

# Application of the SPARROW Model in **the Grande River Basin, Brazil**

March 2023



AGÊNCIA NACIONAL DE ÁGUAS  
E SANEAMENTO BÁSICO

1

## Context

Water quality management in Brazil

2

## Deliveries

Publications

3

## Application of the SPARROW in Brazil

Pilot study in the Grande River (MG/SP)

4

## Conclusions

Potential application for the water quality management



# Context

## Water quality management in Brazil

# Water quality management in Brazil

Brazilian Water Resources Policy  
Federal Law 9.433/1997

## Instruments

- ◊ Water Resources Plans;
- ◊ Permits for water resources users (water allocation);
- ◊ Charging for the use of water resources;
- ◊ The Water Resources Information System;
- ◊ Water bodies classification system based on water-quality standards and water uses.

---

To **ensure** that **present and future generations** have access to **water of a quality compatible** with their **various uses**.

---

---

To ensure **water of a quality suitable** for the most **stringent water uses** as well as **reducing costs of water pollution control** by constant preventive actions.

---

## Classification system

### Planning

It is a planning tool to be implemented along with the water resources plan developed for the watershed.

### Participation

Water users, water agencies or equivalent institutions associated to the basin committee in articulation with the government institution responsible for the water resources etc.

### Parameters and classes

The freshwater quality class is defined for a group of diverse physical, chemical and biological parameters. The most common water uses are grouped in these classes of quality. Uses define the aimed class.

### Classification proposal

Diagnosis, **prognosis**, water quality goals proposal and implementation program



# Simulation models and water quality

The preparation of a water bodies classification proposal includes a prognosis step. The prognosis must comprise an evaluation of the impacts on the water resources of the implementation of planned actions and development programs based on simulation models (Resolution CNRH n°91/2008).

Such models are used to quantify the effects of land uses on water quality as well as the climatic and hydrological processes that control water and contaminant transport in surface waters across large spatial scales.

---

**Large-domain hydrological models** are needed to support **water-resource assessment and management** in large river basins.

---

# MOU

## COOPERATION WITH THE USGS



### Targets

- ◊ Design e optimization of hydrologic monitoring networks;
- ◊ Webinars, workshops and trainings;
- ◊ Support systems;
- ◊ Remote collaboration on interpretive studies;
- ◊ Water quality mission;

In September 2015, CPRM and ANA representatives visited the USGS offices to prospect tools and methods of water quality analysis to be applied in Brazil.

Brazilian technicians returned interested in the potential application of the water quality modeling tool in watersheds **SPARROW - SPAtially Referenced Regressions On Watershed attributes**.

A series of webinars was initiated in 2016 and resulted in a pilot study aimed at testing the tool in a Brazilian case.

[https://www.usgs.gov/centers/sawsc/science/brazilian-agencies-partner-usgs-water-programs?qt-science\\_center\\_objects=1#qt-science\\_center\\_objects](https://www.usgs.gov/centers/sawsc/science/brazilian-agencies-partner-usgs-water-programs?qt-science_center_objects=1#qt-science_center_objects)







Deliveries  
Publications



# Publications

## Pilot study

A series of webinars initiated in 2016 resulted in a pilot study aimed at testing the tool in a Brazilian case.

Study results were published in the journal Water in 2020.

In 2022 we published a booklet in Portuguese.



Article

### Application of the RSPARROW Modeling Tool to Estimate Total Nitrogen Sources to Streams and Evaluate Source Reduction Management Scenarios in the Grande River Basin, Brazil

Matthew P. Miller <sup>1,\*</sup>, Marcelo L. de Souza <sup>2</sup>, Richard B. Alexander <sup>3</sup>, Lillian G. Sanisaca <sup>4</sup>, Alexandre de Amorim Teixeira <sup>2</sup> and Alison P. Appling <sup>5</sup>

<sup>1</sup> U.S. Geological Survey, Integrated Modeling and Prediction Division, Boulder, CO 80303, USA

<sup>2</sup> Brazilian National Water and Sanitation Agency, Setor Policial, área 5, Quadra 3, Bloco M, Brasília 7010-200, Brazil; marcelo.souza@sana.gov.br (M.L.d.S.); alexandre.amorim@sana.gov.br (A.d.A.T.)

<sup>3</sup> Independent Researcher, 7205 Tall Pine Way, Clarksville, MD 21029, USA; ralexander38@gmail.com

<sup>4</sup> U.S. Geological Survey, Maryland-Delaware-DC Water Science Center, 5522 Research Park Dr, Baltimore, MD 21228, USA; lgormansanisaca@usgs.gov

<sup>5</sup> U.S. Geological Survey, Integrated Information Dissemination Division, University Park, PA 16802, USA; aappling@usgs.gov

\* Correspondence: mamiller@usgs.gov

Received: 10 September 2020; Accepted: 6 October 2020; Published: 18 October 2020

**Abstract:** Large-domain hydrological models are increasingly needed to support water-resource assessment and management in large river basins. Here, we describe results for the first Brazilian application of the SPATIally Referenced Regression On Watershed attributes (SPARROW) model using a new open-source modeling and interactive decision support system tool (RSPARROW) to quantify the origin, flux, and fate of total nitrogen (TN) in two sub-basins of the Grande River Basin (GRB; 43,000 km<sup>2</sup>). Land under cultivation for sugar cane, urban land, and point source inputs from wastewater treatment plants was estimated to each contribute approximately 30% of the TN load at the outlet, with pasture land contributing about 10% of the load. Hypothetical assessments of wastewater treatment plant upgrades and the building of new facilities that could treat currently untreated urban runoff suggest that these management actions could potentially reduce loading at the outlet by as much as 20–25%. This study highlights the ability of SPARROW and the RSPARROW mapping tool to assist with the development and evaluation of management actions aimed at reducing nutrient pollution and eutrophication. The freely available RSPARROW modeling tool provides new opportunities to improve understanding of the sources, delivery, and transport of water-quality contaminants in watersheds throughout the world.

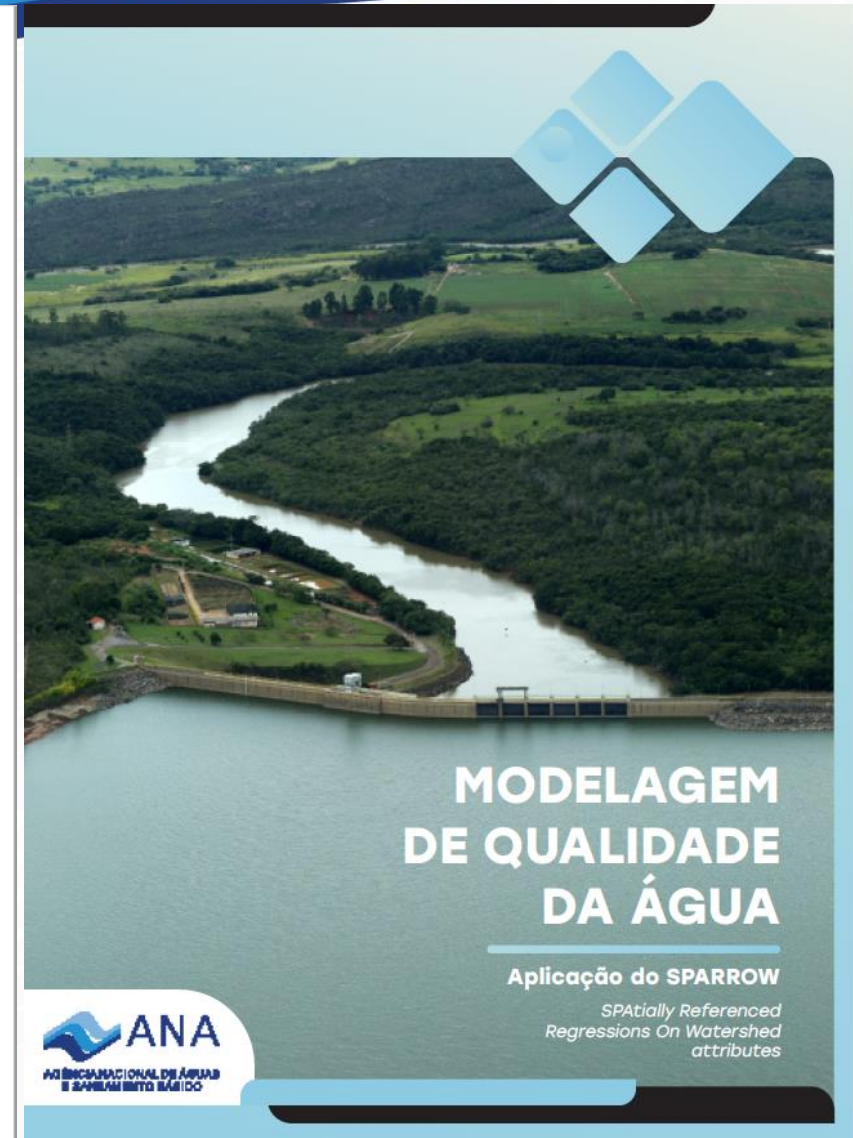
**Keywords:** watershed modeling; Brazil; nutrient source attribution; eutrophication; evaluation of management actions

#### 1. Introduction

Large-domain hydrological models are needed to support water-resource assessment and management in large river basins (e.g., [1]) and coastal and estuarine waters with large contributing drainages [2]. Such models must be able to quantify the effects of a diverse range of land uses on streamflow and water quality as well as the climatic and hydrological processes that control water and contaminant transport in surface waters across large spatial scales [1]. Progress has been made

Water 2020, 12, 2911; doi:10.3390/w12102911

www.mdpi.com/journal/water




<https://www.mdpi.com/2073-4441/12/10/2911>

[https://biblioteca.ana.gov.br/sophia\\_web](https://biblioteca.ana.gov.br/sophia_web)



# RSPARROW

Open-source version

 An official website of the United States government [Here's how you know](#) ▼



SCIENCE PRODU

The results of the study were published in the *Water* magazine in October 2020.

## RSPARROW Now Available

An R system for SPARROW modeling

[Access the software](#)

<sup>1</sup>Alexander, R.B.; Gorman Sanisaca, L. RSPARROW: An R System for SPARROW Modeling (Software Release); U.S. Geological Survey: Reston, VA, USA, 2019; doi:10.5066/P9UAZ6FO.

<https://www.usgs.gov/news/software-release-rsparrow-r-system-sparrow-modeling>

The **RSPARROW** was developed by **USGS** in a cooperation with the **Brazilian National Water and Sanitation Agency (ANA)** and the **Brazilian Geological Survey (CPRM)**.

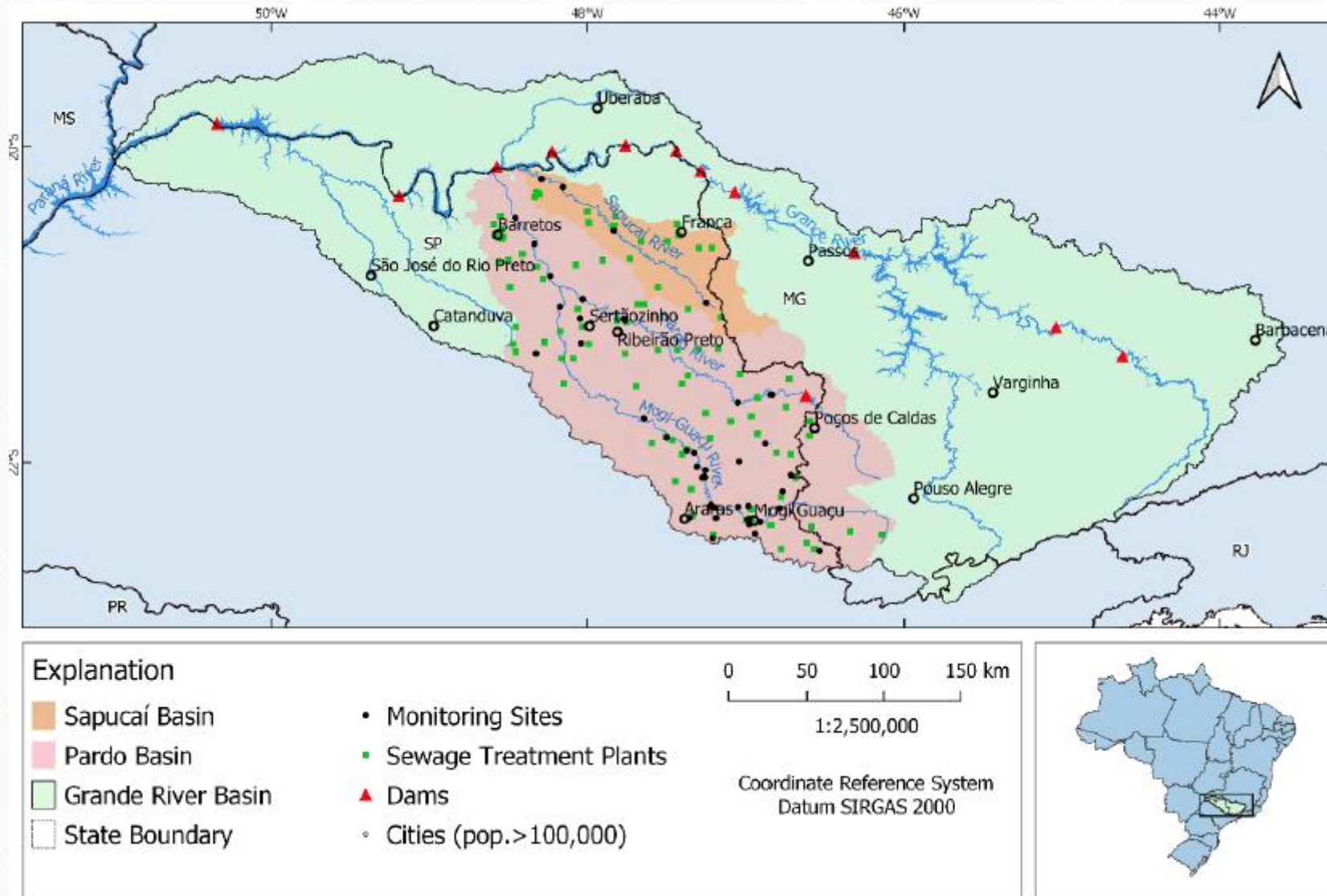
# SPARROW in Brazil

Pilot study



# Pilot study

## Grande River Basin



We developed a model of total (inorganic and organic) nitrogen (TN) in streams, using historical data from 41 stream monitoring sites in the Pardo-Sapucaí sub-basins of the Grande River Basin (43,000 km<sup>2</sup>).

The study site was chosen in virtue of the availability of data gathered for elaboration of the Rio Grande Basin Integrated Water Resources Plan.

Among the actions foreseen in this plan is the implementation of the water quality studies aimed at the control of water pollution, especially related nutrients capable of causing eutrophication of reservoirs

# Pilot study

## Aims

In this study, the SPARROW total nitrogen model was used to:

- 1 Quantify spatial variability in mean annual TN loads in all streams across the GRB sub-basins;
- 2 Quantify the major natural and human sources of nitrogen in the GRB, including the contaminant mass loading contributions from major land uses (urban, pasture, sugar cane) and wastewater treatment facilities in the river basin;
- 3 Illustrate an application of the model to evaluate the potential stream water-quality effects of hypothetical nutrient-reduction management actions in urban areas of the watersheds.



# Pilot study

## Explanatory variables

Variable	Dataset Used	Parameter Tested
Land cover	Integrate Water Resources Plan of the Grande River Basin [35]	Percent of catchment area composed of urban areas
		Percent of catchment area composed of sugarcane crops
		Percent of catchment area composed of soybeans/corn crops
		Percent of catchment area composed of forestry
		Percent of catchment area composed of pasture
		Percent of catchment area composed of orange crops
		Percent of catchment area composed of coffee
		Percent of catchment area composed of other crops
		Percent of catchment area composed of central pivots
		Percent of catchment area composed of open waters
		Percent of catchment area composed of Cerrado (tropical savanna)
		Percent of catchment area composed of Atlantic Forest
Population	Census sector [50]	inhabitants of the basin area
Temperature	WorldClim2 [51]	Mean annual temperature (mm/year)
Precipitation	WorldClim2 [51]	Mean total annual precipitation (°C)
Point sources	Estimated with basis on the Sewage Atlas [52]	TN load (tons/year)

Total nitrogen (TN) sources and landscape transport characteristics tested for potential inclusion in the SPARROW model for the Grande River Basin.

The SPARROW model is based on a synthetic stream reach network and associated drainage area polygons. We used the Ottocodified Hydrographic Base developed by ANA.

Bi-monthly discrete TN concentration data were obtained from the Environmental Company of Sao Paulo State (CETESB) and daily discharge data were obtained from the Brazilian National Hydrometeorological Network (RHN). TN load estimates from 41 sites were generated to calibrate the SPARROW model. The USGS Loadflex R package was used to estimate loads.

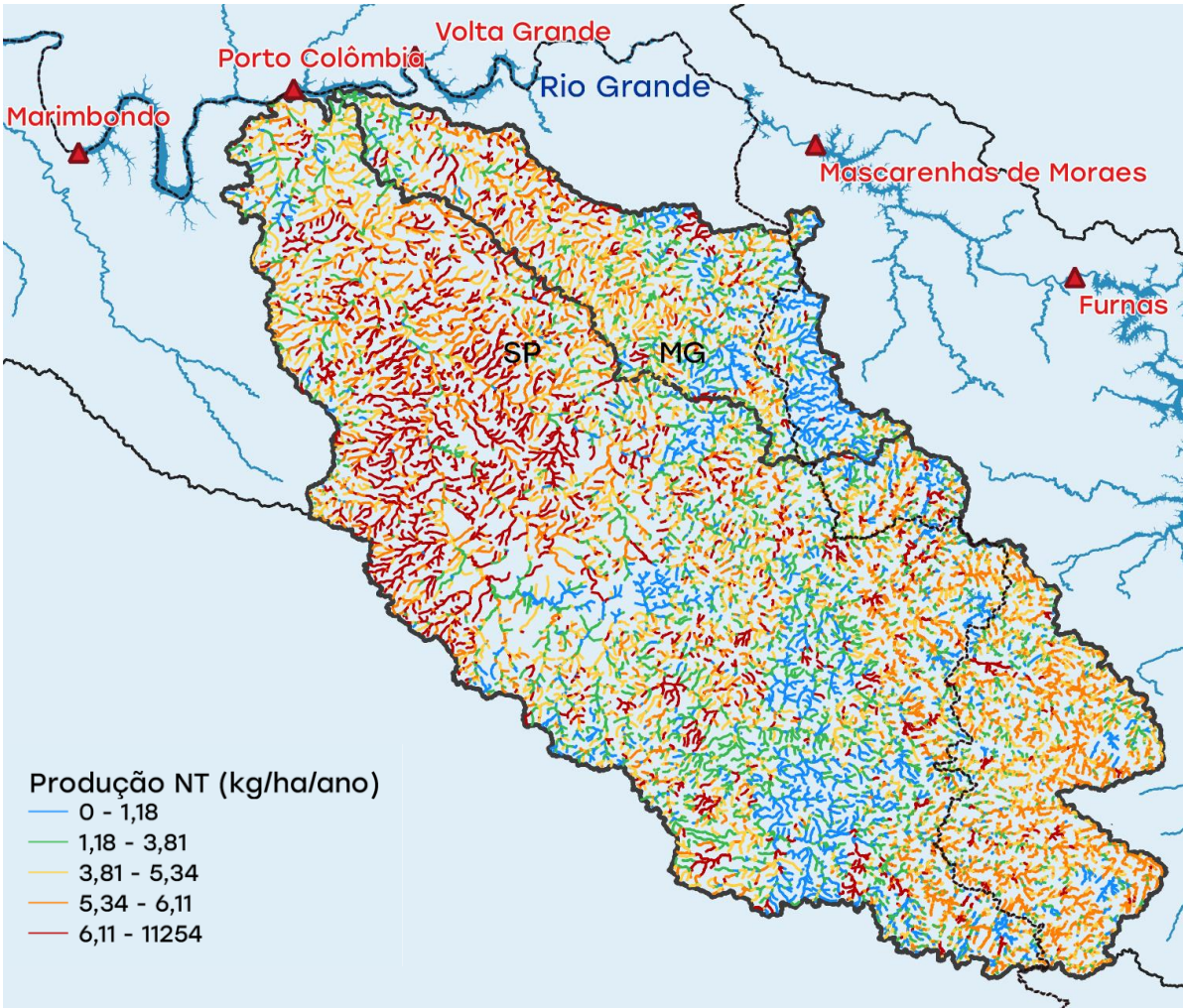
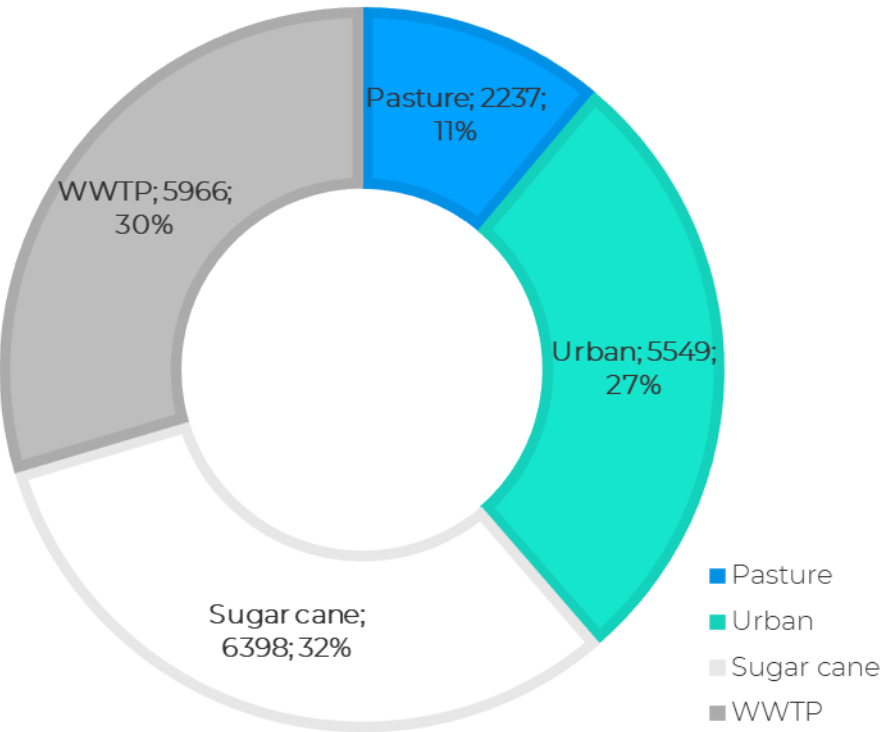


# Pilot study

## Results

The model estimates that 20,000 tons/year of TN is delivered to the outlet of the watershed.

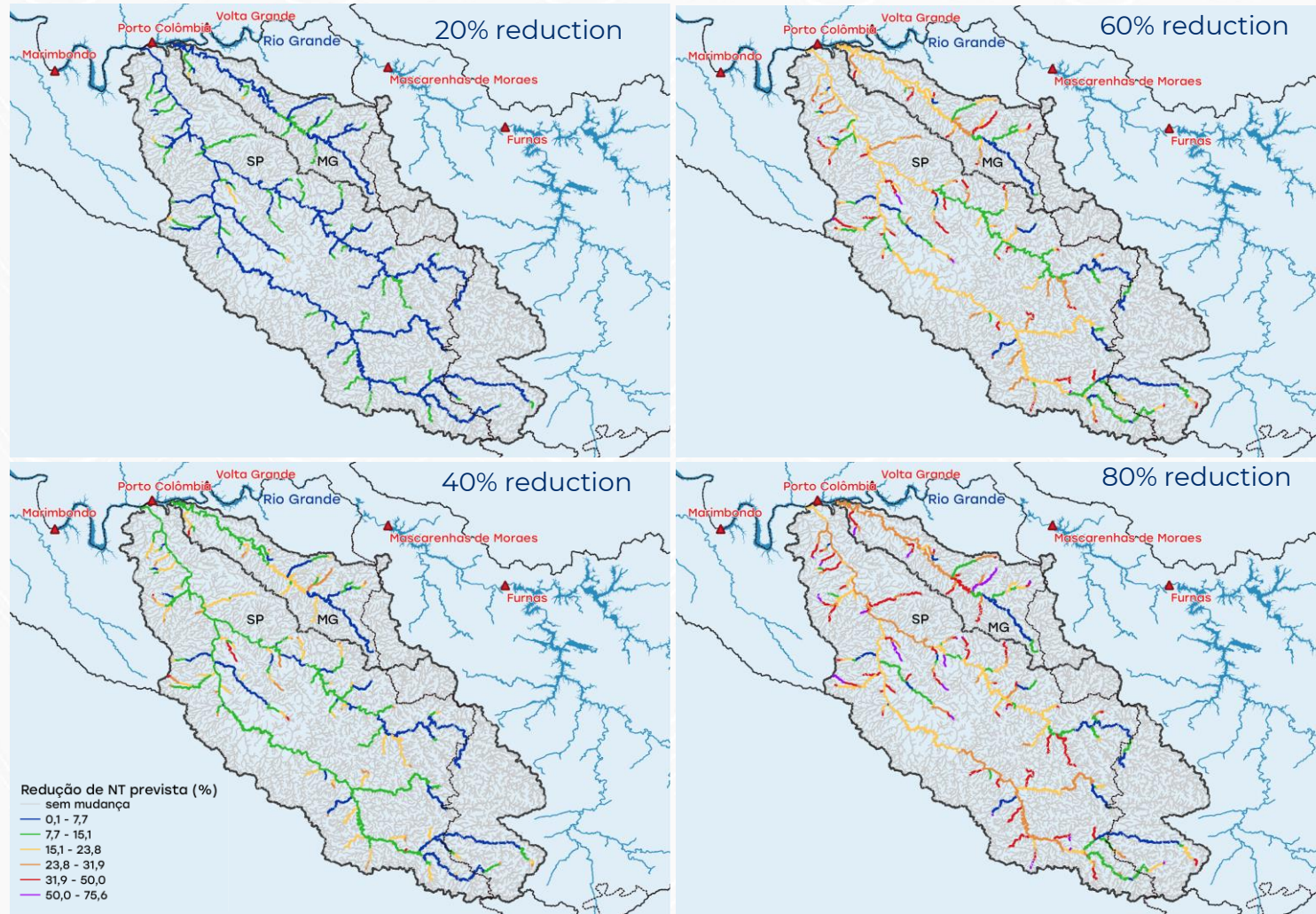
ESTIMATED ANNUAL MASS (TONS) AND SHARE OF TOTAL NITROGEN



Source	Area of Watershed (km²) <sup>a</sup>	Mass Delivered to Outlet (Tons)	Share of Total Load (%)
Combined Pardo-Sapucaí Basins			
Pasture	901 (2.1)	2237	11
Urban	9735 (23)	5549	28
Sugar Cane	15,432 (36)	6398	32
Wastewater Treatment	NA	5966	30

# Scenarios

## Wastewater point source



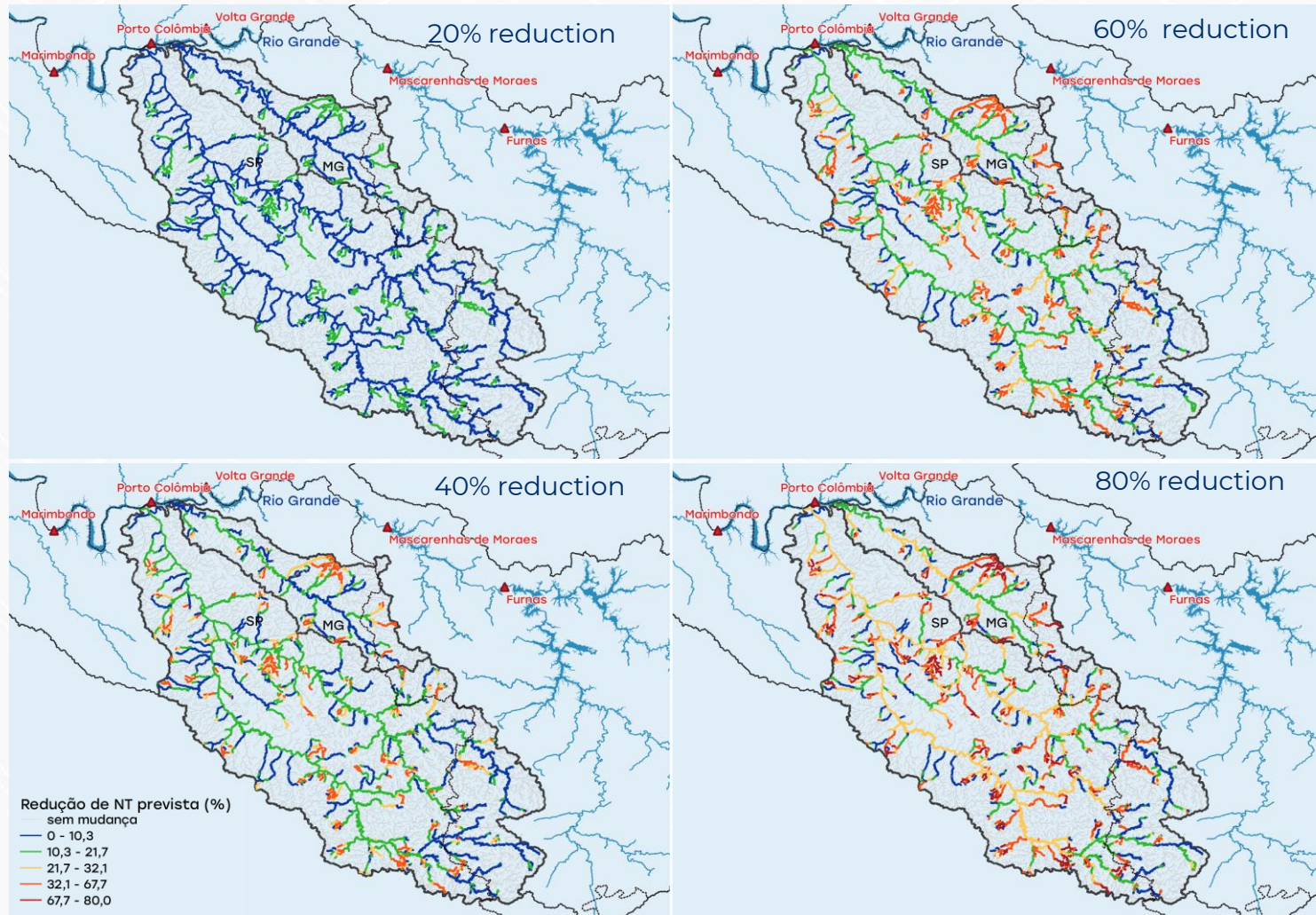
The SPARROW model predicts that, relative to baseline conditions, TN loading at the outlet of the Pardo-Sapucaí sub-basins decreased by:

- 1200 tons (6%) for the 20% reduction in wastewater point source inputs;
- 2400 tons (12%) for the 40% reduction scenario,
- 3600 tons (18%) for the 60% reduction scenario and
- 4800 tons (24%) for the 80% source reduction scenario



# Scenarios

## Urban runoff



Hypothetical assessments of wastewater treatment plant upgrades and the building of new facilities that could treat currently untreated urban runoff suggest that these management actions could potentially reduce loading at the outlet by as much as 20–25%.

Relative to baseline conditions, TN loading at the outlet of the Pardo-Sapucaí sub-basins decreased by:

- 1100 tons (6%) for the 20% reduction in loading per unit area from diffuse urban land sources;
- 2200 tons (11%) for the 40% reduction scenario;
- 3300 tons (17%) for the 60% reduction scenario and;
- 4400 tons (22%) for the 80% source reduction scenario.



# Conclusions

This application of the new interactive modeling and management RSPARROW mapping tool developed by the USGS in coordination with ANA and CPRM provided a first assessment of TN sources and transport in the Grande River Basin.

Example management scenarios demonstrate the ability of SPARROW and the RSPARROW mapping tool to inform management efforts aimed at controlling nutrient loads and preventing eutrophication.

We were able to develop the model from information available at the agency and historical data from existing Brazilian water-quality and -quantity monitoring networks. The modelling activity can support the strategic development of new stream monitoring information.

The open-source nature of RSPARROW provides new opportunities to develop SPARROW model-based water-quality assessments in additional sub-basins of the GRB as well as other river basins of Brazil and other countries.

The model-based water resource assessment approach that we illustrate here could also be expanded and applied to other water contaminants (e.g., phosphorus, sediment, biochemical oxygen demand, fecal bacteria, and pathogens).

---

The **SPARROW** system has characteristics that fit the **management model** provided for in our **water resources policy** such as the adoption of the **watershed as the management territorial unit**.

---

# Technical team

## USGS

Paul Conrads (*in memorian*)

Ana Garcia

Richard Alexander

Steve Ator

Alison Appling

Steve Preston

Lillian Gorman Sanisaca

Matt Miller

Olivia Miller

Dan Restivo

## CPRM

Eber Andrade (CPRM)

## ANA

Alexandre Amorim

Alexandre Abdalla

Saulo Aires

Teresa de Carvalho

Marcos Pufal

Marcelo Luiz de Souza





NATIONAL WATER AND  
SANITATION AGENCY - BRAZIL

**Marcelo Luiz de Souza**

Water Resources and Sanitation Regulation Specialist

[marcelo.souza@ana.gov.br](mailto:marcelo.souza@ana.gov.br)

Thanks!