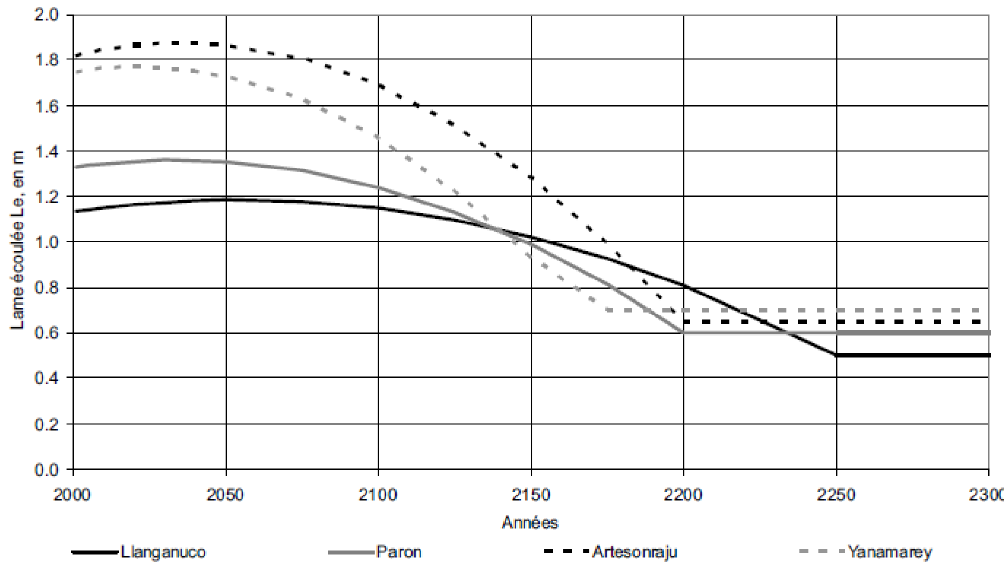
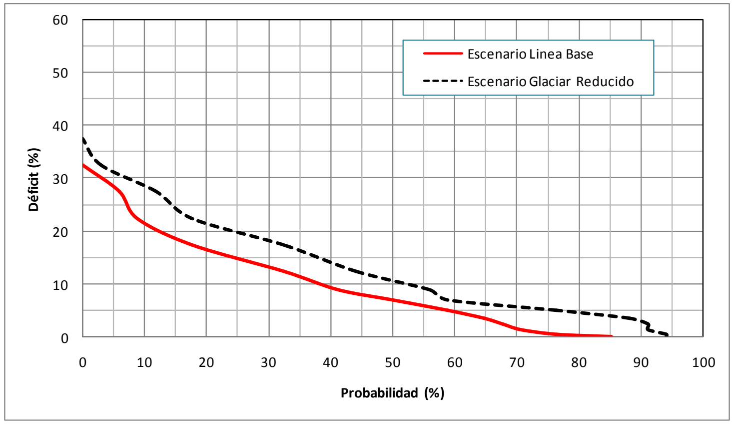
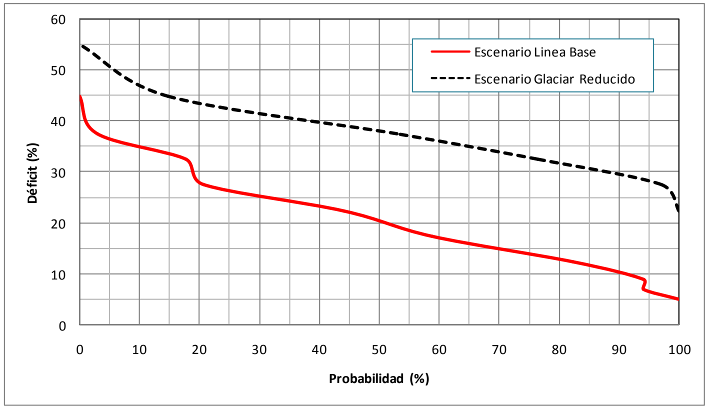



Fig. 11 Résultats de la simulation de l’évolution jusqu’à l’année 2400 de la lame écoulée $L_e$ pour quatre bassins versants de la Cordillère Blanche: Llanganuco, Parón, Artesonraju et Yanamarey.

Unfortunately at that time there was not adequate capacity in Bolivia to simulate the dynamics of glacier accumulation and meltwater contribution to the outflow from each glaciated sub-watershed. Thus the RGE scenario had to be described as a new “steady-state” one, with smaller glacier area and higher equilibrium line.

# Results: RGE scenario




Duration curves of relative deficit (%), Tahuapalca (left) and Canal 3 (right) irrigation systems

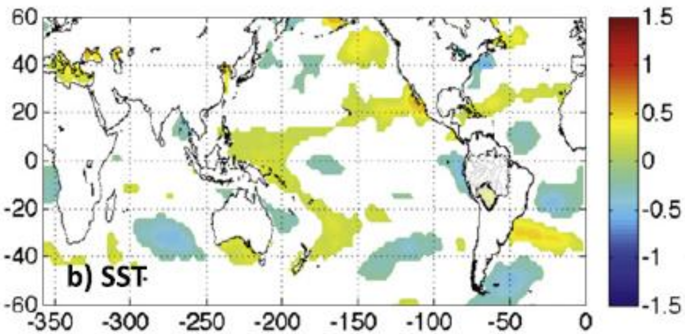
- Glacier shrinking deserves the “critical” scenario characterization in the long term. Further studies should be carried out on this topic.
- Several conclusions and recommendations on scientific (i.e. on the need to develop glacier hydrology in Bolivia) and water management topics were developed in the study (report available on https://www.researchgate.net/publication/316524955_Modelado_del_uso_y_asignacion_del_agua_en_la_cuenca_del_rio_Illimani_Informe_Final_Modelling_water_use_and_allocation_in_the_Sajhuaya-Illimani_River_basin
- Several projects were designed and built on field with the aim of improving water management at the community level.

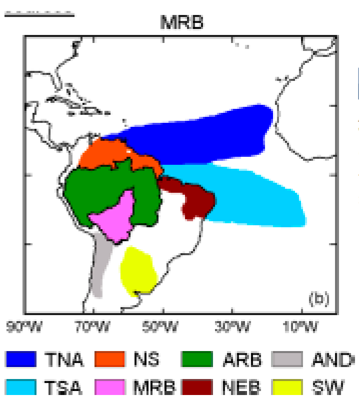
# Is spatio-temporal variability related with GCM uncertainty?

## Precipitation variability: Tropical Central Andes and southwestern Amazon

**The extreme 2014 flood in south-western Amazon basin: the role of tropical-subtropical South Atlantic SST gradient**

Jhan Carlo Espinoza[1], José Antonio Marengo[2], Josyane Ronchail[3], Jorge Molina Carpio[4], Luís Noriega Flores[5] and Jean Loup Guyot[6]




water 2018 MDPI

*Article*

The Atmospheric Branch of the Hydrological Cycle over the Negro and Madeira River Basins in the Amazon Region

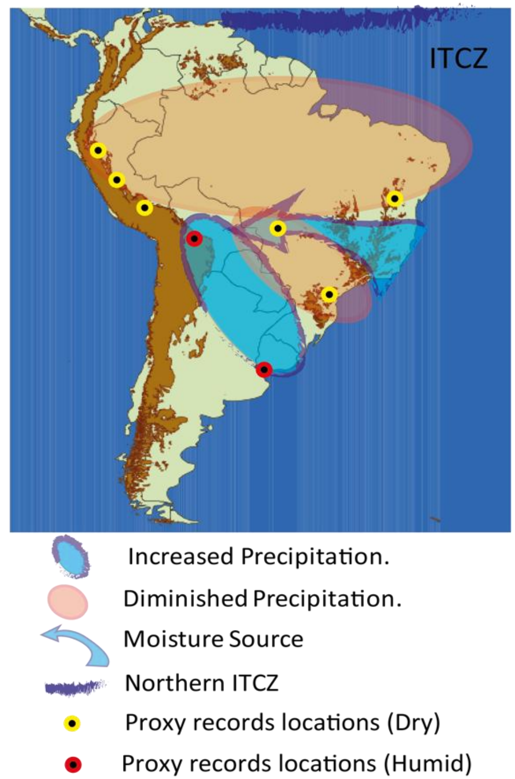
Rogert Sori[1,*], José A. Marengo[2], Raquel Nieto[1], Anita Drumond[1] and Luis Gimeno[1]

Moisture sources
Madeira basin MRB

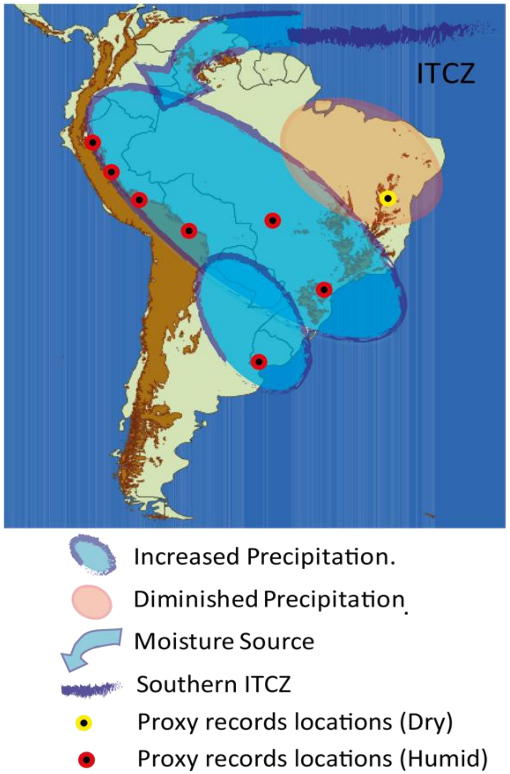
Precipitation changes over the eastern Bolivian Andes inferred from speleothem ($\delta^{18}$O) records for the last 1400 years 2018

James Apaéstegui[a,b,*], Francisco William Cruz[c], Mathias Vuille[d], Jens Fohlmeister[e,f],

**MCA Scenario**




**LIA Scenario**




- Relative complex precipitation pattern and variability, in the short and long term
- Tropical North (TNA) and South (TSA) Atlantic as ocean moist sources.
- The importance of the tropical Atlantic (North and South) and south subtropical Atlantic and the teleconnections with the Equatorial Pacific and western Pacific-Indian oceans

# Uncertainty and Robust Decision Making (RDM)

**Climate Scientist perspective**

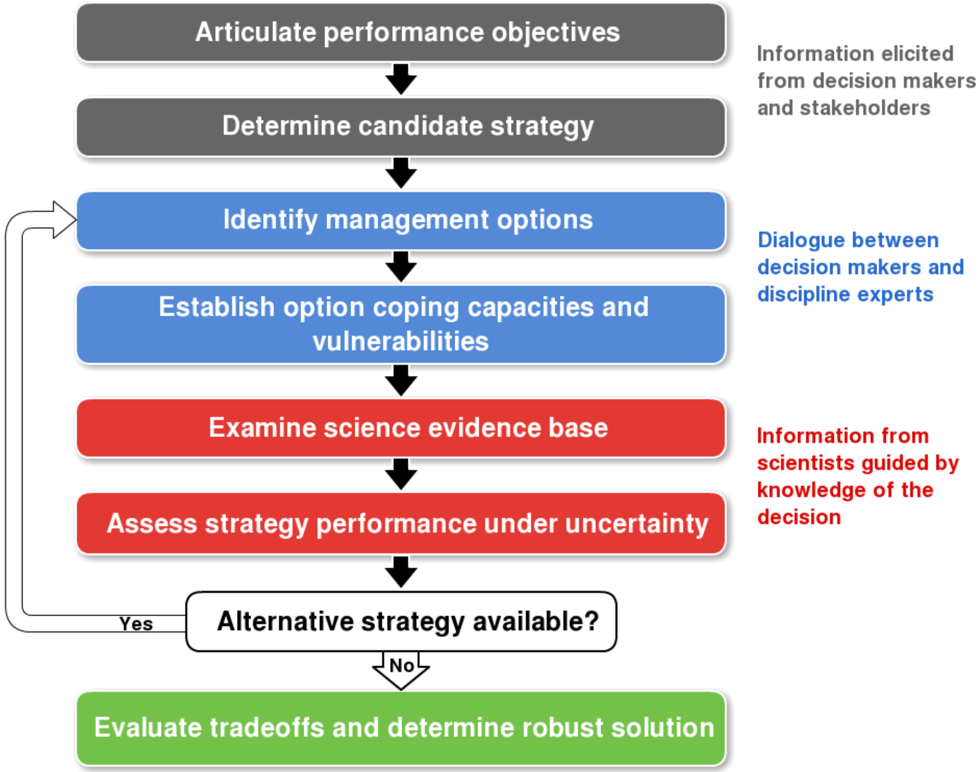
- Can we quantify the full extent of climate-related uncertainties?
- How far can we theoretically reduce uncertainties?
- How far can we realistically reduce uncertainties?

**"Water user" perspective**

- Do we need reduced uncertainty to determine meaningful output from impacts models?
- Do we need reduced uncertainty to make informed decisions?
- What level of uncertainty can we tolerate?

**What are the consequences of not exploring uncertainty?**

## The Heuristic RDM approach




Daron (2014) Challenges in using a Robust Decision Making approach to guide climate change adaptation in South Africa, *Climatic Change.*

*"Climate uncertainties are not the only important uncertainties in climate change decisions; often they can be relatively unimportant!"*

## Some considerations

- Hydroclimatic variability is (probably) a source of uncertainty in the Central Andes
- Understanding hydroclimatology, and having the capacity to model it, is crucial in Andean tropical mountains as part of efforts to plan and manage water resources. The challenge in this region is to be able to simulate the hydrology with scarce meteorological and hydrological data and with high spatio-*temporal* variability. (Condom et al. 2012)
- The effects of climate change and other stressors can be captured in an analytical framework that will allow key actors to explore different management strategies as part of the development of watershed plans .
- A basin-centric governance approach with stakeholders participation is required, with models that respond to their needs for information and allow exploring management options that can support their contribution to the reduction of water-related conflicts (Condom et al. 2012).
- Water management actions/strategies are climate adaptation ones.


Thanks
GRACIAS !