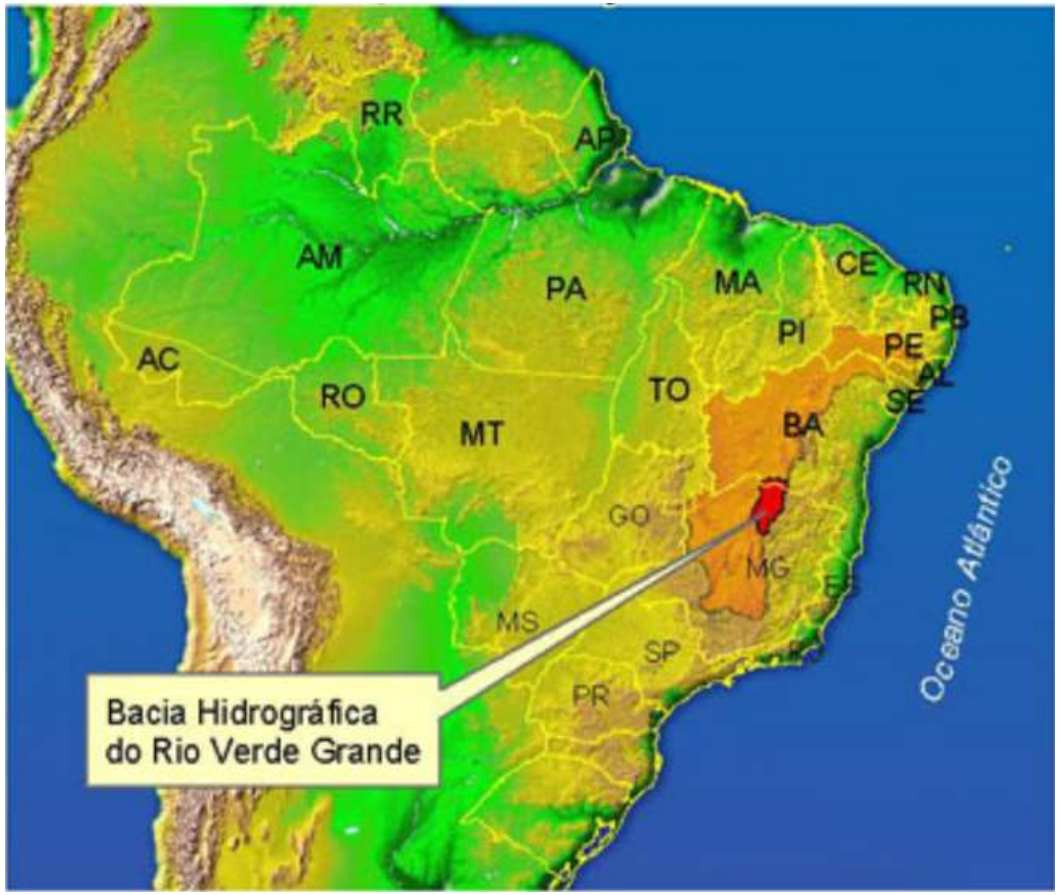
SUSTAINABILITY INDEX AND INTEGRATED WATER RESOURCES MANAGEMENT OF THE RIO VERDE GRANDE BASIN IN BRAZIL

Edson de Oliveira Vieira
Instituto de Ciências Agrárias/UFMG

Samuel Sandoval Solis
Land, Air and Water Resources/Univ. of California - Davis

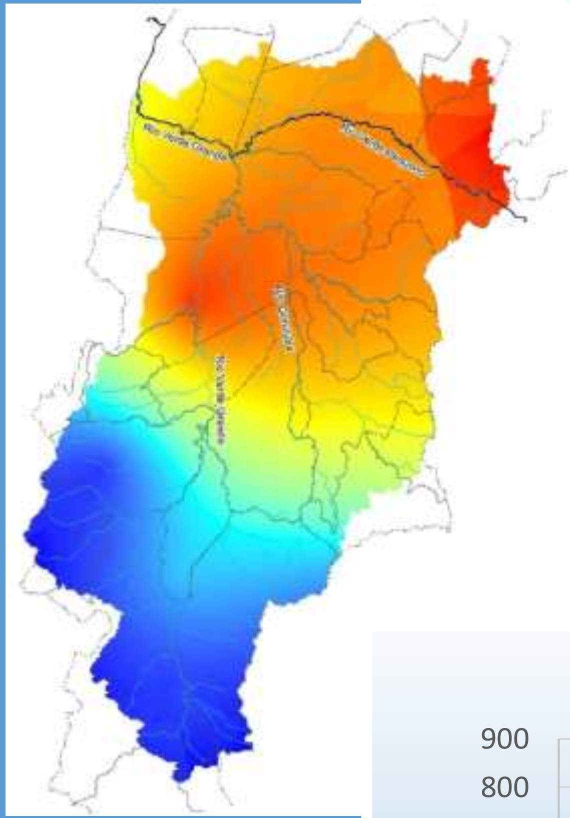
1. Introduction

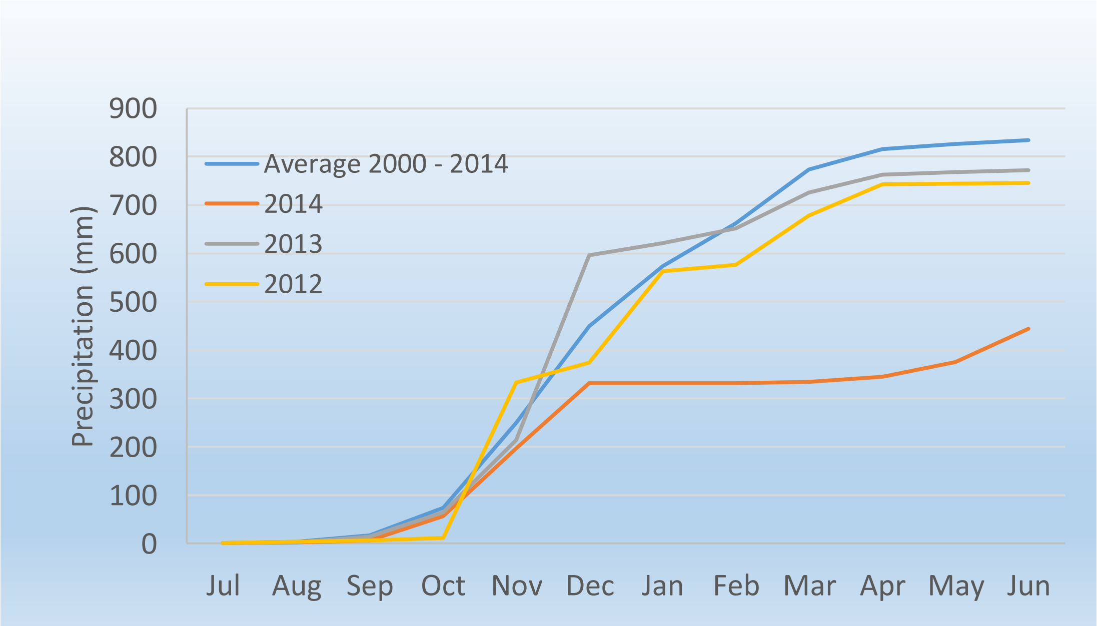
- Verde Grande River Basin
- Several problems
  - High variability in time and space of water resources
  - Activities that demand a lot of water
  - There is almost no infrastructure for WR



1. Introduction

- Droughts
- PET ≈ 2000 mm/year
- Precip ≈ 830 mm/year





2. Background

- Verde Grande Basin stands out for:
  - Agricultural production (irrigated areas)
  - Livestock
  - Expansion of Population (Urban)
  - Industry (only AVG Subbasin)
- Water Conflicts have been recorded since 1980’s

2. Background

- In 2003, the creation of the Verde Grande river basin Committee (CBHVG – Comitê da Bacia Hidrográfica do Verde Grande) was approved by the National Water Resources Council (CNRH – Conselho Nacional de Recursos Hídricos)

- In 2011, "Water Resources Plan of the Verde Grande river basin (PRH Verde Grande)" was approved, which aimed to articulate the instruments of the National Water Resources Policy (PNRH)

2. Background

In the Water Plan of Verde Grande, three scenarios were envisaged for policy implementation:

- Interventions that were already planned or underway in relation to the increase in water supply - considered in the Trend Scenario.
- And Normative 1 and 2 in which performance of water management is present with successive efficiencies to increase both the water supply and efficient water use

2. Background

- However, in Verde Grande Basin, there are no studies that allow us to evaluate and compare the sustainability of different actions or methods of water management in different scenarios.

3. Sustainability Index

- Sustainable water resource systems are those designed and managed to contribute fully to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity (Loucks, 1997)

LOUCKS, D. P. Quantifying trends in system sustainability. Hydrology Science Journal. vol . 42,n.4, 1997, p. 513-530.

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3. Sustainability Index

- Large emphasis has been given to the adaptability of water resources and to measures that reduce the vulnerability of these systems for a proposed future scenario (Ceron et al, 2011; Sandoval-Solis et al, 2011; Ceron et al, 2012; Cortés et al 2012).
- The vulnerability is the magnitude of an adverse impact on a system.

Cerón,W. L.; Trujillo, A. R ; Escobar, Y. C. Modelo para el monitoreo y seguimiento de indicadores de sostenibilidad del recurso hídrico em el sector agrícola. Cuadernos de Geografía, Vol.20, n.2, 2011, p.77-89.

Cerón,W. L.; Trujillo, A. R ; Escobar, Y. C. Aplicacion del índice de sostenibilidad del recurso hídrico em la agricultura (ISRHA) para definir estrategias tecnológicas sostenibles em la microcuenca Centella. Ingenieria y Desarrollo. Universidad del Norte. Vol.30, n.2, 2012, p.160-181.

Cortés, A. E.; Oyarzún, R. ; Kretschmer, N. ; Chaves, H. ; Soto, G. ; Soto, M. ; Amézaga, J. ; Oyarzún, J. ; Rötting, T. ; Señoret, M. ; Maturana, H. Application of the Watershed Sustainability Index to the Elqui river basin, North-Central Chile. Obras y Proyectos, vol.12, 2012, p.57-69.

SANDOVAL-SOLIS, S.; McKinney, D. C.; Loucks, D. P. Sustainability index for water resources planning and management. Journal of water resources planning and management. vol. 137, n.5, Sep/Out. 2011. p381-390.

3. Sustainability Index

- Sustainability index (SI) of water resources allows the user to evaluate and compare different methods of management and water uses with regard to its sustainability.

- SI takes into account measures of Reliability, Vulnerability and Resilience

3. Sustainability Index

- Thus, given the increasing conflicts between water users in the Verde Grande Basin, it becomes necessary to evaluate and compare the many actions proposed in the Water Plan using the sustainability index, taking into account the many water users and future scenarios

4. Objectives

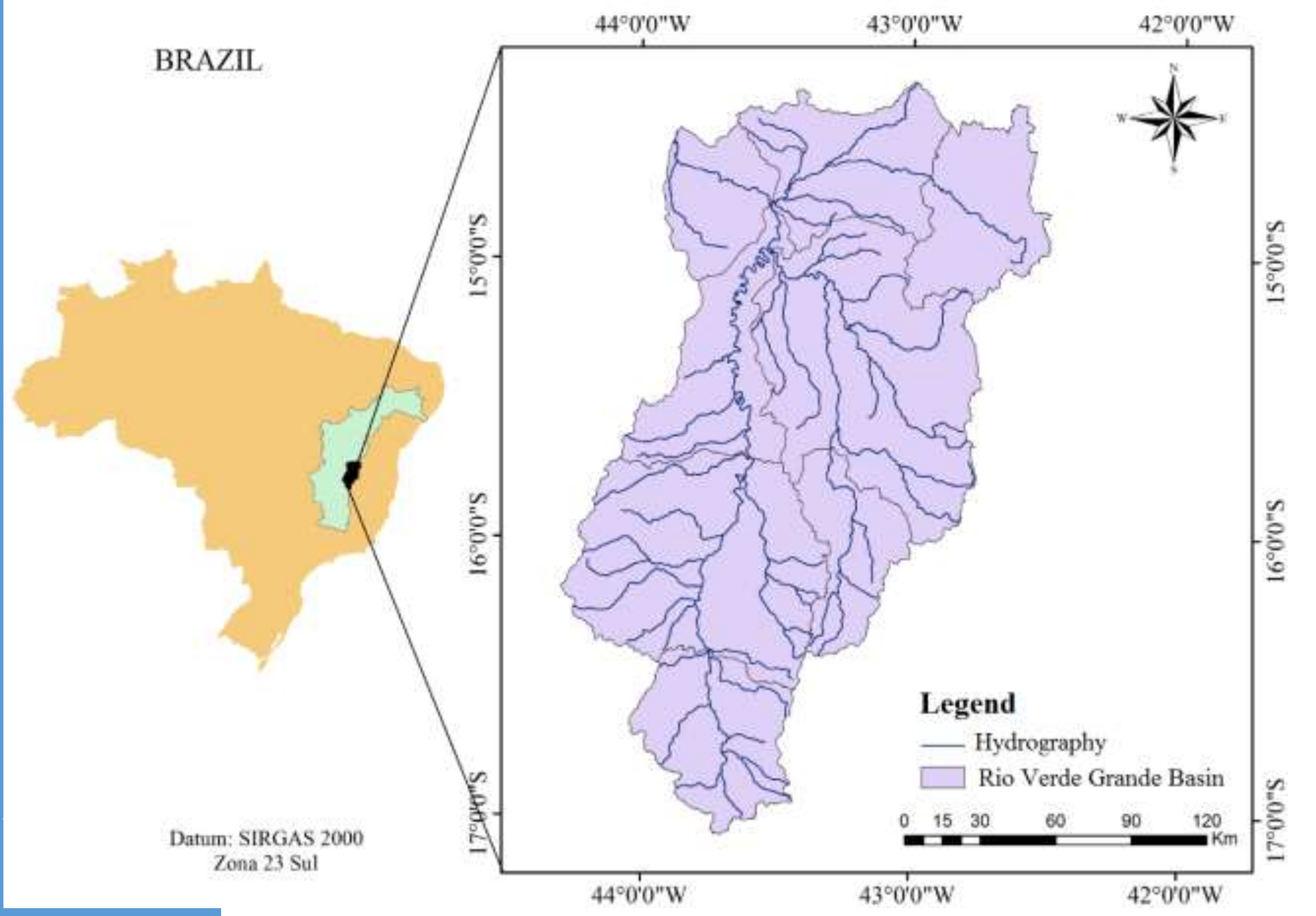
Evaluate water management of Verde Grande River Basin, Minas Gerais State, Brazil:

- 1. Evaluate the current and future water management scenarios
- 2. Calculate the Sustainability Index (SI) of water resources;
- 3. Evaluate and compare water demand and water supply for activities of the Water Resources Plan of Verde Grande basin in three scenarios of water availability.

5. Methodology

- **Characterization of the study area**

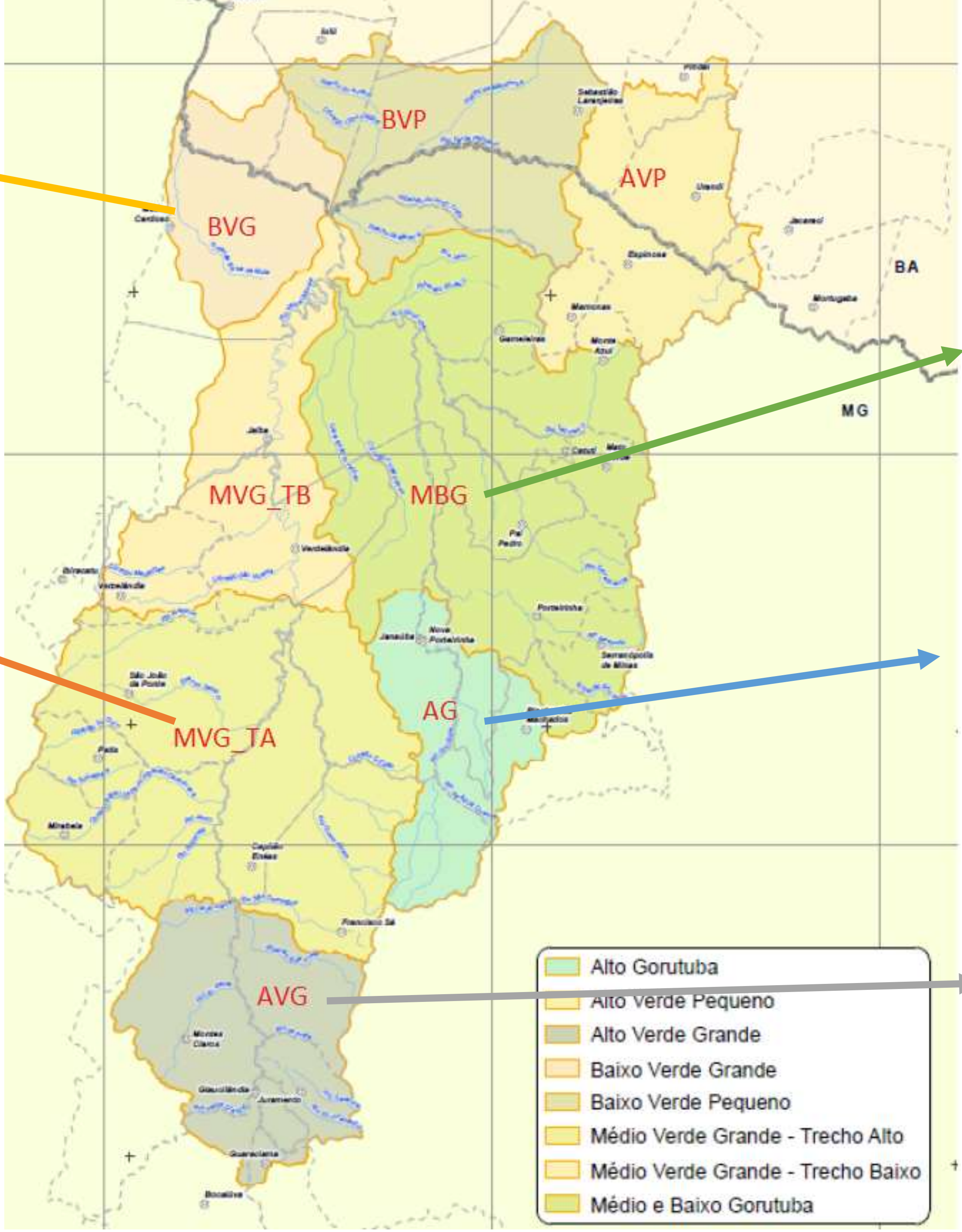
  - Area = 31,410 km²
  - Main river (VG) = 577 km
  - 768,000 inhabitants at 2011, (ANA, 2011)
  - 8 Subbasins (Water Plan)



ANA, Agência Nacional das Águas. Plano dos Recursos Hídricos da Bacia Hidrográfica do Rio Relatório síntese. Brasília, 2011. 182p.

- Area 1,934 Km²,
- Smallest subbasin of VGB
- Smallest population of whole basin
- Largest irrigated area with more than 21,000 ha irrigated

Area 7,107 Km²,
- Largest cattle of VGB

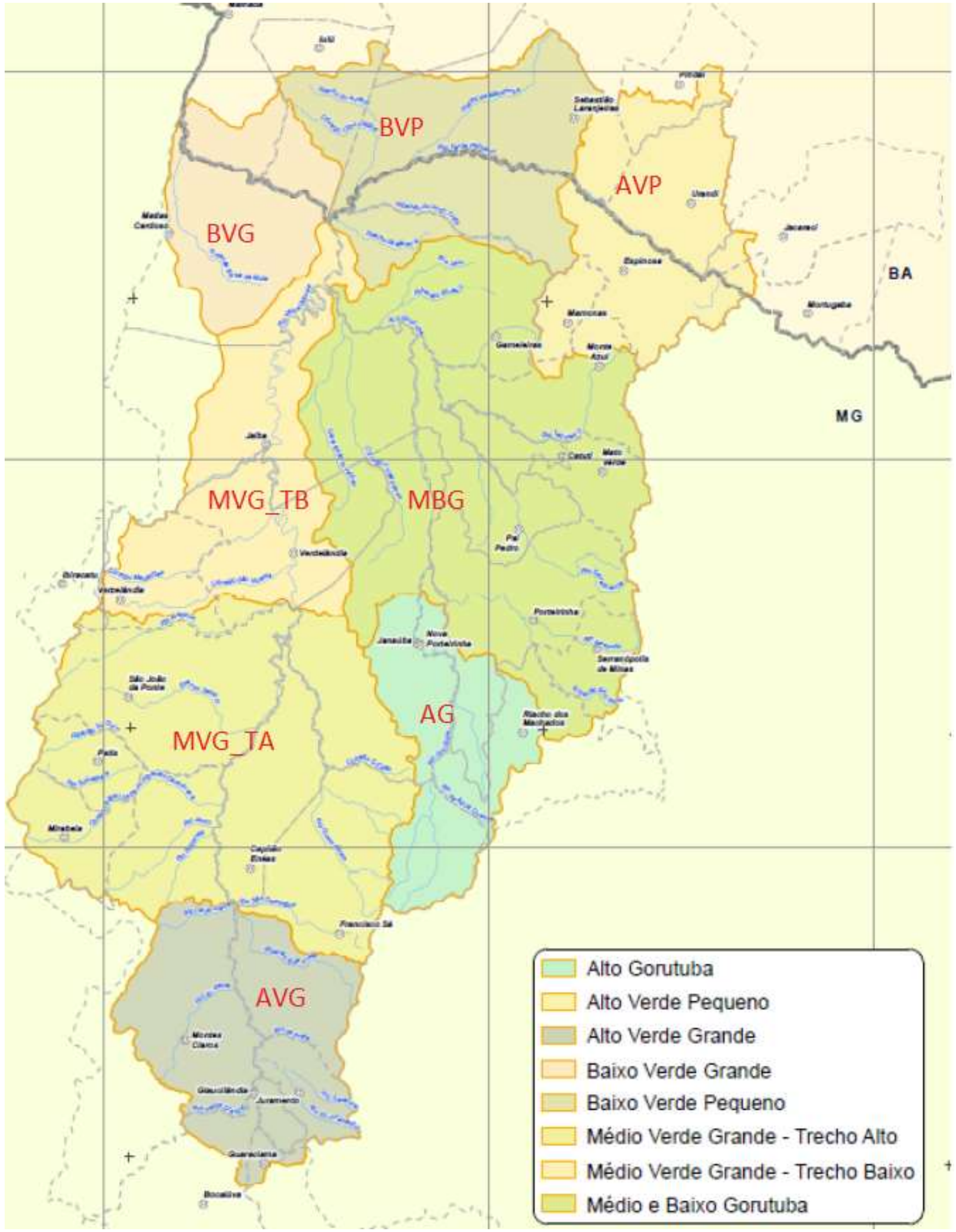


- Area is 7,715 Km²,
- Largest Subbasin of VGB

Area is 2,113 Km²,
- Largest reservoir of VGB
- Second largest population of the whole basin

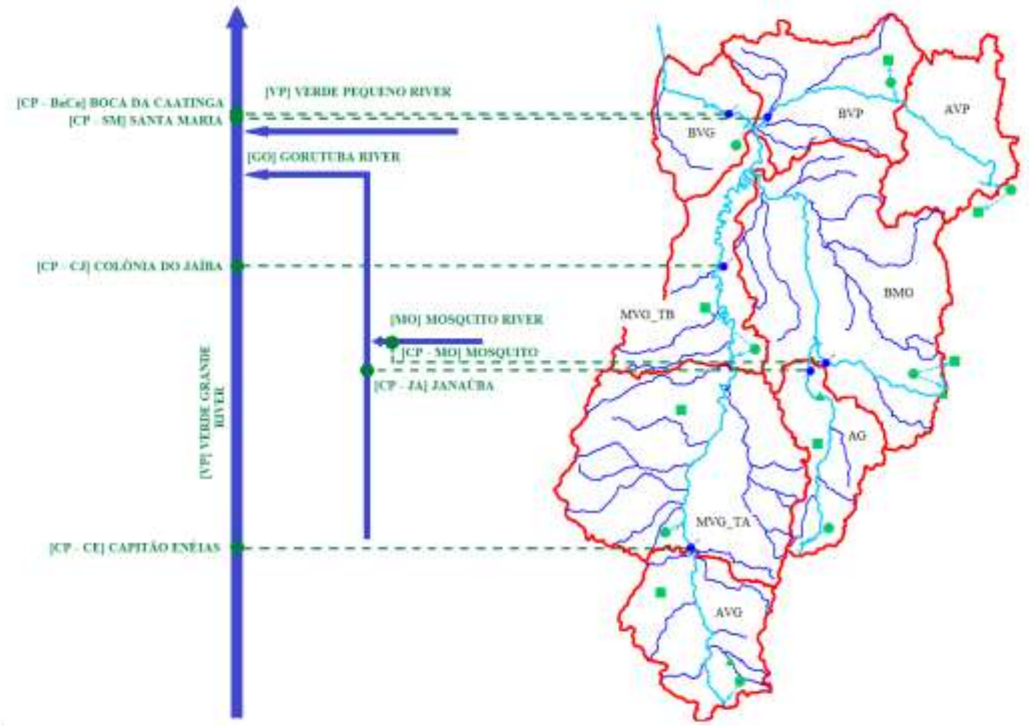
- Area 3,098 Km²,
- Highest stretches of VGB,
- Concentrates about 48% of all population and the almost all industries of the VGB

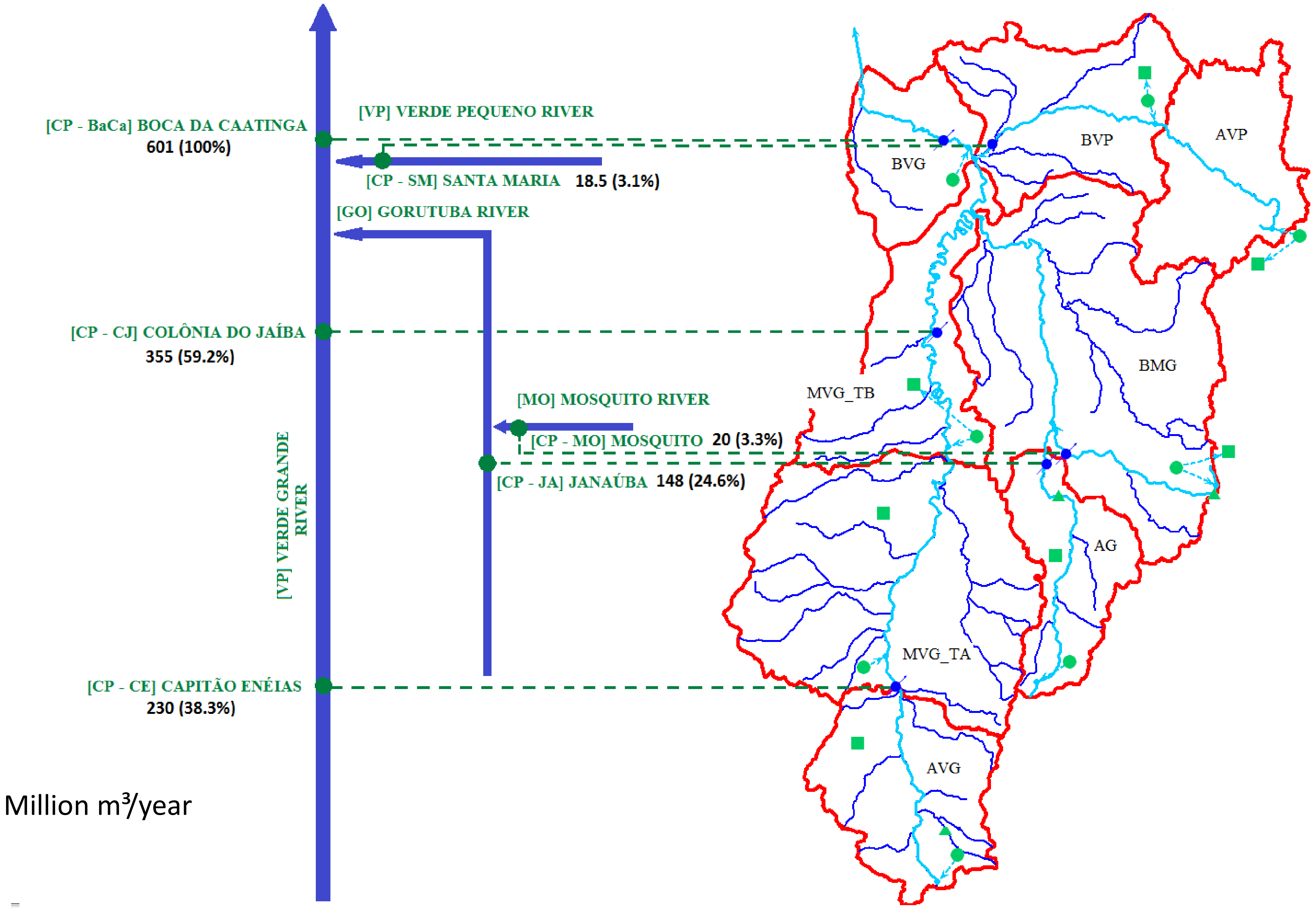
Water Demand by Subbasin



Geography of the model

- 6 Control points
  - 3 in Verde Grande River
  - 1 in Gorutuba River
  - 1 in Mosquito River
  - 1 in Verde Pequeno River




[VP] VERDE PEQUENO RIVER
[CP - BaCa] BOCA DA CAATINGA
601 (100%)
[CP - SM] SANTA MARIA 18.5 (3.1%)
[GO] GORUTUBA RIVER
[CP - CJ] COLÔNIA DO JAÍBA
355 (59.2%)
[MO] MOSQUITO RIVER
[CP - MO] MOSQUITO 20 (3.3%)
[CP - JA] JANAÚBA 148 (24.6%)
[VP] VERDE GRANDE RIVER
[CP - CE] CAPITÃO ENÉIAS
230 (38.3%)
Million m³/year
BVG
BVP
AVP
BMG
MVG_TB
AG
MVG_TA
AVG

Performance Criteria

1. **Reliability** (Frequency of sucess)

$$Rel^i = \frac{No. of\ times\ D_t^i = 0}{n}$$

2. **Resilience** (Quickness of recovery)

$$Res^i = \frac{No. times\ D_t^i = 0\ follows\ D_t^i > 0}{No. times\ D_t^i > 0\ ocorred}$$

3. **Vulnerability** (Severity of deficits)

$$Vul^i = \frac{\left(\frac{\sum_{t=0}^{t=n} D_t^i}{No.\ of\ times\ D_t^i > 0\ ocorred}\right)}{X_{Target}^i}$$

Deficits

$$D_t^i = \begin{cases} X_{Target,t}^i - X_{Supplied,t}^i, & If\ X_{Target,t}^i > X_{Supplied,t}^i \\ 0, & If\ X_{Target,t}^i = X_{Supplied,t}^i \end{cases}$$

4. **Maximum Deficit**

$$Max\ Def^i = \frac{\max(D_{annual}^i)}{Water\ demand^i}$$

D_t^i = *Deficits*
X_{Target}^i = *water demand*
$X_{Supplied}^i$ = *water Supplied*
t = time period
i = water user

Sustainability Index

- Sustainability (SI) Index proposed by Sandoval-Solis et al. (2011) variation of Loucks' SI (Loucks 1997)
  - Values vary from 0 – 1
  - There is implicit weighting because the index gives added weight to the criteria with worst performence

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$$SI^i = \left[\prod_{m=1}^{M} C_m^i\right]^{\frac{1}{M}}$$

$$SI^i = \left[Rel^i * Res^i * \left(1 - Vul^i\right) * \left(1 - Max\ Def^i\right)\right]^{1/4}$$

$$SG_{GroupK} = \sum_{i=1 \in k}^{i=j=k} W_{user\ i} \text{ x } SI_{User\ i}$$

C_m^i = *Performance Criteria*
M = *No. of Performance Criteria*

WEAP Software

- Input data:
  - Land use
    - Land cover information
  - Climate
    - Precipitation
    - Temperature
    - Relative Humidity
    - Wind Velocity
  - Stream flow
  - Reservoir data

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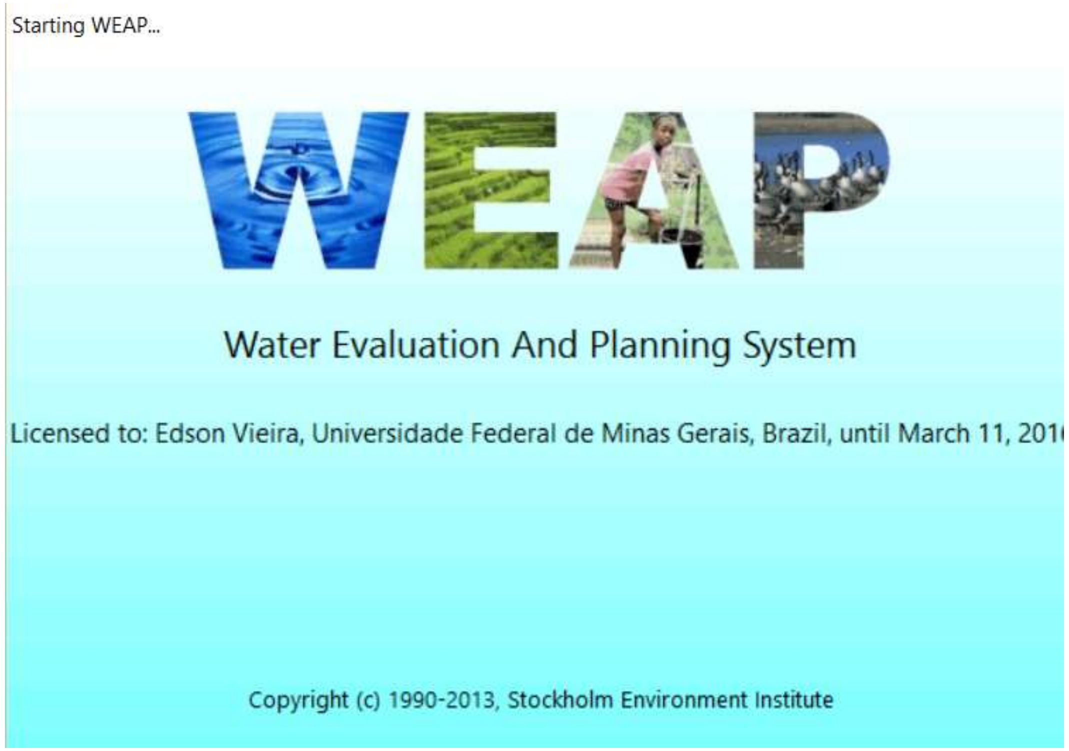

WEAP Software

- Demand data: (Water Users)
  - Urban Population
  - Rural Population
  - Livestock
  - Irrigation
  - Industry (AVG)

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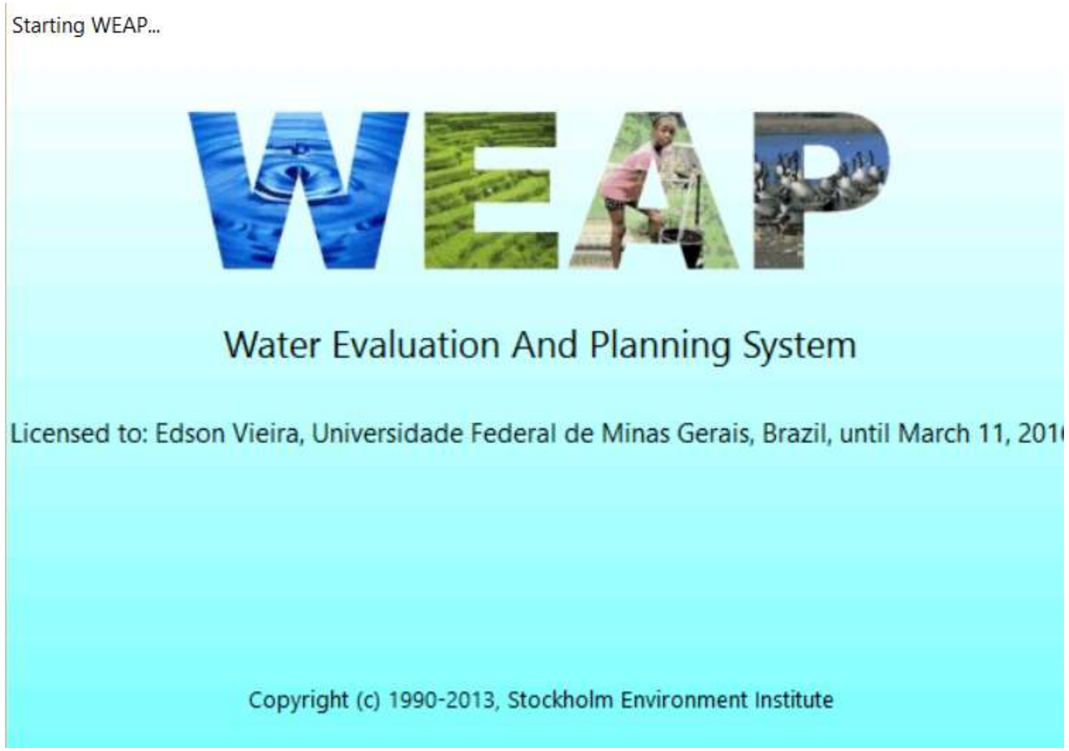
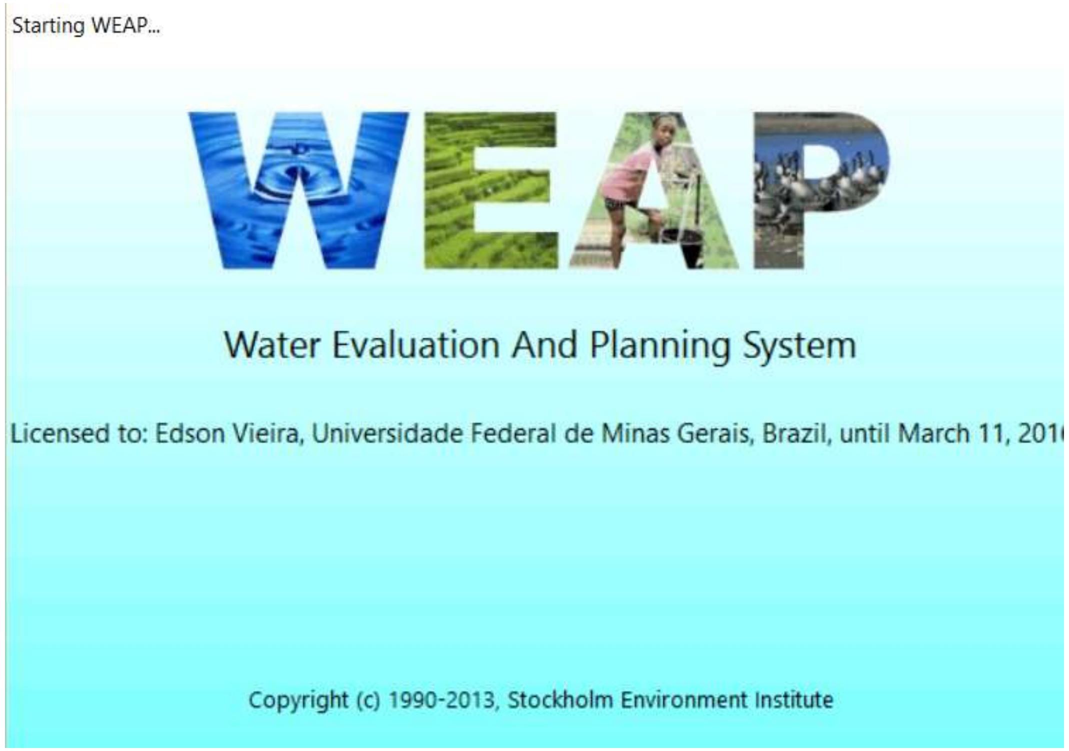


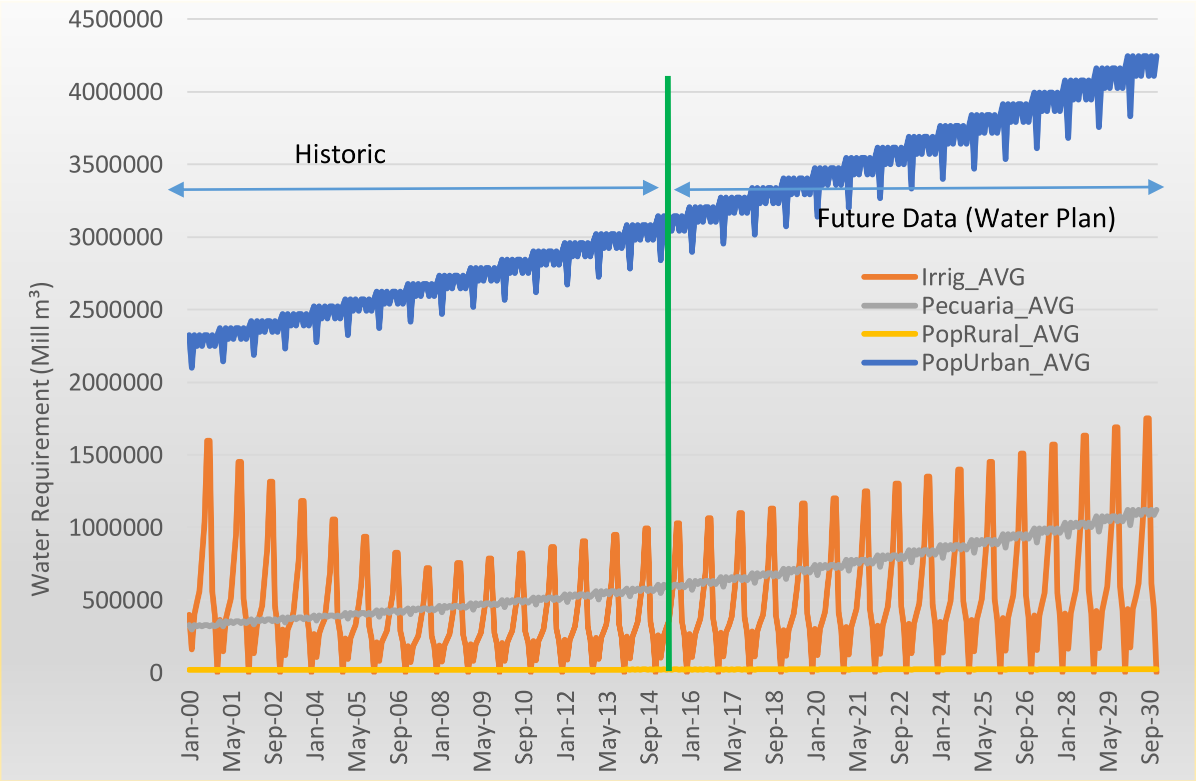
WEAP Software

- Period of analysis:
  - Time step - Monthly
  - 2000 – 2014 – Historic (Calibration and Validation)
  - 2015 – 2030 – Future Scenarios

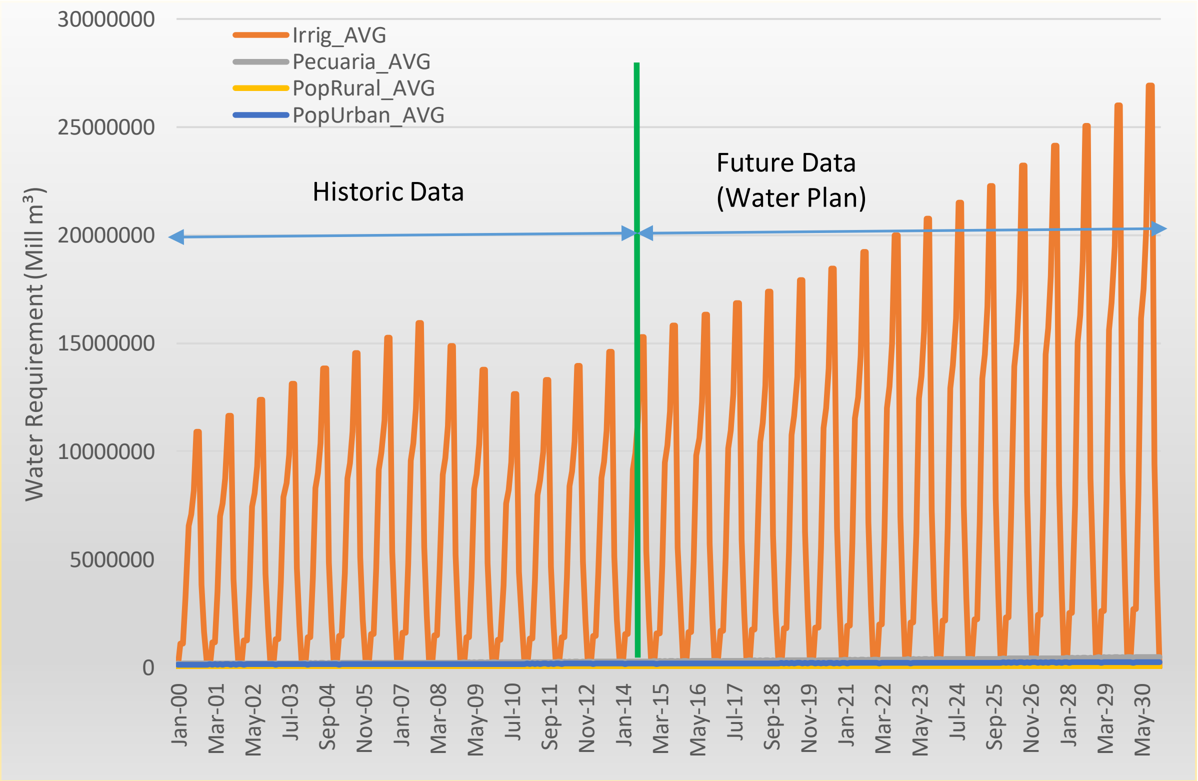


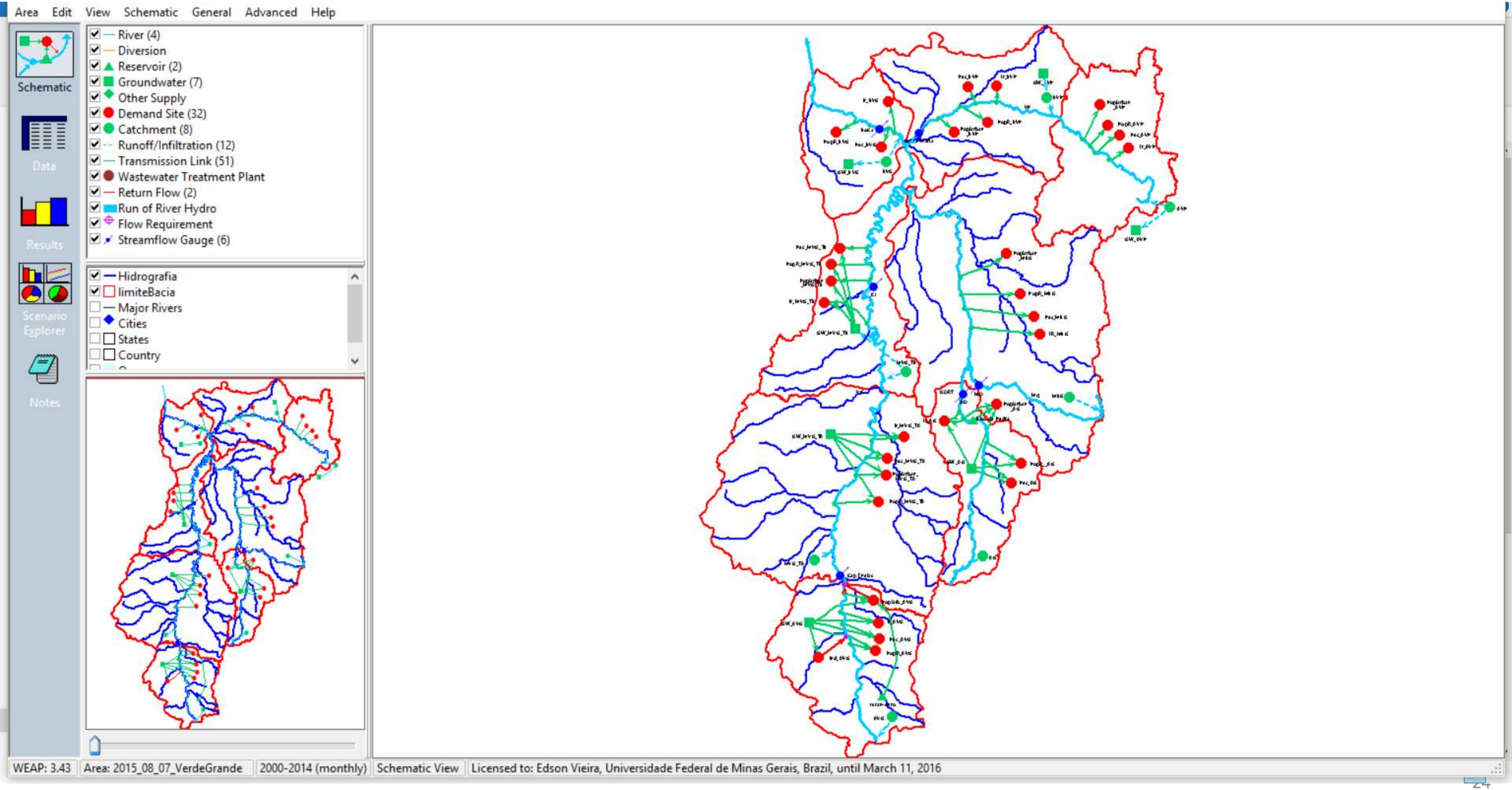
Water Demand Foreseen in Water Plan of Verde Grande

Water Required - AVG



Water Required – MVG_TA




Area
Edit
View
Schematic
General
Advanced
Help
Schematic
Data
Results
Scenario Explorer
Notes
River (4)
Diversion
Reservoir (2)
Groundwater (7)
Other Supply
Demand Site (32)
Catchment (8)
Runoff/Infiltration (12)
Transmission Link (51)
Wastewater Treatment Plant
Return Flow (2)
Run of River Hydro
Flow Requirement
Streamflow Gauge (6)
Hidrografia
limiteBacia
Major Rivers
Cities
States
Country
WEAP: 3.43
Area: 2015_08_07_VerdeGrande
2000-2014 (monthly)
Schematic View
Licensed to: Edson Vieira, Universidade Federal de Minas Gerais, Brazil, until March 11, 2016

Scenarios of Analysis

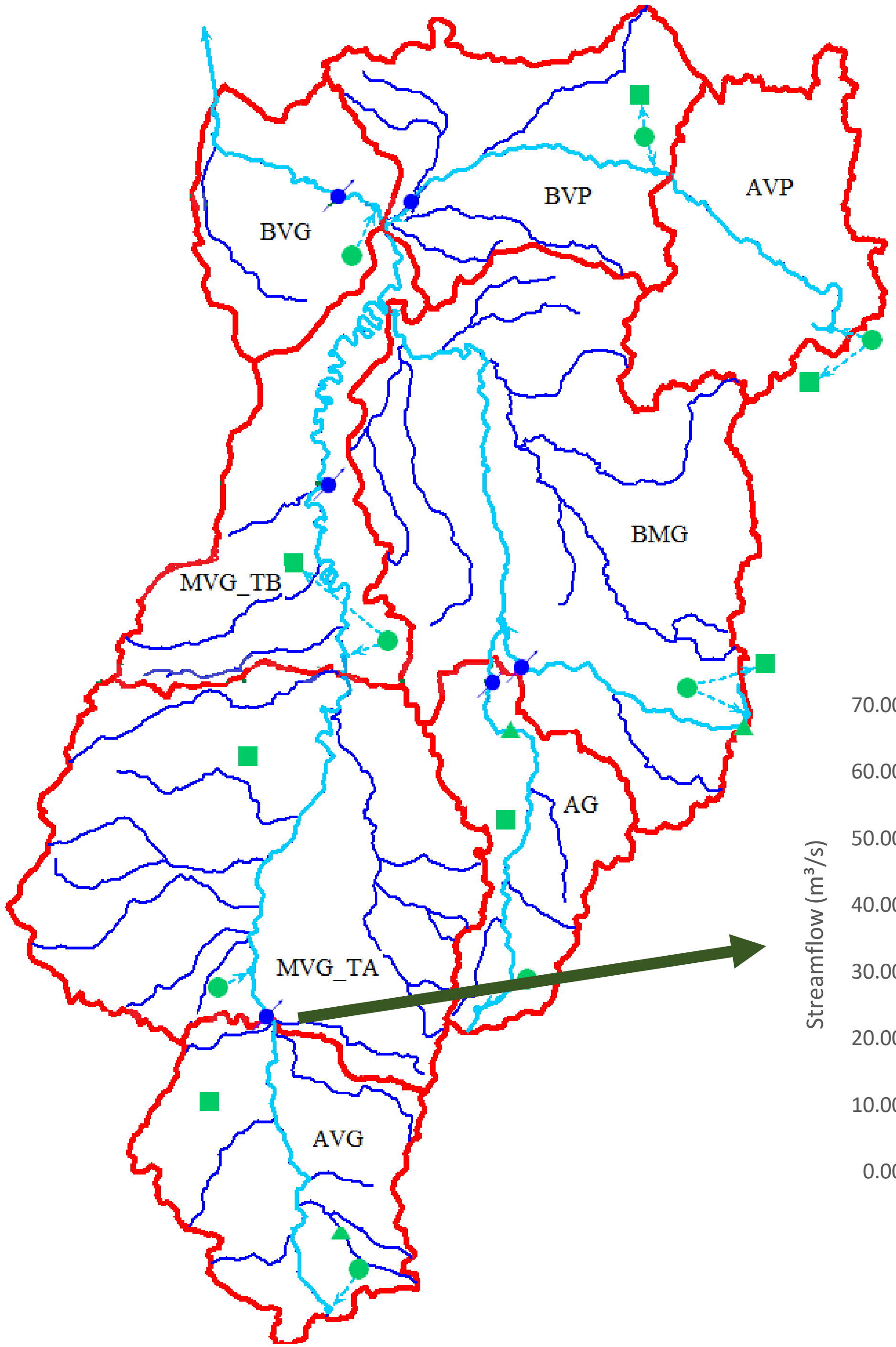
- Baseline (no actions)
- Trend
- Normative 1
- Normative 2

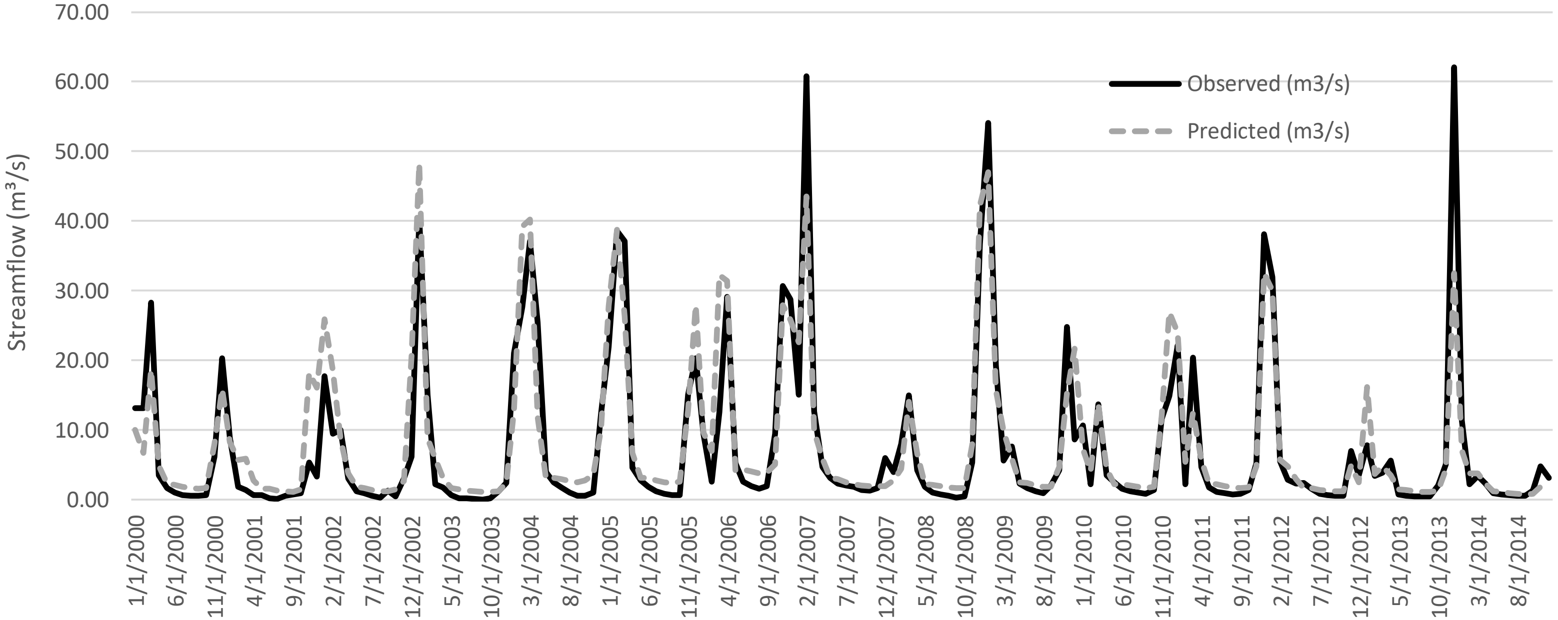
ACTIONS	Nº	Start Year
Import water from Congonhas Dam 2m³/s	1	2018
Water Diversion From São Francisco River 1.5m³/s	2	2020
Water Diversion From São Francisco River 1.5 (3m³/s)	3	2025
Water Diversion From São Francisco River 1.5 (4.5m³/s)	4	2028
Rio Verde Dam 0.15m³/s	5	2025
Cocos Dam 0.05m³/s	6	2025
Pedras Dam 0.04m³/s	7	2028
Mamonas Dam 0.05m³/s	8	2028
São Domingos Dam 0.42m³/s	9	2028

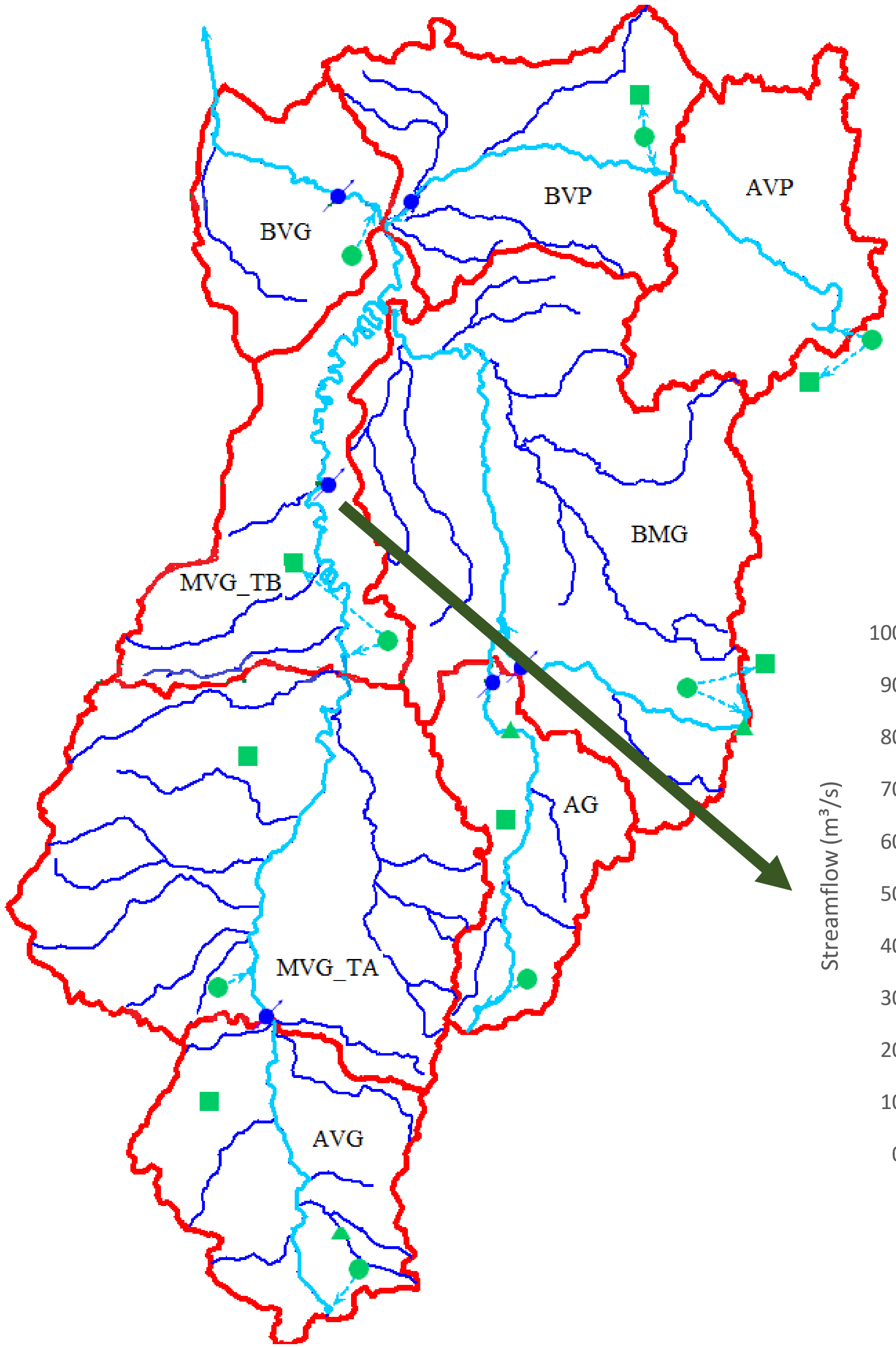
SCENARIOS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Trend				1	1	1	1	1	1	1	1	1	1	1	1	1
Normative 1				1	1	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
Normative 2				1	1	1,2	1,2	1,2	1,2	1,2	1 - 6	1 - 6	1 - 6	1 - 9	1 - 9	1 - 9

Calibration

STATISTIC	
Mean, m³/s	7.83
Median, m³/s	2.95
Standard Deviation, m³/s	10.44
Pearson's Correlation	0.91
Coefficient of Determination	0.82
Index of Agreement (Willmott)	0.95
Coefficient of Efficiency (Nash)	0.82

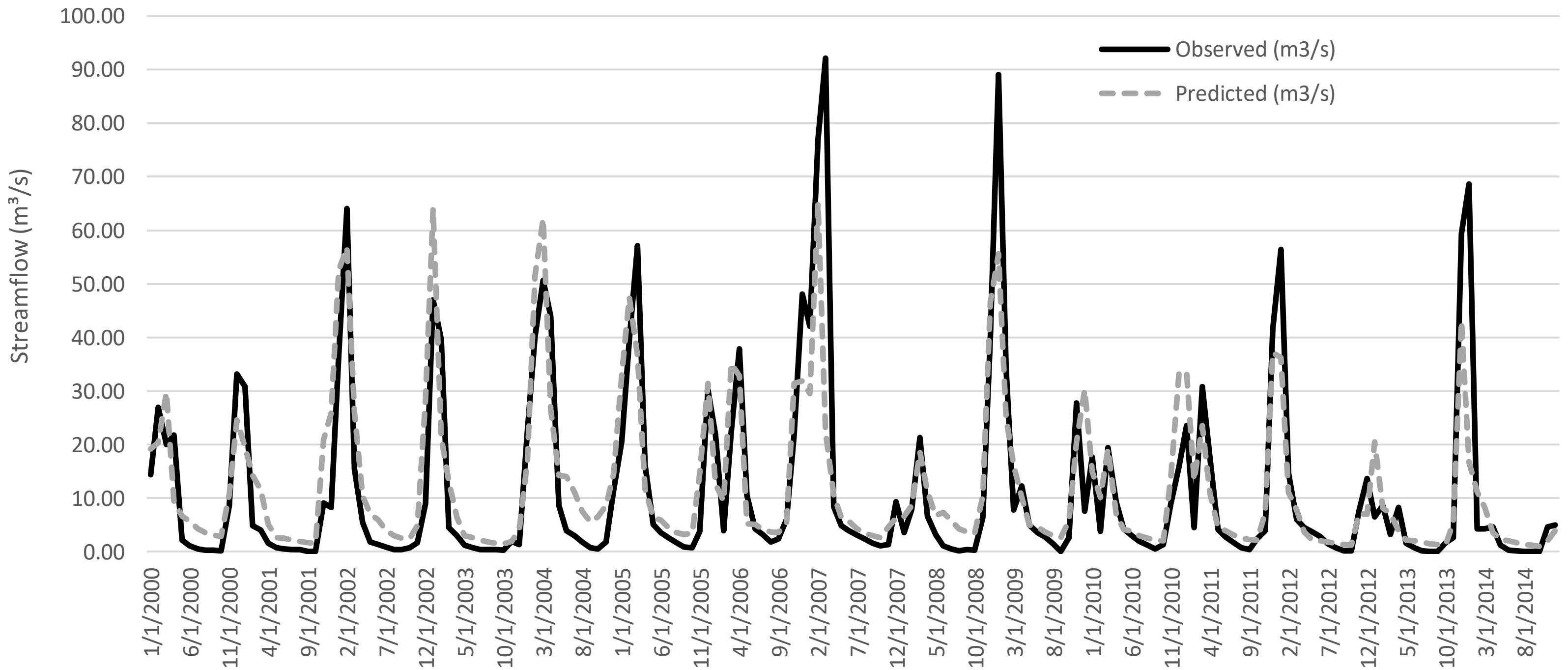




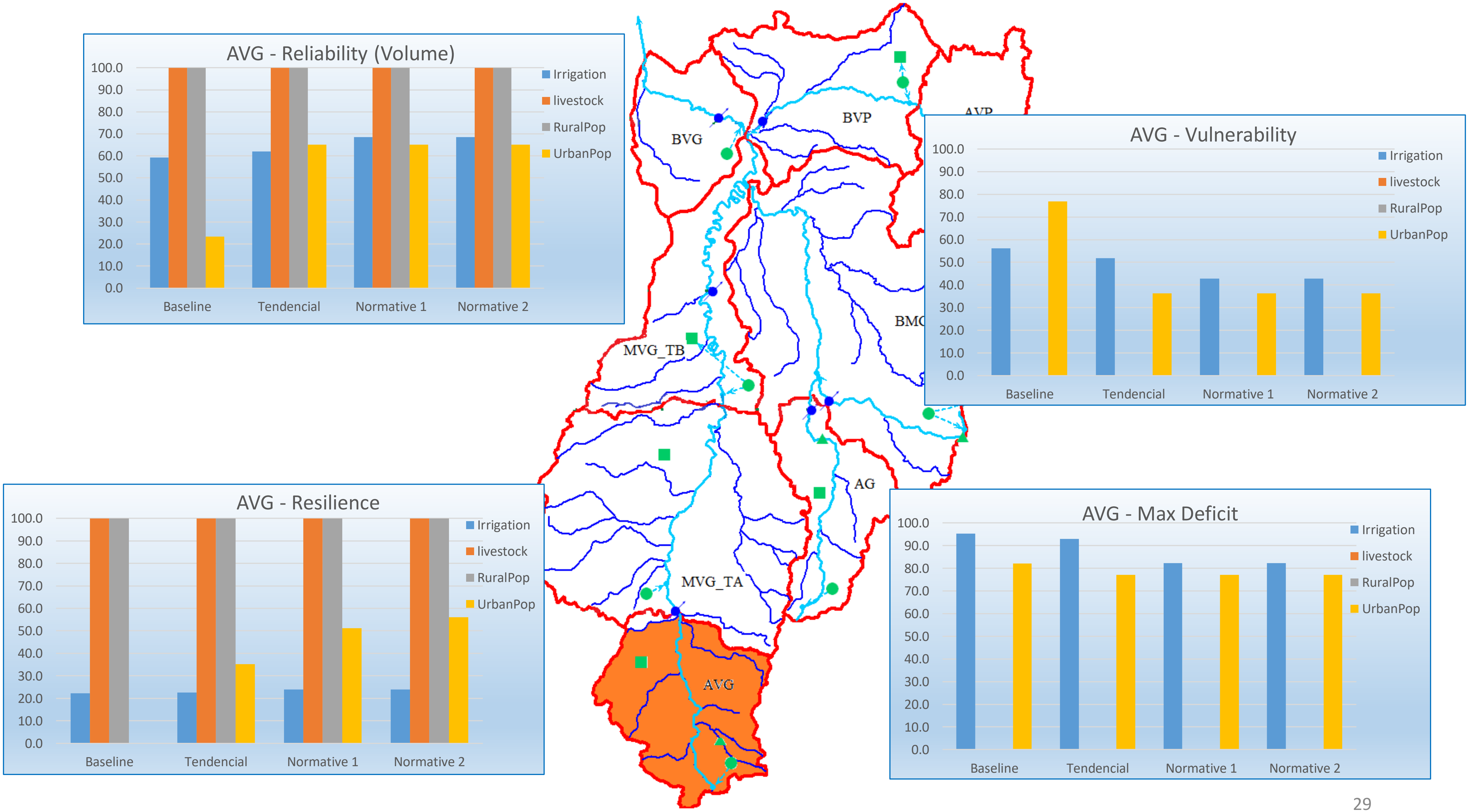


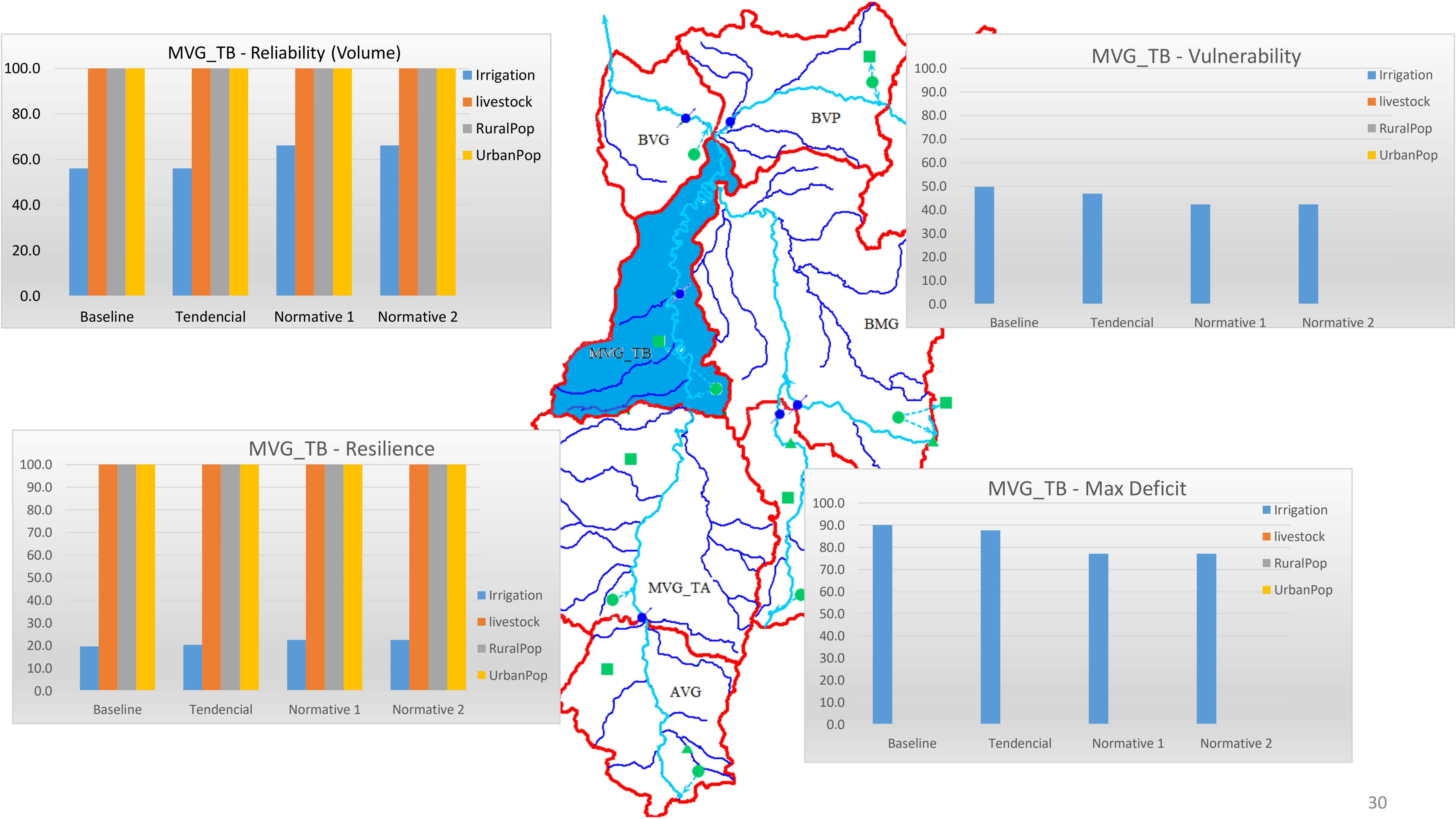
Calibration

STATISTIC	
Mean, m³/s	12.10
Median, m³/s	6.15
Standard Deviation, m³/s	13.92
Pearson's Correlation	0.83
Coefficient of Determination	0.70
Index of Agreement (Willmott)	0.90
Coefficient of Efficiency (Nash)	0.69



RESULTS


AVG - Reliability (Volume)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Baseline
Tendencial
Normative 1
Normative 2
Irrigation
livestock
RuralPop
UrbanPop
AVG - Vulnerability
AVG - Resilience
AVG - Max Deficit
BVG
BVP
AVP
BMC
MVG_TB
AG
MVG_TA
AVG


MVG_TB - Reliability (Volume)
100.0
80.0
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Normative 2
Irrigation
livestock
RuralPop
UrbanPop
MVG_TB - Vulnerability
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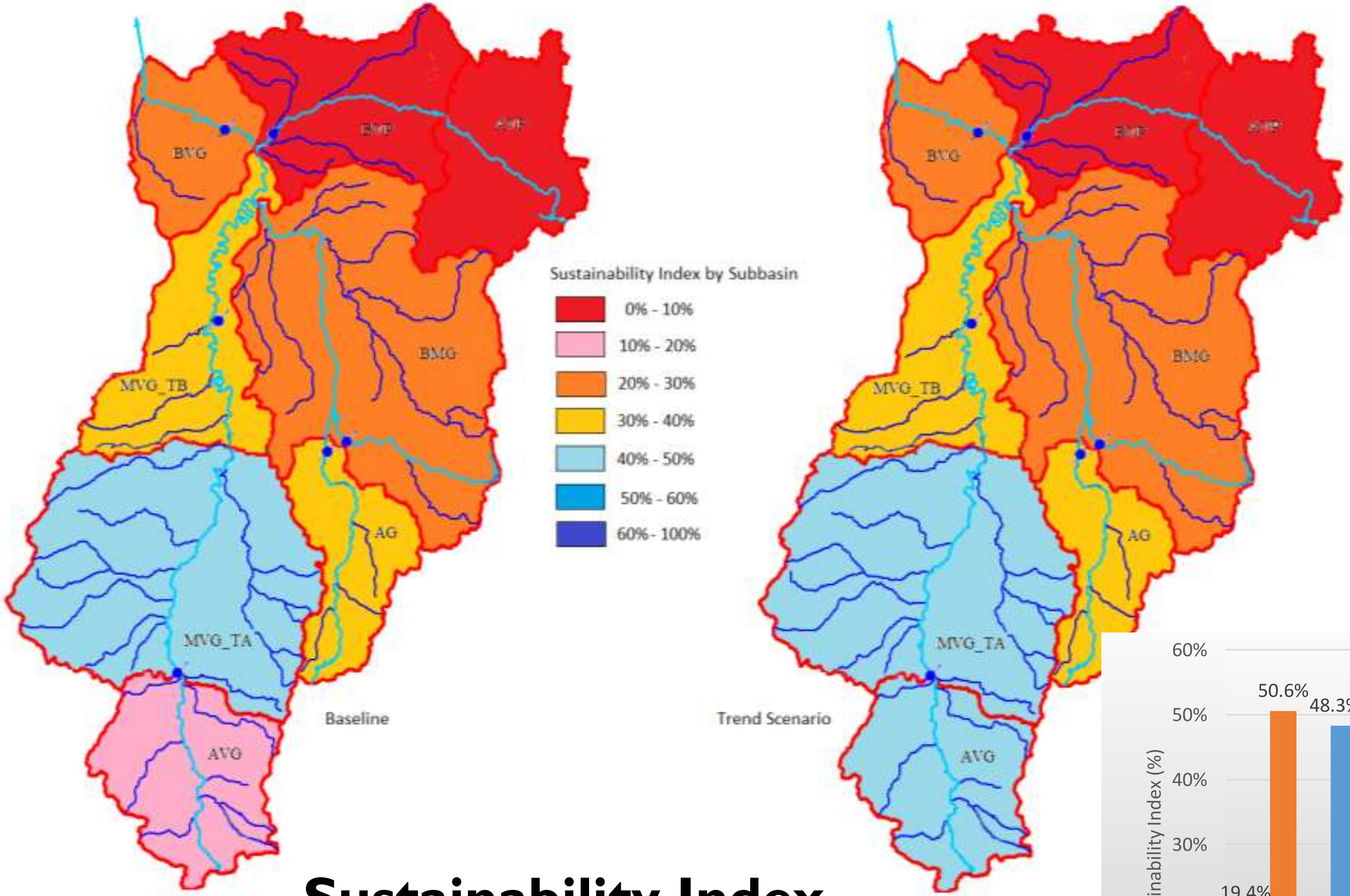
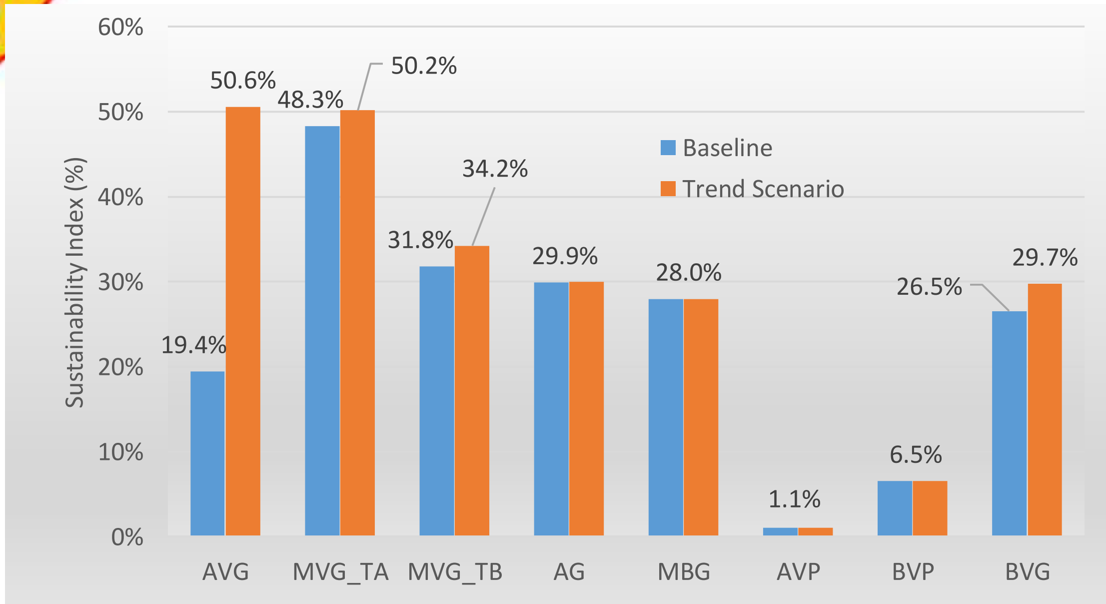
BVG
BVP
BMG
MVG_TB
MVG_TA
AVG

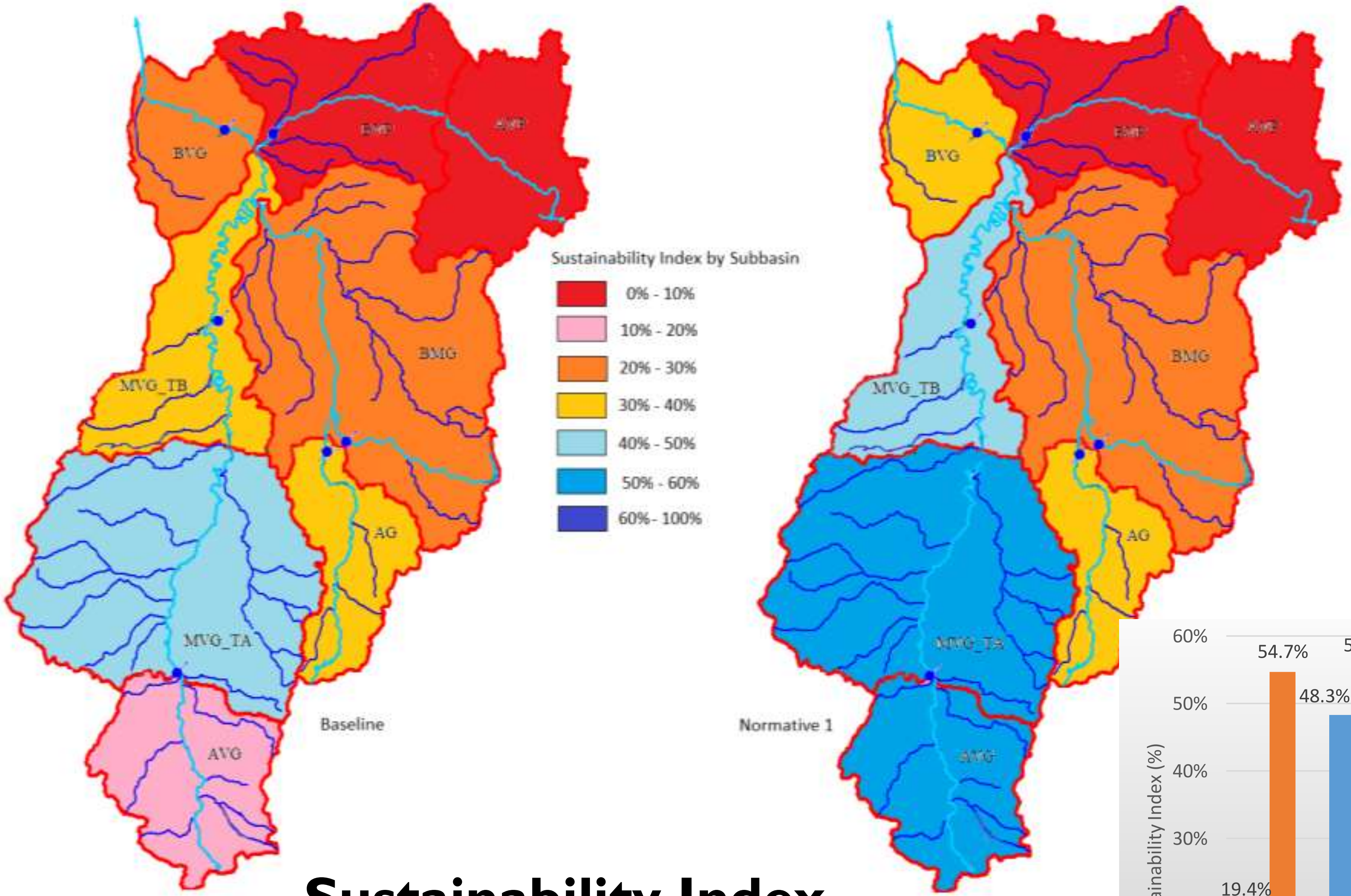
Baseline vs Trend Scenario



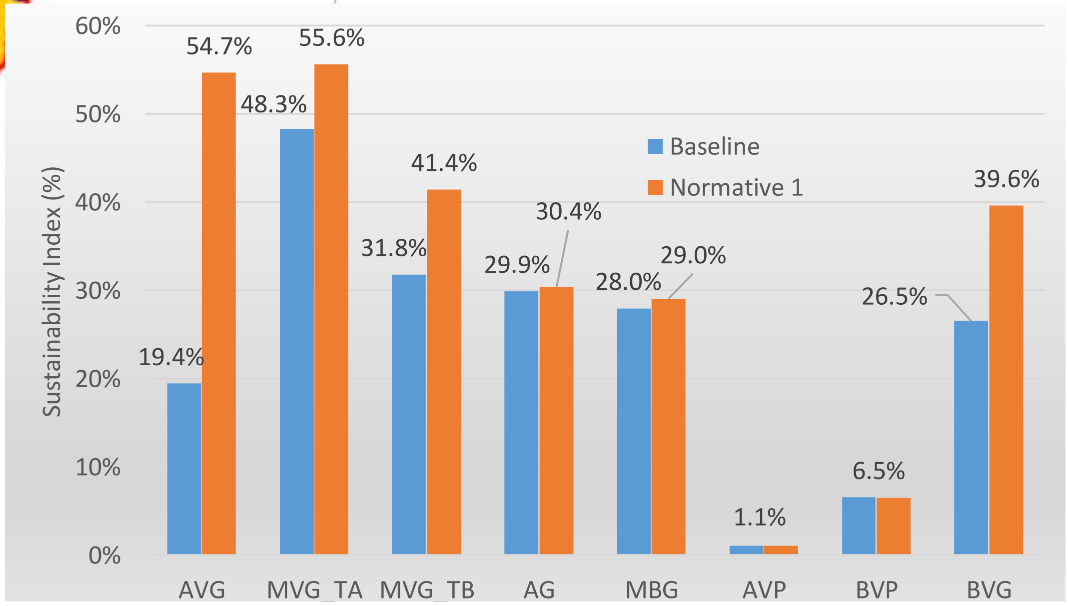
Sustainability Index



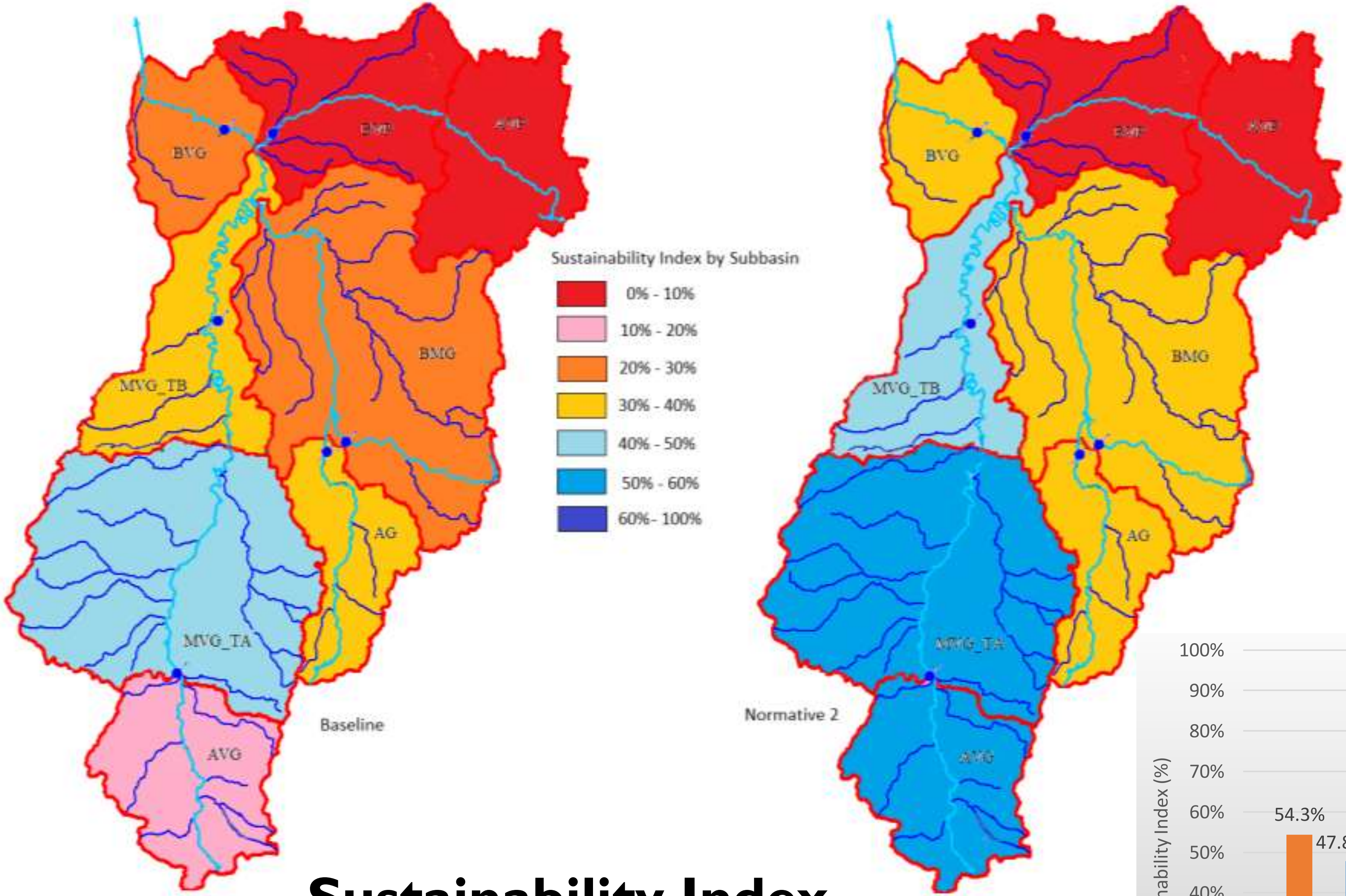
Baseline vs Normative 1



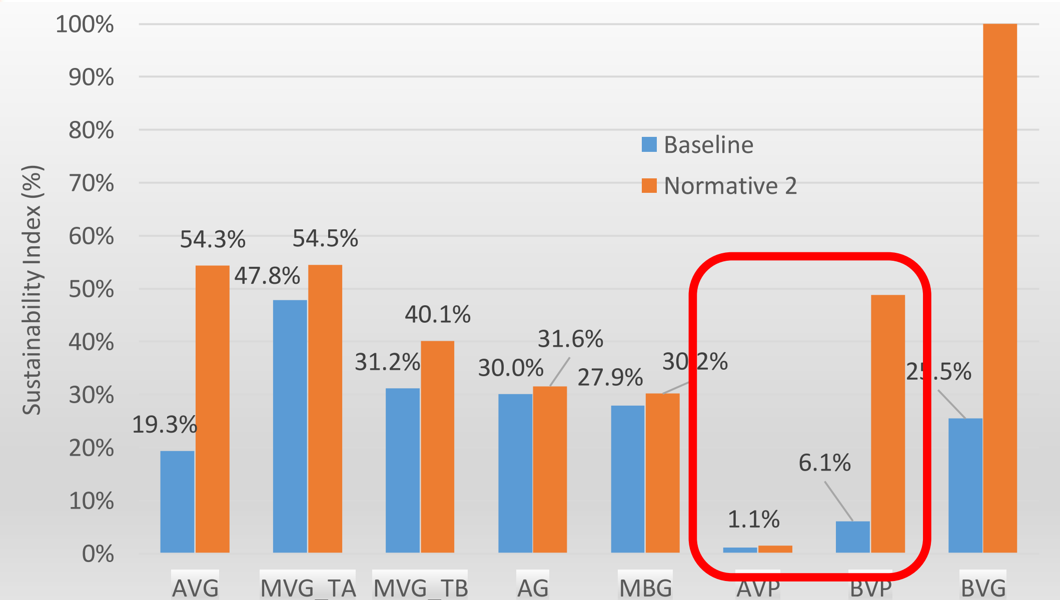
Sustainability Index



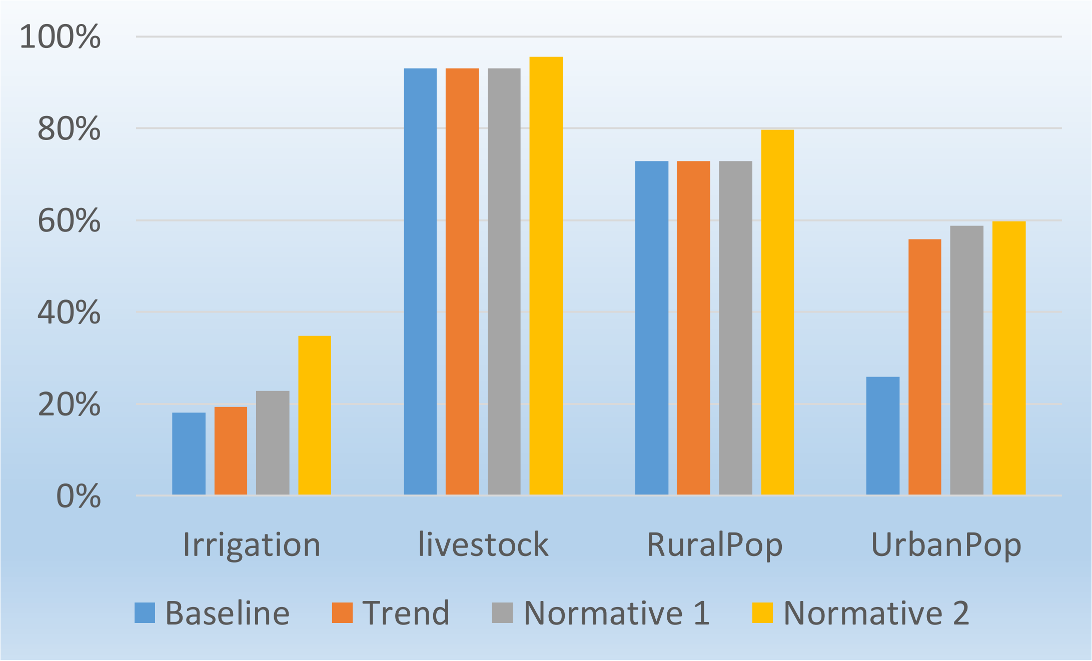
Baseline vs Normative 2



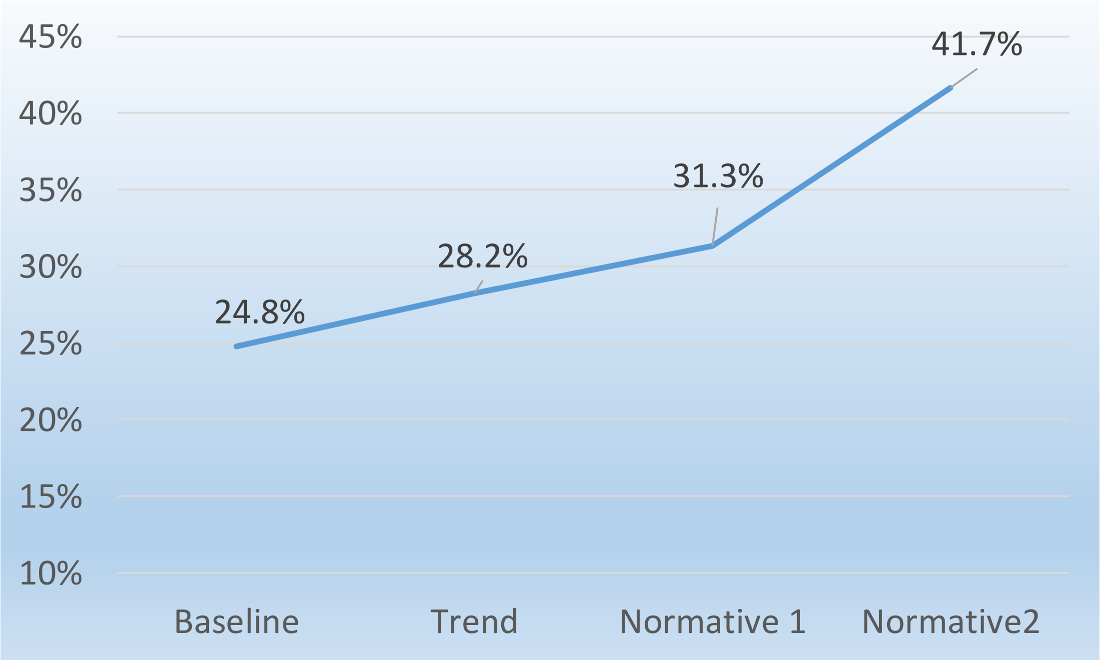
Sustainability Index



Sustainability Index by Group



Sustainability Index of VG Basin



CONCLUSIONS

- The Sustainability Index identified policies that improved the water availability of Verde Grande for the future.
- The Sustainability index shows that water supply in all scenarios in VGB is still unsustainable because the maximum deficit problem has not been solved.
- The comparison of the SG among different water users identified that the water policies have significantly improved the water supply only for the Urban Population user.
- Considering the whole VGB, there are no significant improvements in water supply with implementation of the policies proposed by the Water Resources Plan for the Verde Grande river basin.

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THANK YOU
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GRAZIE
MERCI
SHUKRAN
XIE XIE
오브리
با تشکر از شما