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How much does each part of a watershed contribute annually to hydropower production?

Carlos Ribeiro*; Bruno Martins; Sady Menezes; Devin Mounts;
Alexandre Santos; Alexandre Lorezon; and Delly Oliveira-Filho

* *corresponding author: cribeiro@ufv.br*



Forestry Department

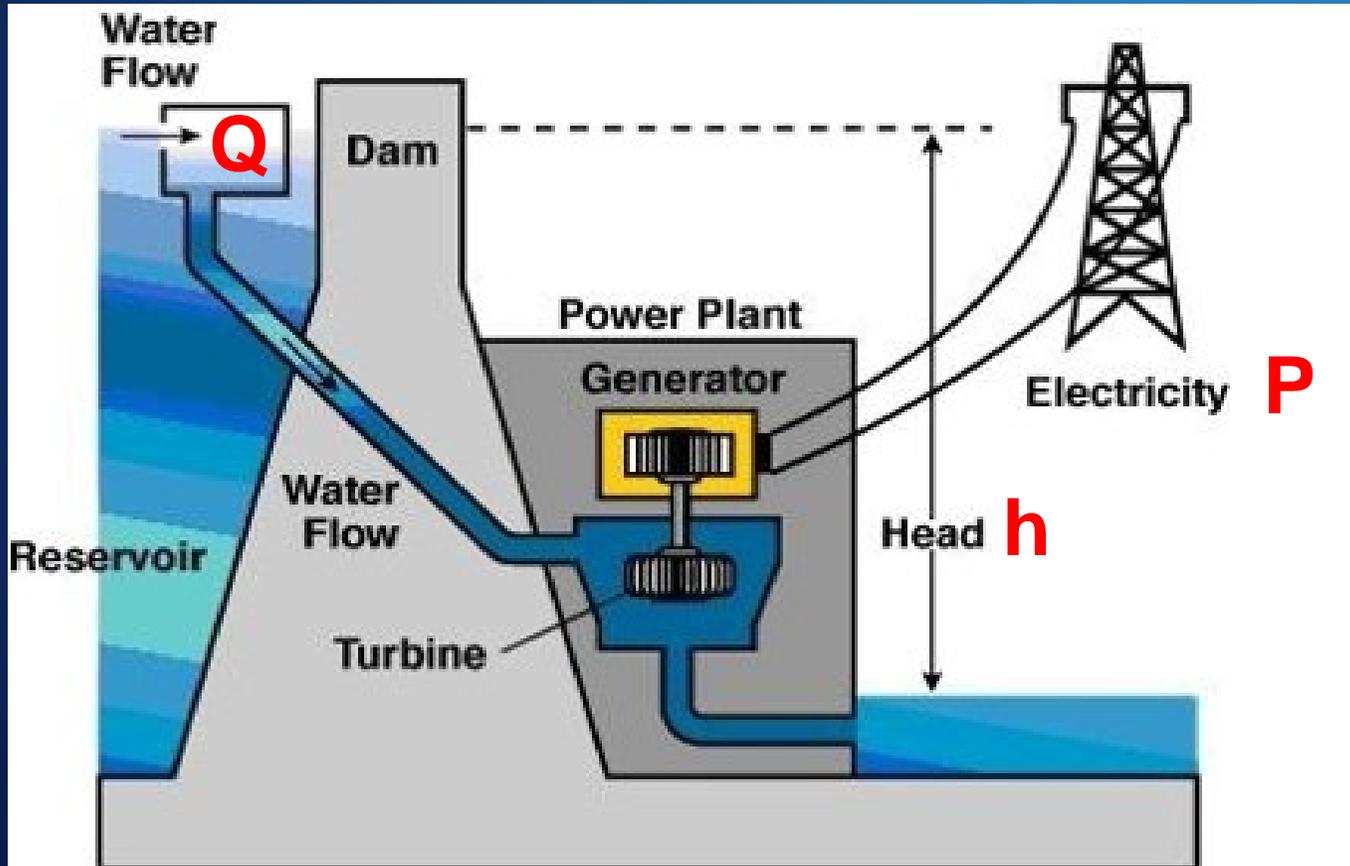
Federal University of Vicosa - Brazil

Starting point

- Brazilian Law nº 7990 of Dec. 28th 1989 (*aka water royalties*):
 - Established a Financial Compensation for the use of water resources for generating electricity
 - *Article 5*: “When the use of hydraulic potential reaches more than one state or municipality, the distribution of the percentages shall be made in proportion, taking into account the flooded areas.”
- *nevertheless...*

Background

... it is well known that the production of **hydropower** stems from both the **falling height (m)** and the **water flow (m³/s)**:



$$\text{(Eq. 1) } P = \eta \times \rho \times g \times h \times Q$$

P = net hydropower [W]

η = system efficiency [≤ 1]

ρ = water density [kg m^{-3}]

g = gravitational constant [m s^{-2}]

h = net falling height [m]

Q = water flow rate [$\text{m}^3 \text{s}^{-1}$]

Background...

... this fact clearly indicates the perversity of taking just one single criterion as north to the apportionment of the water royalties:

- such misconception contaminates the shared values paid by all Brazilian electricity companies, since only those municipalities that had part of their lands flooded by the reservoir of a hydroelectric plant are financially rewarded (*Menezes, 2011*).

Water Royalties Policy

(Eq. 2) **WR** = EM × US\$ 22 × (6% + 0.75%)

- WR = total value monthly paid by the company [US\$]
- EM = total energy production of a given month [MW h]
- US\$ 22 = current value of MW h [US\$]
- 6.75 = percent of the total value of the energy produced:
 - 40% for municipalities intercepted by the reservoir;
 - 40% for the respective state(s);
 - 9% for some federal agencies;
 - 11% to fund the Water Resources Management System.

Objectives

- **Quantify the average contribution of each part of a watershed for the generation of hydropower;**
- **Calculate, for each municipality, the monetary compensation resulting from an equitable distribution of the water royalties, and compare these values with those currently practiced.**

Equitable Distribution Approach

$$(Eq. 3) \quad P_Q = \frac{100 \times h}{Q + h} \quad (Eq. 4) \quad P_h = \frac{100 \times Q}{Q + h}$$

(Oliveira, 2009)

- P_Q – percentage contribution of water flow [%]
- P_h – percentage contribution of net falling height [%]
- Q – water flow rate [m³/s]
- h – net falling height [m]



Study area

Agua Vermelha hydroelectric power plant, Grande river basin, Southeastern Brazil

- Lake: 674 km²
 - volume: 11 km³
 - 17 municipalities
- Watershed: ~ 140,000 km²
 - 414 municipalities

(Menezes, 2011)

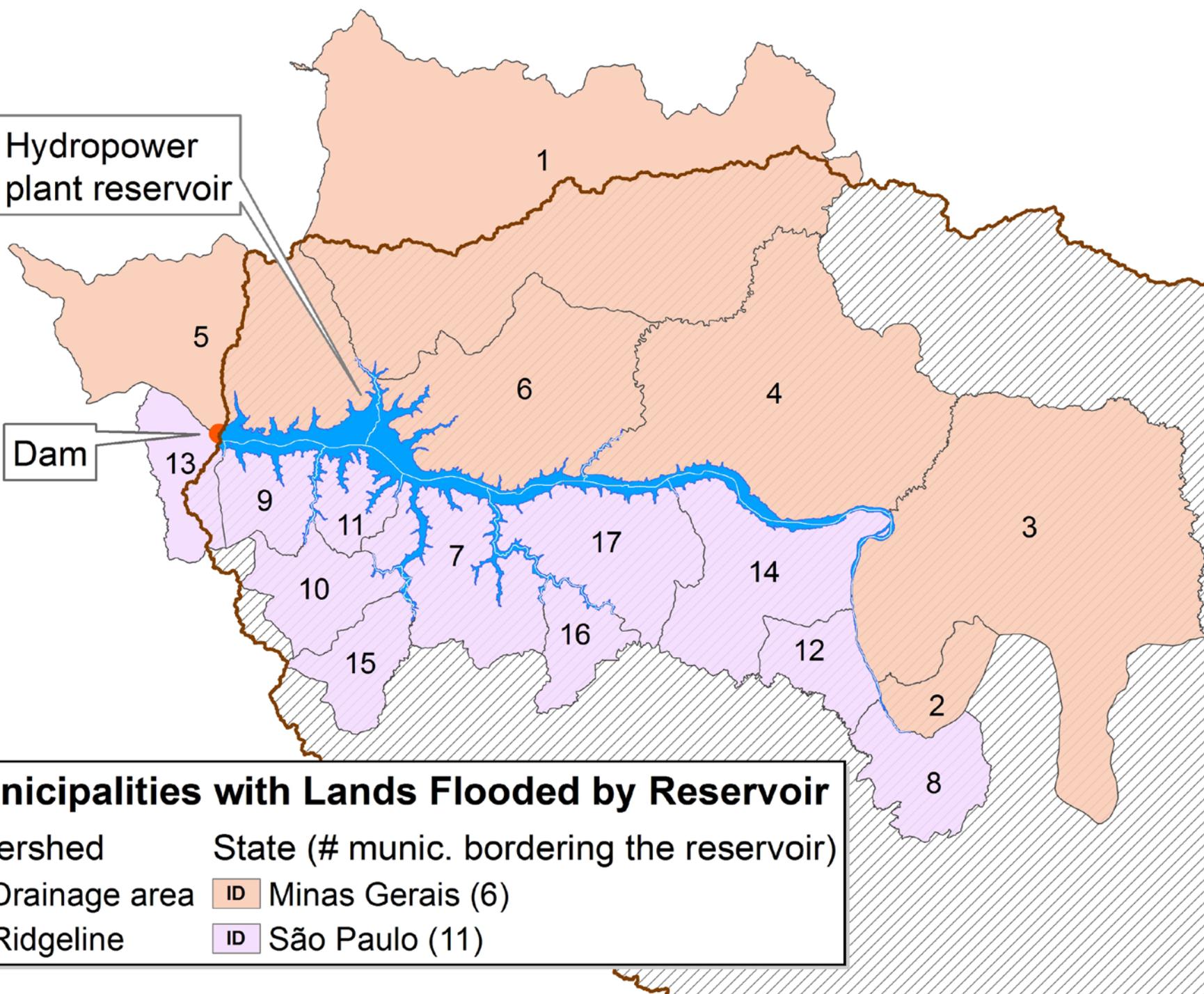


Hydroelectric power plant:

- $h = 57 \text{ m}$
- $Q = 2,226 \text{ m}^3/\text{s}$
- Installed capacity = $\sim 1,400 \text{ MW}$
- 60% of electric energy produced by Minas Gerais
- 12% of total electricity of Brazil

Hydropower plant reservoir

Dam



Municipalities with Lands Flooded by Reservoir

Watershed	State (# munic. bordering the reservoir)
Drainage area	ID Minas Gerais (6)
Ridgeline	ID São Paulo (11)

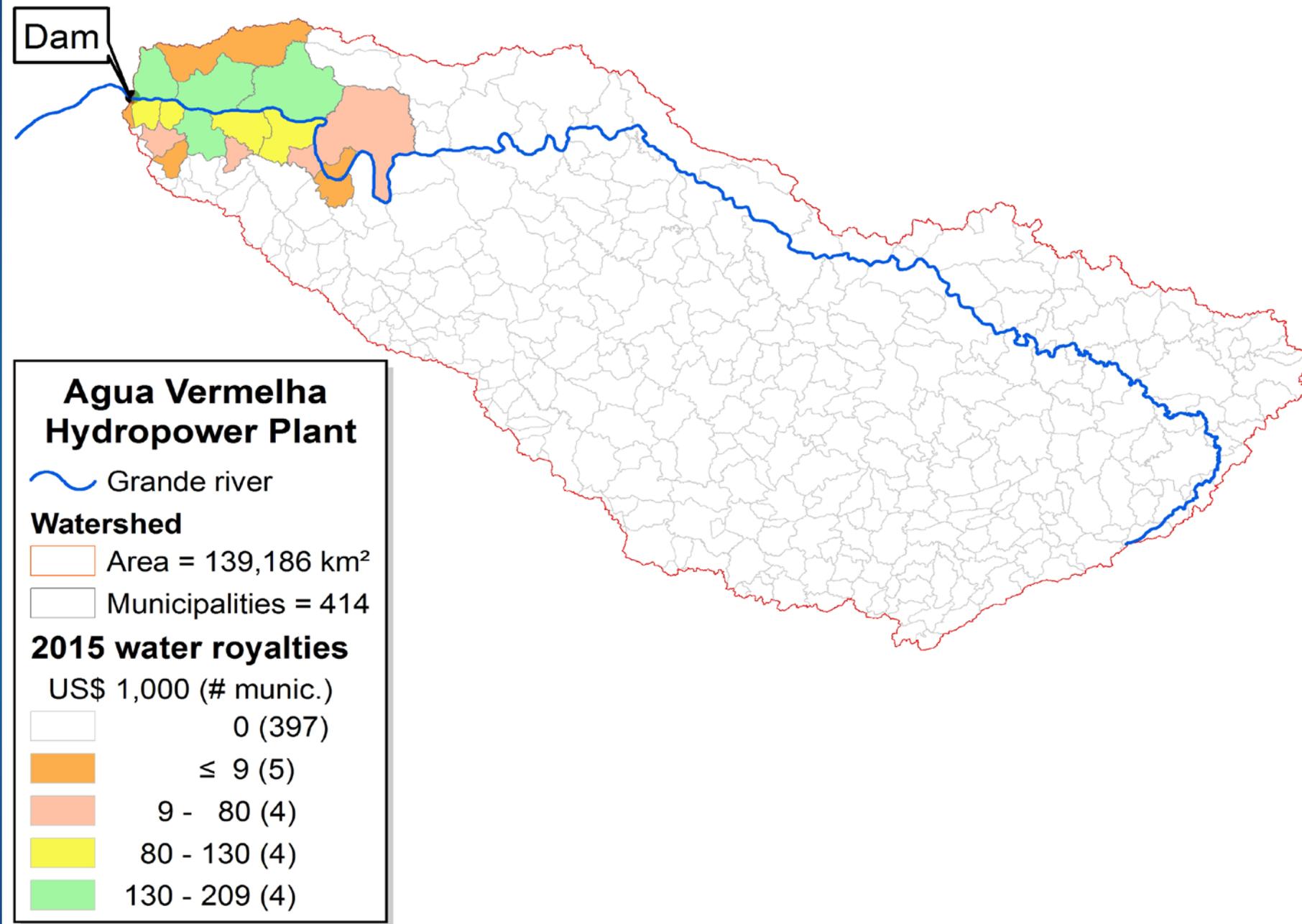
(ONS, 2015)

Current situation:

- US\$ 3.2 million paid by Agua Vermelha hydropower plant as water royalties from Jan. to Aug. 2015.

- Since 1993, it pays annually an average of US\$ 252,000 to each one of the 17 municipalities (6 in MG and 11 in SP) intercepted by the reservoir, plus US\$ 2 million to MG and US\$ 2.3 million to SP.

(ANEEL, 2015)



(Cloropleth map – Quantile classification method: 4 + 1 classes)

Proportional Areal Contributions of Municipalities within Agua Vermelha Watershed to Falling Height and to Water Flow

Municipalities	Quantity	Flooded area (km ²)	Dry area (km ²)	R _h	R _Q
Intercepted by reservoir	17	673.62	11,198.57	100%	8.53 %
Not intercepted by reservoir	397	0.00	127,313.35	0%	91.47%
Total	414	673.62	138,511.92	100%	100%

R_h = relative contributing area of municipalities to head of water (h)

R_Q = relative contributing area of municipalities to water flow (Q)

Proportional Areal Contributions of Municipalities within Agua Vermelha Watershed to the Total Electricity Production

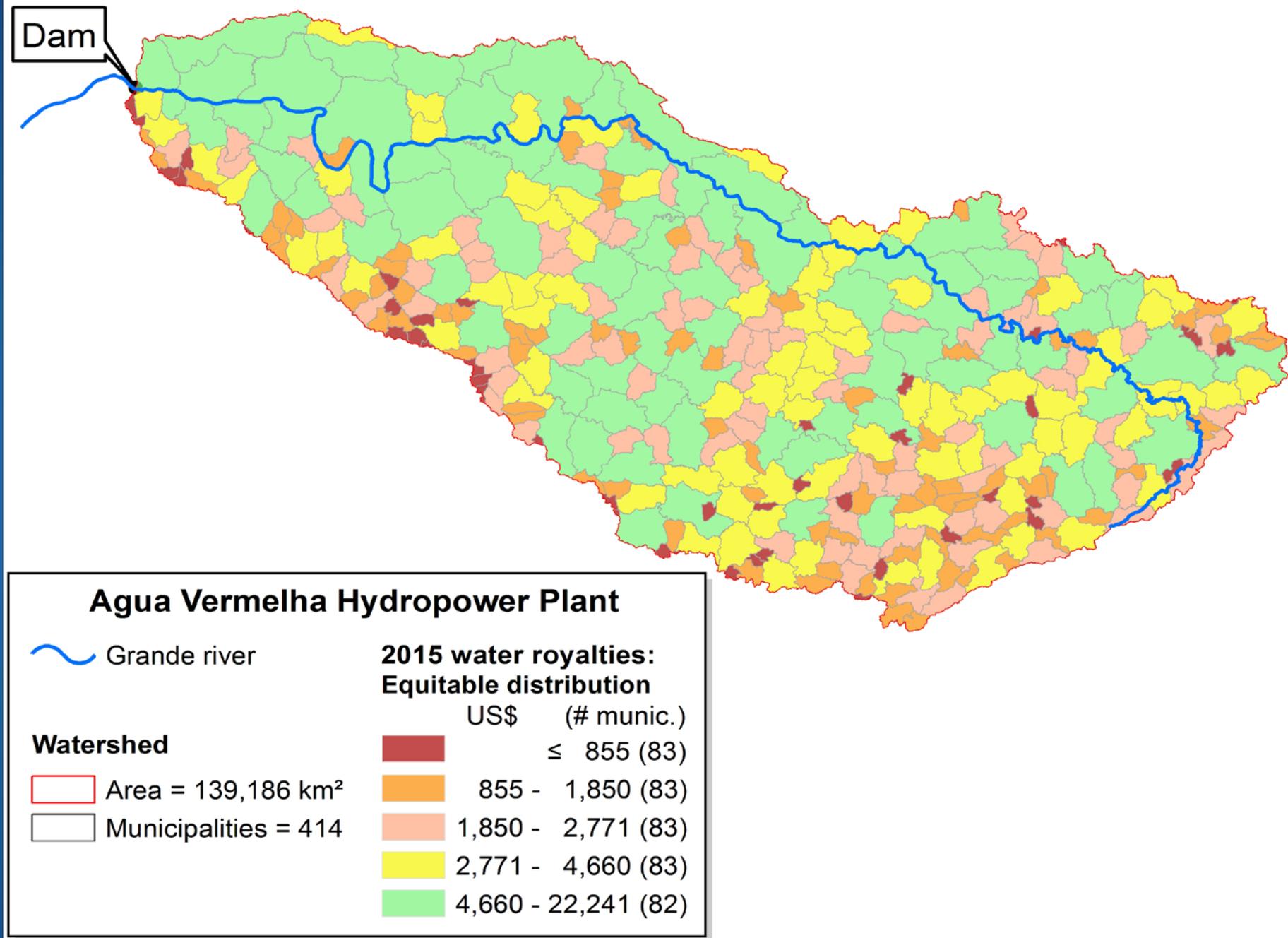
Municipalities	Quantity	P_h	P_Q	Equitable Distribution of Water Royalties
Intercepted by reservoir	17	2.5%	8.3%	10.8%
Not intercepted by reservoir	397	0%	89.2%	89.2%
Total	414	2.5%	97.5%	100%

P_h – percentage contribution of net falling height (h)

P_Q – percentage contribution of water flow (Q)

Modeling Equitable Distribution of Water Royalties

- annual average of ~ US\$ 10,400 to each one of all 414 cities, according to their relative contributions to the total energy produced;
- plus US\$ 2.6 million to MG and US\$ 1.7 million to SP.

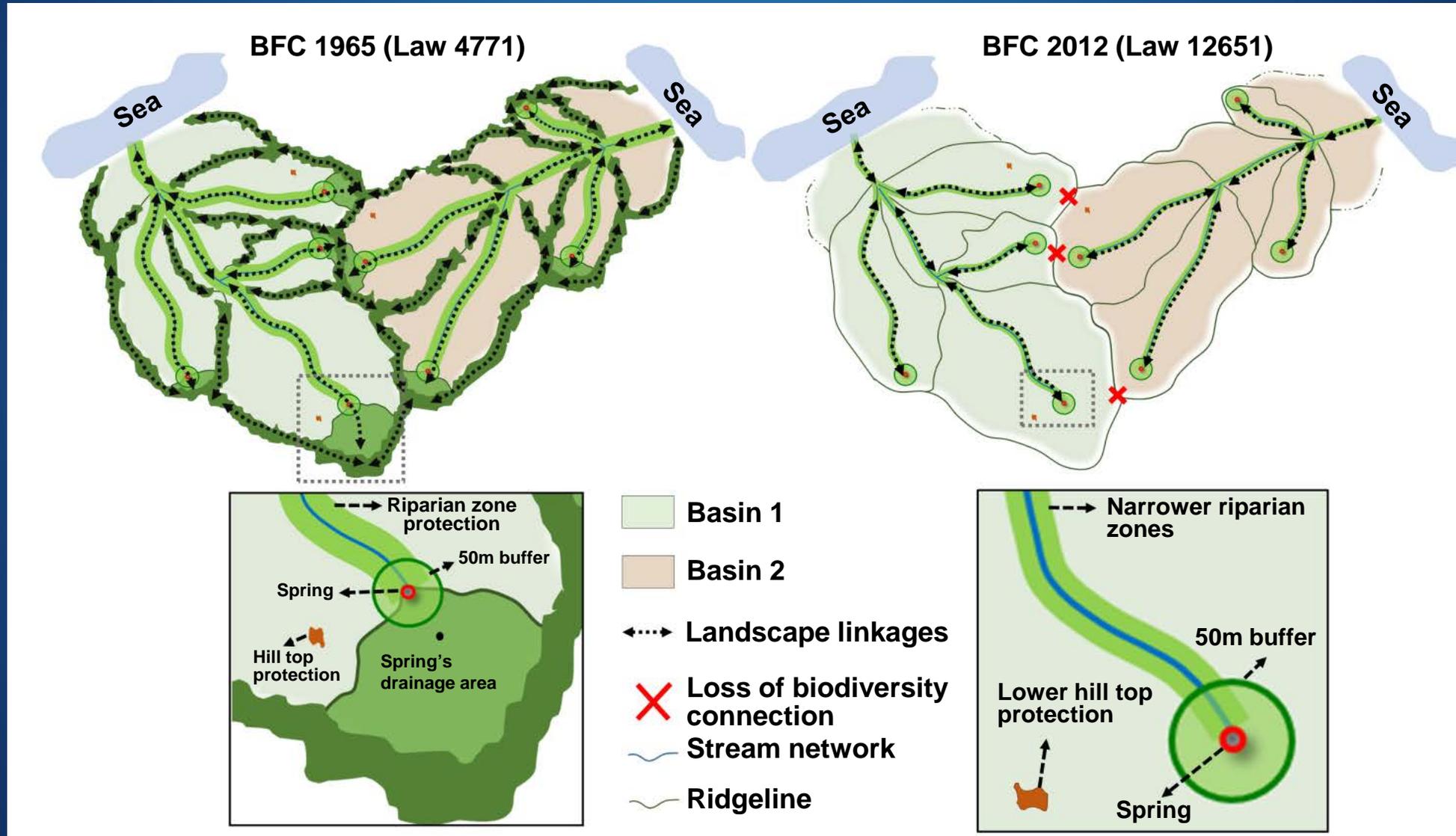


(Choropleth map – Quantile classification method: 5 classes)

Conclusions

- By recognizing water flow as a key component to the production of hydroelectricity, capitals formerly concentrated on towns bordering the reservoir now become evenly distributed throughout the watershed.
- The fair distribution of water royalties has the potential to foster the payment of environmental services originating upstream of a reservoir:
 - *this is the case of the voluntary preservation of remaining native forests along ridgelines, which are no longer protected by the New Brazilian Forest Code.*

Old x New Brazilian Forest Code



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