XXIII SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS
24 A 28 DE NOVEMBRO DE 2019
FOZ DO IGUAÇU - PR

ABRHidro
Associação Brasileira de Recursos Hídricos

# HIDROCOMPLEXIDADE:

## NOVO PARADIGMA PARA OS RECURSOS HÍDRICOS

Francisco de Assis de Souza Filho

Universidade Federal do Ceará

UFC

POSDEHA

G·R·C

# TÓPICOS

1. Definir Complexidade
2. Emergência Prática da Complexidade
3. Teoria em Busca de representar a Complexidade
4. Necessidade de uma Síntese
5. Hidrocomplexidade como Proposta de Síntese
6. Teorias, Métodos e Instrumentos de Análise da Hidrocomplexidade

# DEFINIR
# **COMPLEXIDADE**

# O QUE É COMPLEXIDADE?

"A um primeiro olhar, a complexidade é um tecido (*complexus*: o que é tecido junto) de constituintes heterogêneos inseparavelmente associados: ela elabora o paradoxo do uno no múltiplo.

Num segundo momento, a complexidade é efetivamente o tecido acontecimentos, ações, interações, retroações, determinações, acasos, que constituem nosso mundo fenomênico.

Mas então a complexidade se apresenta com os traços inquietantes do emaranhado do inextricável, da desordem, da ambiguidade, da incerteza...


Por isso o conhecimento necessita ordenar os fenômenos rechaçando a desordem, afastando o incerto, isto é, selecionar os elementos da ordem e da certeza, precisar, clarificar, distinguir, hierarquizar...

Mas tais operações, necessárias à inteligibilidade, correm o risco de provocar a cegueira, se elas eliminarem os outros aspectos do *complexus*; e efetivamente, como eu o indiquei, elas nos deixam cegos"

PAG.13-14.

# Complexity of Coupled Human and Natural Systems

Jianguo Liu,[1*] Thomas Dietz,[2] Stephen R. Carpenter,[3] Marina Alberti,[4] Carl Folke,[5,6] Emilio Moran,[7] Alice N. Pell,[8] Peter Deadman,[9] Timothy Kratz,[10] Jane Lubchenco,[11] Elinor Ostrom,[12] Zhiyun Ouyang,[13] William Provencher,[14] Charles L. Redman,[15] Stephen H. Schneider,[16] William W. Taylor[1]

Integrated studies of coupled human and natural systems reveal new and complex patterns and processes not evident when studied by social or natural scientists separately. Synthesis of six case studies from around the world shows that couplings between human and natural systems vary across space, time, and organizational units. They also exhibit nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and surprises. Furthermore, past couplings have legacy effects on present conditions and future possibilities.

Coupled human and natural systems are integrated systems in which people interact with natural components. Although many studies have examined human-nature interactions (*1*–*5*), the complexity of coupled systems has not been well understood (*6*, *7*). The lack of progress is largely due to the traditional separation of ecological and social sciences (*8*). Although some scholars have studied coupled systems as complex adaptive systems (*9*, *10*), most of the previous work has been theoretical rather than empirical.

An increasing number of interdisciplinary programs have been integrating ecological and social sciences to study coupled human and natural systems (e.g., social-ecological systems and human-environment systems). Here, we synthesize six case studies to demonstrate the approaches used and results found (Fig. 1 and table S1).

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These studies are on five continents: the Kenyan Highlands in Africa (Kenya); the Wolong Nature Reserve for giant pandas in China (Wolong); Central Puget Sound of Washington (Puget Sound) and Northern Highland Lake District of Wisconsin (Wisconsin) in the United States; an area near Altamira, State of Pará, Brazil (Altamira); and Kristianstads Vattenrike of Sweden (Vattenriket) (Fig. 1). They include urban (Puget Sound), semi-urban (Vattenriket), and rural areas (Altamira, Kenya, Wisconsin, and Wolong), and they are in developed countries (Puget Sound, Wisconsin, and Vattenriket) and developing countries (Altamira, Kenya, and Wolong). These studies are in different ecological, socioeconomic, political, demographic, and cultural settings, and they encompass a variety of ecosystem services and environmental problems (table S1).

These studies share four major features. First, they explicitly address complex interactions and feedback between human and natural systems. Unlike traditional ecological research that often excluded human impacts or social research that generally ignored ecological effects, these studies consider both ecological and human components as well as their connections. Thus, they measure not only ecological variables (e.g., landscape patterns, wildlife habitat, and biodiversity) and human variables (e.g., socioeconomic processes, social networks, agents, and structures of multilevel governance) (*11*), but also variables that link natural and human components (e.g., fuelwood collection and use of ecosystem services). Second, each study team is interdisciplinary, engaging both ecological and social scientists around common questions. Third, these studies integrate various tools and techniques from ecological and social sciences as well as other disciplines such as remote sensing and geographic information sciences for data collection, management, analysis, modeling, and integration (*11*–*15*) (table S1). Fourth, they are simultaneously context-specific and longitudinal over periods of time long enough to elucidate temporal dynamics. As such, these studies have offered unique interdisciplinary insights into complexities that cannot be gained from ecological or social research alone.

### Reciprocal Effects and Feedback Loops

In coupled human and natural systems, people and nature interact reciprocally and form complex feedback loops. For example, local residents in Wolong use forests as fuelwood for cooking and heating. As forests near households were depleted due to fuelwood collection (*16*), local residents had to collect fuelwood from areas far away (*17*). Because these forests are bamboo forests (habitat for the endangered giant panda) and the bamboo in the forests is the staple food for the panda, fuelwood collection has led to substantial deterioration in forests and panda habitat (*16*). To prevent further degradation and restore panda habitat, the Chinese government began to implement three major conservation policies several years ago, which help both local residents and panda habitat. In Kenya, local residents convert forests into cropland and intensively cultivate land without supplying additional nutrients, in some cases for more than 100 years. Soil degradation with the resulting decreases in crop yields and greater food insecurity hastens conversion of remaining forests to agriculture. Similarly, in Altamira, 255,739 hectares (ha) of forests had been converted into pasture and cropland as of 2003. As soil quality declines, fertilizers must be applied, crops are shifted to those with lower nutrient requirements, or more forests are converted into cropland (there were still 136,913 ha of forested area in 2003).

Feedback between human and natural systems in the agricultural and tourism sectors of developed countries is in many ways similar to feedback in developing countries. For example, local people (76,000 in 2005) in Vattenriket benefit from ecosystem services that are the result of long-term human management of the agricultural landscape. In Wisconsin, ecosystem conditions affect tourism, which is the mainstay of the economy, but economic development and ecosystem exploitation from tourism often degrade the qualities that attract tourists.

The ecological and socioeconomic patterns and processes in urban coupled systems are different from those in rural areas. They are mediated by factors such as the urban form, built infrastructure, and location and consumption preferences of heterogeneous households and businesses. For example, in Puget Sound, a distinctive spatial heterogeneity can be observed across an urban to rural gradient in relation to diverse development patterns (*18*). Land-cover changes influence biophysical processes (e.g., water purification) and stream biotic integrity (*15*). Furthermore, changes in land cover due to development in turn affect land value and real estate markets, as evidenced by values of real estate having up to a 6.5% premium associated with forest cover (*19*).





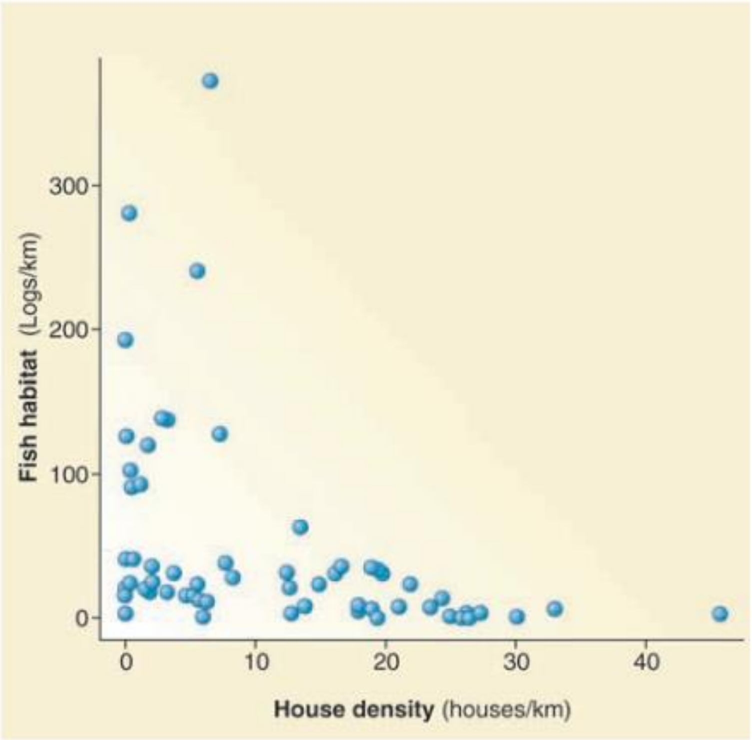


**Fig. 2.** The relationship between fish habitat (logs per kilometer) and house density in the Northern Highland Lake District of Wisconsin, United States. [modified from (*38*), with permission]

# DEFININDO **COMPLEXIDADE**

COMPLEXO
DISTINÇÃO
CONJUNÇÃO

REDUCIONISMO

SIMPLES
DISJUNÇÃO
REDUÇÃO
ABSTRAÇÃO

DIFÍCIL

REDUCIONISMO
X
COMPLEXIDADE

FÁCIL

# DEFININDO **COMPLEXIDADE**

Complex systems are networks made of a number of components that interact with each other, typically in a nonlinear fashion. Complex systems may arise and evolve through self-organization, such that they are neither completely regular nor completely random, permitting the development of emergent behavior at macroscopic scales.

Emergence is a nontrivial relationship between the properties of a system at microscopic and macroscopic scales. Macroscopic properties are called emergent when it is hard to explain simply from microscopic properties.

Self-organization is a dynamic process by which a system spontaneously forms nontrivial macroscopic structures and/or behaviors over time.

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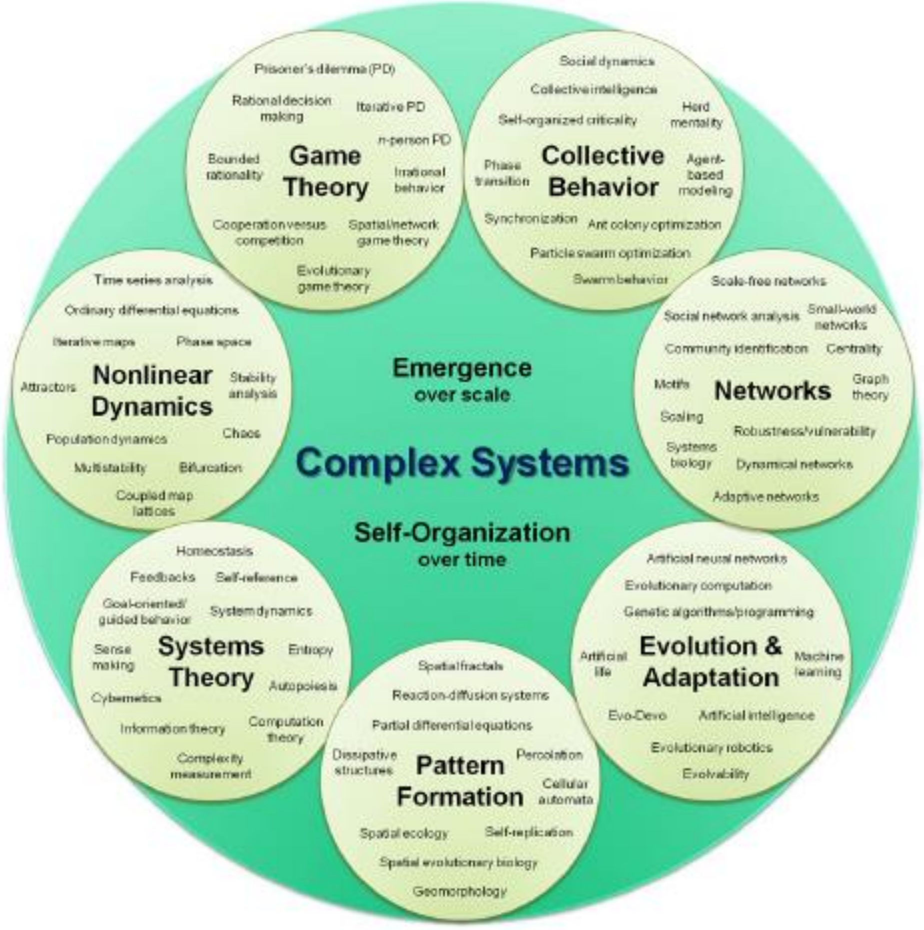
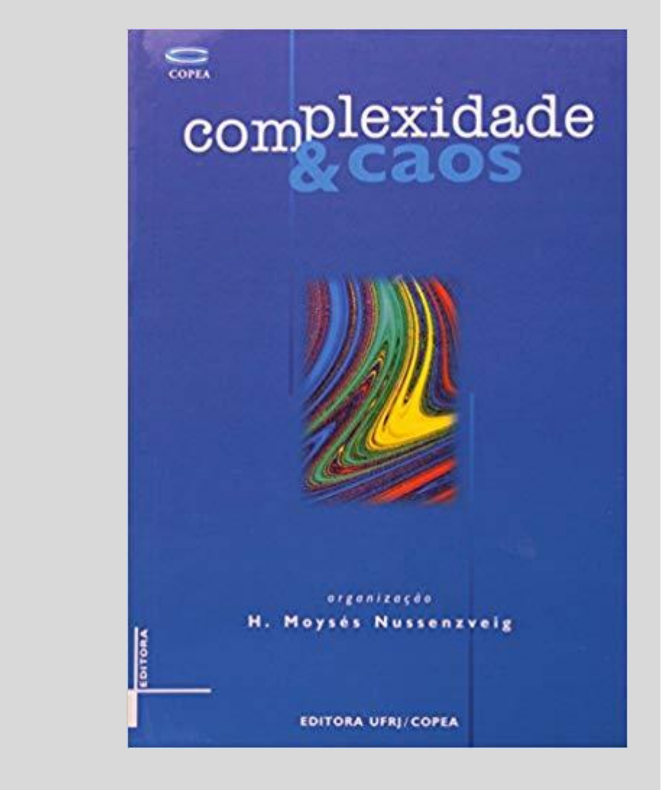



Figure 1.1: Visual, organizational map of complex systems science broken into seven topical areas. The three circles on the left (Nonlinear Dynamics, Systems Theory, and Game Theory) are the historical roots of complex systems science, while the other four circles (Pattern Formation, Evolution and Adaptation, Networks, and Collective Behavior) are the more recently studied topical areas. Created by the author and available from Wikipedia [3].

# CARACTERÍSTICAS DA **COMPLEXIDADE**

1. **SISTEMA DINÂMICO** em evolução constante, formado por **GRANDE NÚMERO DE UNIDADES**
2. Cada unidade interage com um certo número de unidades, bem menor, de outras
3. **SISTEMA ABERTO** interagindo com o ambiente
4. Cada unidade produz resposta aos sinais que recebe, sem guardar relação de proporcionalidade **SISTEMA NÃO LINEAR**
5. **APRENDIZADO**: sistemas complexos adaptativos
6. **ALEATORIEDADE**
7. **ORDEM EMERGENTE:** sistema se auto-organiza
8. **SISTEMA HIERÁRQUICO**
9. **ATRATORES MÚLTIPLOS**
10. **QUEBRA DE ERGODICIDADE**
11. **PROPRIEDADES COLETIVAS EMERGENTES**, qualitativamente novas



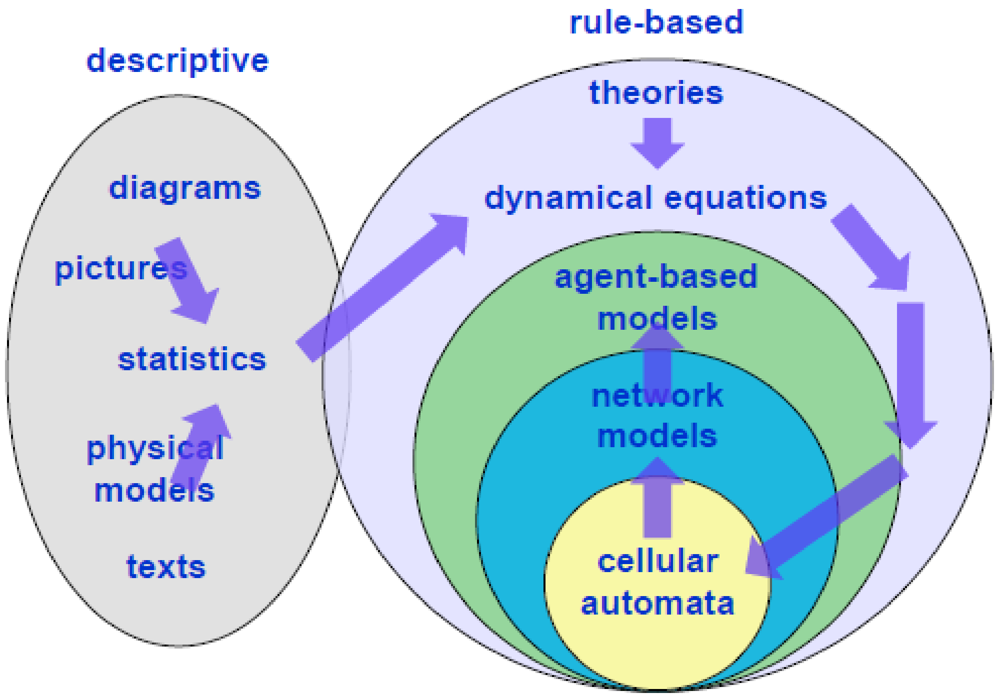

Pag. 11-12

# MODELAGEM DE **SISTEMAS COMPLEXOS**

A *model* is a simplified representation of a system. It can be conceptual, verbal, diagrammatic, physical, or formal (mathematical).

**Descriptive modeling** In this approach, researchers try to specify the actual state of a system at a given time point (or at multiple time points) in a descriptive manner. Taking a picture, creating a miniature (this is literally a "model" in the usual sense of the word), and writing a biography of someone, all belong to this family of modeling effort. This can also be done using quantitative methods (e.g., equations, statistics, computational algorithms), such as regression analysis and pattern recognition. They all try to capture "what the system looks like."

**Rule-based modeling** In this approach, researchers try to come up with dynamical rules that can explain the observed behavior of a system. This allows researchers to make predictions of its possible (e.g., future) states. Dynamical equations, theories, and first principles, which describe how the system will change and evolve over time, all belong to this family of modeling effort. This is usually done using quantitative methods, but it can also be achieved at conceptual levels as well (e.g., Charles Darwin's evolutionary theory). They all try to capture "how the system will behave."

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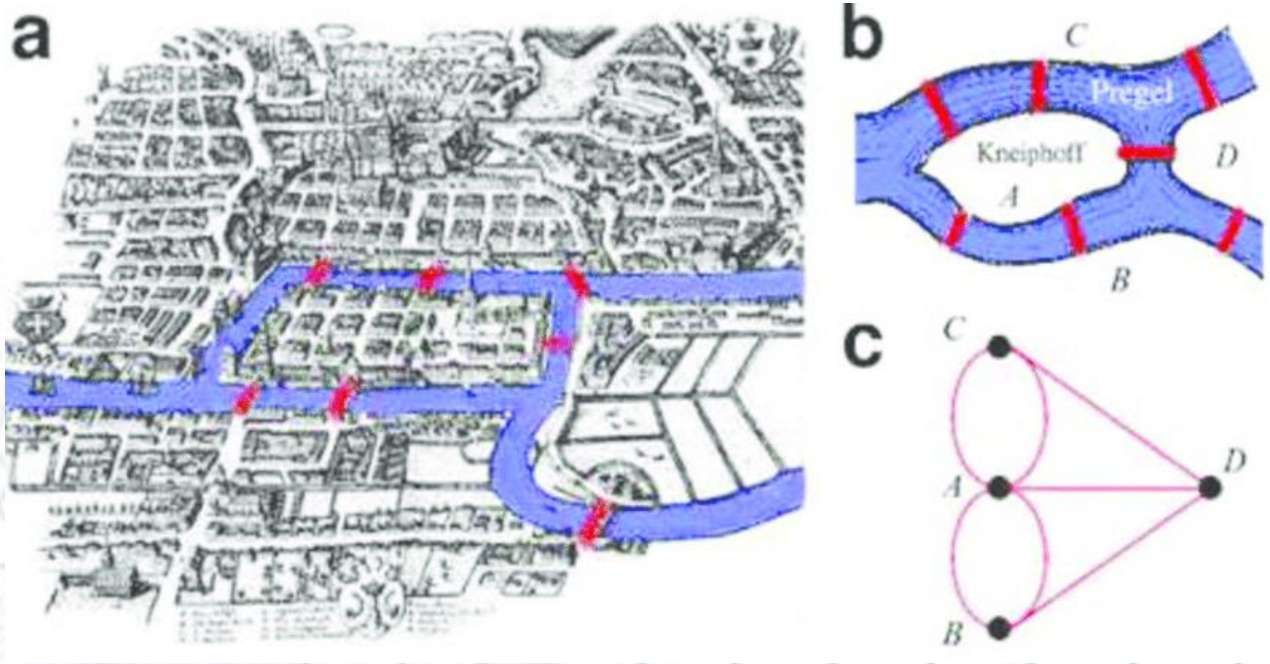


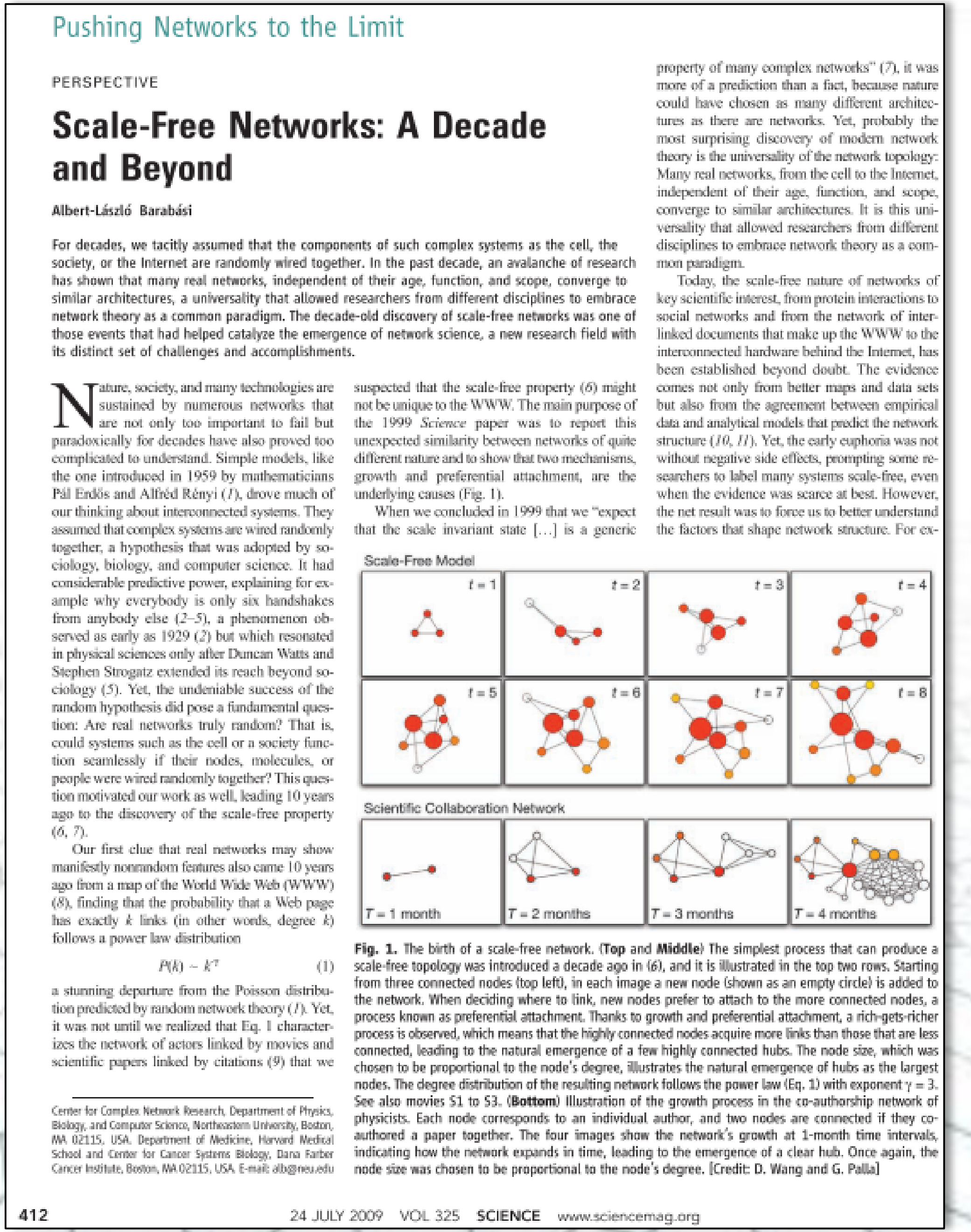


PERSPECTIVE

# Scale-Free Networks: A Decade and Beyond

Albert-László Barabási

For decades, we tacitly assumed that the components of such complex systems as the cell, the society, or the Internet are randomly wired together. In the past decade, an avalanche of research has shown that many real networks, independent of their age, function, and scope, converge to similar architectures, a universality that allowed researchers from different disciplines to embrace network theory as a common paradigm. The decade-old discovery of scale-free networks was one of those events that had helped catalyze the emergence of network science, a new research field with its distinct set of challenges and accomplishments.

Nature, society, and many technologies are sustained by numerous networks that are not only too important to fail but paradoxically for decades have also proved too complicated to understand. Simple models, like the one introduced in 1959 by mathematicians Pál Erdös and Alfréd Rényi (1), drove much of our thinking about interconnected systems. They assumed that complex systems are wired randomly together, a hypothesis that was adopted by sociology, biology, and computer science. It had considerable predictive power, explaining for example why everybody is only six handshakes from anybody else (2–5), a phenomenon observed as early as 1929 (2) but which resonated in physical sciences only after Duncan Watts and Stephen Strogatz extended its reach beyond sociology (5). Yet, the undeniable success of the random hypothesis did pose a fundamental question: Are real networks truly random? That is, could systems such as the cell or a society function seamlessly if their nodes, molecules, or people were wired randomly together? This question motivated our work as well, leading 10 years ago to the discovery of the scale-free property (6, 7).

Our first clue that real networks may show manifestly nonrandom features also came 10 years ago from a map of the World Wide Web (WWW) (8), finding that the probability that a Web page has exactly $k$ links (in other words, degree $k$) follows a power law distribution

$$P(k) \sim k^{\gamma} \quad (1)$$

a stunning departure from the Poisson distribution predicted by random network theory (1). Yet, it was not until we realized that Eq. 1 characterizes the network of actors linked by movies and scientific papers linked by citations (9) that we suspected that the scale-free property (6) might not be unique to the WWW. The main purpose of the 1999 *Science* paper was to report this unexpected similarity between networks of quite different nature and to show that two mechanisms, growth and preferential attachment, are the underlying causes (Fig. 1).

When we concluded in 1999 that we "expect that the scale invariant state […] is a generic property of many complex networks" (7), it was more of a prediction than a fact, because nature could have chosen as many different architectures as there are networks. Yet, probably the most surprising discovery of modern network theory is the universality of the network topology: Many real networks, from the cell to the Internet, independent of their age, function, and scope, converge to similar architectures. It is this universality that allowed researchers from different disciplines to embrace network theory as a common paradigm.

Today, the scale-free nature of networks of key scientific interest, from protein interactions to social networks and from the network of interlinked documents that make up the WWW to the interconnected hardware behind the Internet, has been established beyond doubt. The evidence comes not only from better maps and data sets but also from the agreement between empirical data and analytical models that predict the network structure (10, 11). Yet, the early euphoria was not without negative side effects, prompting some researchers to label many systems scale-free, even when the evidence was scarce at best. However, the net result was to force us to better understand the factors that shape network structure. For ex-



**Fig. 1.** The birth of a scale-free network. (**Top** and **Middle**) The simplest process that can produce a scale-free topology was introduced a decade ago in (6), and it is illustrated in the top two rows. Starting from three connected nodes (top left), in each image a new node (shown as an empty circle) is added to the network. When deciding where to link, new nodes prefer to attach to the more connected nodes, a process known as preferential attachment. Thanks to growth and preferential attachment, a rich-gets-richer process is observed, which means that the highly connected nodes acquire more links than those that are less connected, leading to the natural emergence of a few highly connected hubs. The node size, which was chosen to be proportional to the node's degree, illustrates the natural emergence of hubs as the largest nodes. The degree distribution of the resulting network follows the power law (Eq. 1) with exponent $\gamma = 3$. See also movies S1 to S3. (**Bottom**) Illustration of the growth process in the co-authorship network of physicists. Each node corresponds to an individual author, and two nodes are connected if they co-authored a paper together. The four images show the network's growth at 1-month time intervals, indicating how the network expands in time, leading to the emergence of a clear hub. Once again, the node size was chosen to be proportional to the node's degree. [Credit: D. Wang and G. Palla]

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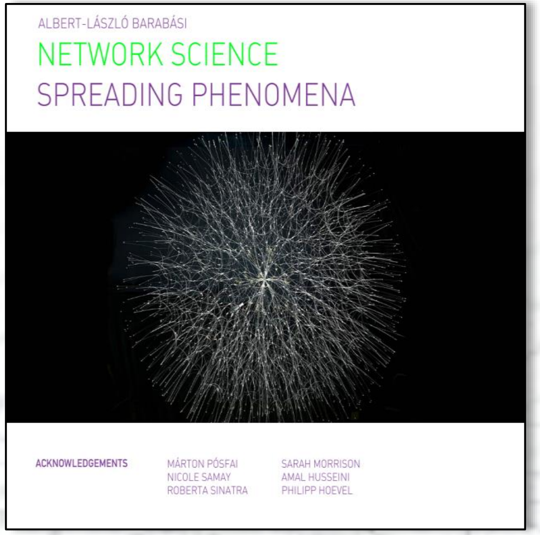
# EXEMPLO DE **REDES COMPLEXAS**



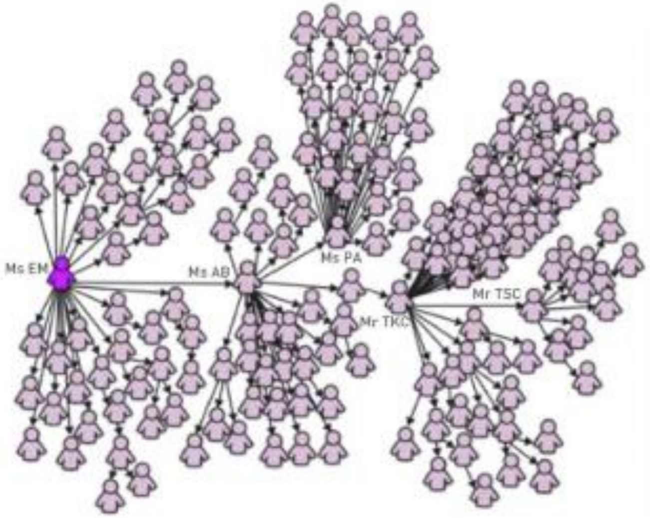




**Figure 10.1**

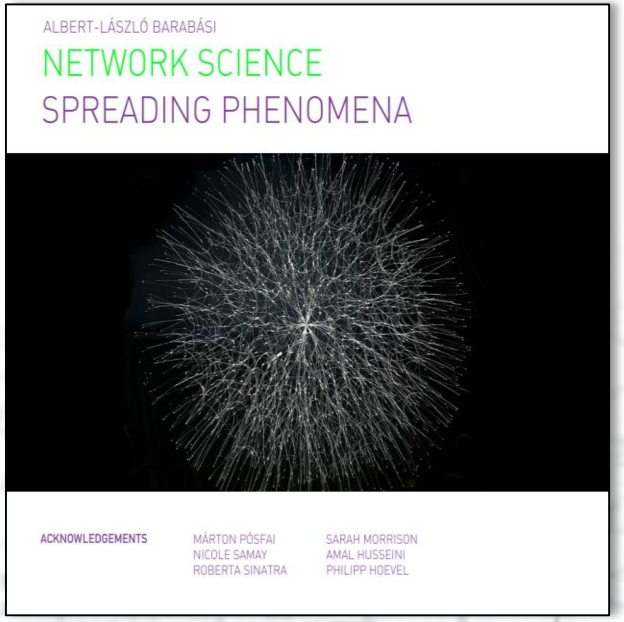
**Super-spreaders**

One-hundred-forty-four of the 206 SARS patients diagnosed in Singapore were traced to a chain of five individuals that included four *super-spreaders*. The most important of these was *Patient Zero*, the physician from Guangdong Province in China, who brought the disease to the Metropole Hotel. After [1].

Na noite de 21 de fevereiro de 2003, um médico da província de Guangdong, no sul da China, entrou no Metropole Hotel em Hong Kong. Ele já tratou pacientes que sofriam de uma doença que, sem um diagnóstico claro, era chamada de pneumonia atípica. No dia seguinte, depois de deixar o hotel, ele foi ao hospital local, desta vez como paciente. Ele morreu lá vários dias depois de pneumonia atípica.

O médico não saiu do hotel sem deixar rastro: naquela noite, dezesseis outros hóspedes do Metropole Hotel e um visitante também contraíram a doença que acabou sendo renomeada para Síndrome Respiratória Aguda Grave (SARS). Esses convidados levaram o vírus da SARS para Hanói, Cingapura e Toronto, provocando surtos em cada uma dessas cidades. Epidemiologistas mais tarde localizaram perto da metade dos 8.100 casos documentados de SARS no Metropole Hotel. Com isso, o médico que trouxe o vírus para Hong Kong se tornou um exemplo de super espalhador, um indivíduo responsável por um número desproporcional de infecções durante uma epidemia.

# EXEMPLO DE **REDES COMPLEXAS**



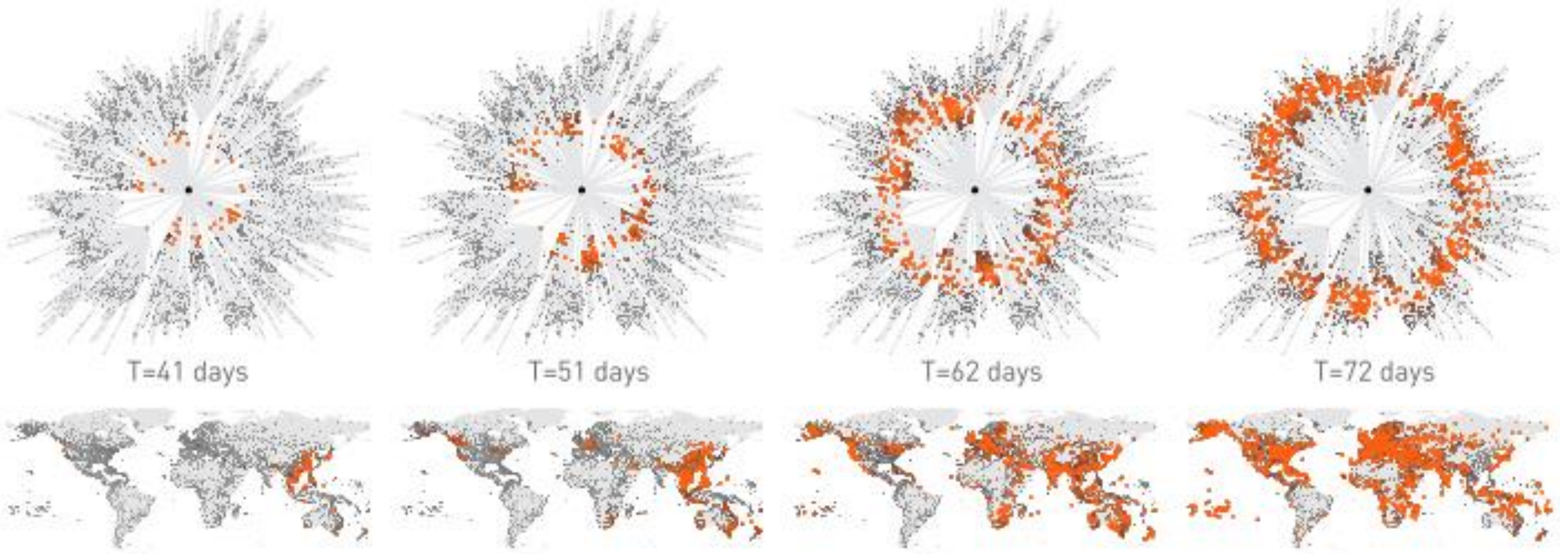




Figure 10.31

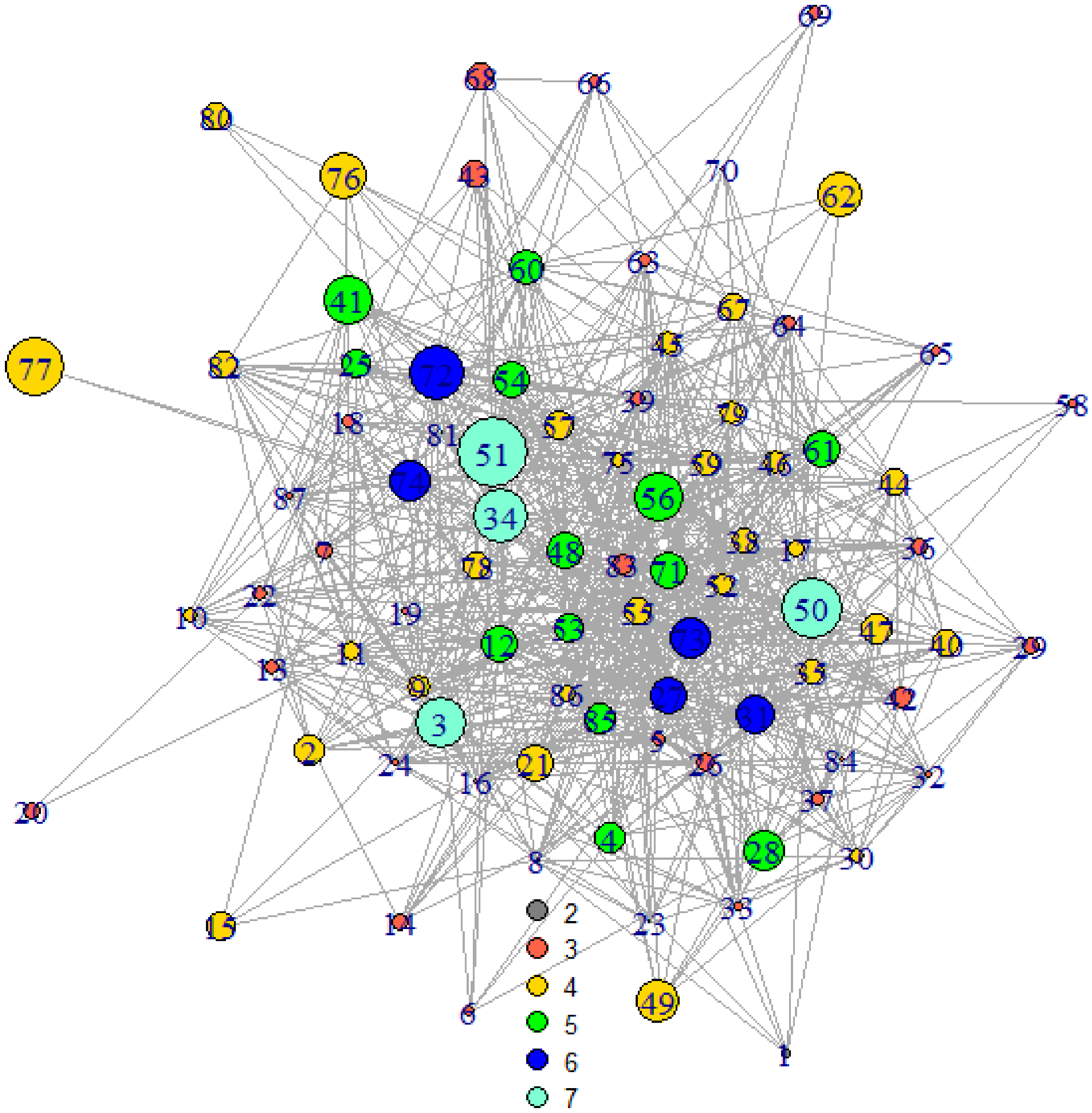
**Effective Distance**

The spread of a pandemic with an initial outbreak in Hong Kong. Regions with a large number of infections are shown as red nodes. Each panel compares the state of the system in the conventional geographic representation (bottom) with the effective distance representation (top). The complex spatial pattern observed in the geographic representation becomes a circular wave that moves outwards at constant speed in the effective distance representation (see also the Online Resource 10.6). After [89].

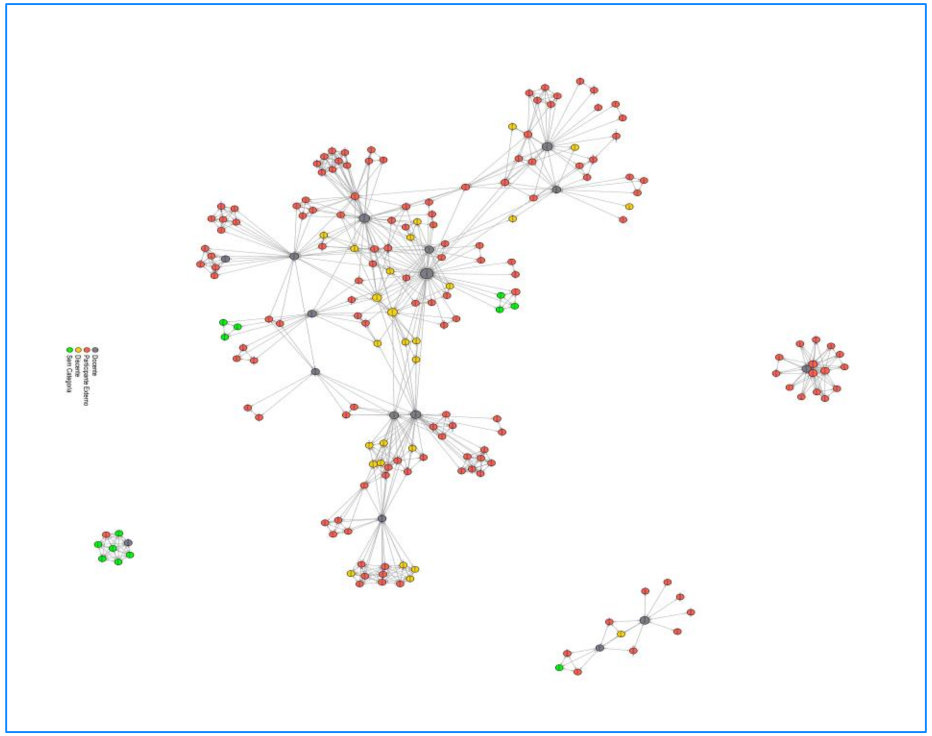
EPIDEMIC PREDICTION

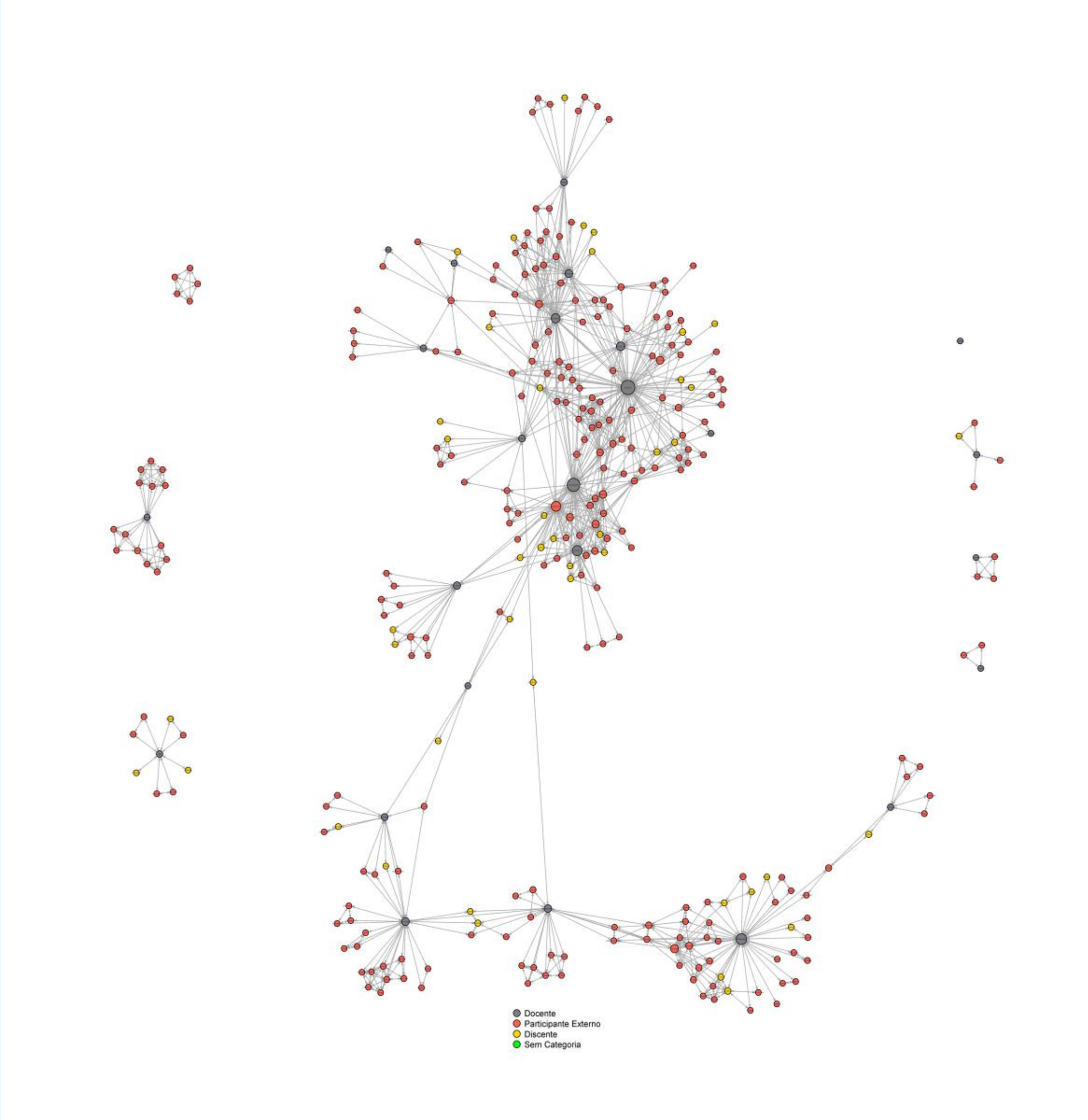
# EXEMPLO DE **REDES COMPLEXAS**

REDE DE PÓS-GRADUAÇÃO DE ENGENHARIAS I – ACADÊMICOS
ARCOS SÃO BANCAS



# EXEMPLO DE **REDES COMPLEXAS**






Rede de colaboração entre pesquisadores em artigos em periódicos por curso de pós-graduação

# EMERGÊNCIA PRÁTICA DA **COMPLEXIDADE**

# EMERGÊNCIA PRÁTICA DA **COMPLEXIDADE**

| | | | |
|---|---|---|---|
| Gestão do risco climático | Gestão de conflito em recursos hídricos | Hidrologia em bacias “engenheiradas” | Águas em ambiente urbano |
| Serviços ambientais em rios e bacias hidrográficas: restauração fluvial | Não estacionariedade devido a mudança do uso do solo e clima | Segurança hídrica e incerteza nas demandas: dinâmica economia | Gestão de secas |

I

# HUMANIDADE - NATUREZA

Hydrol. Earth Syst. Sci., 18, 319–332, 2014
www.hydrol-earth-syst-sci.net/18/319/2014/
doi:10.5194/hess-18-319-2014


Hydrology and Earth System Sciences
Open Access

**Evolving water science in the Anthropocene**

H. H. G. Savenije[1], A. Y. Hoekstra[2], and P. van der Zaag[1,3]

**ANTROPOCENO**: Os seres humanos formam uma força geofísica significativa (Steffen et al., 2007).

Nossa espécie está modificando fortemente o ciclo da água terrestre interceptando o fluxo do rio das terras altas para o mar e, através da mudança da cobertura da terra, alterando o fluxo de vapor de água da terra para a atmosfera.

O conhecimento da engenharia e gestão da hidrologia e dos recursos hídricos ajudou a transformar a paisagem e, portanto, também a própria hidrologia nas próprias bacias hidrográficas.

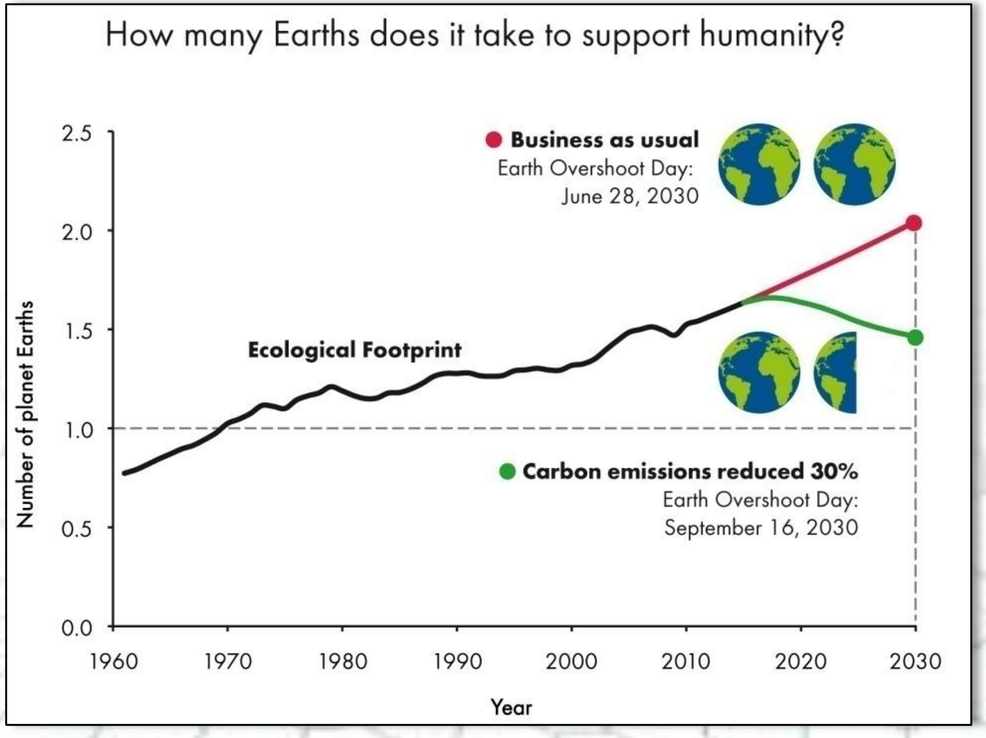
"Testemunhamos um processo de co-evolução entre o sistema natural e a sociedade, pelo qual os limites do sistema de apoio ambiental forçam as sociedades a tomar ações, sejam elas defensivas, evasivas, ofensivas, corretivas ou acomodativas."

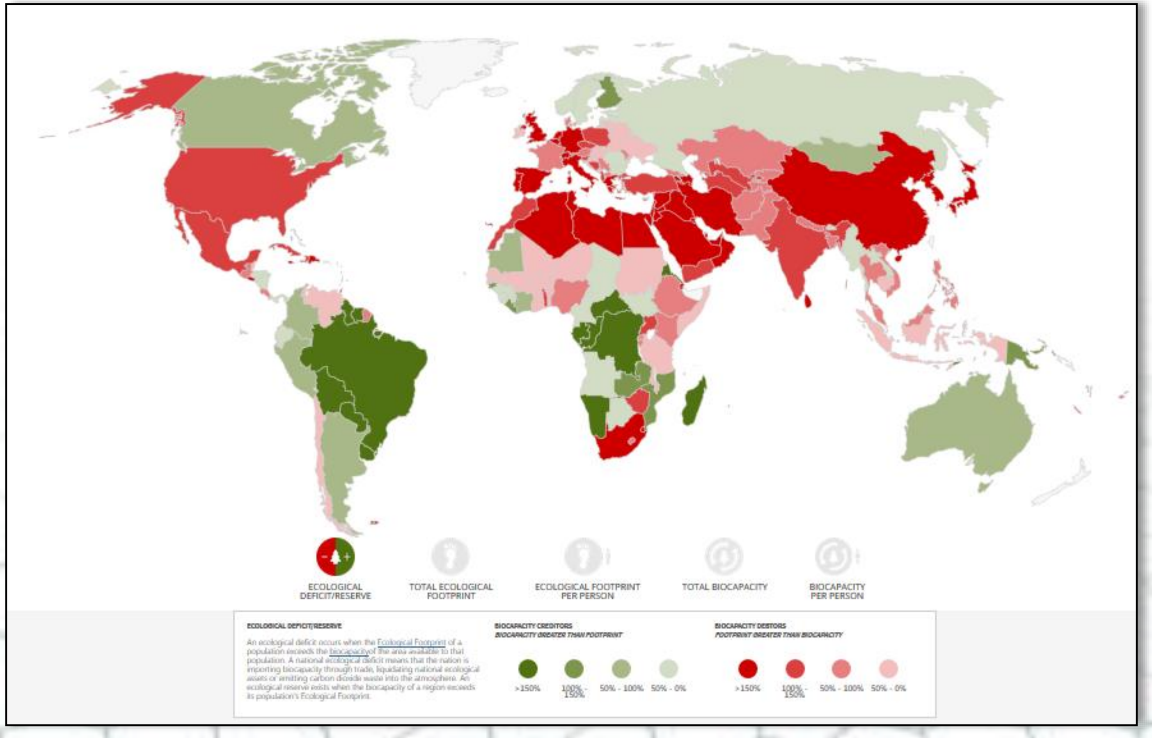
*(H. H. G. Savenije et al.: Evolving water science in the Anthropocene; Hydrol. Earth Syst. Sci., 18, 319–332, 2014)*

Os seres humanos mudaram a resposta hidrológica de muitas bacias hidrográficas do mundo através de um ou mais dos seguintes meios:

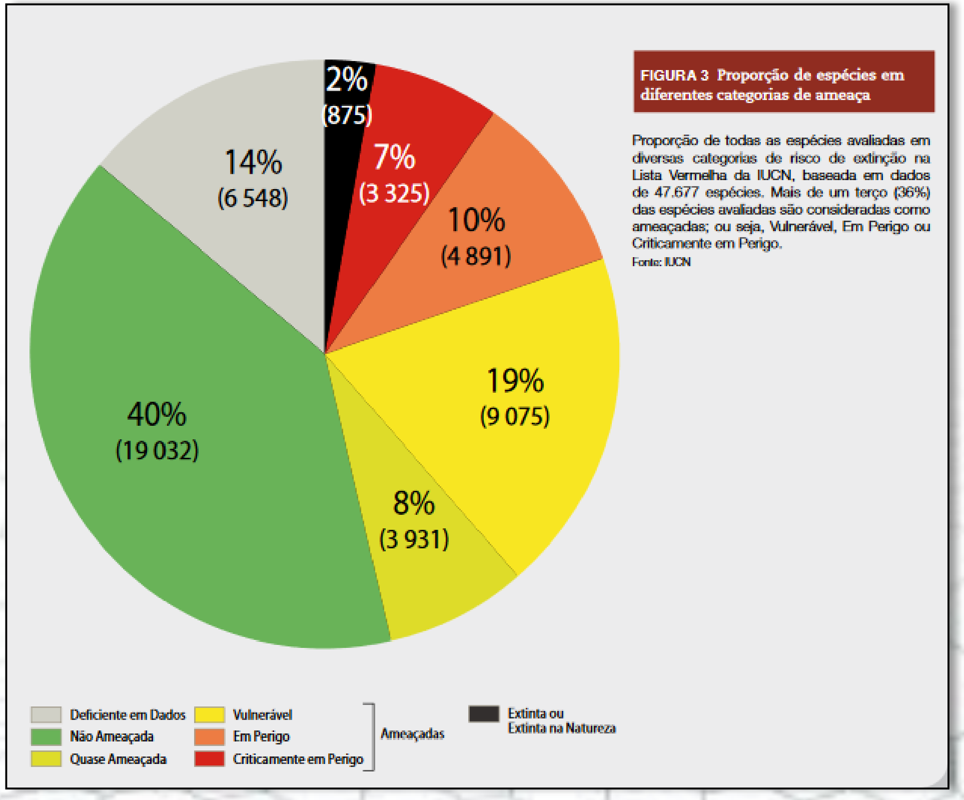
(a) Retirada direta dos fluxos de água, incluindo transferências entre bacias para suprimentos de água para cidades, indústrias e agricultura;
(b) transformação da rede de riachos, por exemplo, através da construção de barragens e reservatórios ou canalização de rios;
(c) alteração das características da bacia de drenagem, por exemplo, através de desmatamento, urbanização, drenagem de áreas úmidas e práticas agrícolas; e
(d) atividades que alteram o clima regional ou global, por exemplo, melhorando as emissões de gases de efeito estufa, as mudanças de cobertura da terra e o consumo de água consumido.
(e) Além disso, os seres humanos influenciaram fortemente a qualidade física, química e biológica de córregos, lagos e massas de águas subterrâneas através de vários tipos de fontes difusas e pontuais de poluição

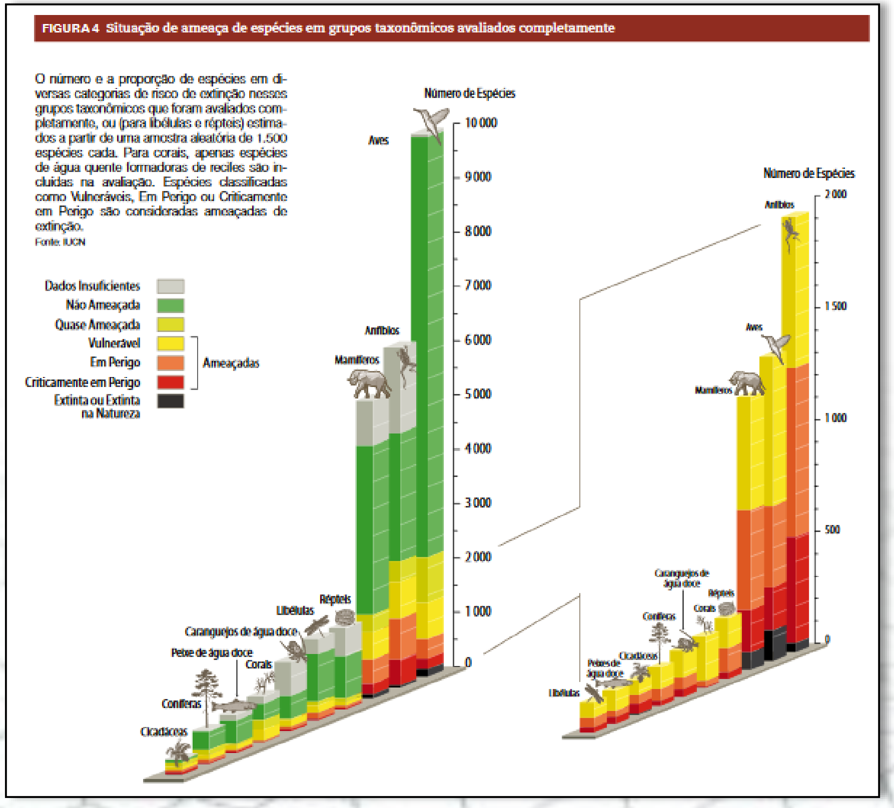
# PEGADA ECOLÓGICA



# MEGA EXTINÇÕES





**EXTINÇÃO DE FUNDO X EXTINÇÕES EM MASSA**
Anfíbios: calcula-se que a taxa de extinção do grupo pode ser até 45 mil vezes superior à taxa de fundo.
Estima-se que um terço de todos os recifes de corais, um terço de todos os moluscos de água doce, um terço dos tubarões e arraias, um quarto dos mamíferos, um quinto de todos os répteis e um sexto de todas as aves estão a caminho do desaparecimento.

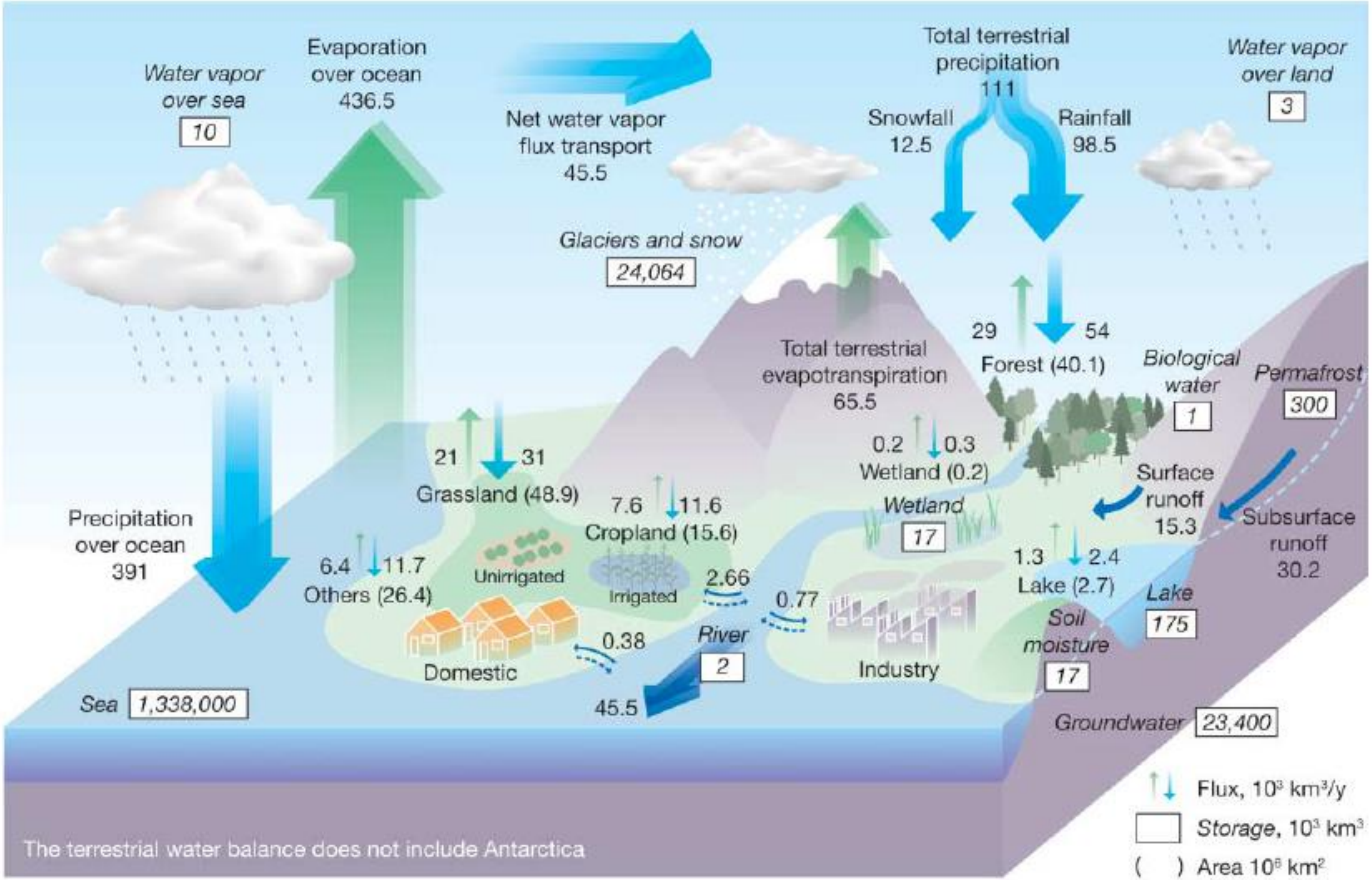



**Fig. 1.** Global hydrological fluxes (1000 km³/year) and storages (1000 km³) with natural and anthropogenic cycles are synthesized from various sources (*1*, *3*–*5*). Big vertical arrows show total annual precipitation and evapotranspiration over land and ocean (1000 km³/year), which include annual precipitation and evapotranspiration in major landscapes (1000 km³/year) presented by small vertical arrows; parentheses indicate area (million km²). The direct groundwater discharge, which is estimated to be about 10% of total river discharge globally (*6*), is included in river discharge.

**Global Hydrological Cycles and World Water Resources**

Taikan Oki[1,2,3]*† and Shinjiro Kanae[1,4]*

Tempo de Residência

PNAS

# Human modification of global water vapor flows from the land surface

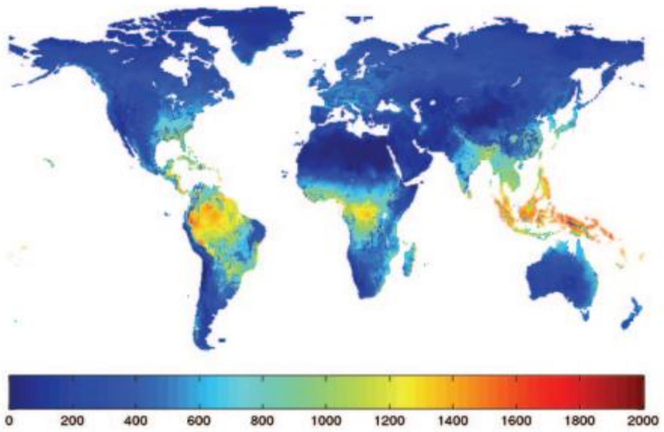
Line J. Gordon*†, Will Steffen‡, Bror F. Jönsson§, Carl Folke*, Malin Falkenmark¶, and Åse Johannessen*

Departments of *Systems Ecology and §Meteorology, Stockholm University, SE-106 91 Stockholm, Sweden; ‡Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Australian Government, G.P.O. Box 858, Canberra ACT 2601, Australia; and ¶Stockholm International Water Institute, Hantverkargatan 5, SE-112 21 Stockholm, Sweden

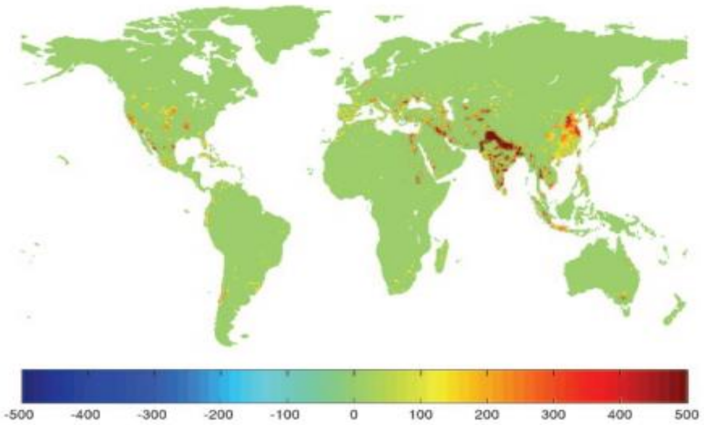
Edited by Stephen R. Carpenter, University of Wisconsin, Madison, WI, and approved April 11, 2005 (received for review January 10, 2005)

7612–7617 | PNAS | May 24, 2005 | vol. 102 | no. 21 www.pnas.org/cgi/doi/10.1073/pnas.0500208102

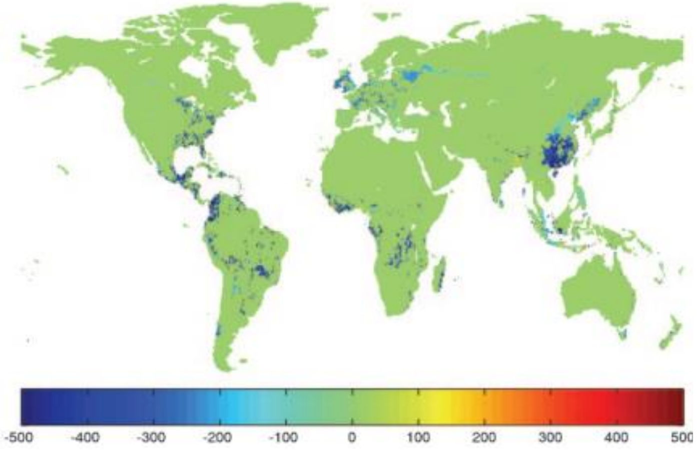
ANTES DO IMPACTO



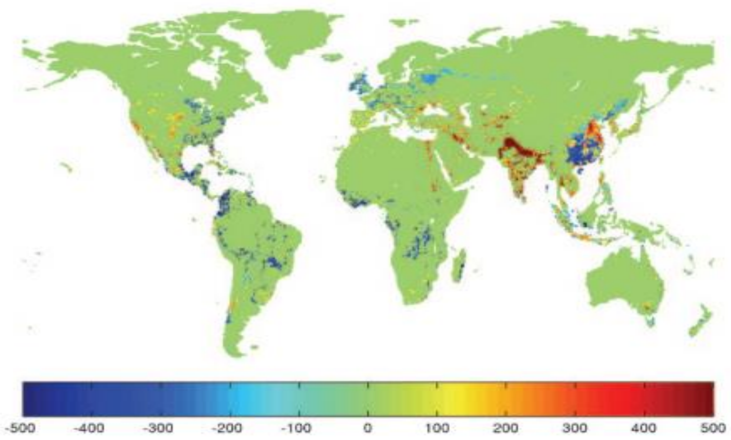

IRRIGAÇÃO




DESMATAMENTO

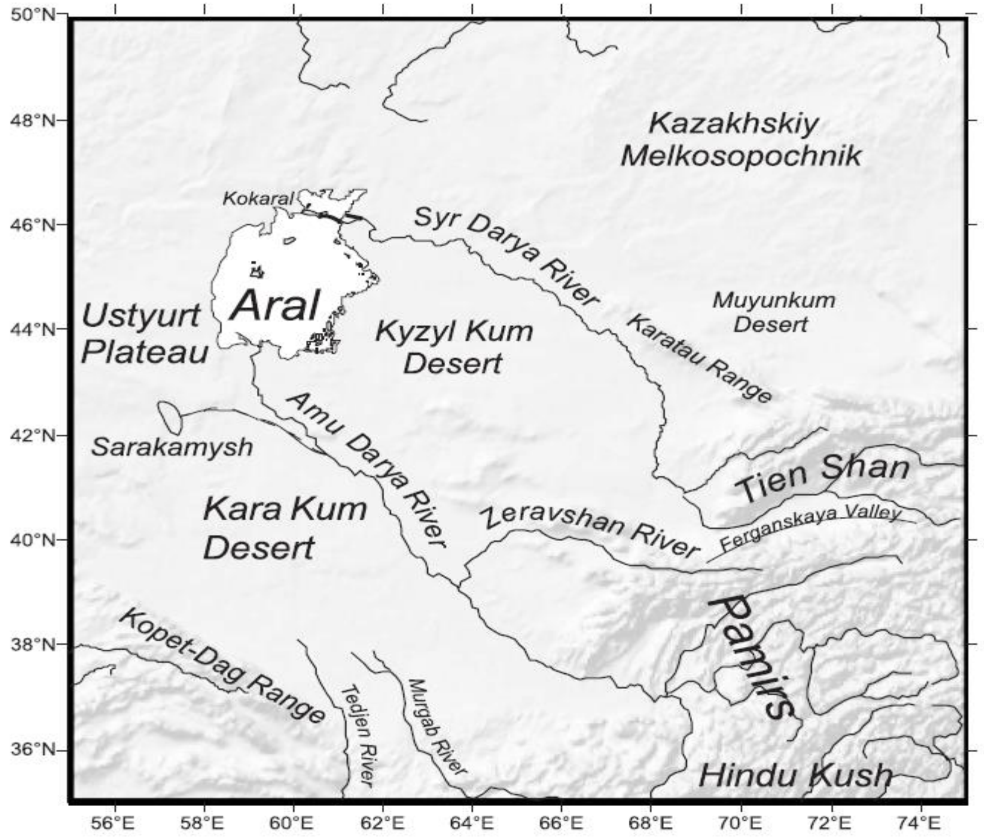


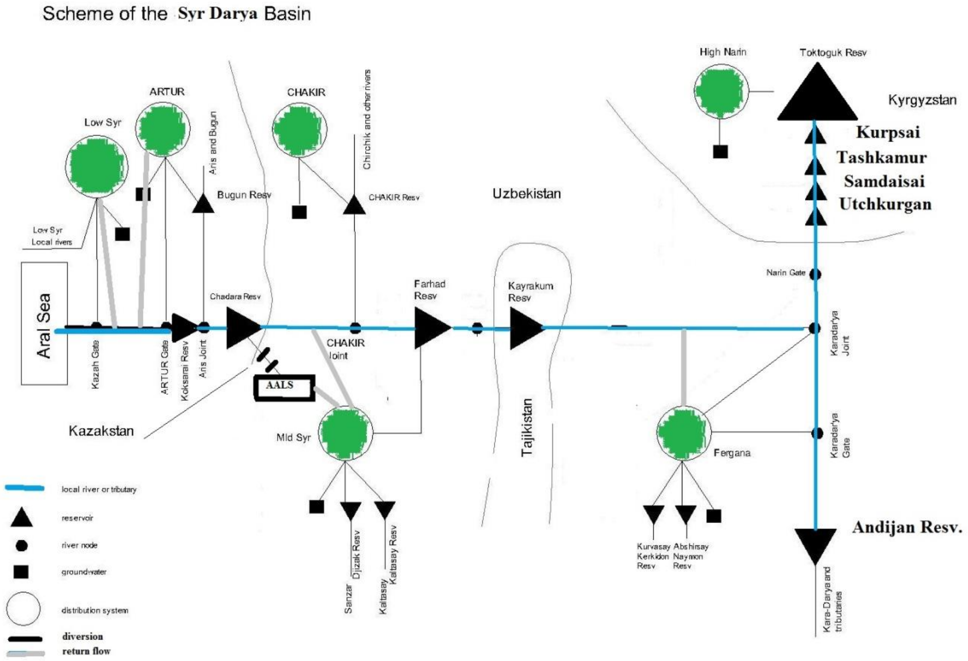

DESMATAMENTO + IRRIGAÇÃO



# MAR DO ARAL

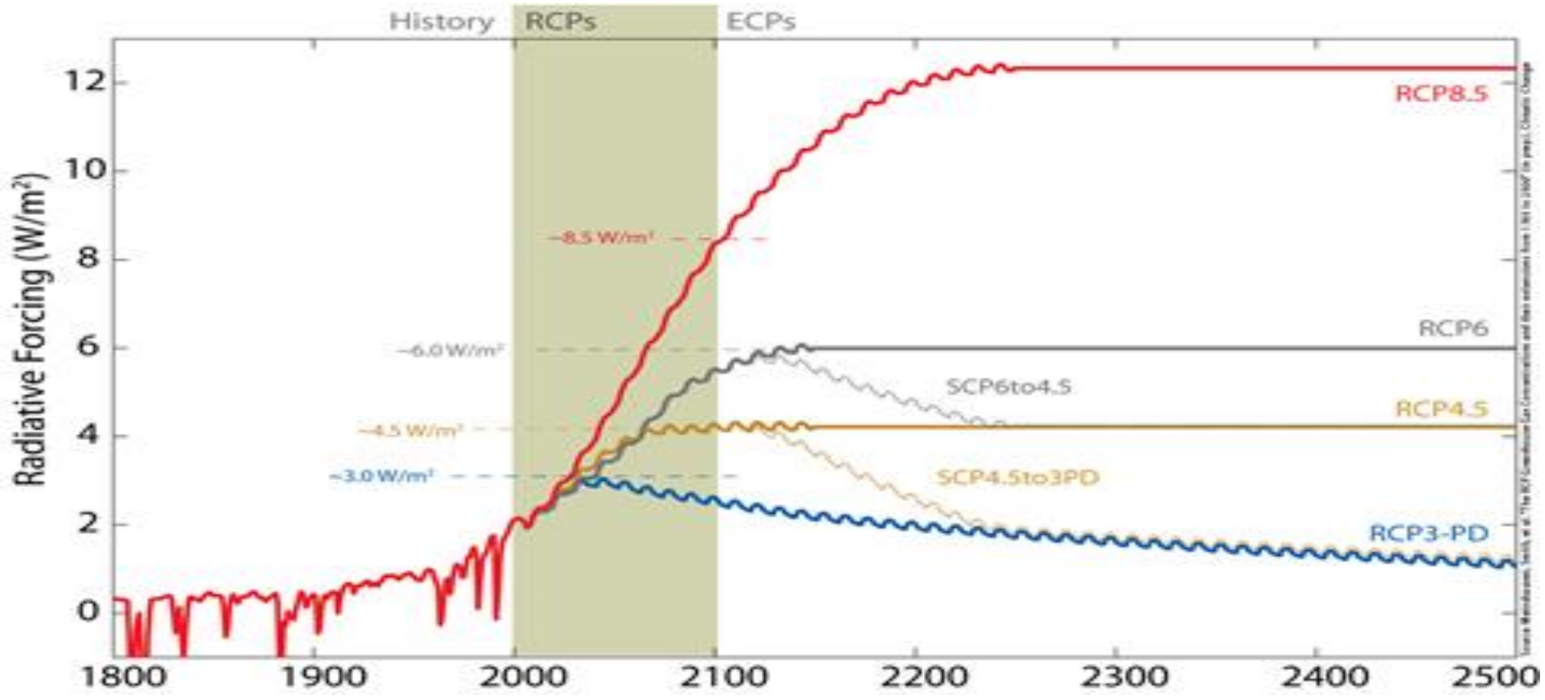

1970
1990
2014


50°N
48°N
46°N
44°N
42°N
40°N
38°N
36°N
56°E
58°E
60°E
62°E
64°E
66°E
68°E
70°E
72°E
74°E
Kazakhskiy Melkosopochnik
Kokaral
Syr Darya River
Aral
Ustyurt Plateau
Kyzyl Kum Desert
Muyunkum Desert
Karatau Range
Amu Darya River
Sarakamysh
Tien Shan
Kara Kum Desert
Zeravshan River
Ferganskaya Valley
Pamirs
Kopet-Dag Range
Tedjen River
Murgab River
Hindu Kush


Scheme of the Syr Darya Basin
High Narin
Toktoguk Resv
Kyrgyzstan
Kurpsai
Tashkamur
Samdaisai
Utchkurgan
ARTUR
CHAKIR
Low Syr
Aris and Bugun
Chirchik and other rivers
Bugun Resv
CHAKIR Resv
Uzbekistan
Low Syr Local rivers
Narin Gate
Aral Sea
Chadara Resv
Farhad Resv
Kayrakum Resv
Kazah Gate
ARTUR Gate
Koksarai Resv
Aris Joint
CHAKIR Joint
AALS
Karadarya Joint
Kazakstan
Mid Syr
Tajikistan
Fergana
Karadarya Gate
Sanzar
Djizak Resv
Kattasay
Kattasay Resv
Kurvasay Kerkidon Resv
Abshirsay Naymon Resv
Andijan Resv.
Kara-Darya and tributaries
local river or tributary
reservoir
river node
groundwater
distribution system
diversion
return flow

# MUDANÇAS CLIMÁTICAS

IPCC AR5 - Cenários de forçantes radioativas

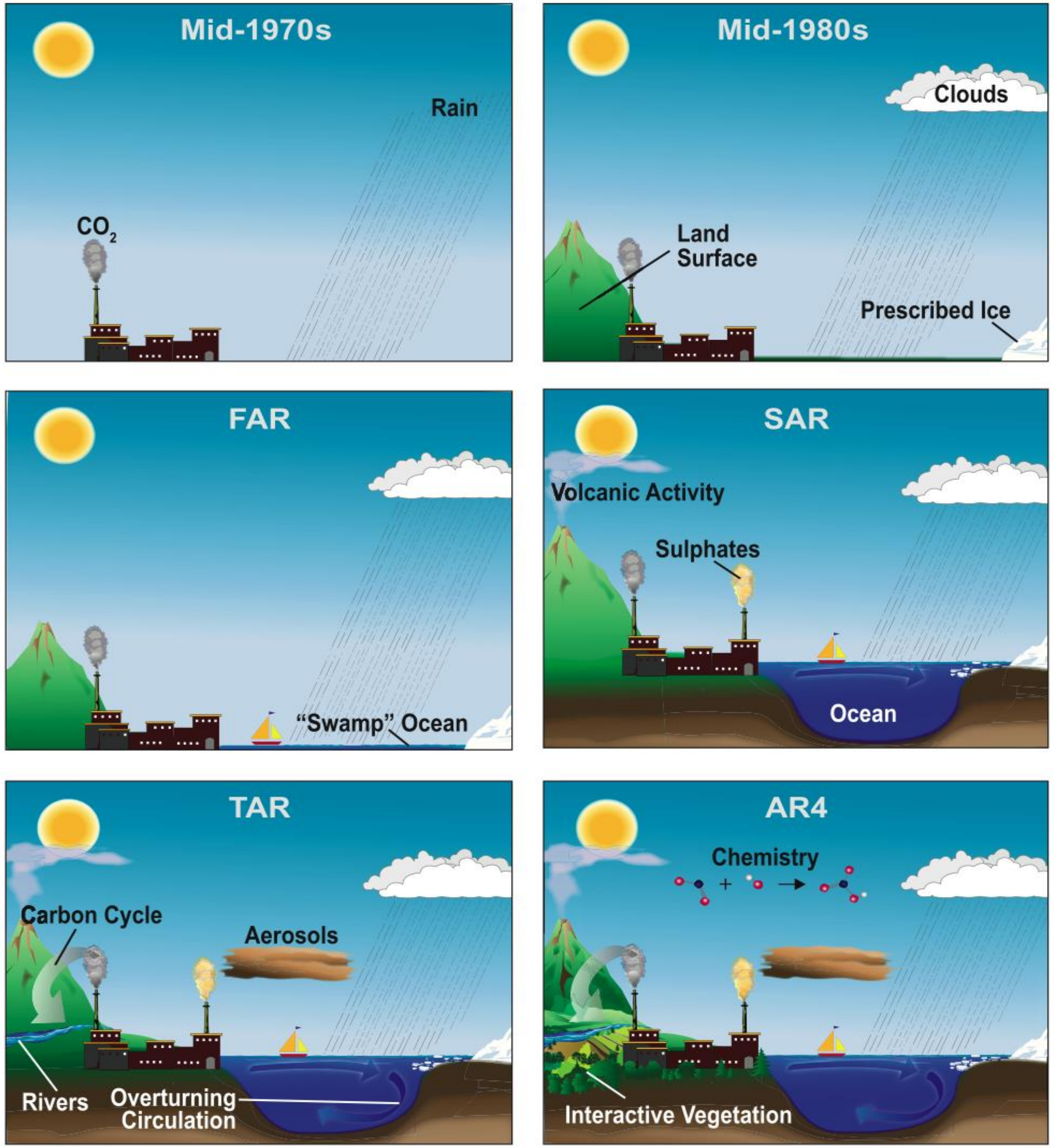



RCP 4.5 - Estabilização das forçantes radioativas em 4,5 W/m² após 2100.

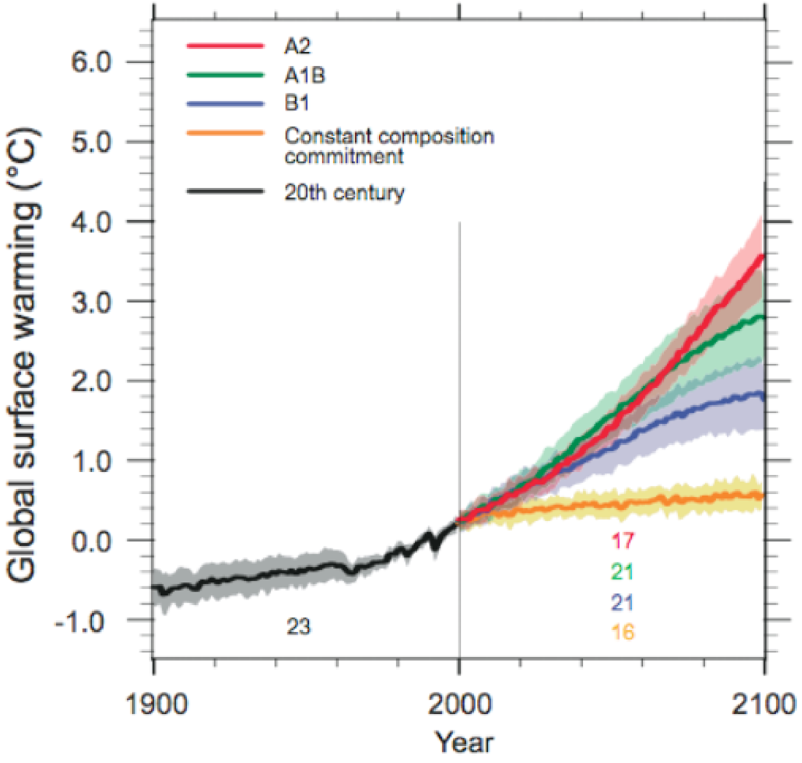
Cenários construídos com os modelos
**BCC-CSM1.1**
**HadGEM2**
**MIROC5**

# PROGRESSOS NA REPRESENTAÇÃO DOS PROCESSOS FÍSICOS NOS **MODELOS CLIMÁTICOS**

The World in Global Climate Models

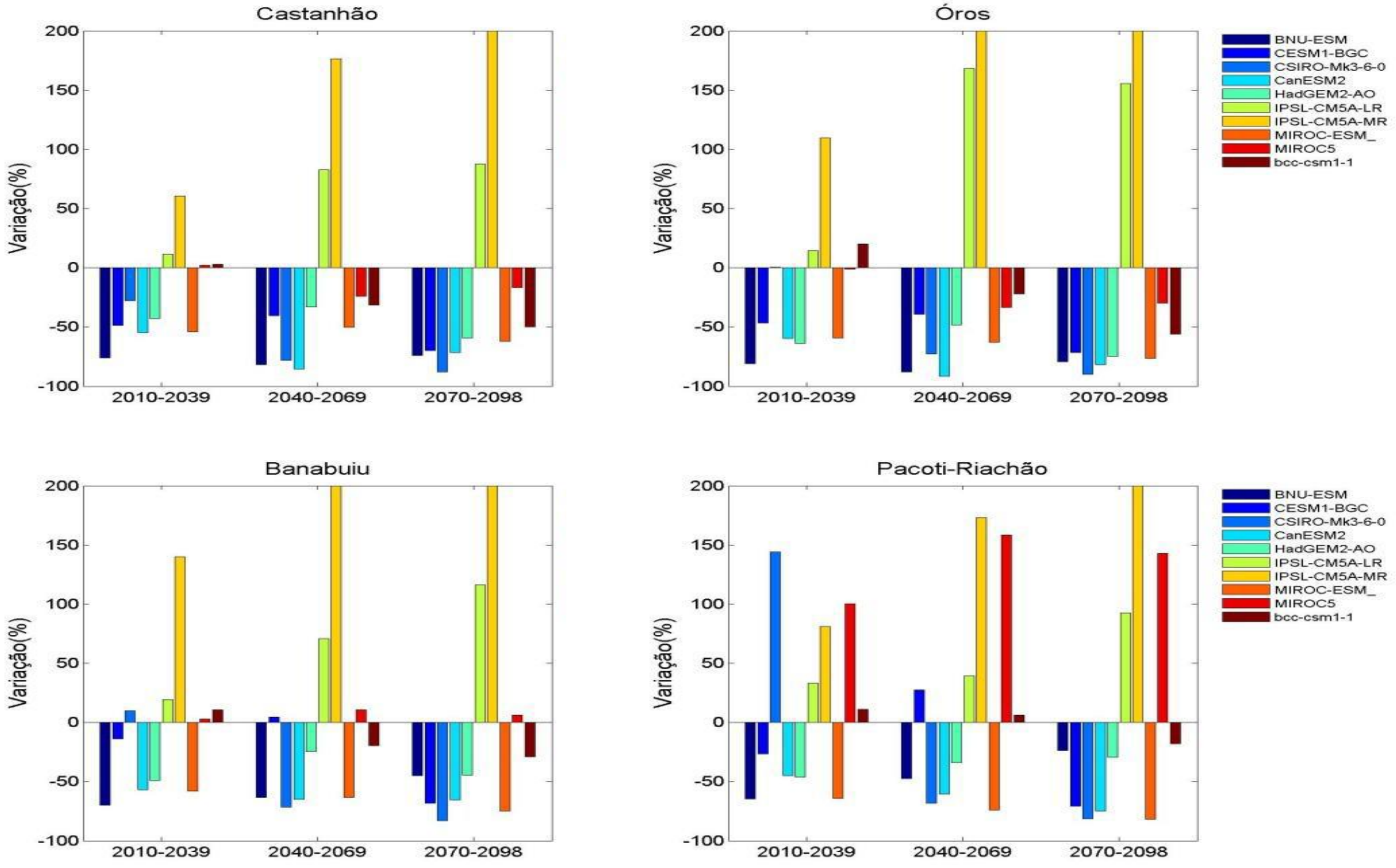


# COMO SERÁ O **AMANHÃ?**




| | Temperature Change (°C at 2090-2099 relative to 1980-1999) [a] | | Sea Level Rise (m at 2090-2099 relative to 1980-1999) |
|---|---|---|---|
| Case | Best estimate | *Likely* range | Model-based range excluding future rapid dynamical changes in ice flow |
| Constant Year 2000 concentrations [c] | 0.6 | 0.3 – 0.9 | NA |
| B1 scenario | 1.8 | 1.1 – 2.9 | 0.18 – 0.38 |
| A1T scenario | 2.4 | 1.4 – 3.8 | 0.20 – 0.45 |
| B2 scenario | 2.4 | 1.4 – 3.8 | 0.20 – 0.43 |
| A1B scenario | 2.8 | 1.7 – 4.4 | 0.21 – 0.48 |
| A2 scenario | 3.4 | 2.0 – 5.4 | 0.23 – 0.51 |
| A1FI scenario | 4.0 | 2.4 – 6.4 | 0.26 – 0.59 |

# MUDANÇAS CLIMÁTICAS




Variação percentual na média anual de vazões no século XXI para os modelos do CMIP5 para o cenário RCP4.5

CLIMATE CHANGE

# *Has there been a hiatus?*

## Internal climate variability masks climate-warming trends

*By* **Kevin E. Trenberth**

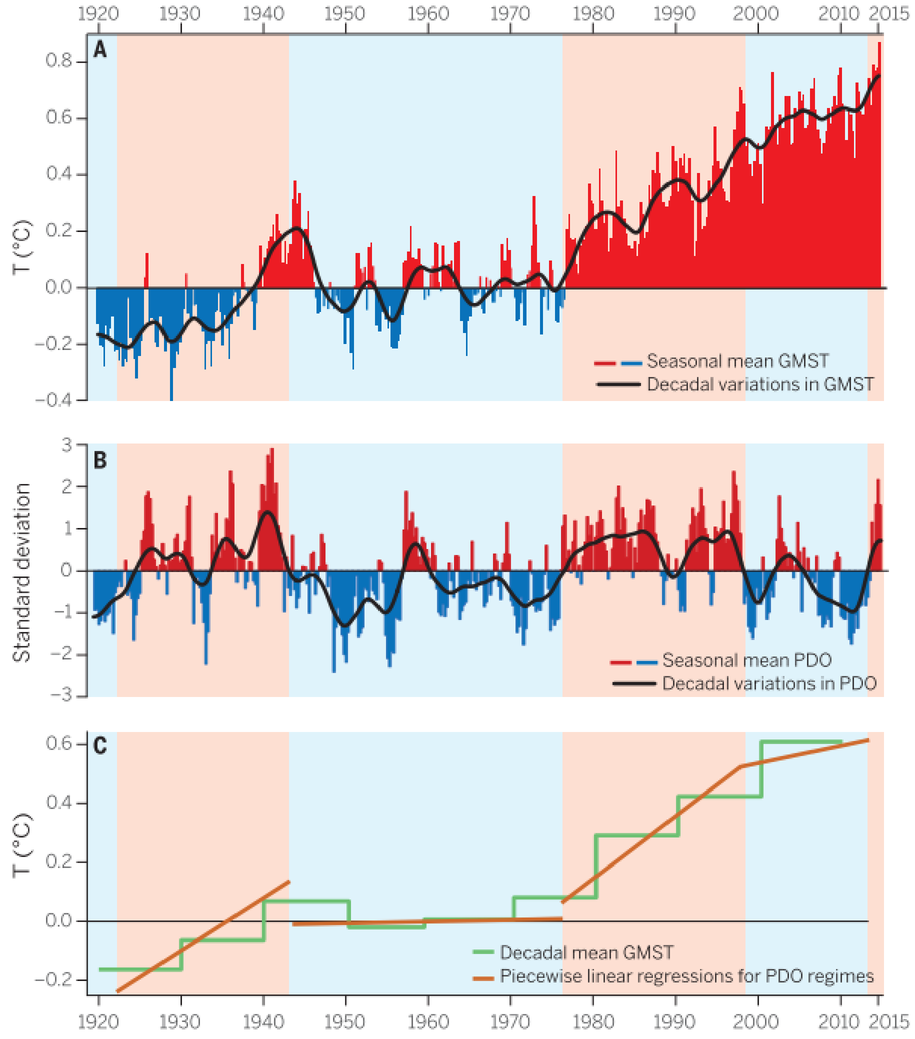
Every decade since the 1960s has been warmer than the one before, with 2000 to 2009 by far the warmest decade on record (see the figure). However, the role of human-induced climate change has been discounted by some, owing to a markedly reduced increase in global mean surface temperature (GMST) from 1998 through 2013, known as the hiatus (*1*–*3*). The upward trend has resumed in 2014, now the warmest year on record, with 2015 temperatures on course for another record-hot year. Although Earth's climate is undoubtedly warming, weather-related and internal natural climate variability can temporarily overwhelm global warming in any given year or even decade, especially locally.

Karl *et al.* recently argued that there has been no slowdown in the rise of GMST and hence no hiatus (*3*). The authors compared slightly revised and improved GMST estimates after 2000 with the 1950–1999 period, concluding that there was hardly any

as a result of internal natural variability. Temperatures have mostly increased since about 1920 and the recent rate is not out of step with the 1950–1999 rate (*3*), but there are two intervals with much lower rates of increase. Only the most recent of these two hiatuses has occurred in the presence of fast-increasing greenhouse gas concentrations. It is thus important to understand its origins and whether or not it indeed indicates a flaw in model projections and thus in climate change theory.

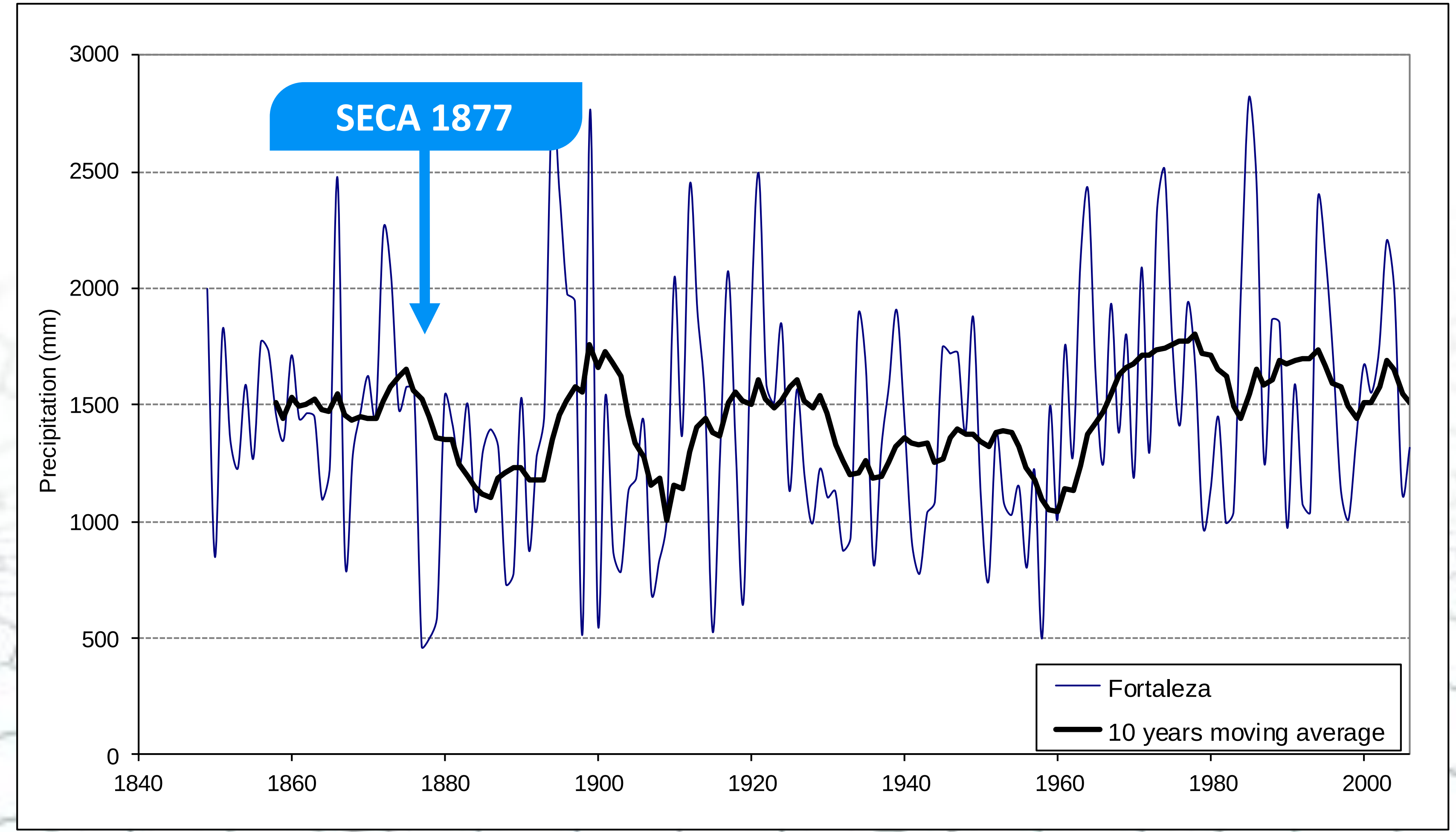
Interannual variability in GMST is partly driven by the El Niño–Southern Oscillation in the Pacific Ocean. The year 1998 was the warmest on record in the 20th century because of the 1997–1998 El Niño, the biggest such event on record. During that El Niño, ocean heat that had previously built up in the tropical western Pacific spread across the Pacific and into the atmosphere, invigorating storms and warming the surface, especially through latent heat release, while the ocean cooled from evaporative cooling (*5*, *6*). Now in 2015, another El Niño is un-

> ***"Natural fluctuations are big enough to overwhelm the steady background warming at any point in time."***

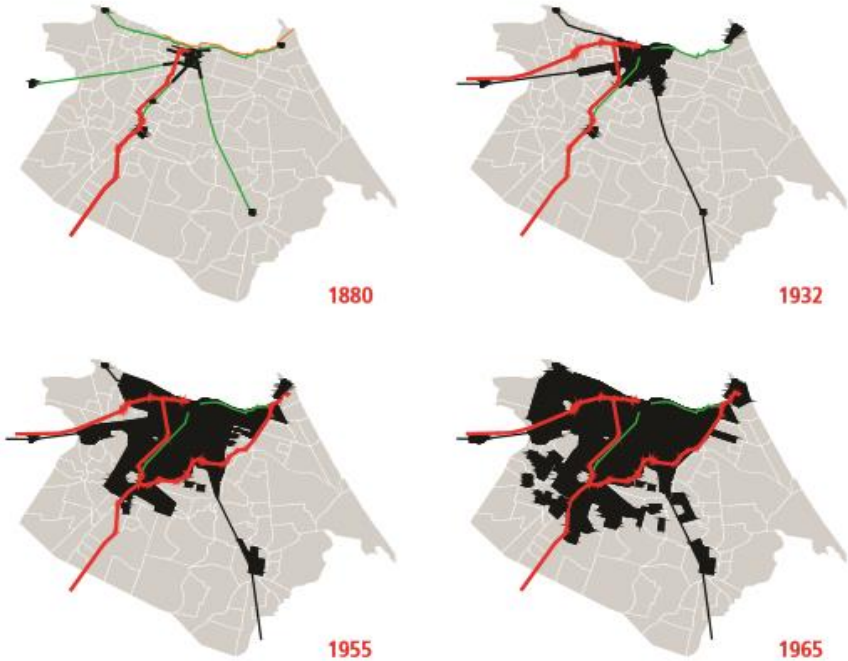


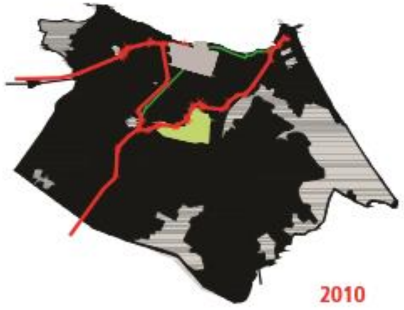

**A staircase of rising temperatures.** (**A**) Seasonal (December-January-February; etc.) global mean surface temperatures since 1920 (relative to the 20th-century mean) vary considerably on interannual and decadal time scales. Data from (*19*). (**B**) Seasonal mean PDO anomalies (*8*) show decadal regimes (positive in pink; negative in blue) as well as short-term variability. A 20-term Gaussian filter is used in both to show decadal variations, with anomalies reflected about the end point of March to May 2015 (heavy black curves). (**C**) Decadal average anomalies (starting 1921 to 1930) of GMST (green) along with piecewise slopes of GMST for the phases of the PDO (orange). Note how the rise in GMST (A) coincides with the positive (pink) phase (B) of the PDO at the rate given in (C).

# **VARIABILIDADE CLIMÁTICA** EM MÚLTIPLAS ESCALAS TEMPORAIS



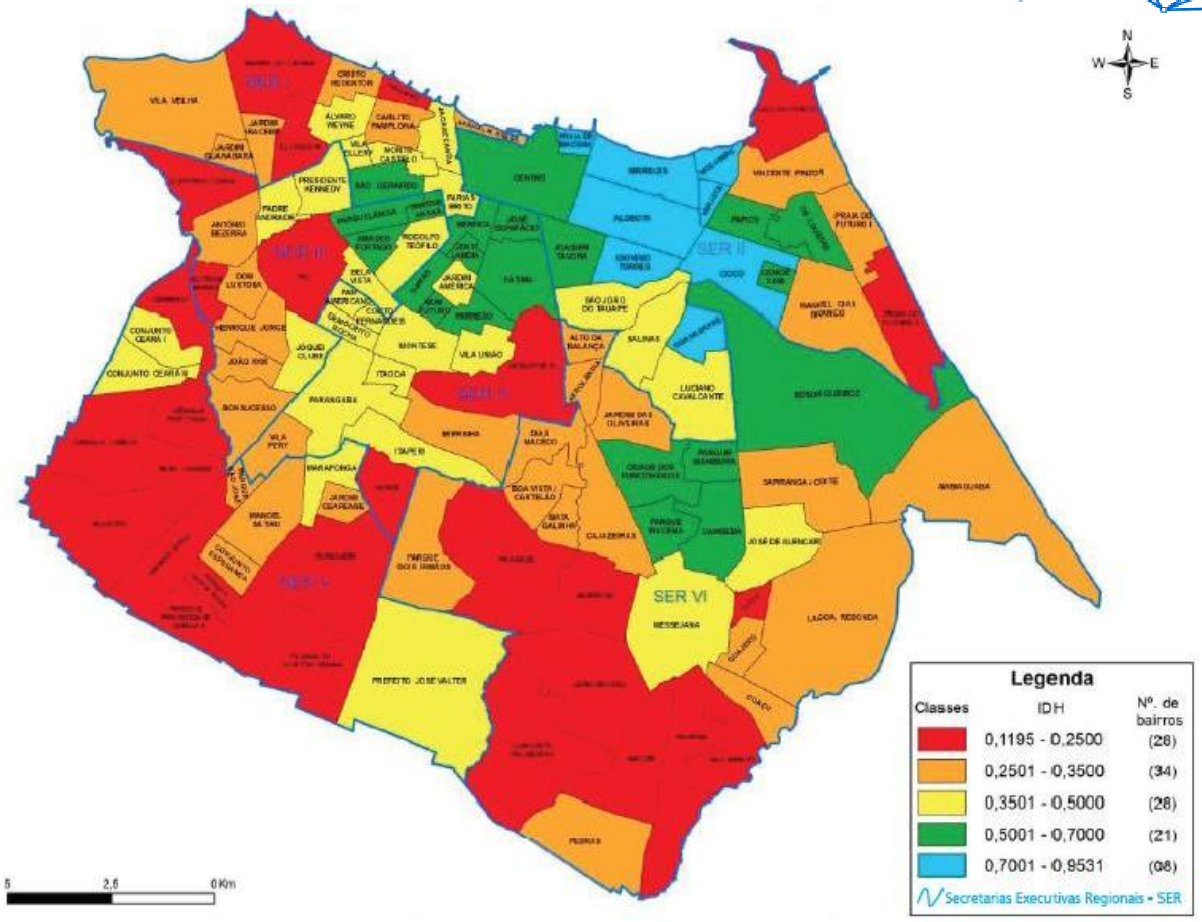
# **CRESCIMENTO** DAS CIDADES




# DESIGUALDADE SOCIAL

IDH dos bairros de Fortaleza - 2010



# RESTAURAÇÃO FLUVIAL


Kondolf, G. M., A. J. Boulton, S. O'Daniel, G. C. Poole, F. J. Rahel, E. H. Stanley, E. Wohl, A. Bång, J. Carlstrom, C. Cristoni, H. Huber, S. Koljonen, P. Louhi, and K. Nakamura 2006. Process-based ecological river restoration: visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages. *Ecology and Society* **11**(2): 5. [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art5/

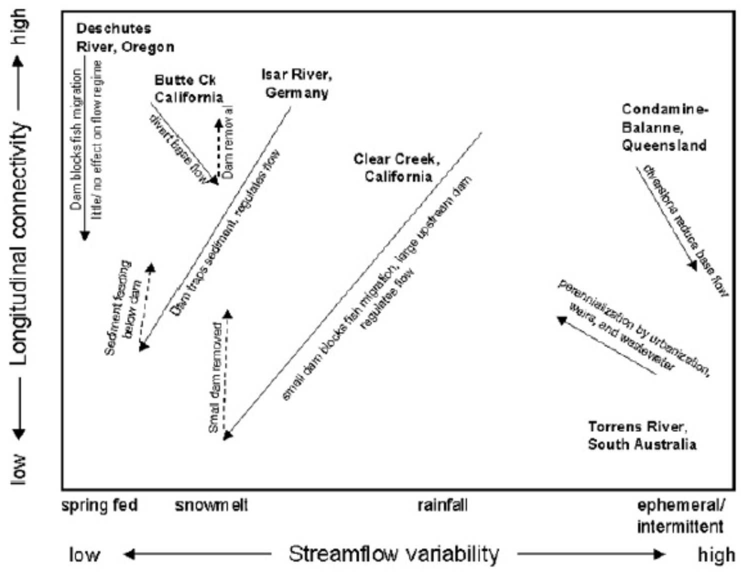
E&S

*Insight*, part of a Special Feature on Restoring Riverine Landscapes

**Process-Based Ecological River Restoration: Visualizing Three-Dimensional Connectivity and Dynamic Vectors to Recover Lost Linkages**

*G. Mathias Kondolf*[1], *Andrew J. Boulton*[2], *Scott O'Daniel*[3], *Geoffrey C. Poole*[4], *Frank J. Rahel*[5], *Emily H. Stanley*[6], *Ellen Wohl*[7], *Asa Bång*[8], *Julia Carlstrom*[9], *Chiara Cristoni*, *Harald Huber*[10], *Saija Koljonen*[11], *Pauliina Louhi*[12], *and Keigo Nakamura*[13]

**Fig. 1.** Solid arrows represent ecological degradation and dashed arrows represent restoration trajectories plotted on axes of longitudinal connectivity and flow dynamics. See Appendix 1 for a discussion of trajectories.






ECOLOGY

## Synthesizing U.S. River Restoration Efforts

E. S. Bernhardt,[1*†] M. A. Palmer,[1] J. D. Allan,[2] G. Alexander,[2] K. Barnas,[3] S. Brooks,[4] J. Carr,[5] S. Clayton,[6] C. Dahm,[7] J. Follstad-Shah,[7] D. Galat,[8,9] S. Gloss,[10] P. Goodwin,[6] D. Hart,[5] B. Hassett,[1] R. Jenkinson,[11] S. Katz,[3] G. M. Kondolf,[12] P. S. Lake,[4] R. Lave,[12] J. L. Meyer,[13] T. K. O'Donnell,[9] L. Pagano,[12] B. Powell,[14] E. Sudduth[13]

The importance of rivers and streams for fresh water, food, and recreation is well known, yet there is increasing evidence that degradation of running waters is at an all-time high (*1*). More than one-third of the rivers in the United States are listed as impaired or polluted (*2*), and freshwater withdrawals in some regions are so extreme that some major rivers no longer flow to the sea year round (*3*). Extinction rates of freshwater fauna are five times that for terrestrial biota (*4*, *5*). Fortunately, stream and river restoration can lead to species recovery, improved inland and coastal water quality, and new areas for wildlife habitat and recreational activities (*6*–*11*).

River restoration has become a highly profitable business (*12*, *13*) and will play an increasing role in environmental management and policy decisions (*7*). A few high-profile and large restoration projects such as those on the Kissimmee River (*11*, *14*) and the Grand Canyon (*15*, *16*) are well documented. However, most restoration projects are small scale (implemented on less than 1 km of stream length), and information on their implementation and outcome is not readily accessible. This prompted us to build a database of river restoration across the United States with the goal of determining the common elements of successful projects.

We found that existing restoration databases are highly fragmented and often rely on ad hoc or volunteer data entry. Thus, we developed methods for the unbiased collection and cataloging of river and stream restoration projects. Here, we report a synthesis of information on 37,099 projects in the National River Restoration Science Synthesis (NRRSS) database.

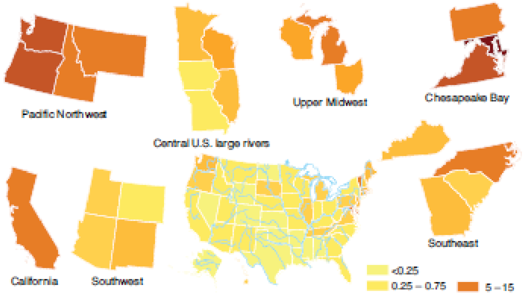
The NRRSS database includes all stream and river restoration projects present in national databases as of July 2004, as well as a large sample of river and stream restoration projects from seven geographic regions (see figure, below) [(*17*) part a]. Because we wanted to document how restoration dollars and efforts were allocated, we did not limit data collection to projects that fit our definition of restoration. No judgments were made of the validity of the terms "stream restoration" or "project." Use of national coverage data sources] (*17*) part b] ensured inclusion of projects from all 50 states. For the seven specific regions, we also collected information on all restoration projects for which we could obtain data, regardless of project size, restoration method, implementer, or perceived success or failure of the project. We identified a priori 13 categories of restoration and classified each project according to its stated goal [see table, page 637 and (*17*) pa…

The number of river restor… increased exponentially du… decade, paralleling the incre… media and scientific reports [fig… d]. However, restoration efforts… geographic regions. Most proje… from the Pacific Northwest, th… Bay watershed, or California… below). Data from national cov… [(*17*) part b] made up <8% of p… NRRSS database. Thus, while fe… supports some tracking effo… restoration databases are not… majority of projects and lack in… the regional differences in exp… effort found with our approach.

The most commonly stat… river restoration in the United… to enhance water quality, (ii… riparian zones, (iii) to impro… habitat, (iv) for fish passage… bank stabilization (see figure… Projects with these goals are ty… in scale with median costs of… table, page 637). A large pr… restoration dollars are spent o… expensive projects aimed at… floodplains, modifying flow… aesthetics or recreation, and r… river and stream channels (see… 637). Of the projects in our d… had no listed goals; in many cases, descriptions were too limited to determine whether projects were undertaken to restore stream ecosystems or were merely river manipulation projects (e.g., bank stabilization) (*18*).

[1]University of Maryland, College Park, MD; [2]School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI; [3]Northwest Fisheries Science Center (NWFSC), National Oceanographic and Space Administration (NOAA), Seattle, WA, USA. [4]Monash University, Clayton, VIC, Australia. [5]Academy of Natural Sciences, Philadelphia, PA; [6]University of Idaho, Boise, ID; [7]University of New Mexico, Albuquerque, NM; [8]U.S. Geological Survey (USGS), Cooperative Research Units, Columbia, MO; [9]University of Missouri, Columbia, MO; [10]Southwest Biological Science Center, USGS, Tucson, AZ; [11]University of Idaho, Moscow, ID; [12]University of California, Berkeley, CA; [13]University of Georgia, Athens, GA; [14]Center for Biological Informatics, USGS, Denver, CO, USA. Complete addresses are available online.

*Present address: Duke University, Durham, NC, USA.
†Author for correspondence. E-mail: emily.bernhardt@duke.edu



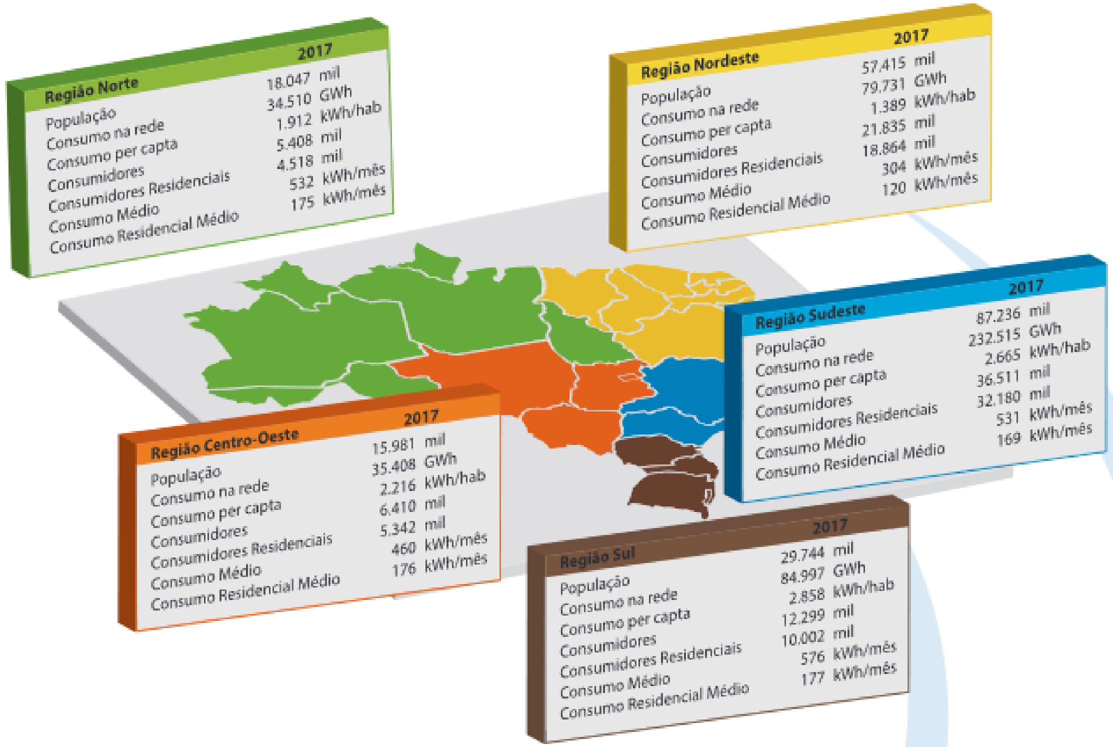

**Project density (no. of projects per 1000 river km) from national coverage databases only versus in-depth regional project record summaries (all data sources) [table S1 (*17*) part h].**

II

# ESCALA E HETEROGENEIDADE DOS SISTEMAS

# **ENERGIA ELÉTRICA:**
# CONSUMO POR REGIÃO

**Figura 3.2 Brasil Regiões Geográficas 2017**
Brazil Geographic Regions Totals 2017



# SETOR HIDROELÉTRICO

**HIDRELÉTRICA**
2018: 109.212 MW (67,6%)
2023: 114.641 MW (64,9%)

**TERM. GÁS + GNL**
2018: 12.821 MW (7,9%)
2023: 16.188 MW (9,2%)

**EÓLICA**
2018: 14.305 MW (8,9%)
2023: 17.261 MW (9,8%)

**TERM. ÓLEO + DIESEL**
2018: 4.614 MW (2,9%)
2023: 4.840 MW (2,7%)

**BIOMASSA**
2018: 13.353 MW (8,3%)
2023: 13.840 MW (7,8%)

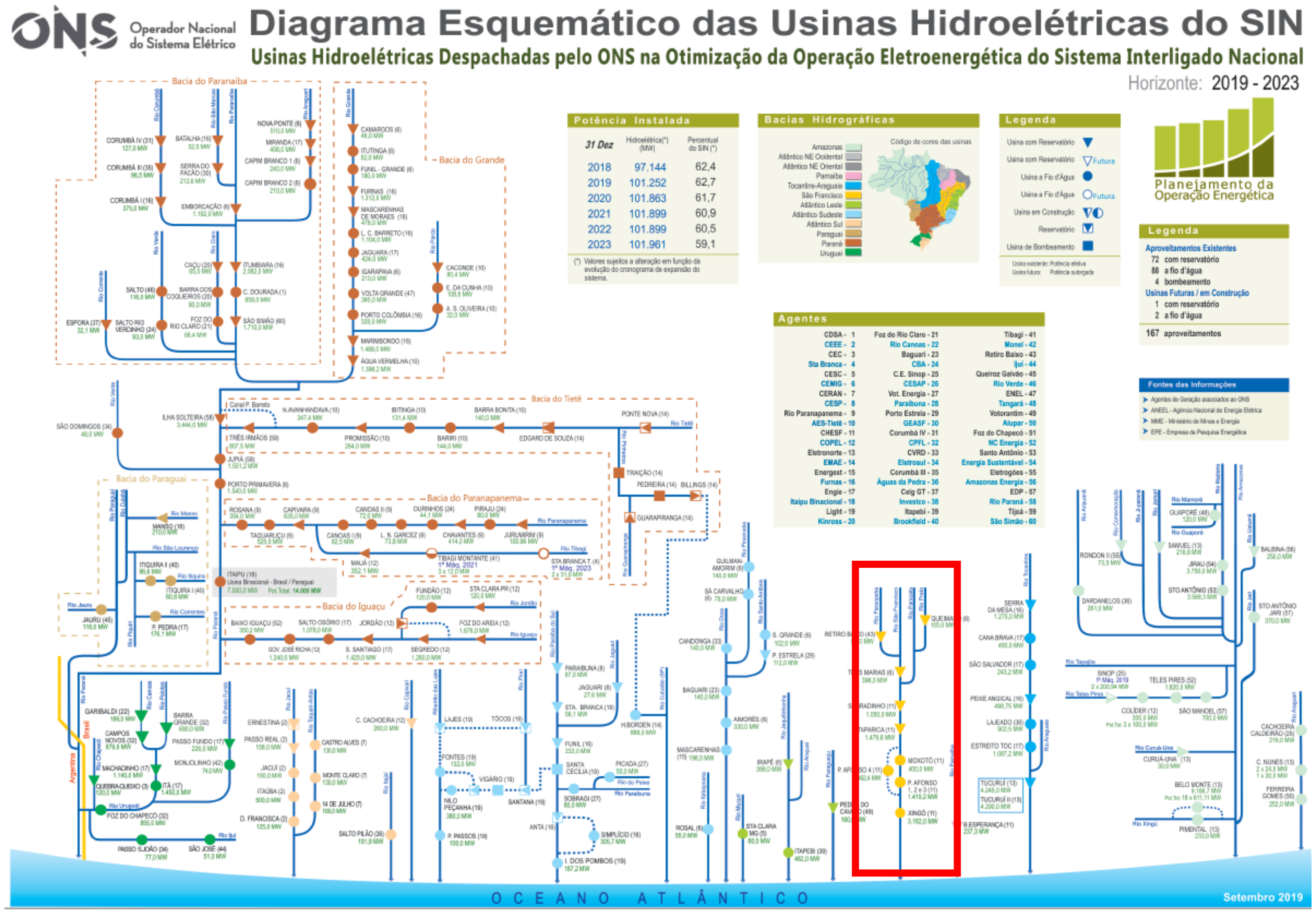
**TERM. CARVÃO**
2018: 2.672 MW (1,7%)
2023: 3.017 MW (1,7%)

**SOLAR**
2018: 1.780 MW (1,1%)
2023: 3.766 MW (2,1%)

**NUCLEAR**
2018: 1.990 MW (1,2%)
2023: 1.990 MW (1,1%)

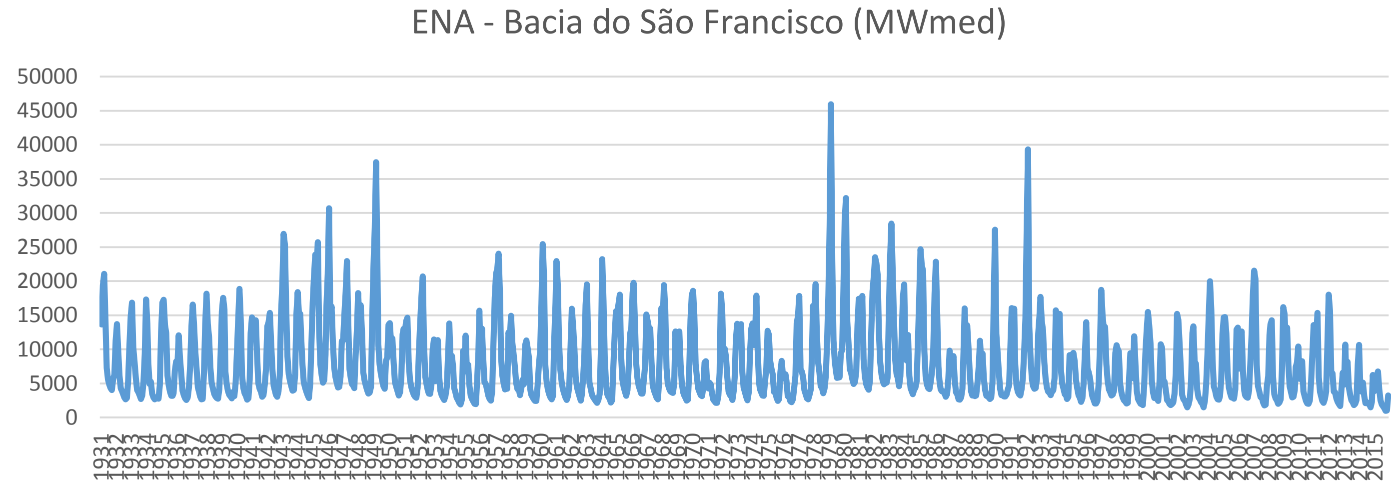
**OUTRAS**
2018: 779 MW (0,5%)
2023: 1.000 MW (0,6%)

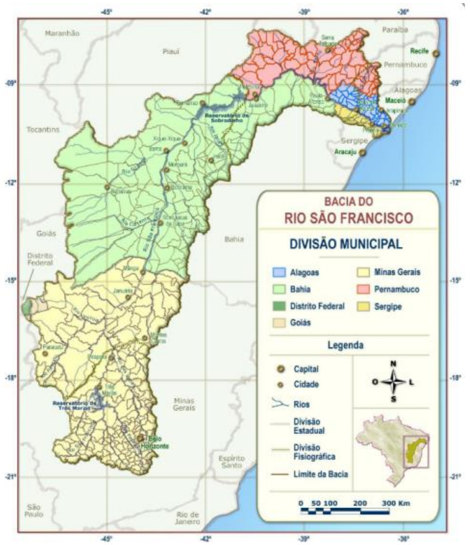
**TOTAL** 2018: 161.526 MW — 2023: 176.543 MW



# BACIA DO RIO SÃO FRANCISCO


ENA mensal Média 7938 MWmed




| Uso | Demanda | |
|---|---|---|
| | Vazão ($m^3/s$) | Proporção |
| **Abastecimento urbano** | 31,3 | 10% |
| **Abastecimento rural** | 3,7 | 1% |
| **Irrigação (2013)** | 244,4 | 79% |
| **Criação animal** | 10,2 | 3% |
| **Abastecimento industrial** | 19,8 | 6% |
| **Total** | 309,4 | 100% |

# SEGURANÇA HÍDRICA

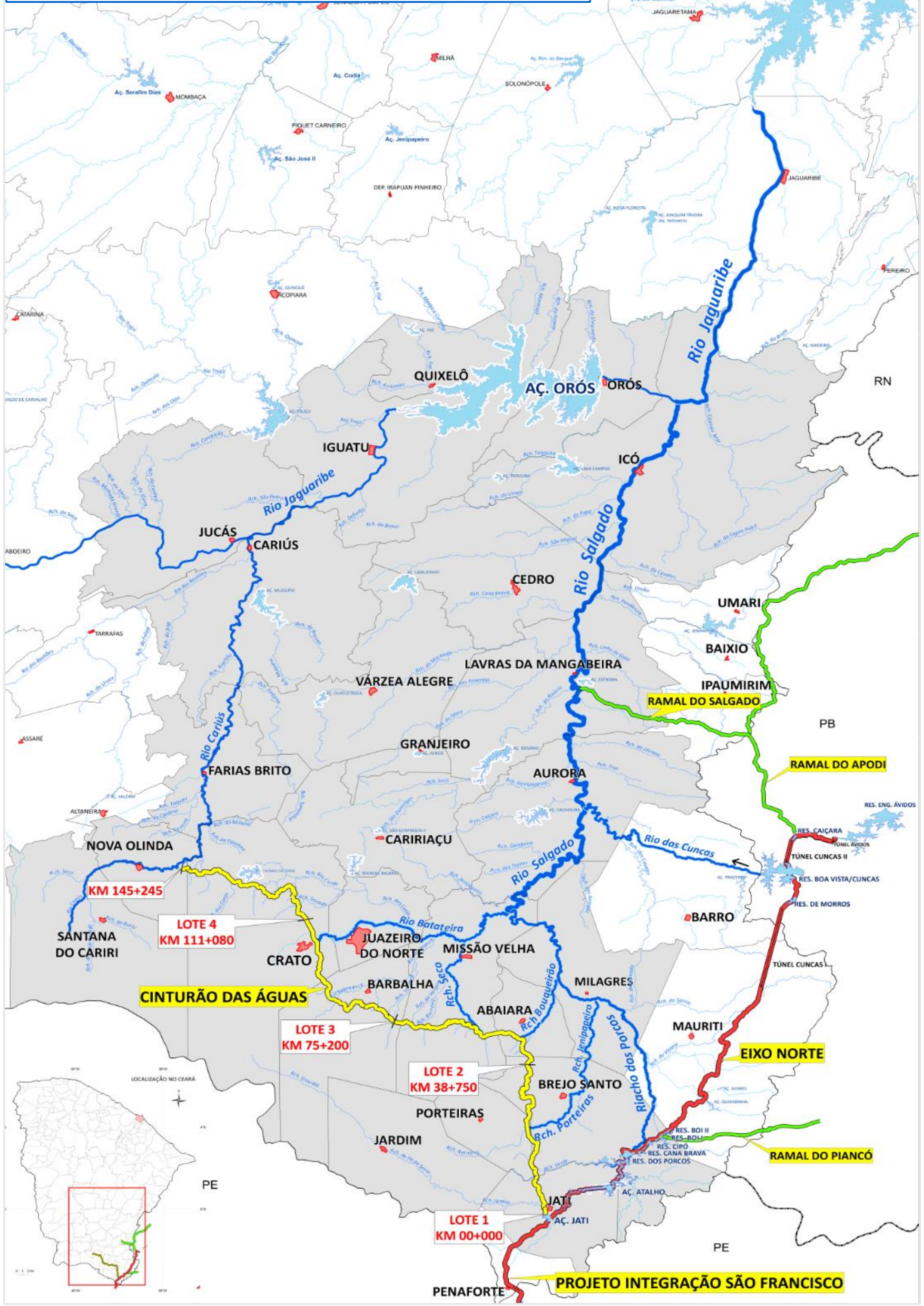
"Capacidade de uma população para garantir o acesso sustentável a quantidades adequadas de água, com qualidade aceitável para a subsistência, o bem-estar humano e o desenvolvimento socioeconômico, assegurando a proteção dos recursos hídricos contra a poluição e os desastres relacionados com a água, bem como a preservação dos ecossistemas em um clima de paz e estabilidade política."

**UN-Water, 2013**

**SEGURANÇA ALIMENTAR, AMBIENTAL E ENERGÉTICA**

FORTALEZA
Quixadá
Crateús
Quixeramobim
Limoeiro do Norte
Eixão das Águas
Mossoró
Macau
Touros
Alto Oeste
Apodi
Castanhão
Angicos
Ceará-Mirim
CEARÁ
Jaguaribe
Santa Cruz
A. Ribeiro
RIO GRANDE DO NORTE
NATAL
P. Ferros
Oiticica
Orós
Catolé do Rocha
Iguatu
Icó
Caicó
Aiuaba
Serra Negra do Norte
Souza
Pombal
Cajazeiras
Vertente Litorânea
Coremas
Patos
PARAÍBA
Sapé
Crato
Campina Grande
JOÃO PESSOA
Juazeiro do Norte
Missão Velha
Mãe D'Água
Brejo Santo
Exu
Araripina
Boqueirão
EIXO NORTE
Cinturão das Águas
Chapéu
Rio Pajeú
Monteiro
Ouricuri
Serra Talhada
Salgueiro
Olinda
Ramal do Agreste
Entremontes
Açude Serrita
RECIFE
Adutora do Oeste
Gravatá
Adutora do Agreste
P. Cruz
Floresta
Cabrobó
Ibimirim
PERNAMBUCO
Adutora do Pajeú
EIXO LESTE
S. Maria da Boa Vista
RIO SÃO FRANCISCO
Barreiros
Inajá
Garanhuns
Nova Petrolândia
Barragem de Itaparica
ALAGOAS
Delmiro Golveia
Barragem de Paulo Afonso
Palmeiras dos Índios
Juazeiro
Canal S. Alagoano
Barragem de Sobradinho
Barragem de Xingó
Arapiraca

## ENTRADA DO PISF NO CEARÁ

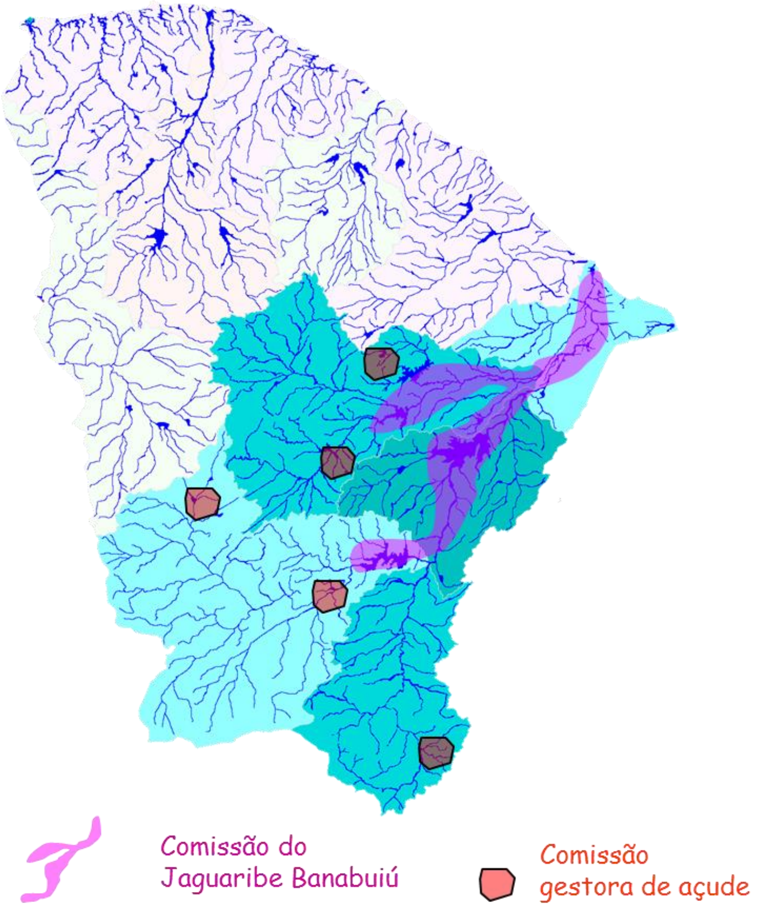



## PISF E A REGIÃO METROPOLITANA DE FORTALEZA

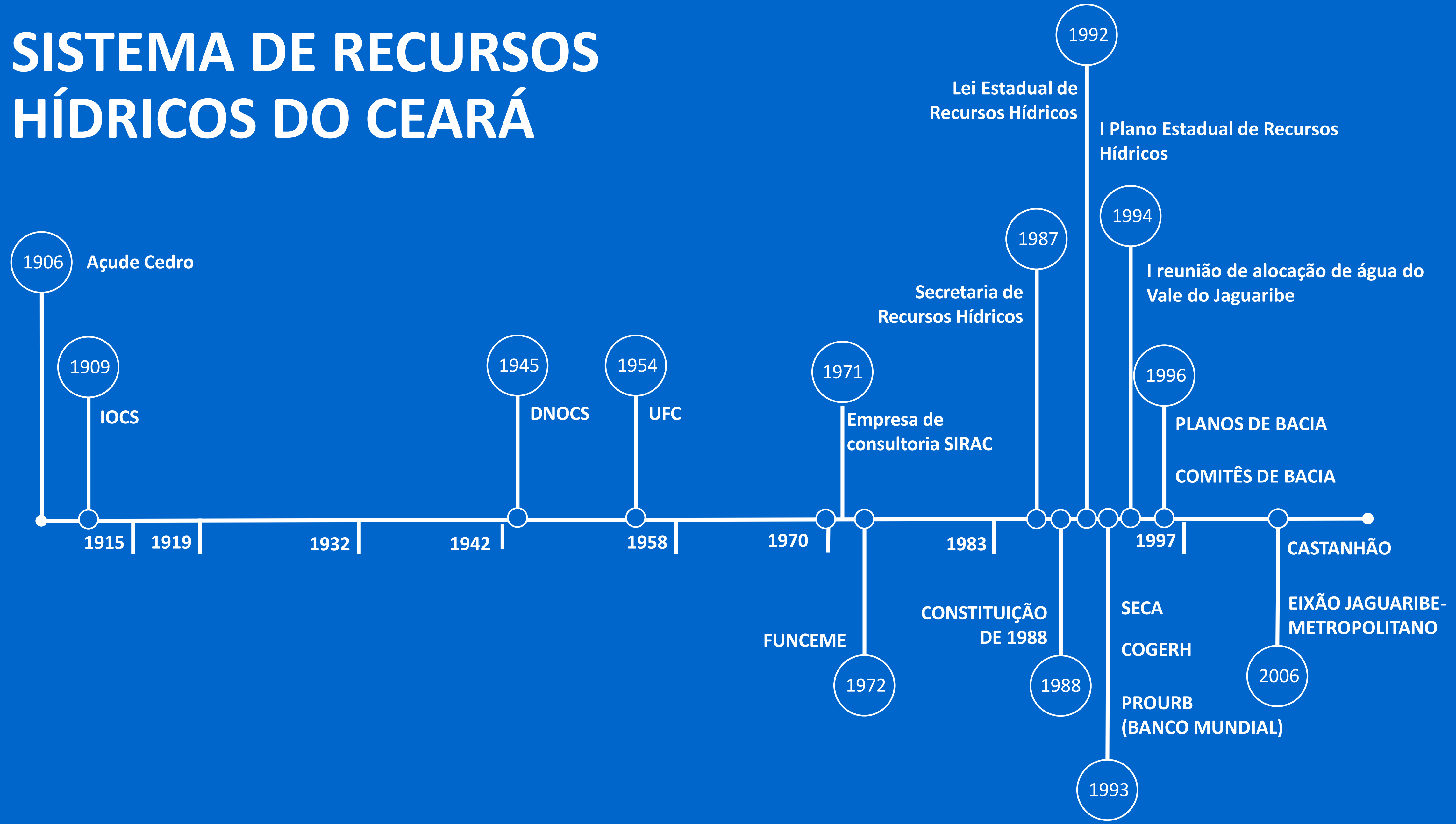
# **MACROALOCAÇÃO NEGOCIADA DE ÁGUA**
# PROCESSO PARTICIPATIVO

Reunião de Alocação de água na bacia do Curu (2011)

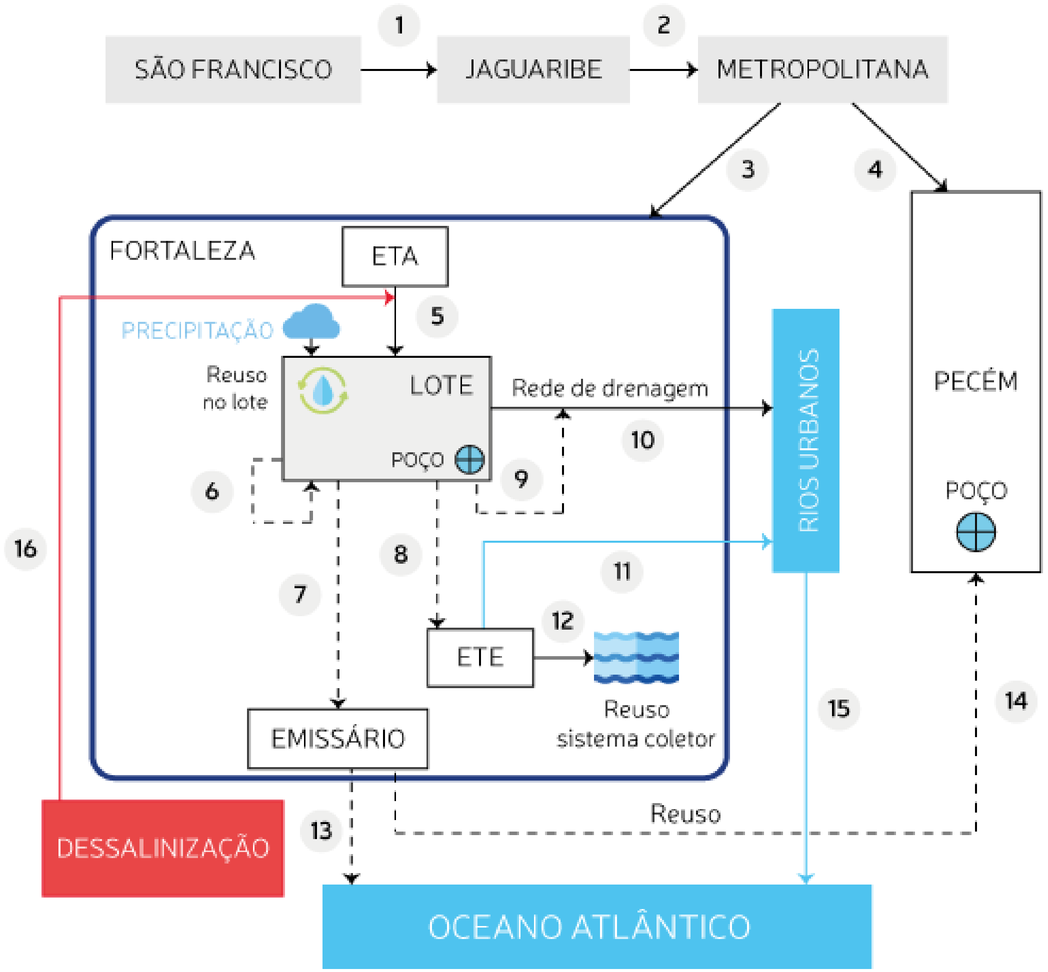
Bacia do rio Jaguaribe (1995)



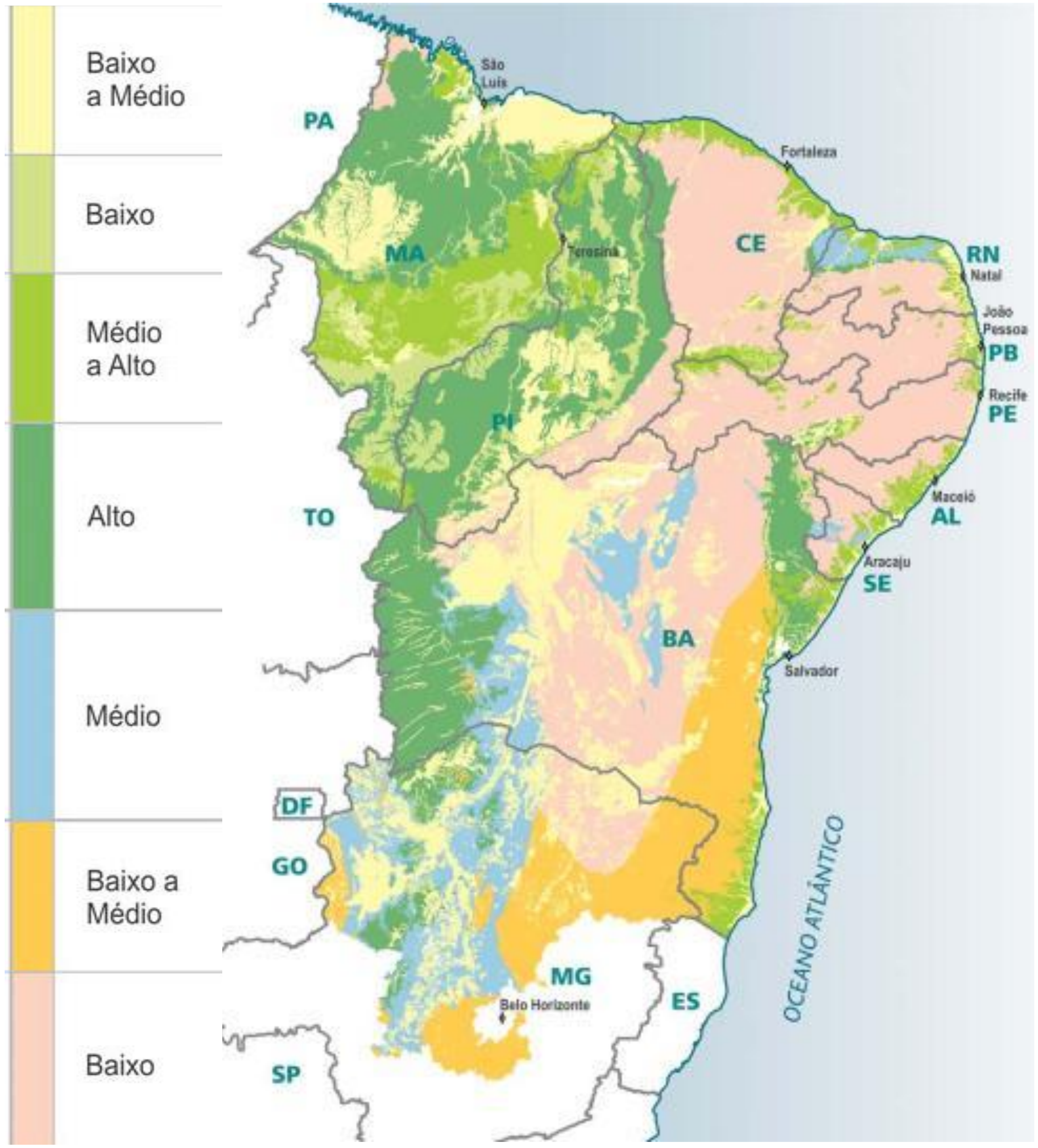
# SISTEMA DE RECURSOS HÍDRICOS DO CEARÁ



# SEGURANÇA HÍDRICA E
# **ÁGUAS URBANAS**

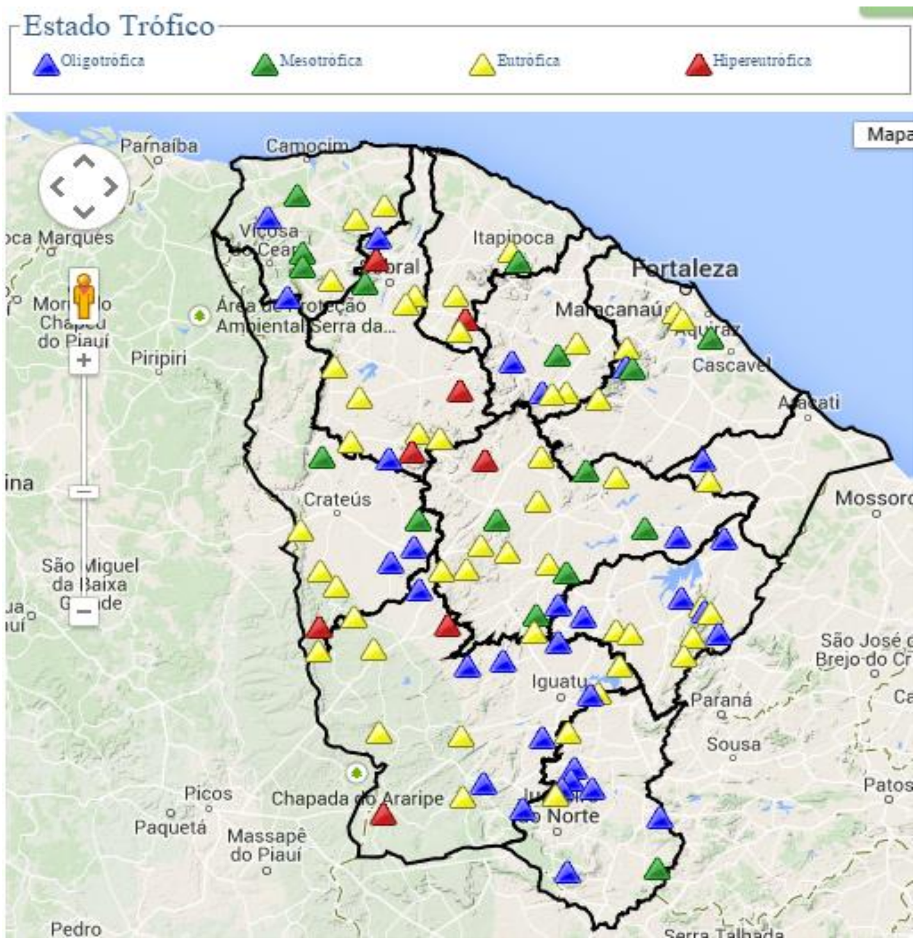


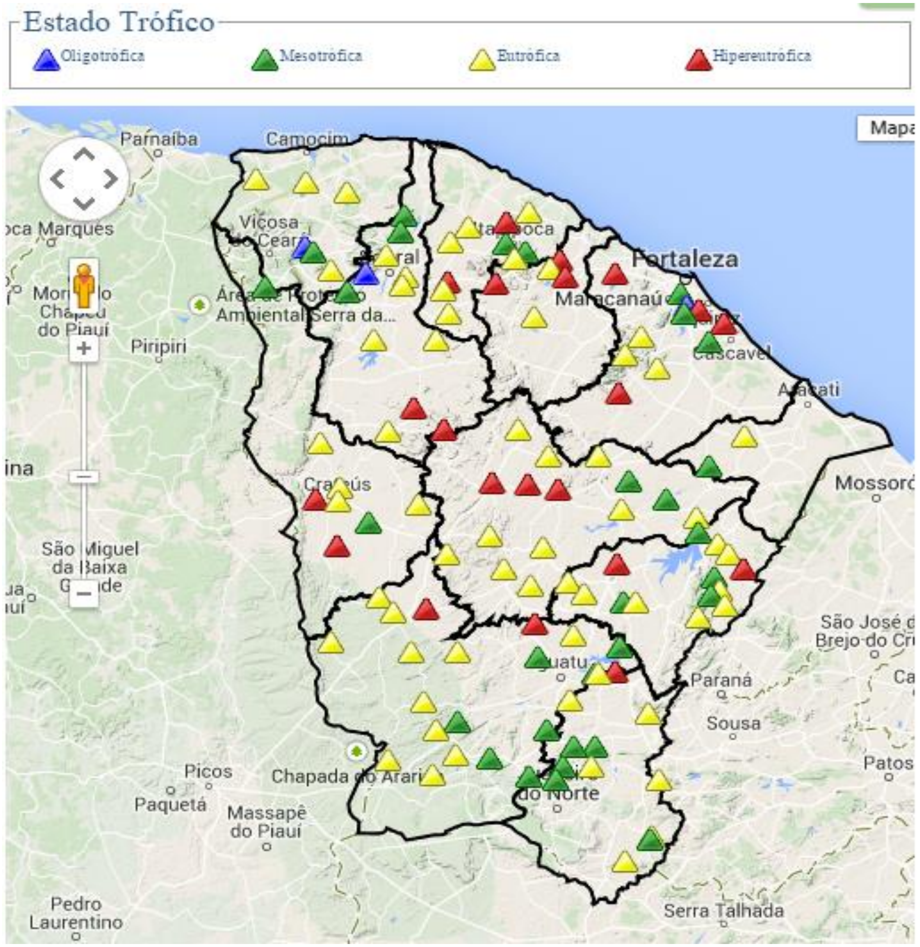
# POTENCIAL HIDROGEOLÓGICO




Fonte: ANA- Atlas - NE

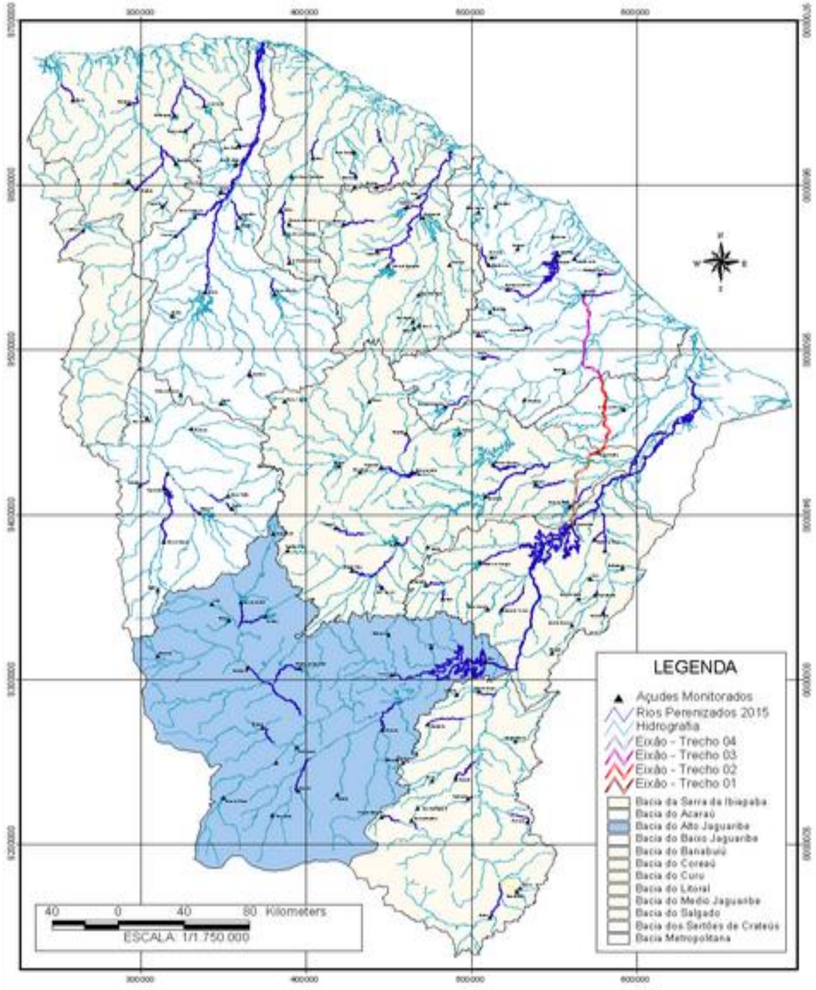
# **ESTUDO DE CASO**: EUTROFIZAÇÃO EM RESERVATÓRIOS




$$t_d = \frac{V_L}{Q_o}$$

# ANTROPOCENO




**Área do Estado:** 148.000 km²
**Regiões hidrográficas do Estado:** 12
**Precipitação média:** 806 milímetros
**Evaporação média anual** é de 2.000 a 2.500 mm/ano.
**Pequenos Reservatórios:** 28.000 (acima de 0,5 hectares de área)
**Reservatórios Estratégicos:** 153 reservatórios
**Capacidade de Regularização** (90% de Garantia): 130,21 $m^3/s$
**Capacidade de Armazenamento:** 18,93 bilhões de m³
**Comprimento de Canais:** 408 km de canais
**Adutoras:** 1.784 km de adutoras
**Comprimento de Rios Perenizados** (2012): 2.582 km
**População:** 8,95 milhões de habitantes
**Área Irrigada** (com infraestrutura): 72.000 hectares

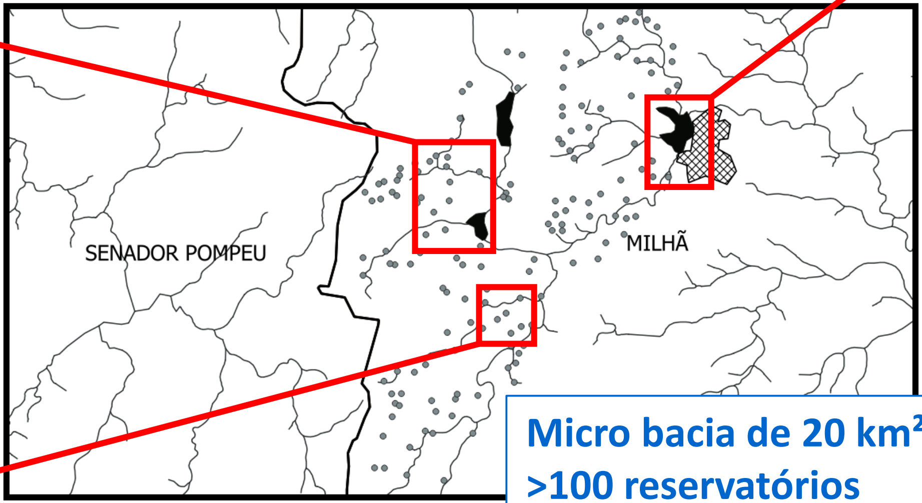
# IMPACTOS DA SECA

## ESTRATÉGIAS LOCAIS → IMPACTOS MULTI-ESCALA

Aumento do numero de pequenos reservatórios multiuso

Crescimento forte da pecuária de Leite
-> manutenção da atividade produtiva, “homem no campo”

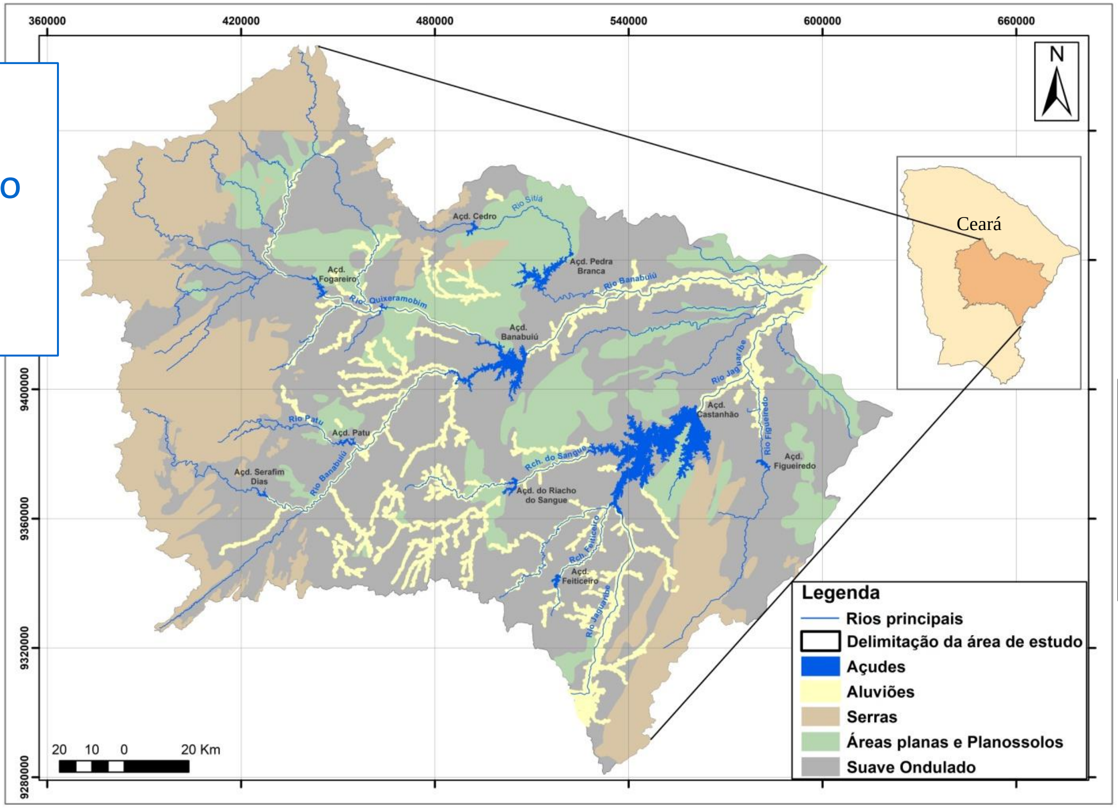
Açude de Milha seca enquanto os açudes a montante tem agua
-> impactos ate para os grandes reservatórios estratégicos



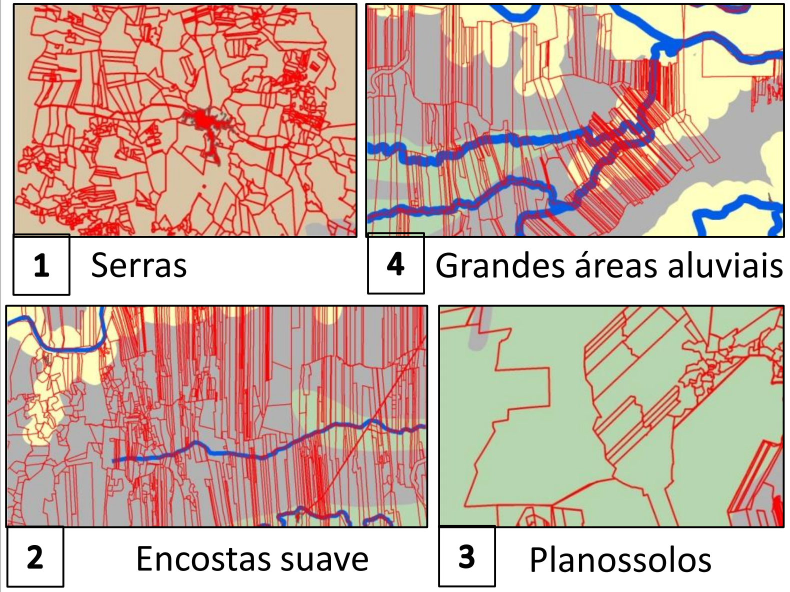

**Micro bacia de 20 km²**
**>100 reservatórios**

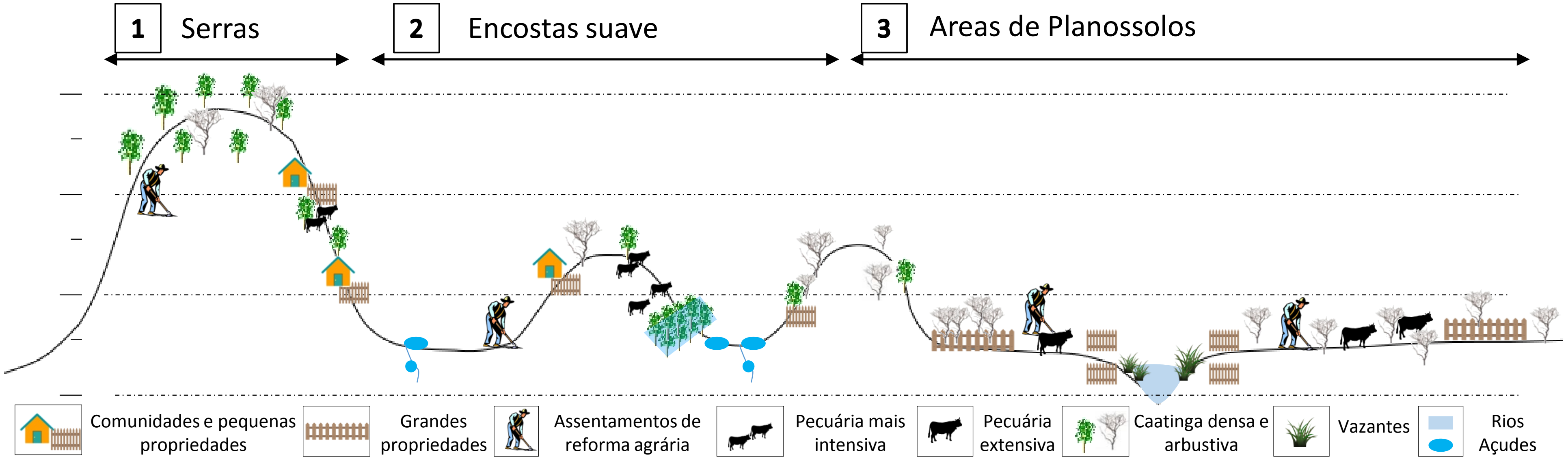
Burte (2019)

Zoneamento agroecológico
Realidade múltipla

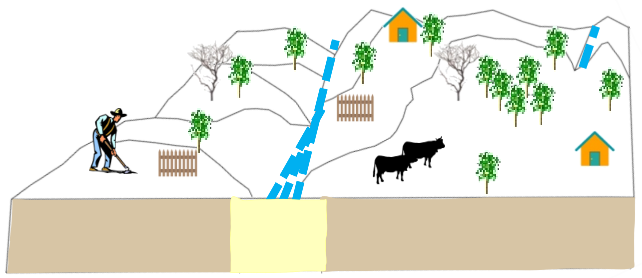
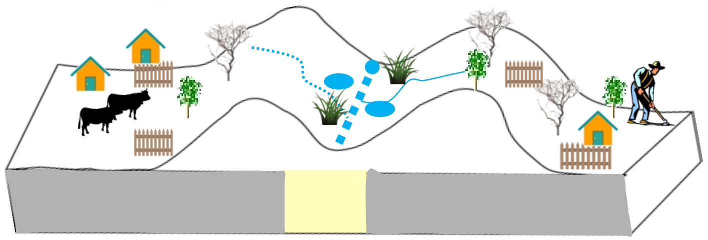
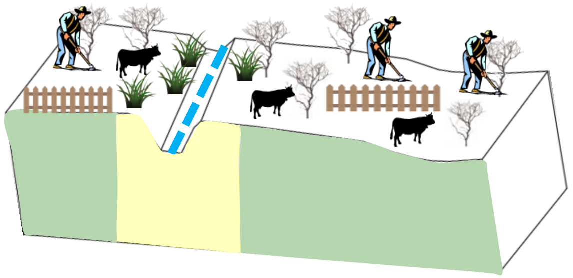



Malha Fundiária




Burte (2019)

| | | |
|---|---|---|
|  |  | •Serras secas e dissecadas localizadas principalmente na borda oeste da bacia do Banabuiú e sul do médio Jaguaribe.<br>•Solos rasos e afloramentos rochosos em áreas com declives íngremes.<br>•Áreas de reserva legal de caatinga.<br>•Pecuária mais intensiva com pequenas propriedades em comunidades mais isoladas. |
|  |  | •Terrenos suavemente aplainados, com menor altitudes que as serras.<br>•Pequenas e médias propriedades.<br>•Grande ocorrência de pequenos açudes em função da drenagem.<br>•Predominância do cultivo de milho e feijão e pecuária mais intensiva.<br>•Solos rasos ou medianamente profundos com fertilidade natural variável. |
|  |  | •Terrenos com maior ocorrência de Planossolos que apresentam limitações físicas e químicas.<br>•Grandes propriedades de terra e assentamentos de reforma agrária nas áreas planas.<br>•Nas áreas aluvionares estendem-se pequenas propriedades.<br>•Predomínio da pecuária extensiva. |

Burte (2019)

Ecological Complexity 7 (2010) 260–272

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

# Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making

R.S. de Groot [a,*], R. Alkemade [b], L. Braat [c], L. Hein [a], L. Willemen [a,d]

[a] Environmental Systems Analysis Group, Wageningen University, The Netherlands
[b] National Environmental Assessment Agency (PBL), Bilthoven, The Netherlands
[c] Alterra, Wageningen University & Research Centre, The Netherlands
[d] Land Dynamics Group, Wageningen University, The Netherlands

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Ecosystem services
Valuation
Modelling
Landscape planning

ABSTRACT

Despite the growing body of literature on ecosystem services, still many challenges remain to structurally integrate ecosystem services in landscape planning, management and design. This paper therefore aims to provide an overview of the challenges involved in applying ecosystem service assessment and valuation to environmental management and discuss some solutions to come to a comprehensive and practical framework.

First the issue of defining and classifying ecosystem services is discussed followed by approaches to quantify and value ecosystem services. The main part of the paper is focussed on the question how to analyze trade-offs involved in land cover and land use change, including spatial analysis and dynamic modelling tools. Issues of scale are addressed, as well as the question how to determine the total economic value of different management states.

Finally, developments and challenges regarding the inclusion of ecosystem services in integrative landscape planning and decision-making tools are discussed.

It is concluded that the ecosystem service approach and ecosystem service valuation efforts have changed the terms of discussion on nature conservation, natural resource management, and other areas of public policy. It is now widely recognized that nature conservation and conservation management strategies do not necessarily pose a trade-off between the "environment" and "development". Investments in conservation, restoration and sustainable ecosystem use are increasingly seen as a "win-win situation" which generates substantial ecological, social and economic benefits.



R.S. de Groot et al. / Ecological Complexity 7 (2010) 260–272

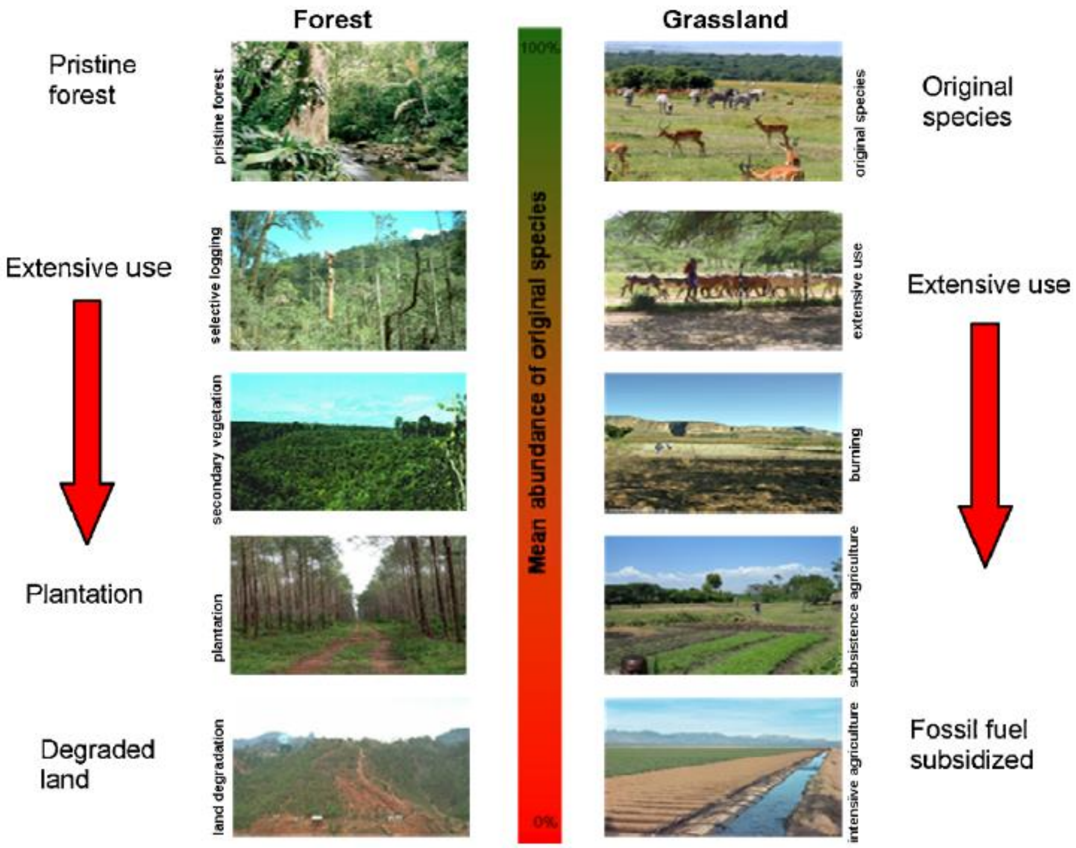



**Fig. 3.** Transition phases between natural and human-dominated (eco)systems.Source: CBD (2004) and MNP (2006).

CONCEPTS AND QUESTIONS

# Putting people in the map: anthropogenic biomes of the world

Erle C Ellis[1*] and Navin Ramankutty[2]

Humans have fundamentally altered global patterns of biodiversity and ecosystem processes. Surprising
existing systems for representing these global patterns, including biome classifications, either igno
humans altogether or simplify human influence into, at most, four categories. Here, we present the fi
characterization of terrestrial biomes based on global patterns of sustained, direct human interaction wi
ecosystems. Eighteen "anthropogenic biomes" were identified through empirical analysis of global popu
tion, land use, and land cover. More than 75% of Earth's ice-free land showed evidence of alteration as
result of human residence and land use, with less than a quarter remaining as wildlands, supporting ju
11% of terrestrial net primary production. Anthropogenic biomes offer a new way forward by acknowled
ing human influence on global ecosystems and moving us toward models and investigations of the terr
trial biosphere that integrate human and ecological systems.

*Front Ecol Environ* 2008; 6(8): 439–447, doi: 10.1890/070062

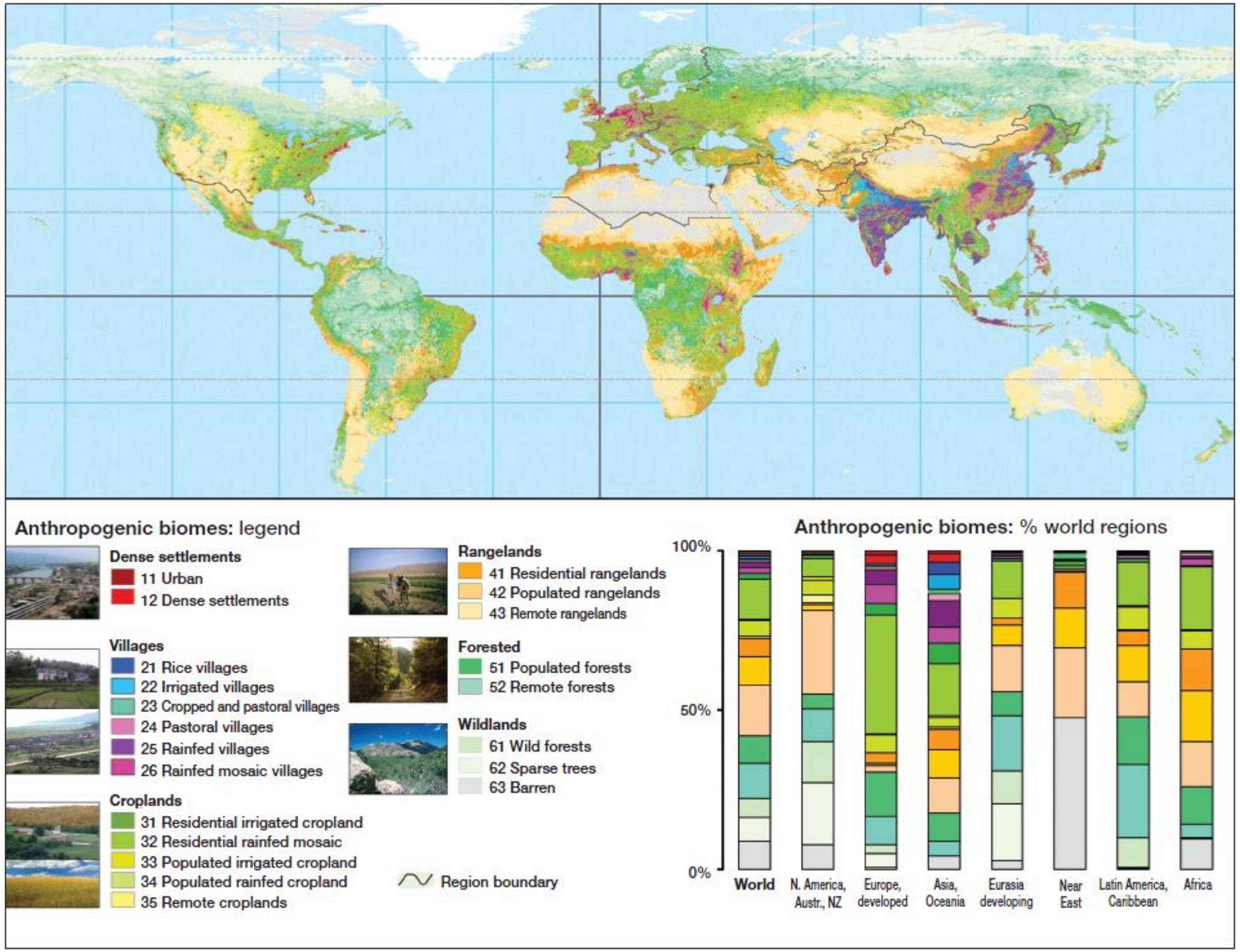



***Figure 1.*** *Anthropogenic biomes: world map and regional areas. Biomes are organized into groups (Table 1), and sorted in order of population density. Map scale = 1:160 000 000, Plate Carrée projection (geographic), 5 arc minute resolution (5' = 0.0833°). Regional biome areas are detailed in WebTable 3; WebPanel 2 provides interactive versions of this map.*

# TEOREIA EM BUSCA DE REPRESENTAR A **COMPLEXIDADE**

# TEORIA EM BUSCA DE REPRESENTAR A **COMPLEXIDADE**

- Gestão Integrada dos Recursos Hídricos
- Nexus
- Sociohidrologia
- Hidromorfologia
- Ecohidrologia
- Ecohidráulica
- Recursos Hídricos e Clima
- Caos em Hidrologia
- Incerteza dos modelos hidrológicos
- Não Estacionariedade: LUCC e Clima

# GESTÃO INTEGRADA DOS RECURSOS HÍDRICOS

- O Propósito da gestão dos recursos hídricos é prover água de forma água para o ambiente natural e humano.
- *IWRM balanceia as visões e objetivos dos grupos políticos afetados, regiões geográficas, propósitos da gestão de águas, e proteção do suprimento para os sistemas naturais e ecossistemas*
- Integração
  - Componentes do ciclo hidrológico
  - Água com Ambientes Ecológico e Intersetorial
  - Desenvolvimento social e econômico

Niel Grig, 1996

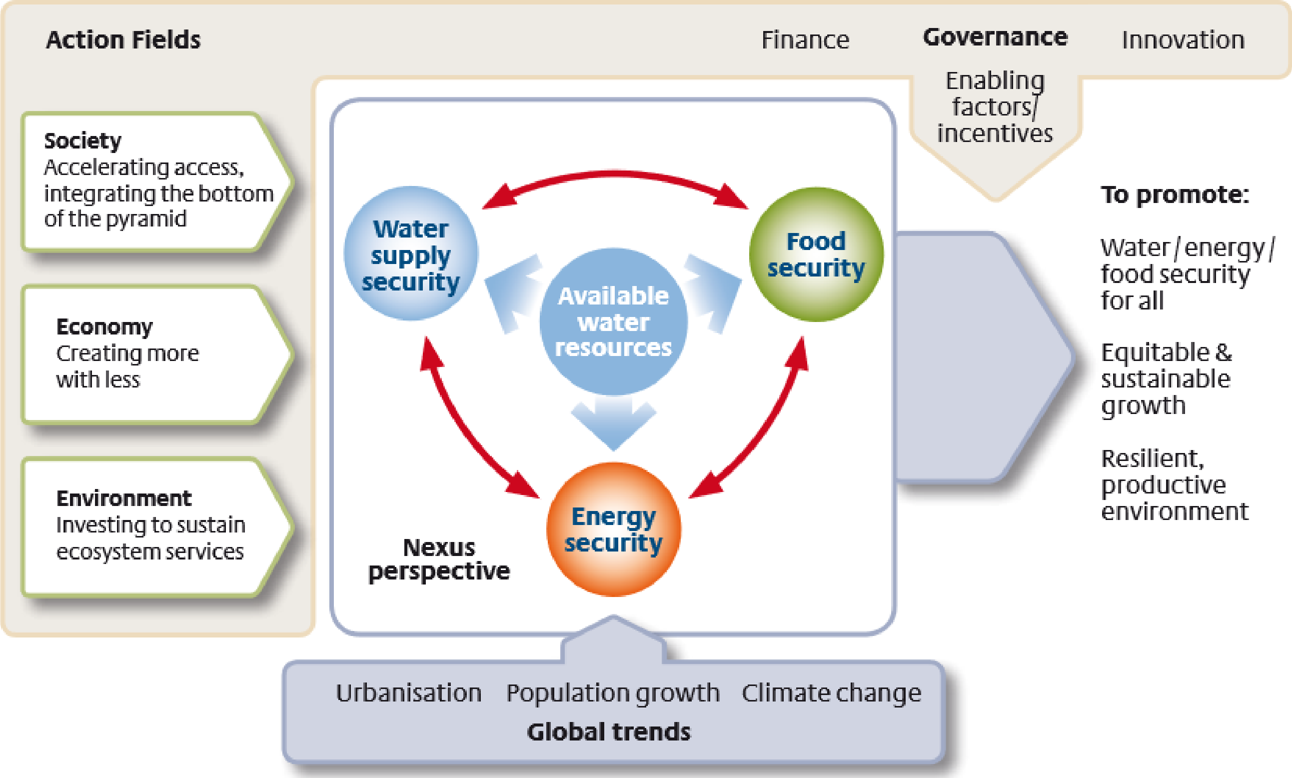
GESTÃO INTEGRADA (de que ?)

- Integração dos Componenetes do Ciclo Hidrológico (aérea, superficial, subsuperficial, subterrâneo)
- Integração dos Aspectos quantitativos e qualitativos dos recursos hídricos
- Integração das esferas de poder público (municipal, estadual e federal)
- Integração das Políticas Públicas (Recursos Hídricos, Ambiental, Saneamento, Energia...)
- Integração das esferas econômicas do setor público e privado
- Integração das componentes do desenvolvimento (social, econômico e proteção ao meio ambiente)

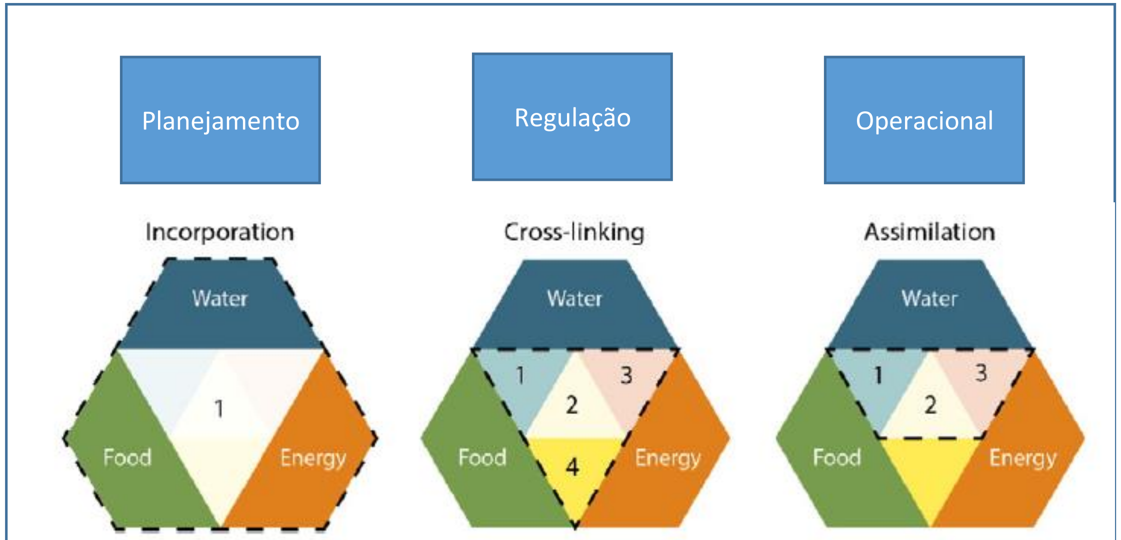
# Gestão Integrada dos Recursos Hídricos (IWRM)

- Há um amplo consenso sobre a IWRM
  - Processo no qual promove-se a coordenação do desenvolvimento e gestão dos recursos hídricos, terra e recursos relacionados de forma a maximizar os resultados econômicos e bem estar social de forma equilibrada sem comprometer a vida dos ecossistemas
- Há críticas
  - Conceito vago
  - Não é possível integrar diversos tópicos e gestão em um propósito específico de forma simultânea
  - Falta de exemplos de sucesso de IWRM
  - Ênfase no processo sem clara definição de objetivos mensuráveis

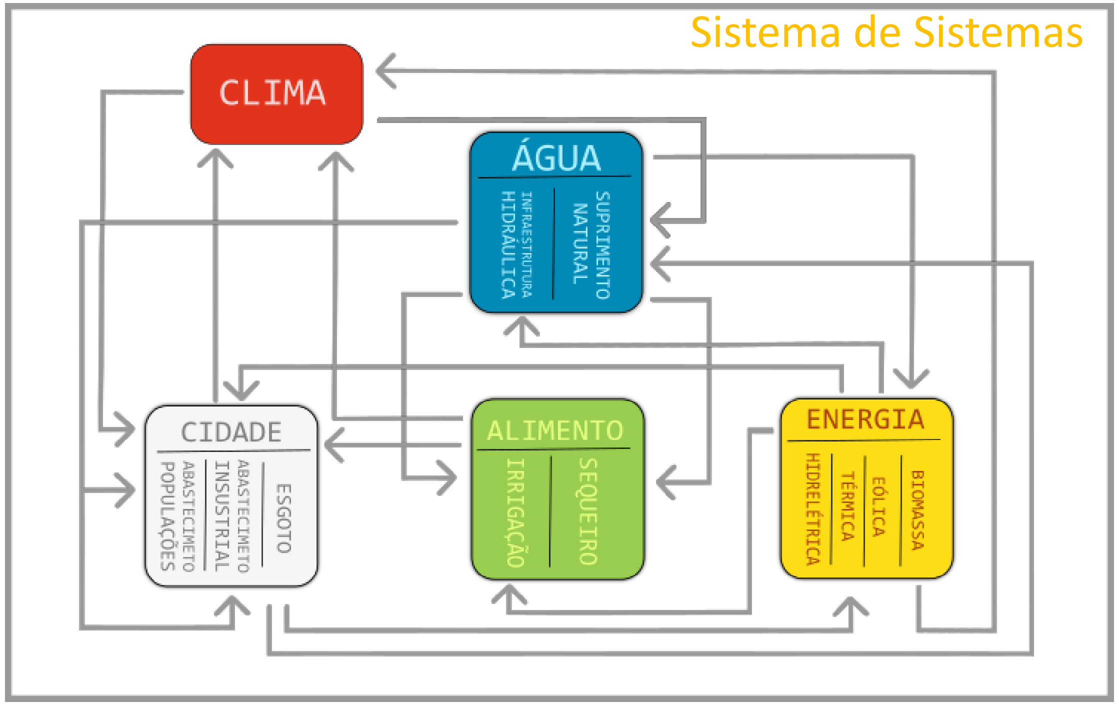
# NEXUS




Bonn2011 Conference:
The Water, Energy and Food Security Nexus – Solutions for a Green Economy*

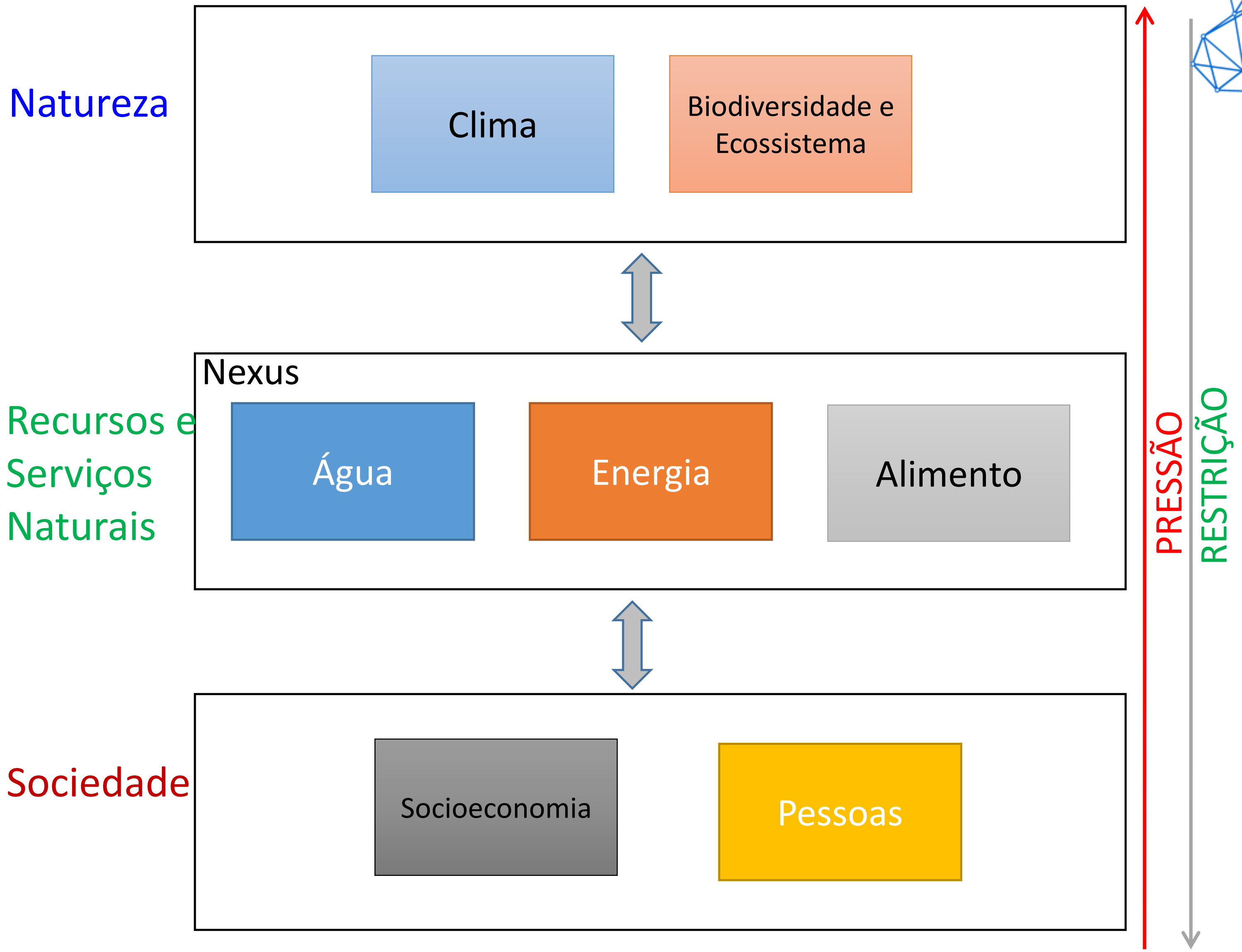


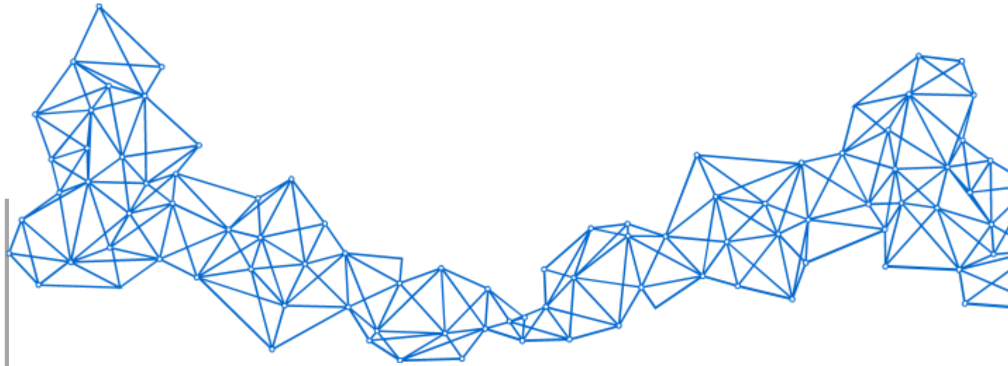

Fonte: Al-Saidi & Elagib (2016)




**NEXUS SHAE-SF**

# NEXUS


Natureza
Clima
Biodiversidade e Ecossistema
Recursos e Serviços Naturais
Nexus
Água
Energia
Alimento
Sociedade
Socioeconomia
Pessoas
PRESSÃO
RESTRIÇÃO



# HIDROECONOMIA

Journal of Hydrology 375 (2009) 627–643

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Review

## Hydro-economic models: Concepts, design, applications, and future prospects

Julien J. Harou [a,*], Manuel Pulido-Velazquez [b], David E. Rosenberg [c], Josué Medellín-Azuara [d], Jay R. Lund [d], Richard E. Howitt [e]

[a] Environment Institute and Department of Civil, Environmental and Geomatic Engineering, University College London, Pearson Building, Gouwer Street, London, UK
[b] Departamento de Ingeniería Hidráulica y Medio Ambiente, Universidad Politécnica de Valencia, Cami de Vera, s/n. 46022, Valencia, Spain
[c] Department of Civil and Environmental Engineering, Utah Water Research Laboratory, Utah State University, UT, USA
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Hydro-economic models
Integrated water resource management (IWRM)
Systems analysis
Water value
Water demand

SUMMARY

Future water management will shift from building new water supply systems to better operating existing ones. The variation of water values in time and space will increasingly motivate efforts to address water scarcity and reduce water conflicts. Hydro-economic models represent spatially distributed water resource systems, infrastructure, management options and economic values in an integrated manner. In these tools water allocations and management are either driven by the economic value of water or economically evaluated to provide policy insights and reveal opportunities for better management. A central concept is that water demands are not fixed requirements but rather functions where quantities of water use at different times have varying total and marginal economic values. This paper reviews techniques to characterize the economic value of water use and include such values in mathematical models. We identify the key steps in model design and diverse problems, formulations, levels of integration, spatial and temporal scales, and solution techniques addressed and used by over 80 hydro-economic modeling efforts dating back 45-years from 23 countries. We list current limitations of the approach, suggest directions for future work, and recommend ways to improve policy relevance.



**Table 1**
Some design choices, options, and implications for building a hydroeconomic model.

| Options | Summary | Advantages | Limitations |
|---|---|---|---|
| ***Simulation/optimization*** | | | |
| Simulation | Time-marching, rule-based algorithms; Answers question: "what if?" | Conceptually simple; existing simulation models can be used, reproduces complexity and rules of real systems | Model only investigates simulated scenarios, requires trial and error to search for the best solution over wide feasibility region |
| Optimization | Maximizes/minimizes an objective subject to constraints*; answers question: "what is best?" | Optimal solutions can recommend system improvements; reveals what areas of decision space promising for detailed simulation | Economic objectives require economic valuation of water uses; ideal solutions often assume perfect knowledge, central planning or complete institutional flexibility |
| ***Representing time*** | | | |
| Deterministic time series | Model inputs and decision variables are time series, historical or synthetically generated | Conceptually simple: easy to compare with time series of historical data or simulated results | Inputs may not represent future conditions; limited representation of hydrologic uncertainty (system performance obtained just for a single sequence of events) |
| Stochastic and multi-stage stochastic | Probability distributions of model parameters or inputs; use of multiple input sequences ('Monte-Carlo' when equiprobable sequences, or 'ensemble approach' if weighted | Accounts for stochasticity inherent in real systems | Probability distributions must be estimated, synthetic time series generated; presentation of results more difficult; difficulties reproducing persistence (Hurst phenomenon) and non-stationarity of time series |
| Dynamic optimization | Inter-temporal substitution represented | Considers the time varying aspect of value; helps address sustainability issues | Requires optimal control or dynamic programming |
| ***Submodel integration*** | | | |
| Modular | Components of final model developed and run separately | Easier to develop, calibrate and solve individual models | Each model must be updated and run separately; difficult to connect models with different scales |
| Holistic | All components housed in a single model | Easier to represent causal relationships and interdependencies and perform scenario analyses | Must solve all models at once; increased complexity of holistic model requires simpler model components |

* If optimized time-horizon is a single time period, the model can be considered a simulation model that uses an optimization computational engine.

## Optimization of California's Water Supply System: Results and Insights

Marion W. Jenkins[1]; Jay R. Lund[2]; Richard S. Howitt[3]; Andrew J. Draper[4]; Siwa M. Msangi[5]; Stacy K. Tanaka[6]; Randall S. Ritzema[7]; and Guilherme F. Marques[8]

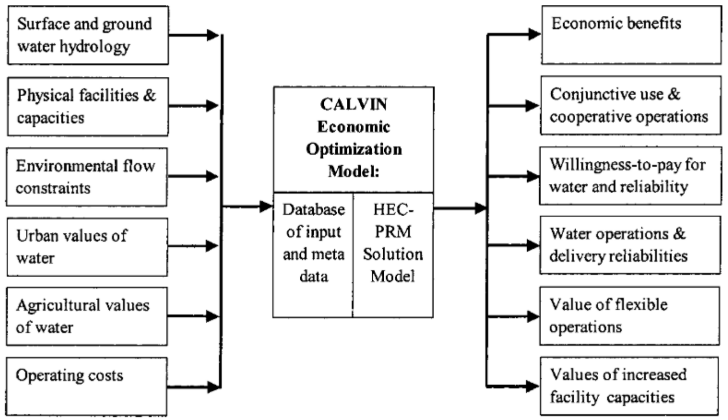



**Fig. 3.** Data flow for CALVIN

# SOCIOHIDROLOGIA

INVITED COMMENTARY

HP TODAY

HYDROLOGICAL PROCESSES
*Hydrol. Process.* **26**, 1270–1276 (2012)
Published online 24 January 2012 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/hyp.8426

## Socio-hydrology: A new science of people and water

Murugesu Sivapalan,[1,2]* Hubert H. G. Savenije[3] and Günter Blöschl[4]

[1] *Department of Civil and Environmental Engineering, Department of Geography, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA*
[2] *Department of Civil and Environmental Engineering, University of Technology Sydney, Broadway, NSW 2007, Australia*
[3] *Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands*
[4] *Institute for Hydraulic and Water Resources Engineering, Vienna University of Technology, Vienna, Austria*

*Correspondence to:
Sivapalan, Murugesu, Geography and Civil and Environmental Engineering, University of Illinois at Urbana-Champaign
E-mail: sivapala@illinois.edu

***Humans have changed the way the world works. Now they have to change the way they think about it, too.*** **The Economist, May 26, 2011**

### THE COUPLED HUMAN-WATER SYSTEM

Dateline November 2010, Murrumbidgee River Basin, Australia: Irrigators are up in arms over proposed government plans to cut their water allocations and return flows back to the basin's rivers to support the environment and restore lost biodiversity. *The Australian* of November 04, 2010 reported on the community backlash, including the resort to 'book burning' to highlight their plight. Community backlash and 'book burning' notwithstanding, the reality is that this conflict had been brewing for decades. Now, wind back the clock 100 years to the early 20th century. Up until 1900, there were virtually no dams and almost no irrigation on the Murrumbidgee. With demand for food for a growing population and the possibility of generating agricultural exports, irrigated farming expanded along the river corridor from 1920 onwards. By 1940, abstractions during low flows had increased to 50% of the natural flow and by 1950 to almost 100% (Roderick, 2011). Over this period, the predominant direction of farming development, construction of water 'assets' (e.g. dams and weirs) as well as water extractions was upstream. However, things came to a head in the 1980s, with increasing deterioration of river health and the recognition that previous farming practices were no longer sustainable. Protection of the environment was on the political agenda, along with a commitment not only to return water to rivers to nurse them back to health, but also to help agricultural industries to rise up to the challenge of a drier future. After 30 years of seemingly ongoing crisis conditions, a protracted drought and a looming federal election precipitated government action in early 2007. The result was a concerted plan by government to buy back water rights of willing farmers and build new assets aimed at increasing water use efficiency and protecting the environment [Murray-Darling Basin Authority (MDBA), 2010]. For example, there has been an increasing trend for upstream rice growers to sell back their annual allocations, and for downstream horticulturalists to purchase fresh allocations during low allocation seasons. This meant that, from 2000 onwards, water abstractions as well as water assets that had been migrating upstream in the early 20th century are now beginning to move back downstream (Figure 1). Whereas the sole customer

**Hydrologists are not exceptions to this. In traditional hydrology, human-induced water resources management activities are prescribed as external forcings in the water cycle dynamics, under the assumption of stationarity (Milly *et al.*, 2008; Peel and Blöschl, 2011). In socio-hydrology, humans and their actions are considered part and parcel of water cycle dynamics, and the aim is to predict the dynamics of both.**

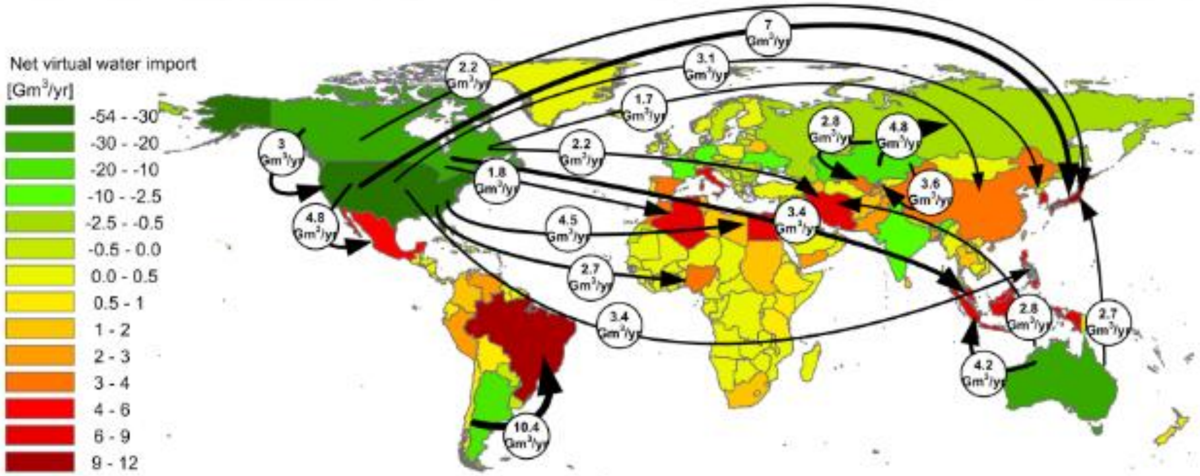



**Figure 3.** National virtual water balances and net virtual water flows related to trade in wheat products in the period 1996–2005. Only the largest net flows (>2Gm³/year) are shown (taken from Mekonnen and Hoekstra, 2010)

"Future trajectories of co-evolution of coupled human-water systems"

# SOCIOHIDROLOGIA

## Abordagens Sociohidrológicas:

- Sociohidrologia Histórica
- Sociohidrologia Comparativa
- Processos Sociohidrológico

INVITED COMMENTARY

HP TODAY

HYDROLOGICAL PROCESSES
*Hydrol. Process.* **26,** 1270–1276 (2012)
Published online 24 January 2012 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/hyp.8426

**Socio-hydrology: A new science of people and water**

## Conceitos da Sociohidrologia:

- Coevolução do sistema humano-hidrológico
- Humanos e suas ações são considerados parte e parcela da dinâmica do ciclo da água, o objetivo é prever a dinâmica de ambos.
- Quantitativa
- Predizer trajetórias futuras dos sistema humano-hidrológico
- Lei das relações de fluxos-gradientes na natureza e sociedade
- Co-evolução e retroalimentação em múltiplas escalas
- Relevância e utilizada dos conceitos de otimalidade e função objetivo

**Socio-hydrology: Use-inspired water sustainability science for the Anthropocene**

M. Sivapalan[1,2], M. Konar[1], V. Srinivasan[3], A. Chhatre[2], A. Wutich[4], C. A. Scott[5], J. L. Wescoat[6], and I. Rodríguez-Iturbe[7]

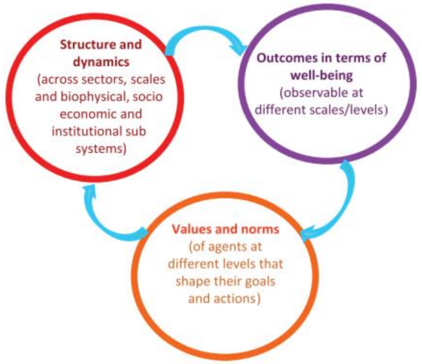



Figure 1. Organizational framework for socio-hydrology.

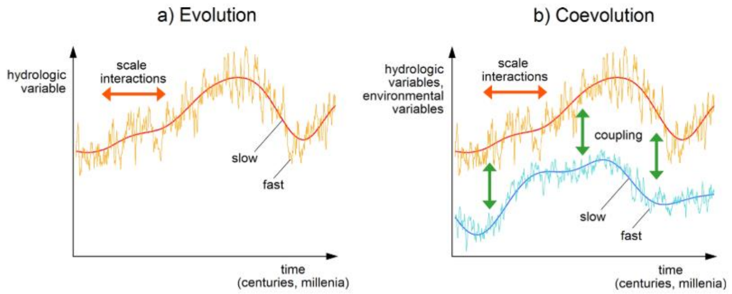
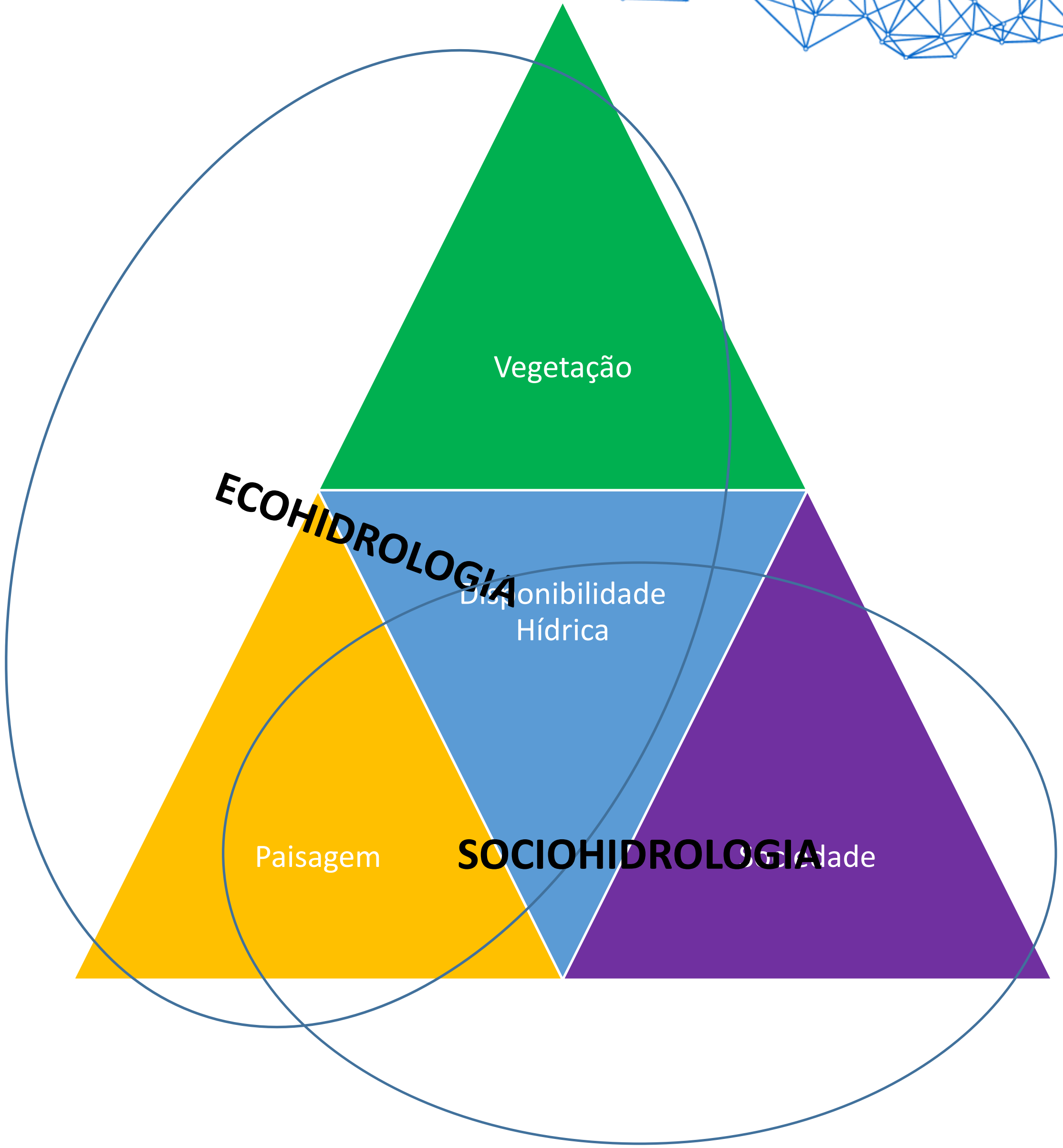



**Figure 2.** Schematic of (a) evolution, i.e., the interactions of slow and fast processes, and (b) coevolution, the interaction of a number of slow processes in addition to fast processes. (a) Redrawn from *Perdigão and Blöschl* [2014].

# SOCIOHIDROLOGIA E ECOHIDROLOGIA

- Existe uma similaridade considerável entre a nova ciência proposta da sociohidrologia e o campo agora estabelecido da ecohidrologia.
- A eco-hidrologia explora a co-evolução e auto-organização da vegetação na paisagem em relação à disponibilidade de água (Eagleson, 1982, 2002; Rodriguez-Iturbe, 2000; Berry et al., 2005).
- A sociohidrologia, por outro lado, explora a co-evolução e auto-organização das pessoas na paisagem, também com relação à disponibilidade de água.
- Acreditamos que a sociohidrologia deve aprender muito com o sucesso da eco-hidrologia, que adicionou nova vida à hidrologia através da introdução dos conceitos de co-evolução e otimização que antes eram estranhos à hidrologia.



# ECOHIDROLOGIA

UNESCO

INTERNATIONAL HYDROLOGICAL PROGRAMME

**Ecohydrology**

*A New Paradigm for the Sustainable Use of Aquatic Resources*

Edited by
M.Zalewski, G.A.Janauer, G.Jolánkai

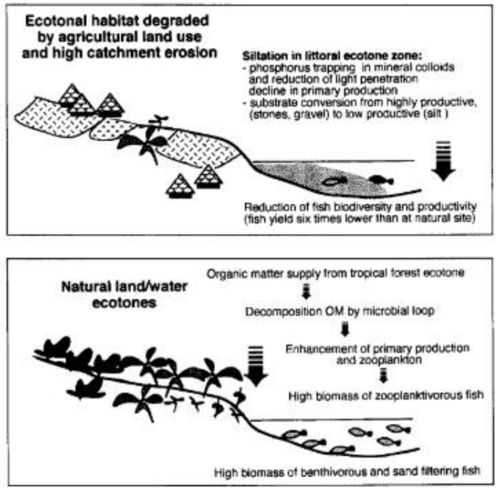
*Conceptual Background, Working Hypothesis, Rationale and Scientific Guidelines for the Implementation of the IHP-V Projects 2.3/2.4*

UNESCO, Paris, 1997

SC-97/WS/12

- Ao longo dos anos 90, foi cada vez mais reconhecido que o sistema de água é parte integrante do ecossistema.
- Isso levou à ecohidrologia como um novo campo da ciência e ao entendimento de que o sistema de recursos hídricos é resultado da co-evolução da paisagem, da hidrologia, da ecologia e da sociedade.

**Box 3.** The effect of the development of the shoreline ecotone zones of Tanganyika Lake on the biogeochemical processes and fish protein production (Zalewski 1995c).



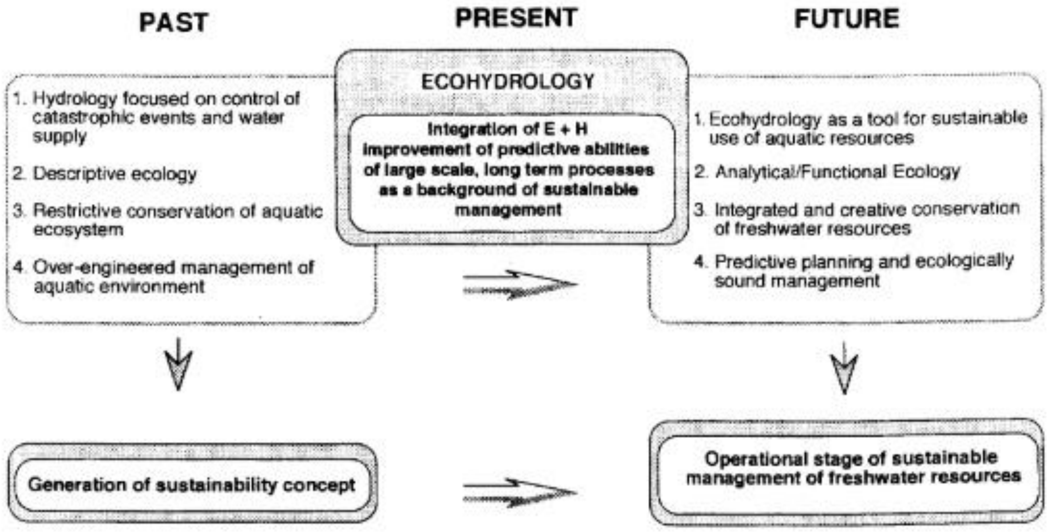




**Fig. 2.** Ecohydrology as a factor accelerating the transition from descriptive ecology, restrictive conservation and over-engineered management of aquatic ecosystems to analytical/functional ecology, and creative management and conservation of fresh waters (Zalewski 1996).

# ECOHIDROLOGIA

ELSEVIER

Advances in Water Resources 24 (2001) 695–705

Advances in Water Resources

www.elsevier.com/locate/advwatres

## Plants in water-controlled ecosystems: active role in hydrologic processes and response to water stress I. Scope and general outline

I. Rodriguez-Iturbe [a,*], A. Porporato [a,b], F. Laio [a,b], L. Ridolfi [a]

[a] *Princeton Environmental Institute and Graduate Program in Environmental Engineering and Water Resources, Princeton University, Princeton, NJ 08544, USA*

[b] *Dipartimento di Idraulica Trasporti e Infrastrutture Civili, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy*

Received 6 September 2000; received in revised form 23 December 2000; accepted 1 January 2001

**Abstract**

This series of four papers studies the complex dynamics of water-controlled ecosystems from the hydro-ecological point of view [e.g., I. Rodriguez-Iturbe, Water Resour. Res. 36 (1) (2000) 3–9]. After this general outline, the role of climate, soil, and vegetation is modeled in Part II [F. Laio, A. Porporato, L. Ridolfi, I. Rodriguez-Iturbe, Adv. Water Res. 24 (7) (2001) 707–723] to investigate the probabilistic structure of soil moisture dynamics and the water balance. Particular attention is given to the impact of timing and amount of rainfall, plant physiology, and soil properties. From the statistical characterization of the crossing properties of arbitrary levels of soil moisture, Part III develops an expression for vegetation water stress [A. Porporato, F. Laio, L. Ridolfi, I. Rodriguez-Iturbe, Adv. Water Res. 24 (7) (2001) 725–744]. This measure of stress is then employed to quantify the response of plants to soil moisture deficit as well as to infer plant suitability to given environmental conditions and understand some of the reasons for possible coexistence of different species. Detailed applications of these concepts are developed in Part IV [F. Laio, A. Porporato, C.P. Fernandez-Illescas, I. Rodriguez-Iturbe, Adv. Water Res. 24 (7) (2001) 745–762], where we investigate the dynamics of three different water-controlled ecosystems. 

*Keywords:* Soil moisture; Vegetation; Ecohydrology; Stochastic processes; Hydrology; Water stress; Water balance; Savannas; Grasslands; Crossing analysis

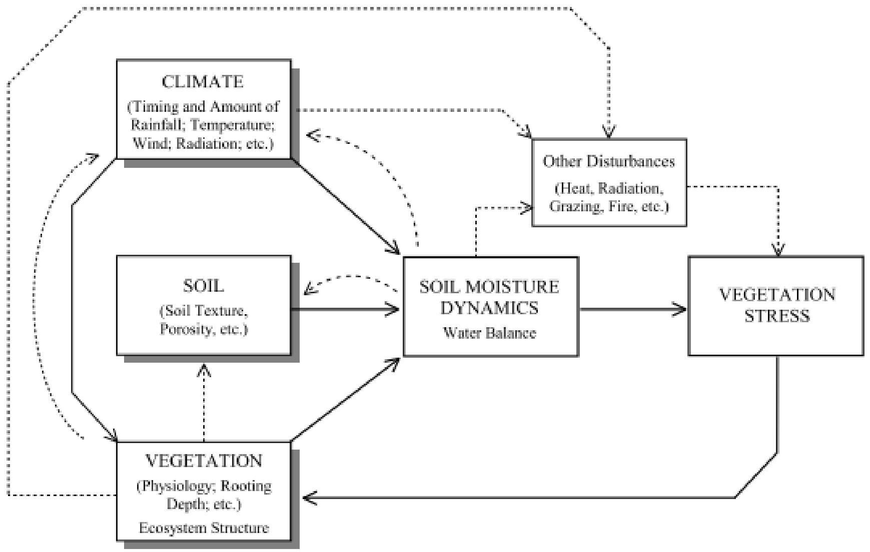
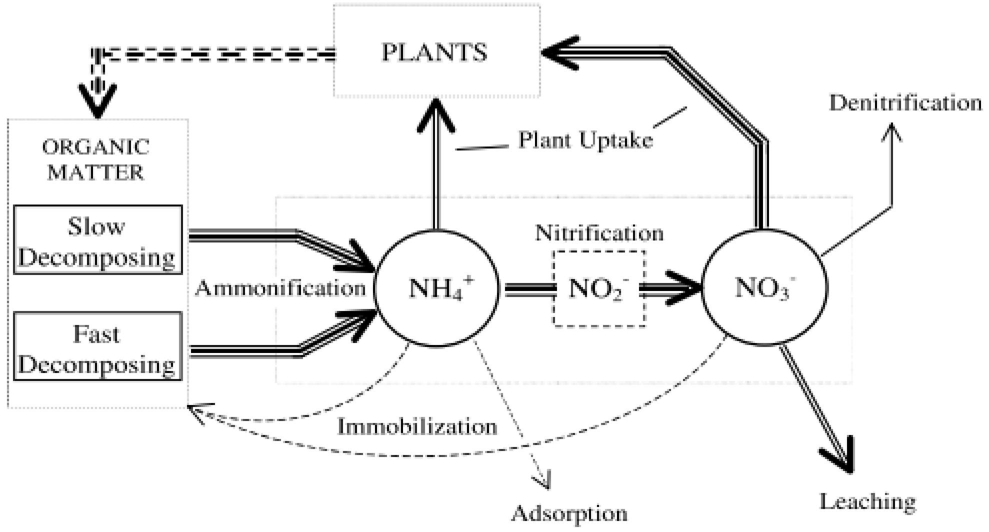



Fig. 1. Schematic representation of the climate, soil, and vegetation system. Solid arrows refer to the main dynamic links, dotted lines to secondary interactions not directly considered here.

## Umidade do Solo e Ciclo de Nutrientes



# INCERTEZA NA MODELAGEM HIDROLÓGICA

*Scientific Procedures Applied to the Planning, Design and Management of Water Resources Systems* (Proceedings of the Hamburg Symposium, August 1983). IAHS Publ. no. 147.

## Hydrological uncertainty in water management context

V. KLEMEŠ
National Hydrology Research Institute,
Department of the Environment, Ottawa, Ontario,
Canada K1A OE7

ABSTRACT The study of hydrological uncertainties, and eventually the development of the discipline referred to as stochastic hydrology, has been stimulated by water management's need to make decisions involving stochastic hydrological variables. It is pointed out that, in spite of this initial stimulus, stochastic hydrology is a discipline essentially independent of water management, and that a hydrological uncertainty need not necessarily be important for a water management decision and may carry a different degree of importance in different contexts. Examples of the lack of sensitivity of various water management problems to various aspects of stochastic hydrological models are shown and the suggestion is made that, for many if not most water management decisions involving stochastic hydrological variables, rough estimates of their two or three lowest-order statistical moments provide all the information of any consequence.

WATER RESOURCES RESEARCH, VOL. 39, NO. 8, 1214, doi:10.1029/2002WR001746, 2003

## Effective and efficient algorithm for multiobjective optimization of hydrologic models

Jasper A. Vrugt,[1] Hoshin V. Gupta,[2] Luis A. Bastidas,[3] Willem Bouten,[1] and Soroosh Sorooshian[2]

Received 2 October 2002; accepted 7 April 2003; published 20 August 2003.

[1] Practical experience with the calibration of hydrologic models suggests that any single-objective function, no matter how carefully chosen, is often inadequate to properly measure all of the characteristics of the observed data deemed to be important. One strategy to circumvent this problem is to define several optimization criteria (objective functions) that measure different (complementary) aspects of the system behavior and to use multicriteria optimization to identify the set of nondominated, efficient, or Pareto optimal solutions. In this paper, we present an efficient and effective Markov Chain Monte Carlo sampler, entitled the Multiobjective Shuffled Complex Evolution Metropolis (MOSCEM) algorithm, which is capable of solving the multiobjective optimization problem for hydrologic models. MOSCEM is an improvement over the Shuffled Complex Evolution Metropolis (SCEM-UA) global optimization algorithm, using the concept of Pareto dominance (rather than direct single-objective function evaluation) to evolve the initial population of points toward a set of solutions stemming from a stable distribution (Pareto set). The efficacy of the MOSCEM-UA algorithm is compared with the original MOCOM-UA algorithm for three hydrologic modeling case studies of increasing complexity. *INDEX TERMS:* 1869 Hydrology: Stochastic processes; 1836 Hydrology: Hydrologic budget (1655); 1894 Hydrology: Instruments and techniques; *KEYWORDS:* parameter optimization, Markov chain Monte Carlo, multicriteria calibration, population diversity, Pareto ranking, hydrologic models

**Citation:** Vrugt, J. A., H. V. Gupta, L. A. Bastidas, W. Bouten, and S. Sorooshian, Effective and efficient algorithm for multiobjective optimization of hydrologic models, *Water Resour. Res.*, *39*(8), 1214, doi:10.1029/2002WR001746, 2003.

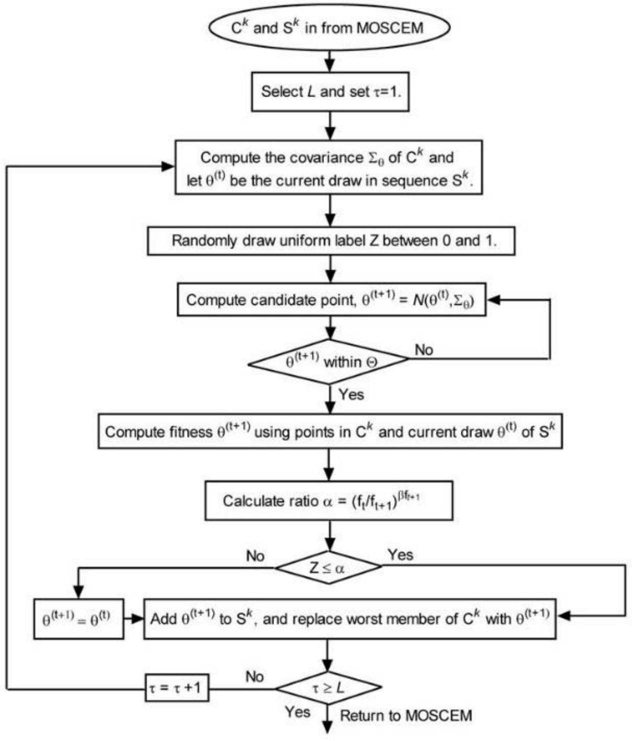



**Figure 4.** Flowchart of the Sequence Evolution Metropolis (SEM) algorithm employed in the MOSCEM-UA algorithm.

# INCERTEZA NA MODELAGEM HIDROLÓGICA

HYDROLOGICAL PROCESSES
*Hydrol. Process.* **26**, 3875–3885 (2012)
Published online 7 February 2012 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.8433

## Uncertainty assessment of hydrologic and climate forecast models in Northeastern Brazil

Hyun-Han Kwon,[1]* Francisco de Assis de Souza Filho,[2] Paul Block,[3] Liqiang Sun,[4] Upmanu Lall[5] and Dirceu S. Reis Jr[6]

[1] *Department of Civil Engineering, Chonbuk National University, 664-14 1Ga Deokjin-Dong, Jeonju-City, , Jeonbuk, 561-756, South Korea*
[2] *Department of Hydraulics and Environmental, Federal University of Ceará, Brazil*
[3] *Department of Civil, Architectural, and Environmental Engineering, Drexel University*
[4] *International Research Institute for Climate and Society, Columbia University*
[5] *Department of Earth and Environmental Engineering, Columbia University*
[6] *Department of Civil and Environmental Engineering, University of Brasilia*

Abstract:

Seasonal streamflow forecasts based on climate information can guide water managers toward superior reservoir operations, leading to improved water resources management efficiency. Uncertainty, however, is always present in seasonal streamflow forecasts, affecting the forecast value. Thus, a forecast should not be considered complete without a description of its uncertainty, which is critical for climate risk and water resources management. This study investigates the uncertainties of a seasonal streamflow forecast system for Northeastern Brazil based on climate precipitation forecasts and hydrologic modeling. These two sources of uncertainty are treated independently and then compared in order to guide future investments in the forecast system. Sea surface temperature is considered to be the primary source of uncertainty for the seasonal precipitation forecasts, based upon a 10-member climate model ensemble. Parameter uncertainty is considered to be the only source of uncertainty for the hydrologic model. Estimation of parameter uncertainty is estimated by the Shuffled Complex Evolution Metropolis algorithm, which employs a Markov Chain Monte Carlo scheme to provide the posterior distribution of the parameters and form uncertainty bounds on streamflow forecasts. Results indicate that uncertainties associated with the climate forecast are much larger than those from parameter estimation in the hydrologic model. Although model structure has not been considered in the evaluation of hydrologic uncertainties, this study indicates that future efforts to address the predominant source of uncertainty should focus on the climate prediction models. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS streamflow forecast; climate forecast; hydrologic model; uncertainty

*Received 26 July 2010; Accepted 10 November 2011*

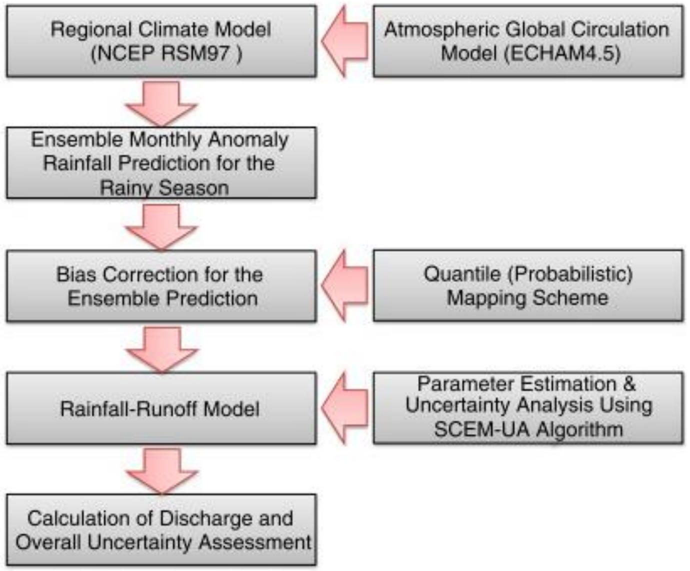



Figure 1. A flowchart of the general procedure used to investigate the uncertainty induced by climate and hydrologic model

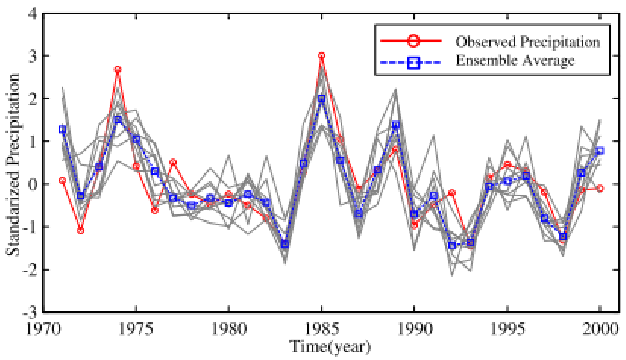



Figure 6. Monthly precipitation anomaly distribution for the rainy season over Jagauribe Basin. Unit is mm/day. Observed precipitation in red, ensemble average in green and gray all the ensemble members

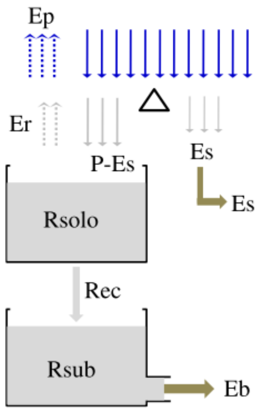



Figure 3. Conceptual illustration of the SMAP Hydrologic Model used in this study

# INCERTEZA HIDROLÓGICA-CLIMÁTICA

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 45, No. 4 AMERICAN WATER RESOURCES ASSOCIATION August 2009

## A STREAMFLOW FORECASTING FRAMEWORK USING MULTIPLE CLIMATE AND HYDROLOGICAL MODELS[1]

*Paul J. Block, Francisco Assis Souza Filho, Liqiang Sun, and Hyun-Han Kwon*[2]

ABSTRACT: Water resources planning and management efficacy is subject to capturing inherent uncertainties stemming from climatic and hydrological inputs and models. Streamflow forecasts, critical in reservoir operation and water allocation decision making, fundamentally contain uncertainties arising from assumed initial conditions, model structure, and modeled processes. Accounting for these propagating uncertainties remains a formidable challenge. Recent enhancements in climate forecasting skill and hydrological modeling serve as an impetus for further pursuing models and model combinations capable of delivering improved streamflow forecasts. However, little consideration has been given to methodologies that include coupling both multiple climate and multiple hydrological models, increasing the pool of streamflow forecast ensemble members and accounting for cumulative sources of uncertainty. The framework presented here proposes integration and offline coupling of global climate models (GCMs), multiple regional climate models, and numerous water balance models to improve streamflow forecasting through generation of ensemble forecasts. For demonstration purposes, the framework is imposed on the Jaguaribe basin in northeastern Brazil for a hindcast of 1974-1996 monthly streamflow. The ECHAM 4.5 and the NCEP/MRF9 GCMs and regional models, including dynamical and statistical models, are integrated with the ABCD and Soil Moisture Accounting Procedure water balance models. Precipitation hindcasts from the GCMs are downscaled via the regional models and fed into the water balance models, producing streamflow hindcasts. Multi-model ensemble combination techniques include pooling, linear regression weighting, and a kernel density estimator to evaluate streamflow hindcasts; the latter technique exhibits superior skill compared with any single coupled model ensemble hindcast.

(KEY TERMS: surface water hydrology; precipitation; computational methods; streamflow; forecast; uncertainty; multi-model; ensemble; Brazil.)

Block, Paul J., Francisco Assis Souza Filho, Liqiang Sun, and Hyun-Han Kwon, 2009. A Streamflow Forecasting Framework Using Multiple Climate and Hydrological Models. *Journal of the American Water Resources Association* (JAWRA) 45(4):828-843. DOI: 10.1111/j.1752-1688.2009.00327.x

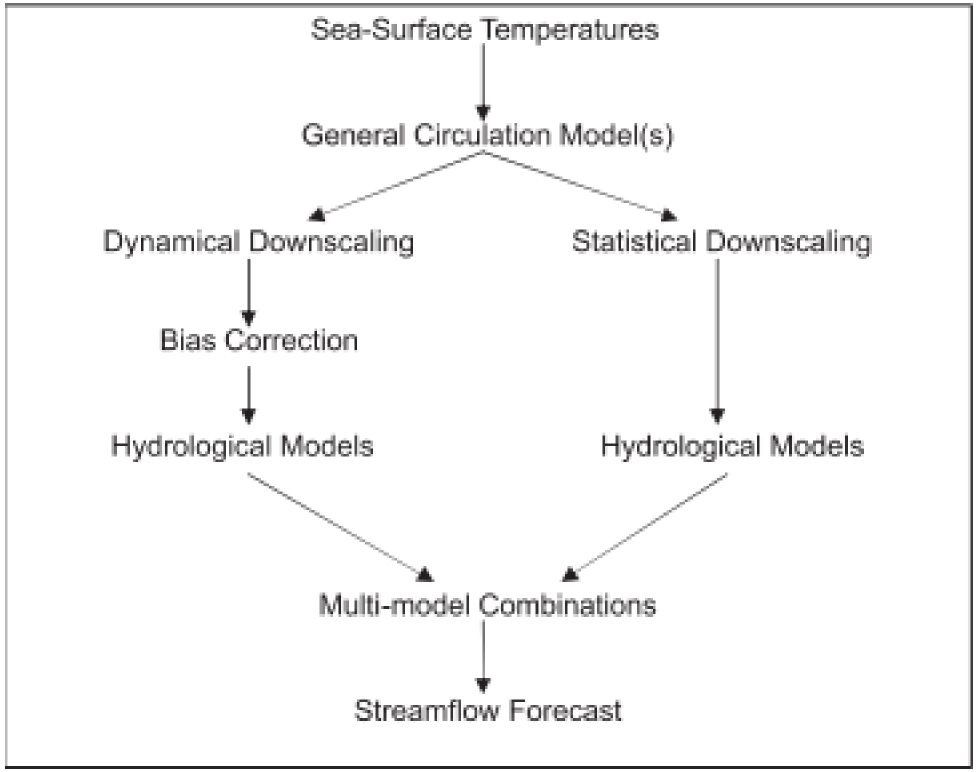


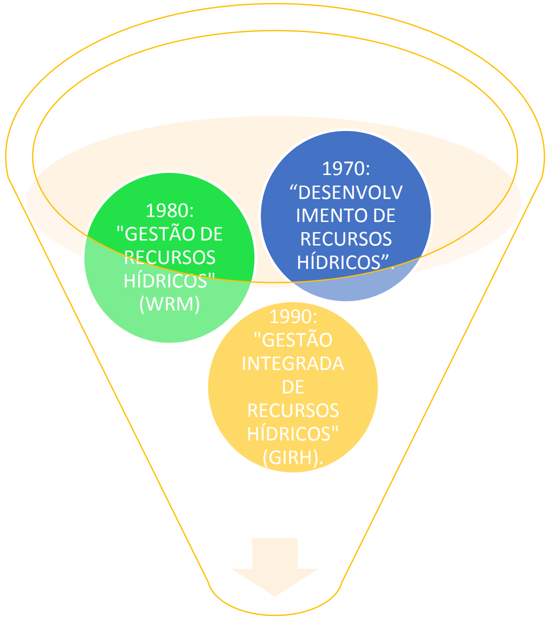

FIGURE 2. Proposed Framework for Streamflow Forecasting.

# NECESSIDADE DE UMA **SÍNTESE**

# NECESSIDADE DE **SÍNTESE**

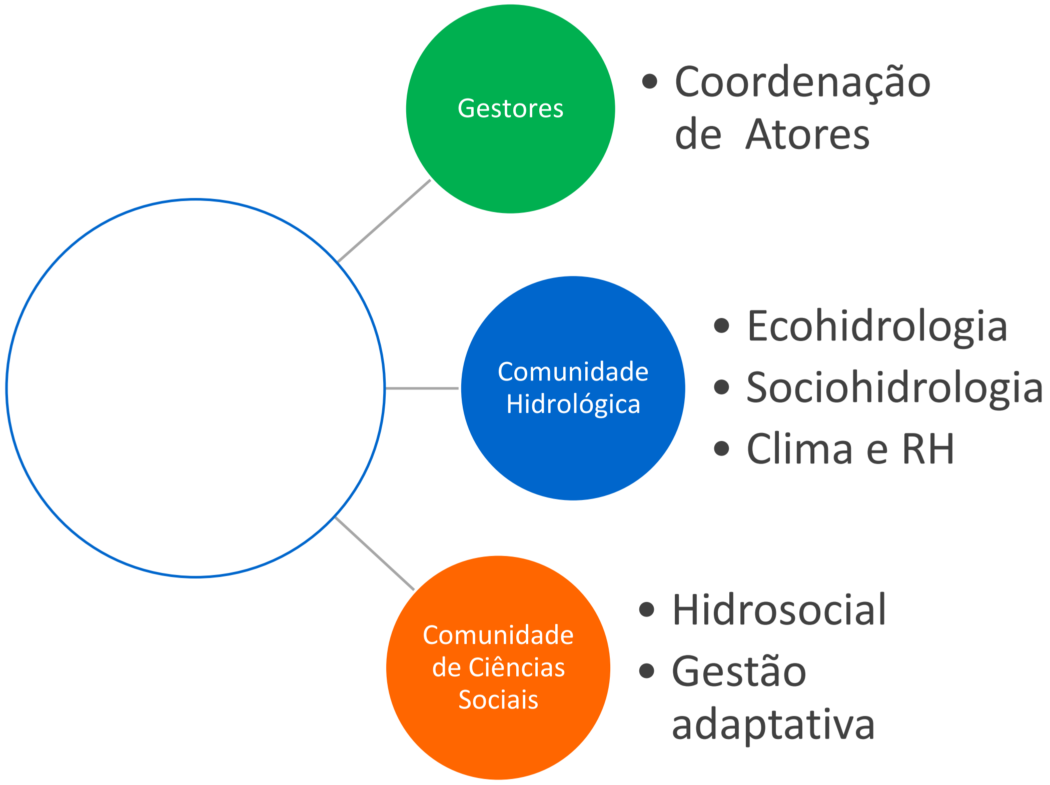
- Até a década de 1970, o campo da gestão da água era conhecido pelo termo “**desenvolvimento de recursos hídricos**”.
- Na década de 1980, tornou-se mais popular se referir à "**gestão de recursos hídricos**" (WRM)
- Na década de 1990 à "**gestão integrada de recursos hídricos**" (GIRH).

> “Testemunhamos um processo de co-evolução entre o sistema natural e a sociedade, pelo qual os limites do sistema de apoio ambiental forçam as sociedades a tomar ações, sejam elas defensivas, evasivas, ofensivas, corretivas ou acomodativas.”
>
> *(H. H. G. Savenije et al.: Evolving water science in the Anthropocene; Hydrol. Earth Syst. Sci., 18, 319–332, 2014)*




# NECESSIDADE DE **SÍNTESE**

- Na prática de gestão da água, a ênfase foi cada vez mais colocada nas interações entre planejadores, decisores e partes interessadas, de acordo com a percepção da GIRH como um processo (GWP, 2000). Como resultado, a comunicação sobre a água se tornou mais importante do que entender como o sistema funciona.
- Na comunidade científica de hidrologia, por outro lado, os pesquisadores aprimoraram gradualmente o escopo de suas análises, da hidrologia à eco-hidrologia e à sócio-hidrologia, em um esforço para entender melhor o metabolismo do sistema complexo e a dinâmica da co-evolução e desenvolvimento.
- Tendência semelhante pode ser discernida nas ciências sociais, onde alguns estudiosos têm analisado a dinâmica “hidro-social” (por exemplo, Swyngedouw, 2009; Norgaard et al., 2009; ; Linton, 2008)



Hydrol. Earth Syst. Sci., 18, 319–332, 2014
www.hydrol-earth-syst-sci.net/18/319/2014/
doi:10.5194/hess-18-319-2014


Hydrology and Earth System Sciences
Open Access

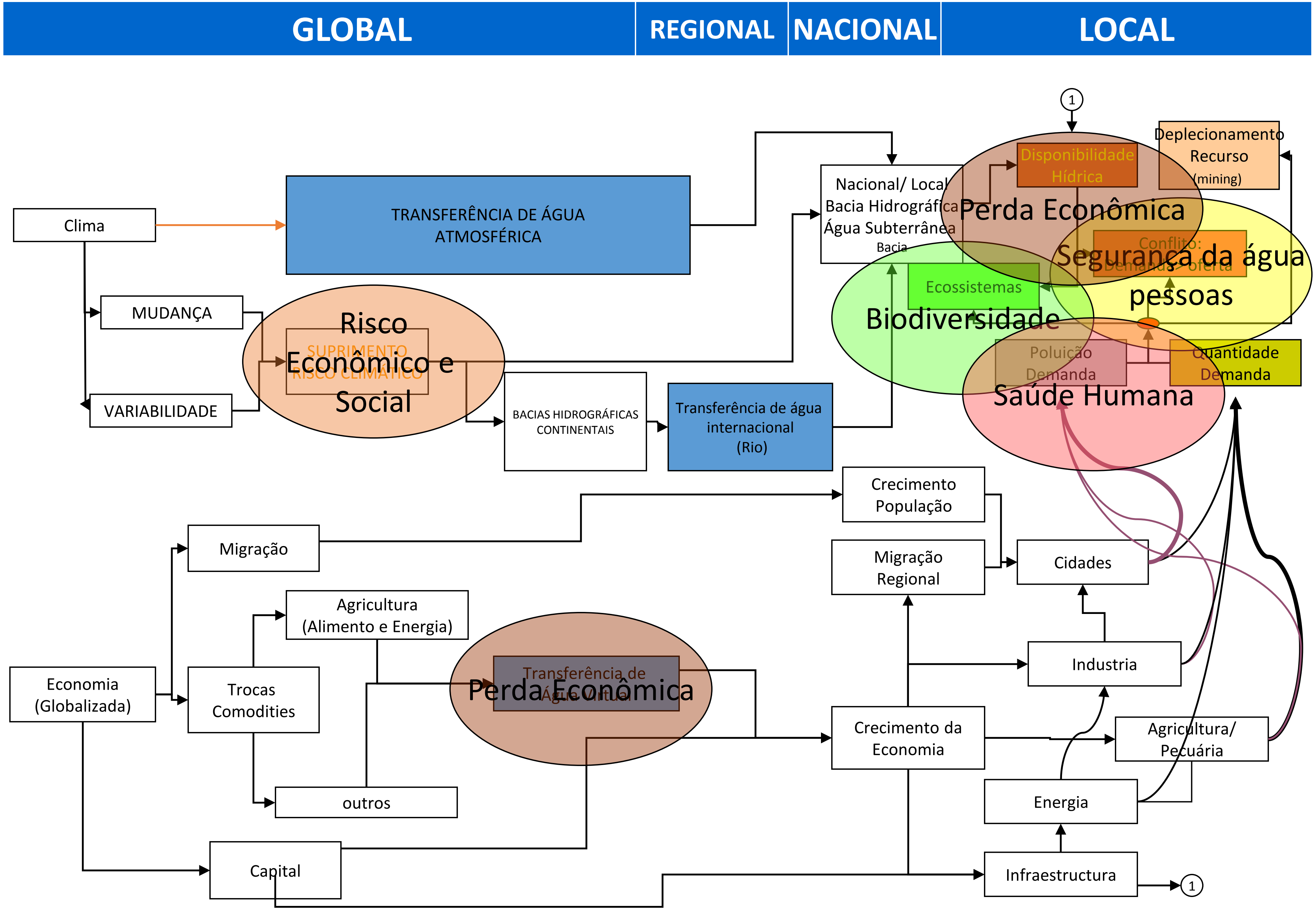
# NECESSIDADE DE **SÍNTESE**

**Evolving water science in the Anthropocene**

H. H. G. Savenije[1], A. Y. Hoekstra[2], and P. van der Zaag[1,3]

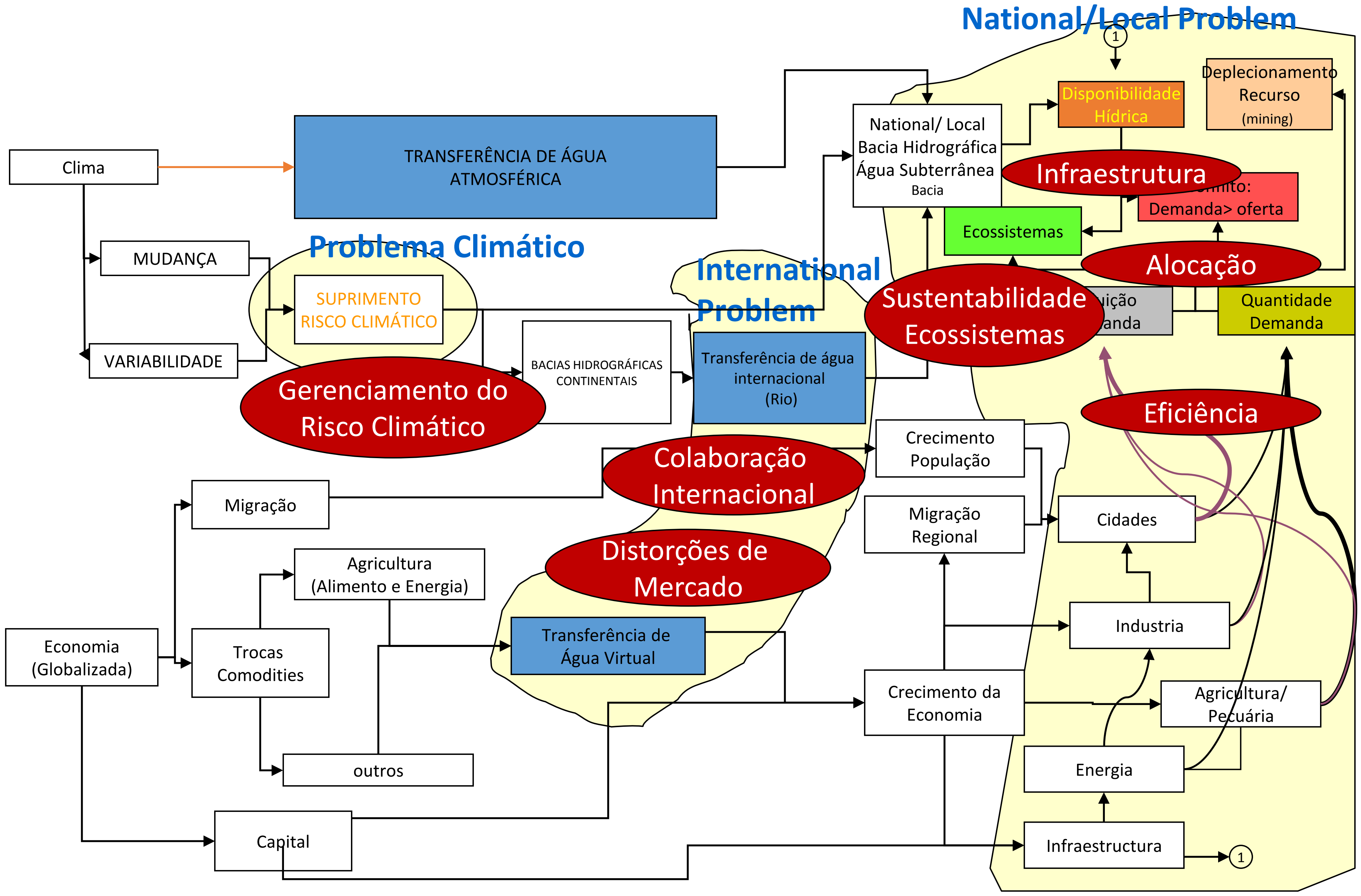
- O sistema de recursos hídricos é **altamente complexo**.
- Possui várias escalas e múltiplos feedbacks com uma variedade de processos físicos, biológicos e sociais.
- O cenário é multi-setorial, multi-ator e interdisciplinar.
- A busca pelo gerenciamento desse sistema de maneira sustentável requer compreensão sistemática dos processos do sistema, reconhecimento das interdependências e novas abordagens para lidar com essa complexidade nas escalas global e local.
- Além disso, requer sistemas de governança apropriados para gerenciar esse sistema complexo.

# ESTRUTURA DO PROBLEMA DA ÁGUA: DIAGRAMA DE INTERINFLUÊNCIA



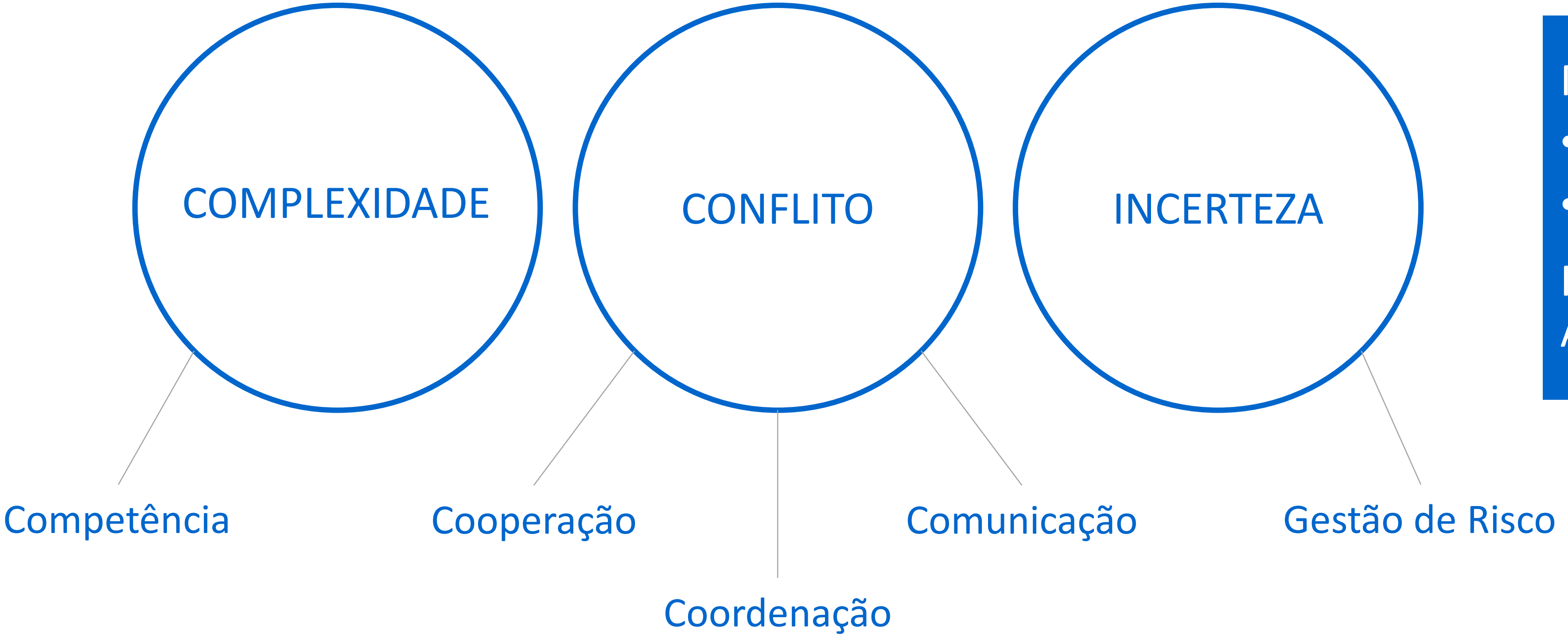
# ESTRUTURA DO PROBLEMA DA ÁGUA: DIAGRAMA DE INTERINFLUÊNCIA

| GLOBAL | REGIONAL | NACIONAL | LOCAL |
| --- | --- | --- | --- |



# CARACTERÍSTICAS DO **SISTEMA DE RECURSOS HÍDRICOS**

O sistema de recursos hídricos necessita de um novo procedimento para tratar com:




MUNDO EM MUDANÇA

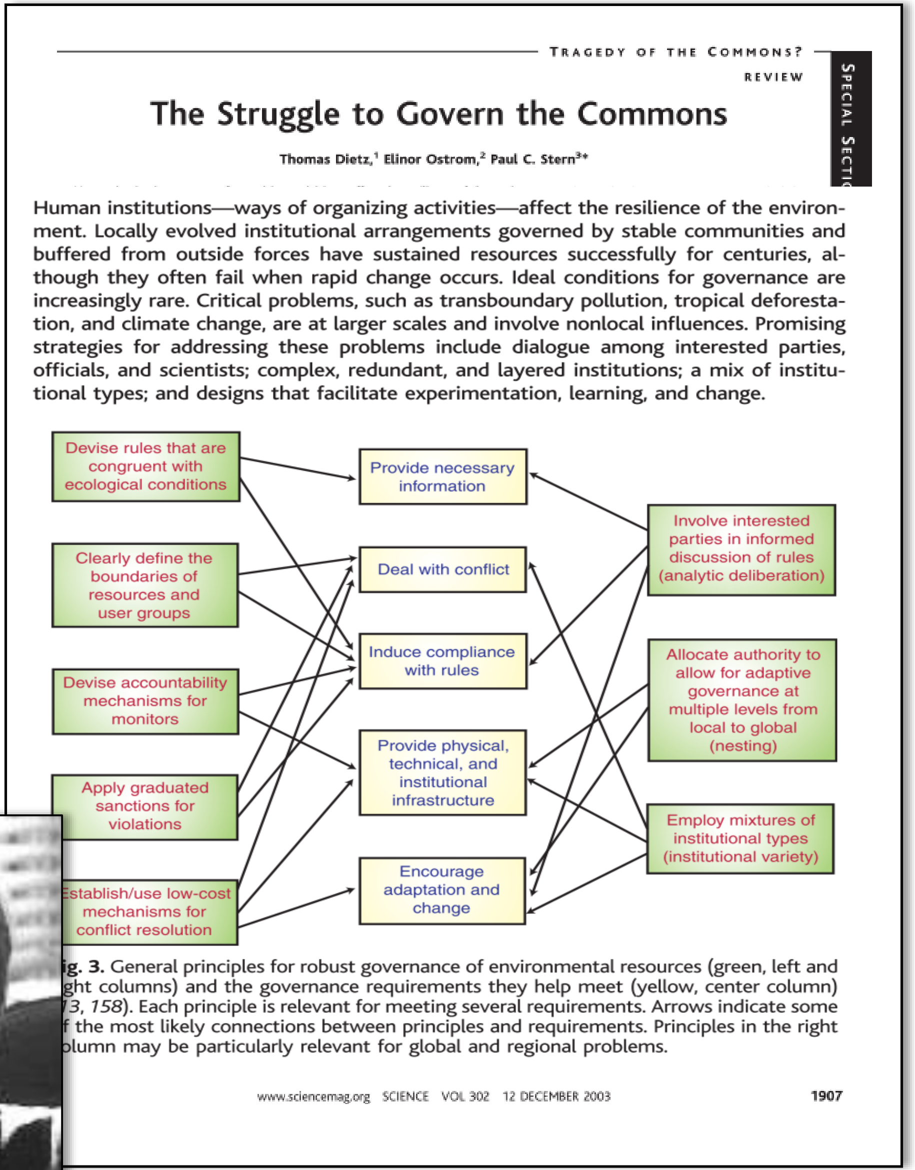
- Incerteza
- Complexidade

FUNDAMENTOS DA GESTÃO ADAPTATIVA

Niel Grig, 1996 modificado

# ADAPTAÇÃO
## Governança Adaptativa em Sistemas Complexos

- Fornecimento de Informação
- Tratar com Conflitos
- Induzir o cumprimento das regras
- Prover Infra-estrutura
- Estar Preparado para Mudanças
- Gerenciar o Risco


TRAGEDY OF THE COMMONS?
REVIEW

SPECIAL SECTIO

The Struggle to Govern the Commons

Thomas Dietz,[1] Elinor Ostrom,[2] Paul C. Stern[3]*

Human institutions—ways of organizing activities—affect the resilience of the environment. Locally evolved institutional arrangements governed by stable communities and buffered from outside forces have sustained resources successfully for centuries, although they often fail when rapid change occurs. Ideal conditions for governance are increasingly rare. Critical problems, such as transboundary pollution, tropical deforestation, and climate change, are at larger scales and involve nonlocal influences. Promising strategies for addressing these problems include dialogue among interested parties, officials, and scientists; complex, redundant, and layered institutions; a mix of institutional types; and designs that facilitate experimentation, learning, and change.



ig. 3. General principles for robust governance of environmental resources (green, left and ght columns) and the governance requirements they help meet (yellow, center column) 3, 158). Each principle is relevant for meeting several requirements. Arrows indicate some f the most likely connections between principles and requirements. Principles in the right olumn may be particularly relevant for global and regional problems.

www.sciencemag.org SCIENCE VOL 302 12 DECEMBER 2003 1907

Elinor Ostrom

# ADAPTAÇÃO

# Governança Adaptativa em Sistemas Complexos


Pahl-Wostl, C., M. Craps, A. Dewulf, E. Mostert, D. Tabara, and T. Taillieu. 2007. Social learning and water resources management. *Ecology and Society* **12**(2): 5. [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art5/

E&S

*Research*, part of a Special Feature on Social Learning in Water Resources Management

## Social Learning and Water Resources Management

*Claudia Pahl-Wostl* [1], *Marc Craps* [2], *Art Dewulf* [2], *Erik Mostert* [3], *David Tabara* [4], *and Tharsi Taillieu* [2]

ABSTRACT. Natural resources management in general, and water resources management in particular, are currently undergoing a major paradigm shift. Management practices have largely been developed and implemented by experts using technical means based on designing systems that can be predicted and controlled. In recent years, stakeholder involvement has gained increasing importance. Collaborative governance is considered to be more appropriate for integrated and adaptive management regimes needed to cope with the complexity of social-ecological systems. The paper presents a concept for social learning and collaborative governance developed in the European project HarmoniCOP (Harmonizing COllaborative Planning). The concept is rooted in the more interpretive strands of the social sciences emphasizing the context dependence of knowledge. The role of frames and boundary management in processes of learning at different levels and time scales is investigated. The foundation of social learning as investigated in the HarmoniCOP project is multiparty collaboration processes that are perceived to be the nuclei of learning processes. Such processes take place in networks or "communities of practice" and are influenced by the governance structure in which they are embedded. Requirements for social learning include institutional settings that guarantee some degree of stability and certainty without being rigid and inflexible. Our analyses, which are based on conceptual considerations and empirical insights, suggest that the development of such institutional settings involves continued processes of social learning. In these processes, stakeholders at different scales are connected in flexible networks that allow them to develop the capacity and trust they need to collaborate in a wide range of formal and informal relationships ranging from formal legal structures and contracts to informal, voluntary agreements.

Key Words: *social learning; collaborative governance; adaptive management; water resources*

Water Resour Manage (2007) 21:49–62
DOI 10.1007/s11269-006-9040-4

ORIGINAL ARTICLE

## Transitions towards adaptive management of water facing climate and global change

**Claudia Pahl-Wostl**

Received: 20 April 2006


**Abstract** Water management is facing major challenges due to increasing u
caused by climate and global change and by fast changing socio-economic boun
tions. More attention has to be devoted to understanding and managing the tra
current management regimes to more adaptive regimes that take into account env
technological, economic, institutional and cultural characteristics of river basins. T
a paradigm shift in water management from a prediction and control to a man
learning approach. The change towards adaptive management could be defined
to manage by managing to learn". Such change aims at increasing the adaptive capacity of river basins at different scales. The paper identifies major challenges for research and practice how to understand a transition in water management regimes. A conceptual framework is introduced how to characterize water management regimes and the dynamics of transition processes. The European project NeWater project is presented as one approach where new scientific methods and practical tools are developed for the participatory assessment and implementation of adaptive water management.

**Keywords** Adaptive water management · Social learning · Transition processes · Water management regimes · Global change

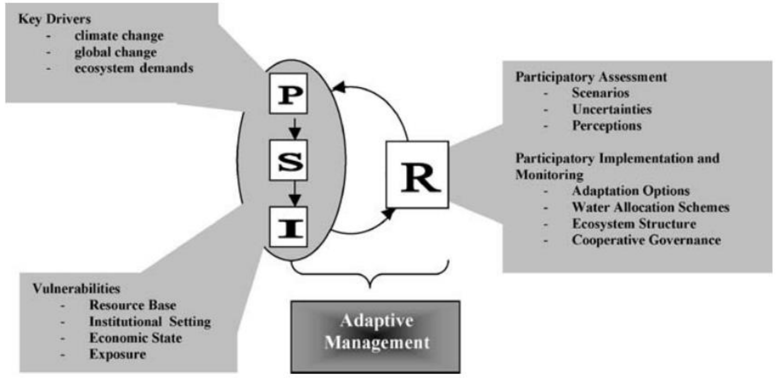
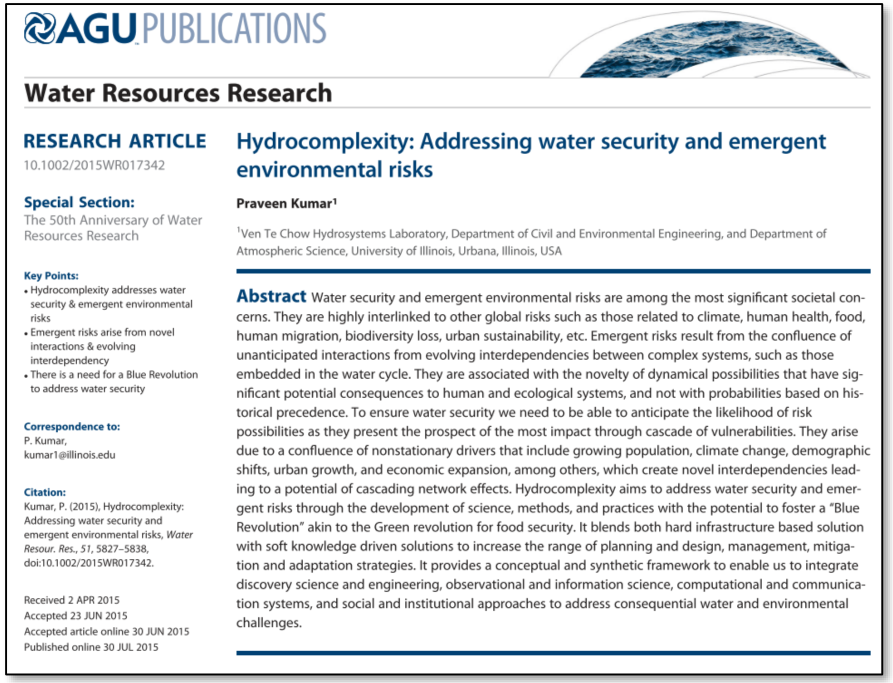



**Fig. 1** Adaptive management represented in an extended PSIR (Pressure-State-Impact-Response) framework – system design to increase the ability of the system to cope with change – R as part of the autonomous response strategies. The whole process has to be perceived as being iterative and proceed in cycles in contrast to the quite linear and sequential approach that is often adopted when using the PSIR scheme. The boxes indicate the type of variables and processes that are of importance

# HIDROCOMPLEXIDADE



AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2015WR017342

**Special Section:**
The 50th Anniversary of Water Resources Research

**Key Points:**
- Hydrocomplexity addresses water security & emergent environmental risks
- Emergent risks arise from novel interactions & evolving interdependency
- There is a need for a Blue Revolution to address water security

**Correspondence to:**
P. Kumar,
kumar1@illinois.edu

**Citation:**
Kumar, P. (2015), Hydrocomplexity: Addressing water security and emergent environmental risks, *Water Resour. Res.*, *51*, 5827–5838, doi:10.1002/2015WR017342.

Received 2 APR 2015
Accepted 23 JUN 2015
Accepted article online 30 JUN 2015
Published online 30 JUL 2015

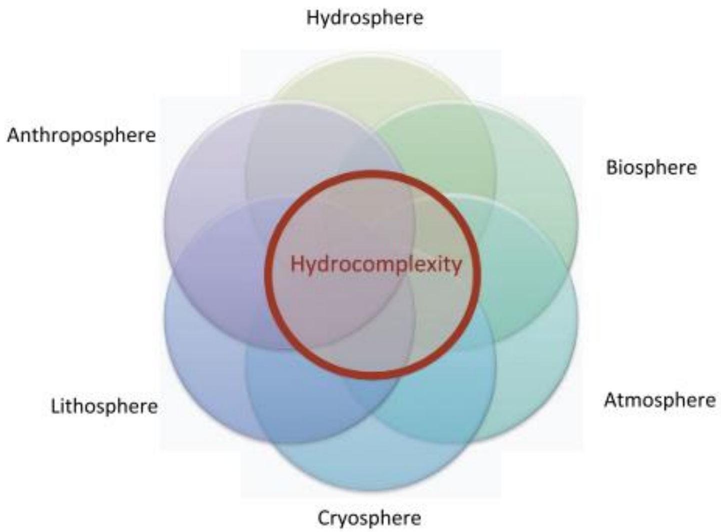
## Hydrocomplexity: Addressing water security and emergent environmental risks

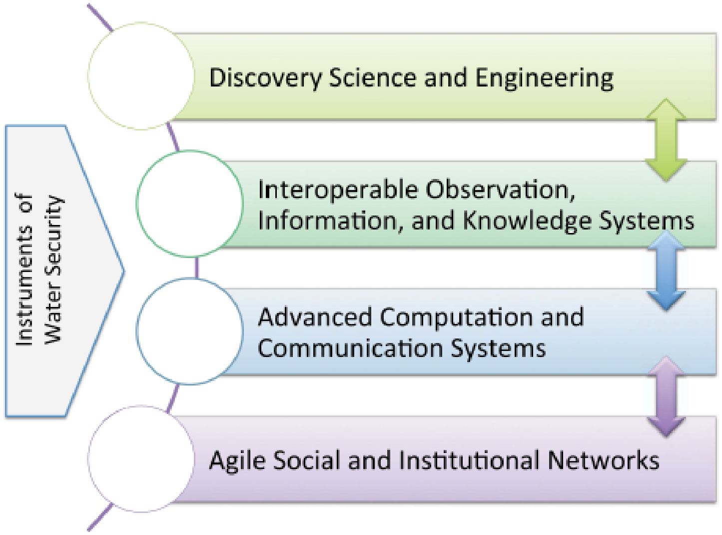
**Praveen Kumar**[1]

[1]Ven Te Chow Hydrosystems Laboratory, Department of Civil and Environmental Engineering, and Department of Atmospheric Science, University of Illinois, Urbana, Illinois, USA

**Abstract** Water security and emergent environmental risks are among the most significant societal concerns. They are highly interlinked to other global risks such as those related to climate, human health, food, human migration, biodiversity loss, urban sustainability, etc. Emergent risks result from the confluence of unanticipated interactions from evolving interdependencies between complex systems, such as those embedded in the water cycle. They are associated with the novelty of dynamical possibilities that have significant potential consequences to human and ecological systems, and not with probabilities based on historical precedence. To ensure water security we need to be able to anticipate the likelihood of risk possibilities as they present the prospect of the most impact through cascade of vulnerabilities. They arise due to a confluence of nonstationary drivers that include growing population, climate change, demographic shifts, urban growth, and economic expansion, among others, which create novel interdependencies leading to a potential of cascading network effects. Hydrocomplexity aims to address water security and emergent risks through the development of science, methods, and practices with the potential to foster a "Blue Revolution" akin to the Green revolution for food security. It blends both hard infrastructure based solution with soft knowledge driven solutions to increase the range of planning and design, management, mitigation and adaptation strategies. It provides a conceptual and synthetic framework to enable us to integrate discovery science and engineering, observational and information science, computational and communication systems, and social and institutional approaches to address consequential water and environmental challenges.

A **hidrocomplexidade** visa abordar a segurança da água e os riscos emergentes por meio do desenvolvimento de ciências, métodos e práticas que encapsulam uma compreensão do comportamento da rede interconectada de processos.



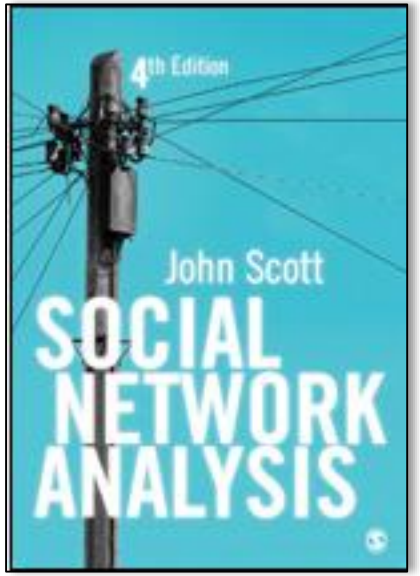

Uma **rede de processos (PROCESS NETWORK)** é definida como uma rede de ciclos de feedback e as escalas de tempo associadas que representam a magnitude e a direção do fluxo de matéria, energia e / ou informações entre as diferentes variáveis.

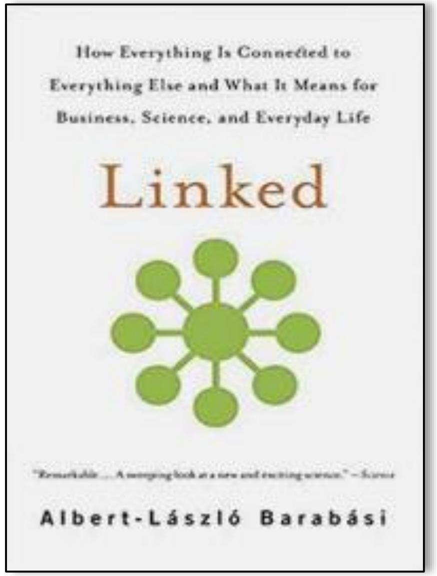
Argumentou-se que a descrição ideal do estado de um sistema complexo é uma rede de processos,

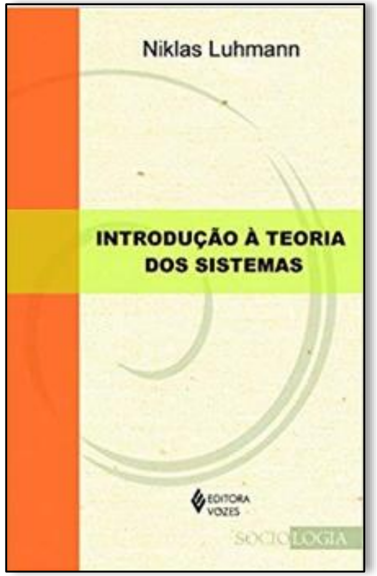
**DESAFIOS**
- Dinâmica emergente e risco
- Integração de sistemas de dados e conhecimento
- Redes Institucionais

# HIDROCOMPLEXIDAD E COMO PROPOSTA DE **SÍNTESE**

# INSPIRAÇÕES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## RESILIENCE AND STABILITY OF ECOLOGICAL SYSTEMS ❖ 4050

*C. S. Holling*
Institute of Resource Ecology, University of British Columbia, Vancouver, Canada

INTRODUCTION

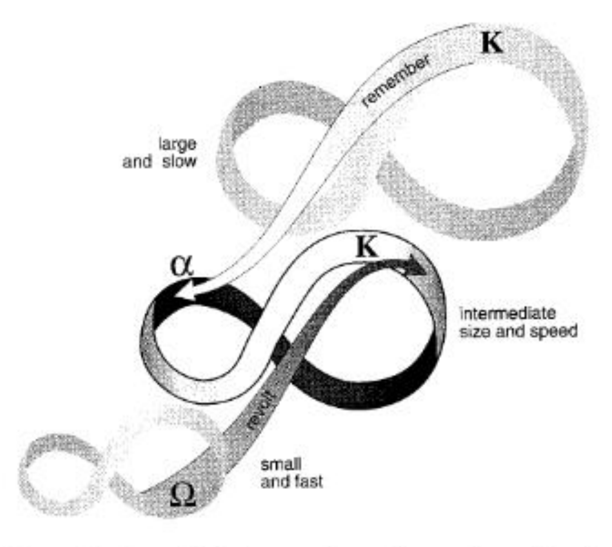



Figure 7. Panarchical connections. Three selected levels

*American Economic Review 100 (June 2010): 1–33*
*http://www.aeaweb.org/articles.php?doi=10.1257/aer.100.3.1*

## Beyond Markets and States: Polycentric Governance of Complex Economic Systems

By Elinor Ostrom*

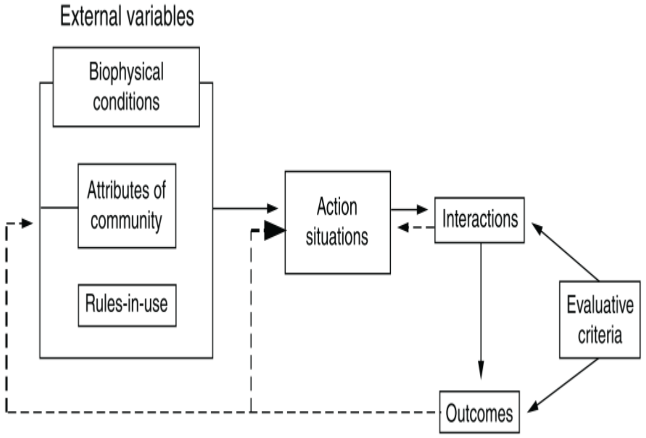
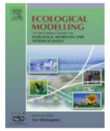



Figure 2. A Framework for Institutional Analysis

*...urce:* Adapted from E. Ostrom 2005: 15.

ECOLOGICAL MODELLING 208 (2007) 49–55
available at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/ecolmodel



## Ecological network analysis: network construction

Brian D. Fath[a,*], Ursula M. Scharler[b,c], Robert E. Ulanowicz[d], Bruce Hannon[e]

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[b] School of Biological and Conservation Sciences, University of KwaZulu-Natal, Howard College Campus, George Campbell Building, 4041 Durban, South Africa
[c] Department of Aquatic Ecology and Water Quality Management (AEW), Wageningen University and Research Centre, Ritzema Bosweg 32-A, 6703 AZ Wageningen, The Netherlands
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ABSTRACT

Ecological network analysis (ENA) is a systems-oriented methodology to analyze within system interactions used to identify holistic properties that are otherwise not evident from the direct observations. Like any analysis technique, the accuracy of the results is as good as the data available, but the additional challenge is that the data need to characterize an entire ecosystem's flows and storages. Thus, data requirements are substantial. As a result, there have, in fact, not been a significant number of network models constructed and development of the network analysis methodology has progressed largely within the purview of a few established models. In this paper, we outline the steps for one approach to construct network models. Lastly, we also provide a brief overview of the algorithmic methods used to construct food web typologies when empirical data are not available. It is our aim that such an effort aids other researchers to consider the construction of such models as well as encourages further refinement of this procedure.

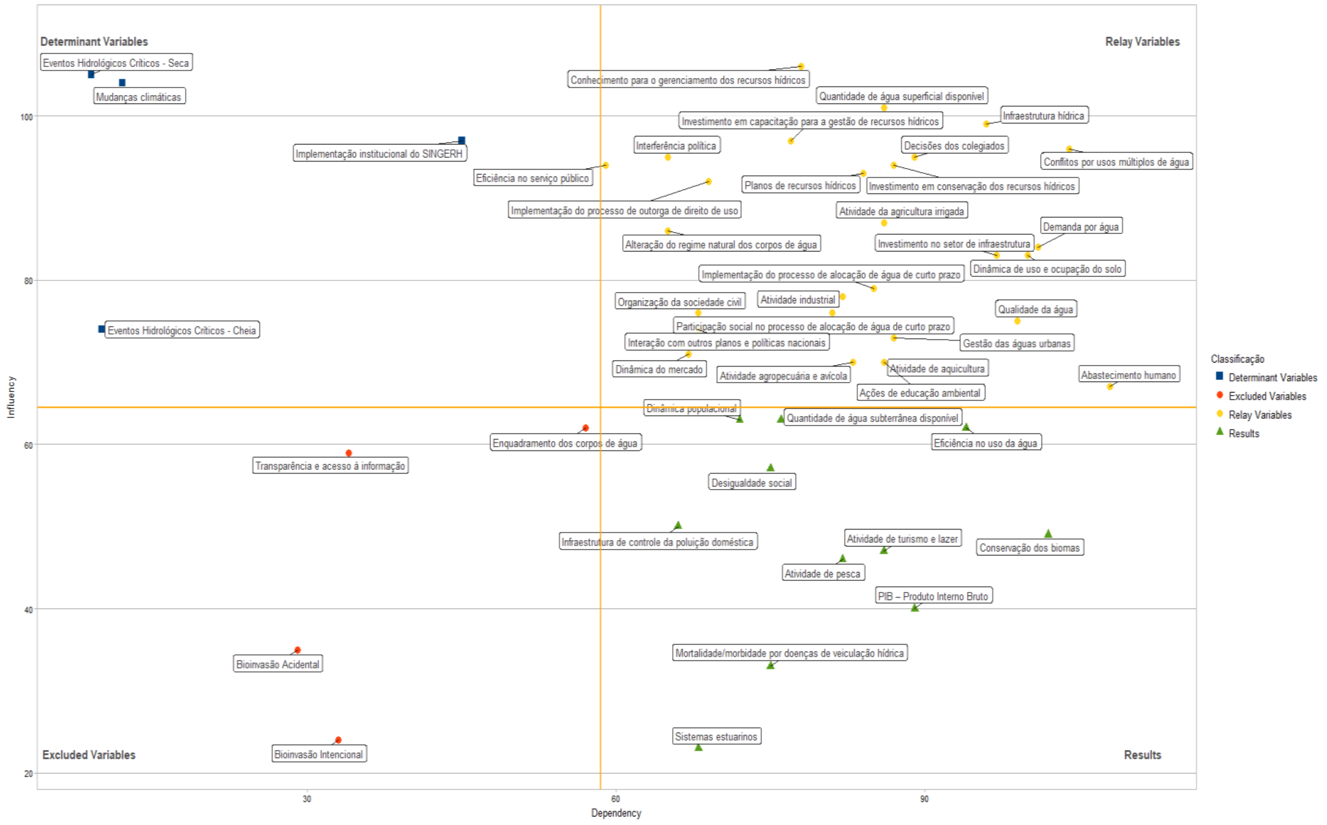
# HIDROCOMPLEXIDADE COMO **MÉTODO**

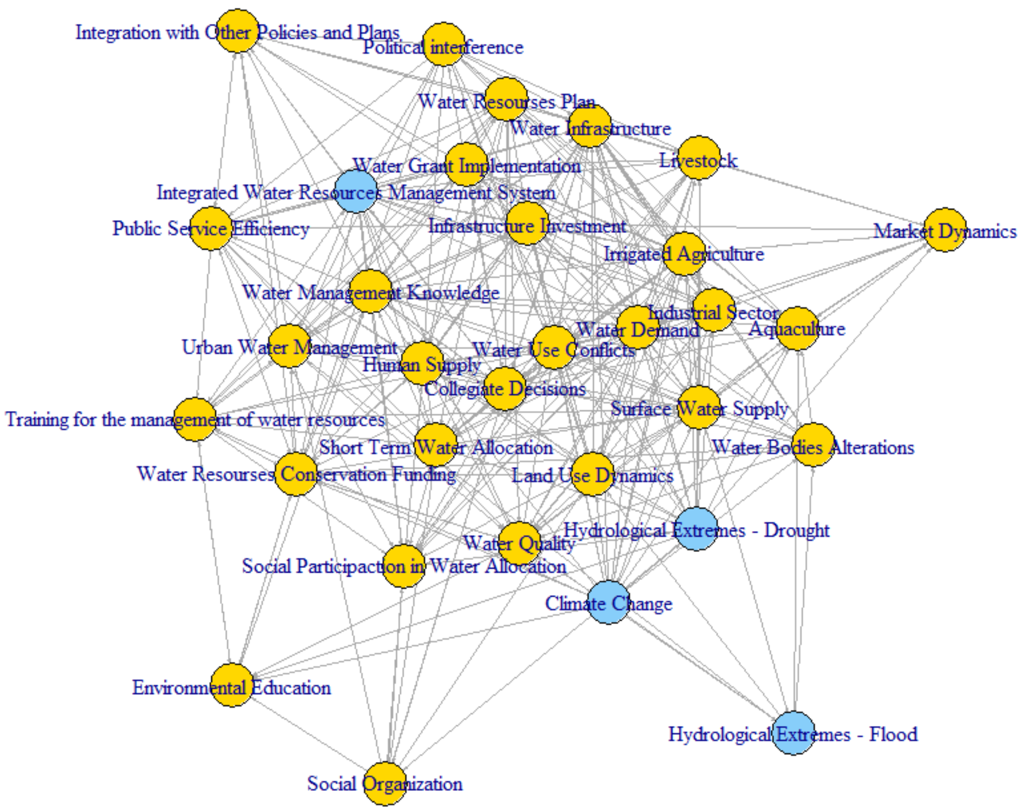
Teorias, Métodos e Instrumentos de Análise

# CONCEITOS

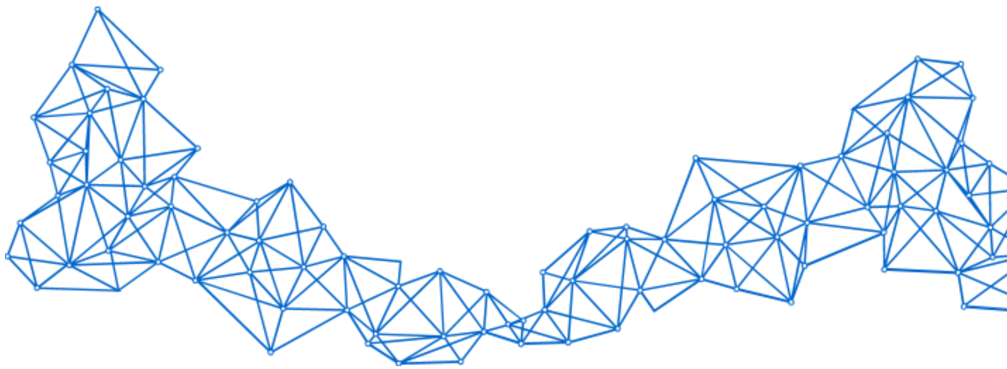

Nexus
Ciência das Redes
Gestão Adaptativa
Poder e Dominação
Sustentabilidade Ecossistemas
Territórios Hidrossociais
Rastreamento do valor dos fluxos de água
Mudança Climática
Conflito e Colaboração
Valores e Ética
Sistemas Autopoiéticos
Água Virtual
Urbanização
Autointeresse e Empatia
Desigualdade Social
Resiliência
Teleconecção atmosférica e rios voadores
Globalização
Transdisciplinariedade
Teoria da Informação
Caos
Reciclar e Reutilizar
Risco
Multiplas Escalas
Teoria dos Sistemas
Reconhecimento
Reciprocidade

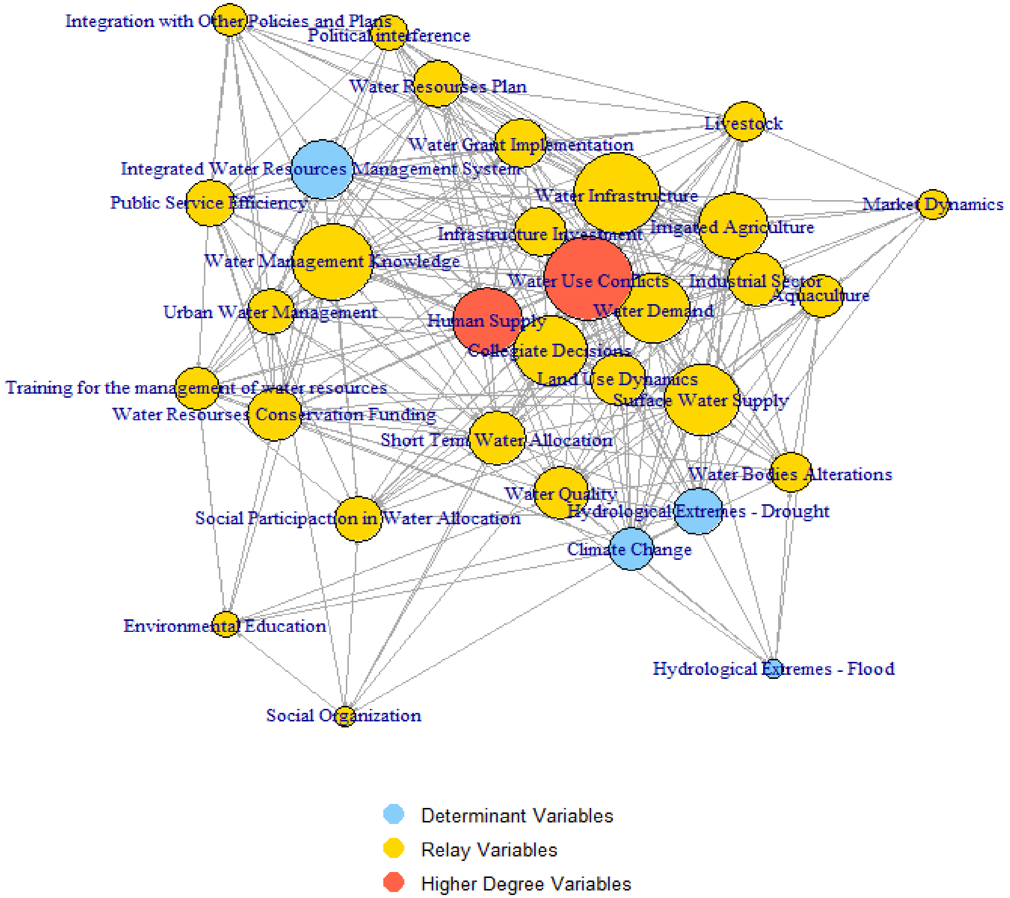
# INICIATIVA 1

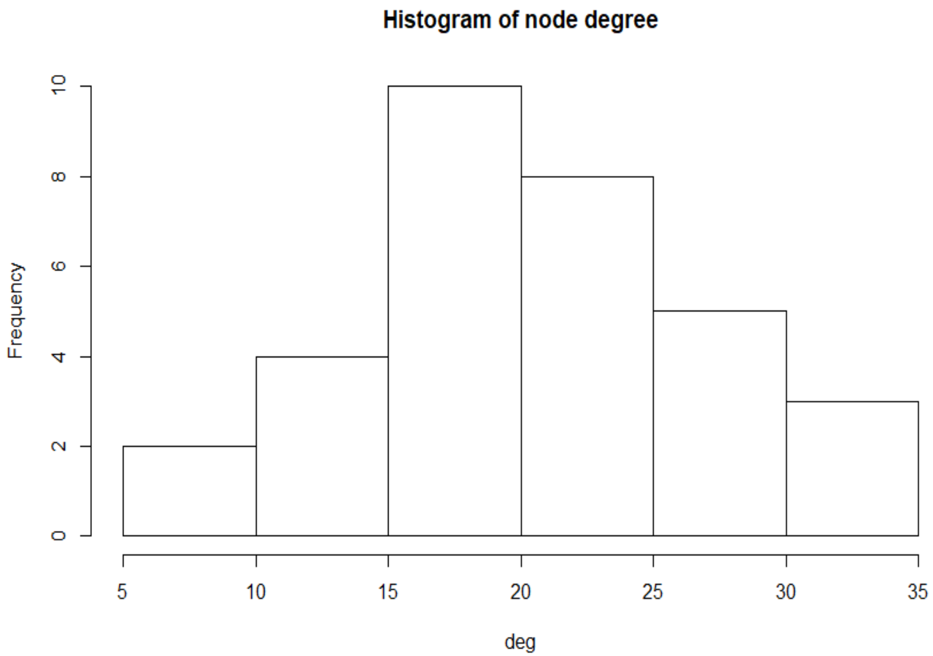


# INICIATIVA 1



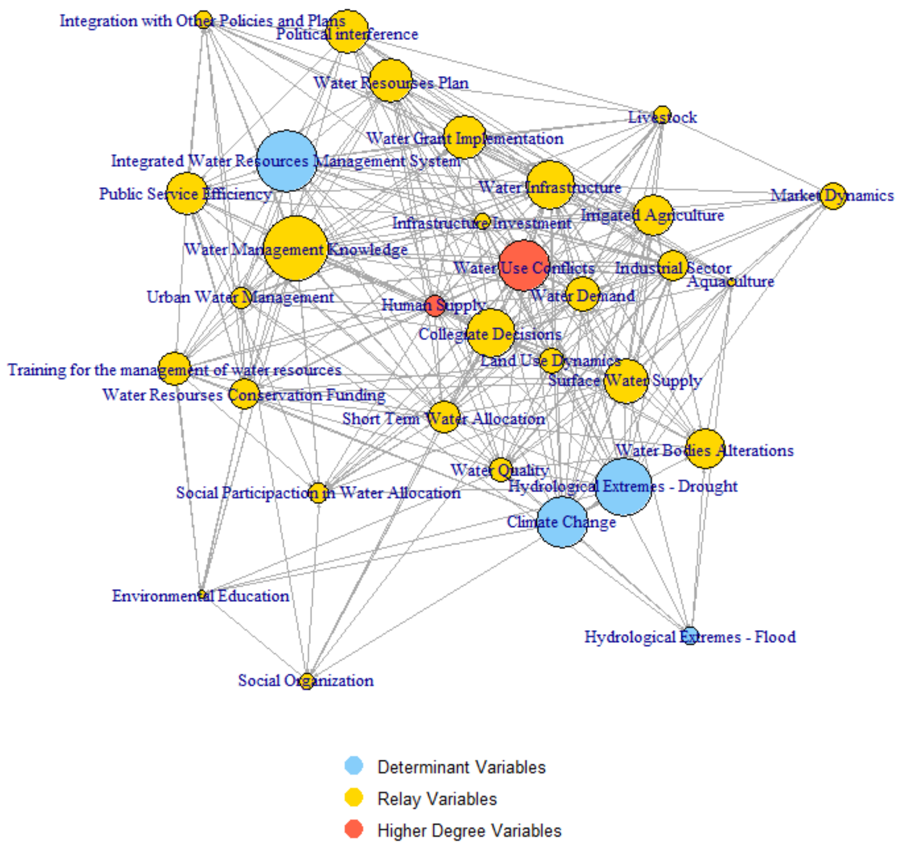


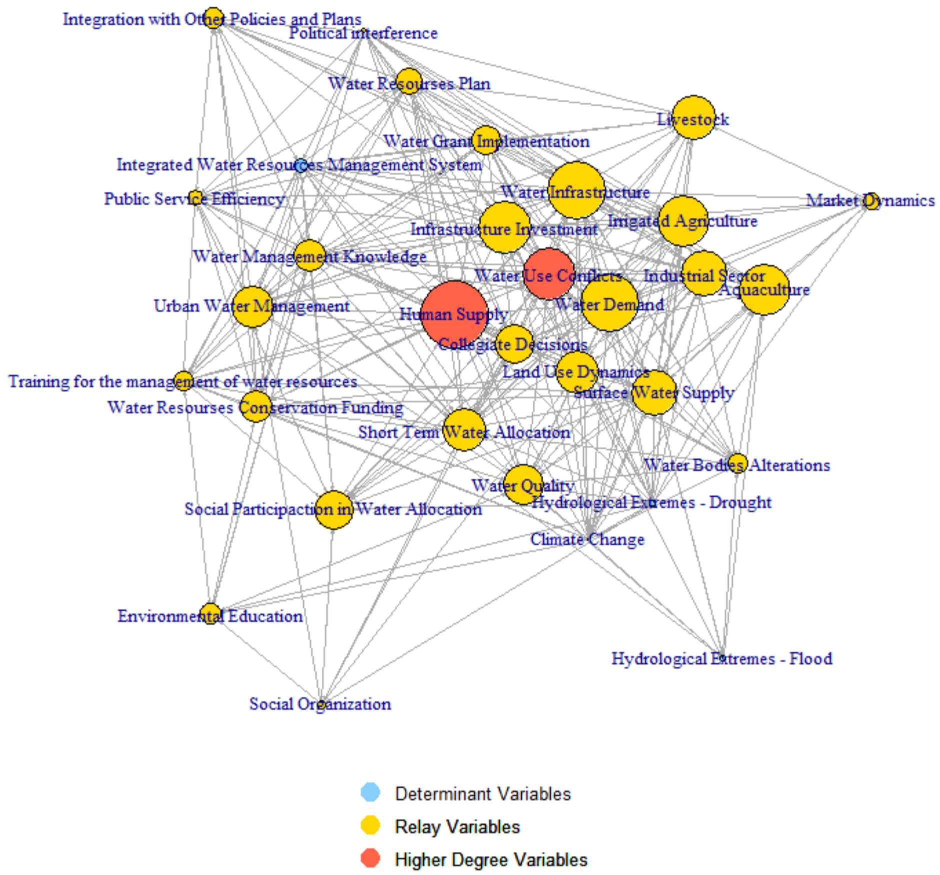

Sistema de Recursos Hídricos

# INICIATIVA 1

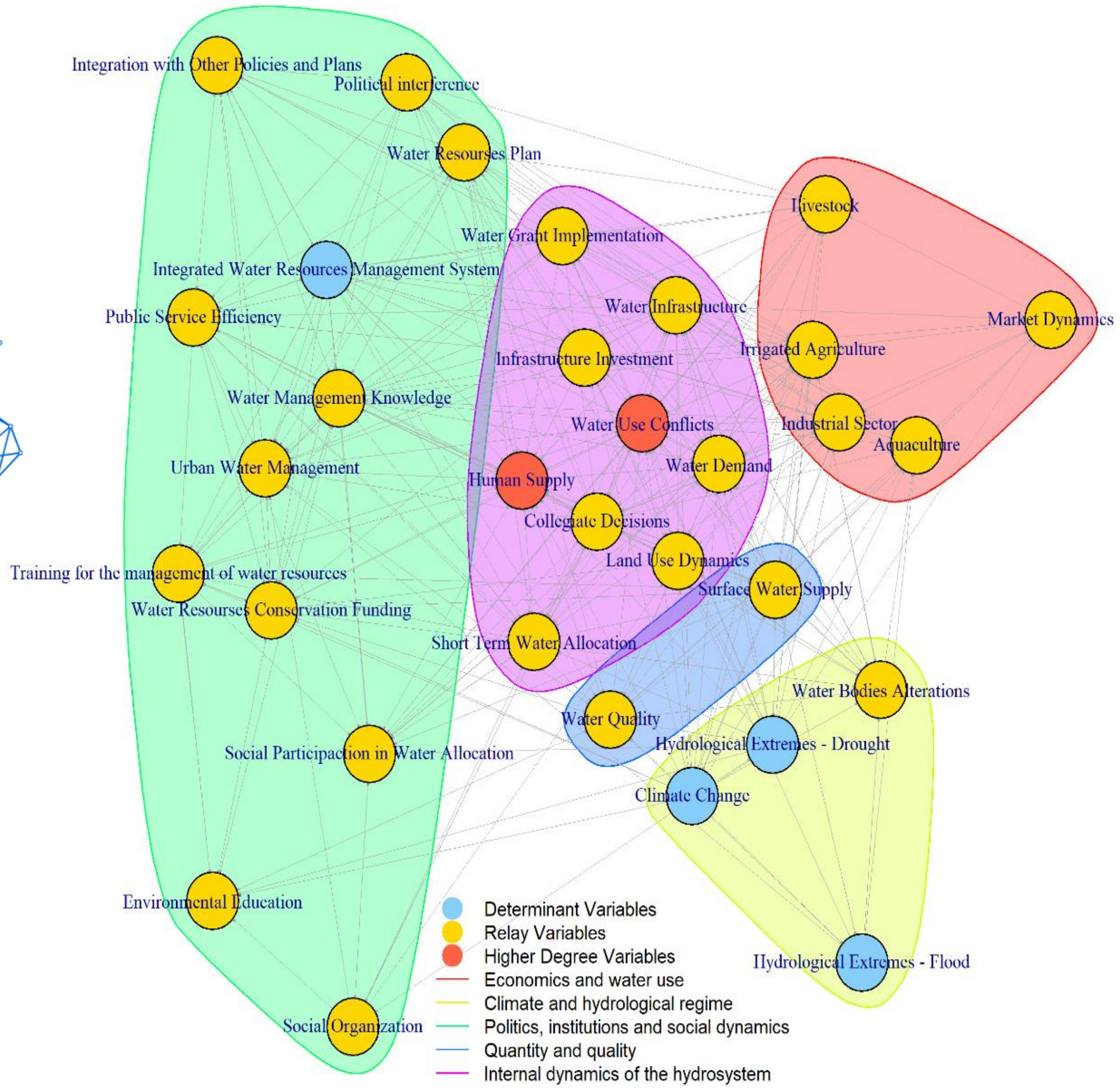
**Hubs**



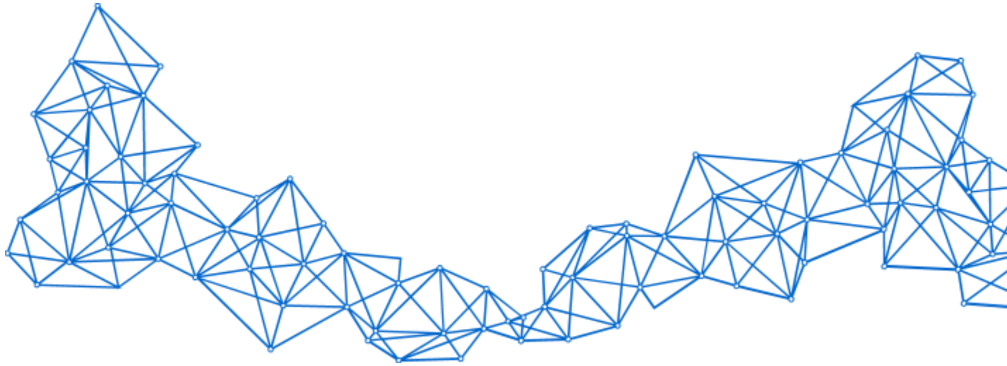

**Authorities**



# INICIATIVA 1



# INICIATIVA 2
## Redes Postos ONS

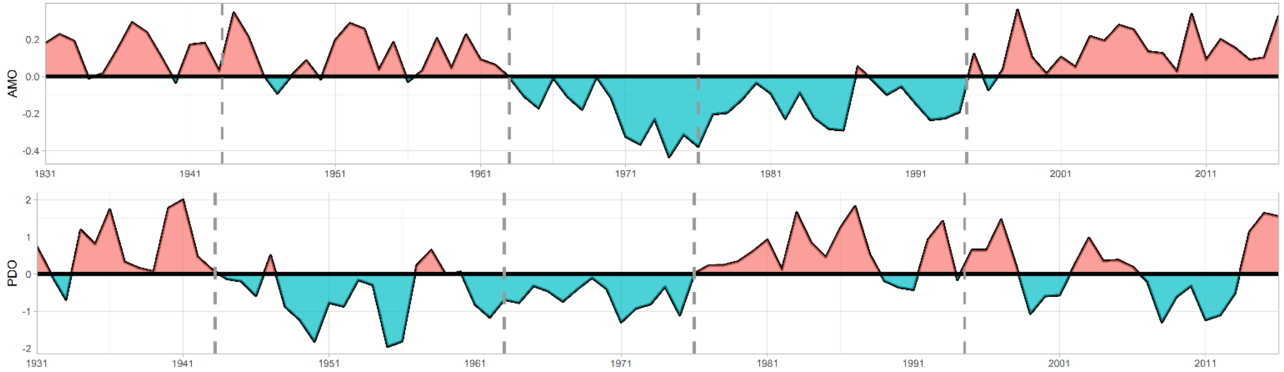


- Rede construída a partir do *Mutual Information* (MI) das estações com dados de vazões naturalizadas;
- Cada nó representa um posto e a ligação é estabelecida se o valor do MI supera um limiar de significância de 95% obtido via *bootstrapping*;
- Processo foi repetido para diversos períodos
  - Série completa (1931 – 2015)
  - Fase quente simultânea da AMO e da PDO (1931 – 1943)
  - Fase quente da AMO e fase fria da PDO (1944 – 1963)
  - Fase fria da AMO e fase quente da PDO (1977 – 1994)
  - Fase quente da AMO e “neutra” da PDO (1995 – 2015)

$$H(X,Y) = -\sum_{i=1}^{L} p(x_i, y_i) log_b p(x_i, y_i)$$

$$MI(X;Y) = H(X) + H(Y) - H(X,Y)$$

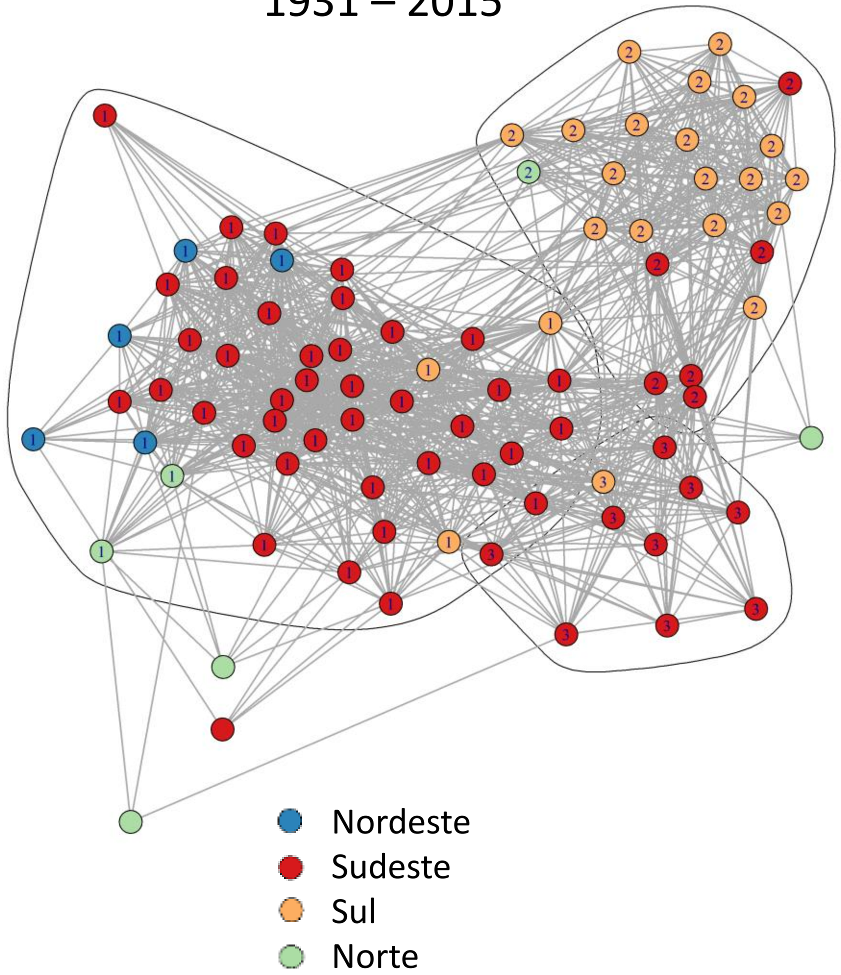
$$MI^*(X;Y) = \frac{MI(X;Y)}{\sqrt{H(X)H(Y)}}$$



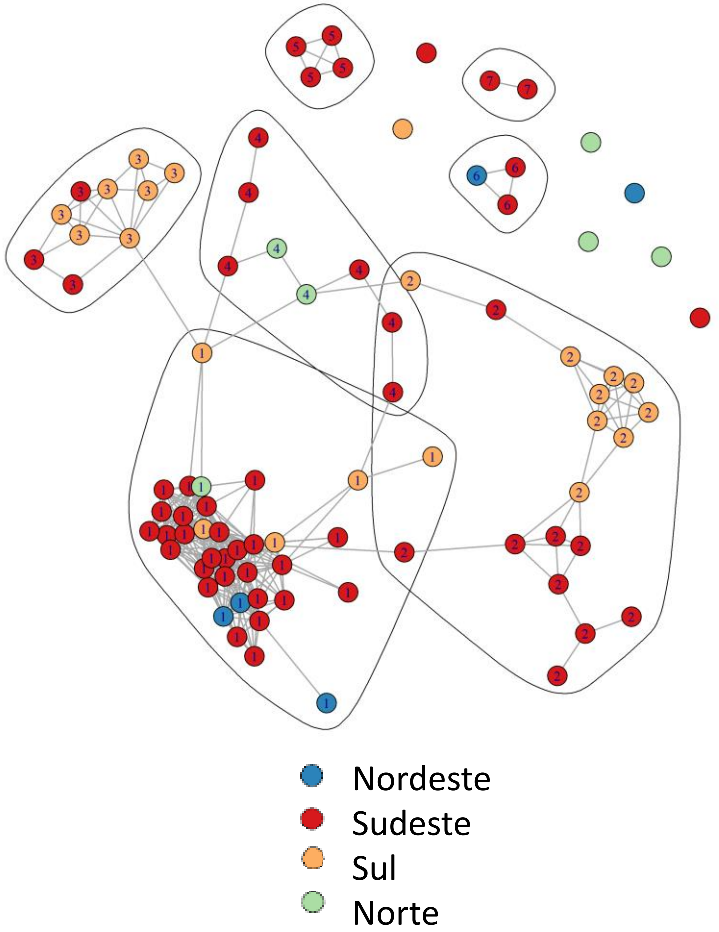
# INICIATIVA 2

## Redes Postos ONS

1931 – 2015



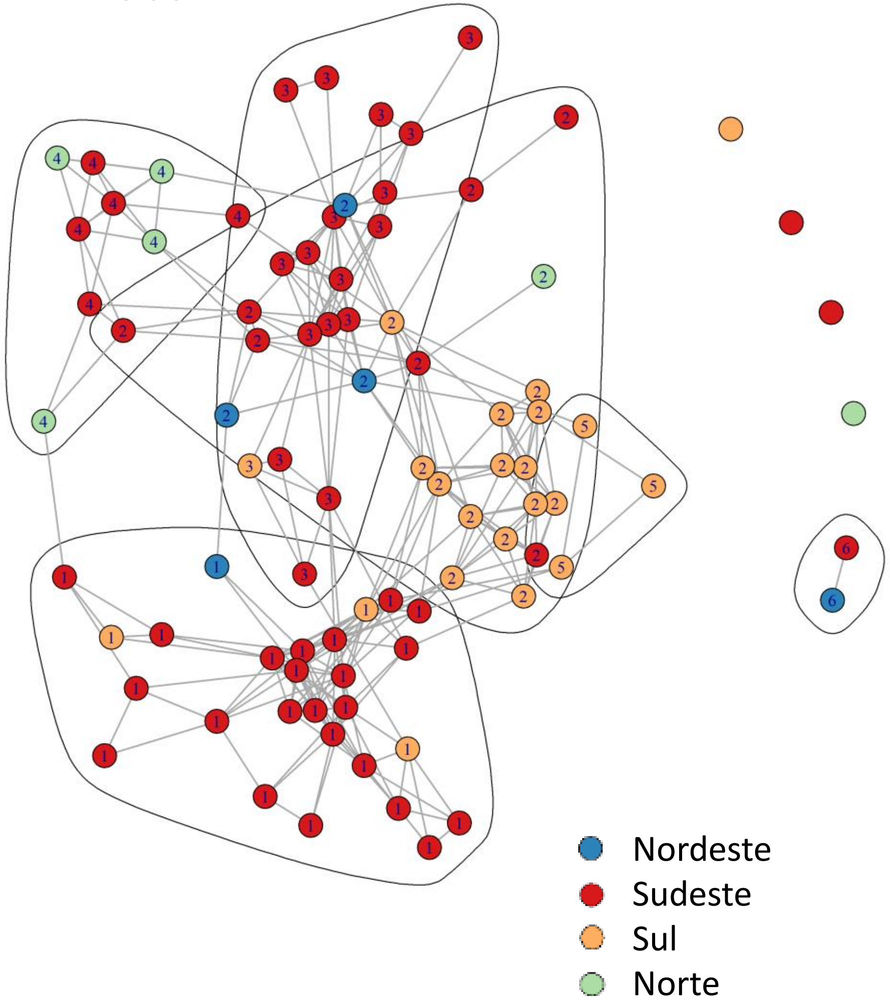

1931 – 1943



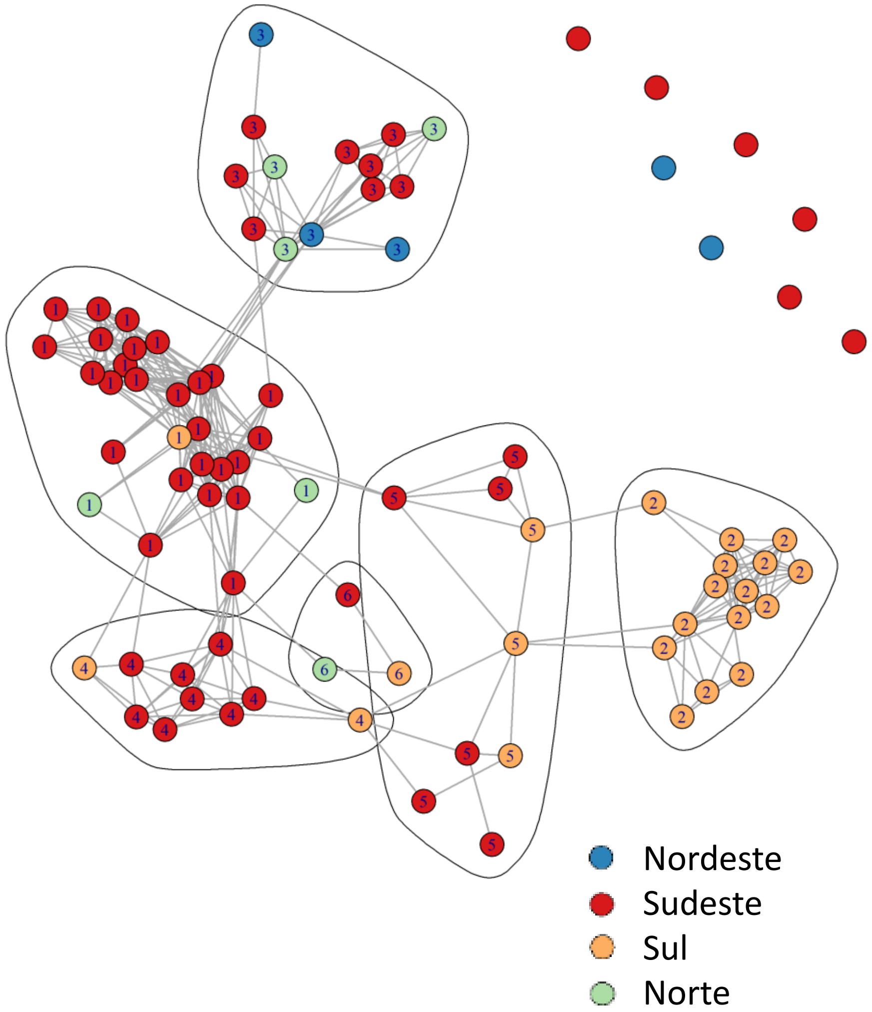
# INICIATIVA 2

## Redes Postos ONS

1944 – 1963

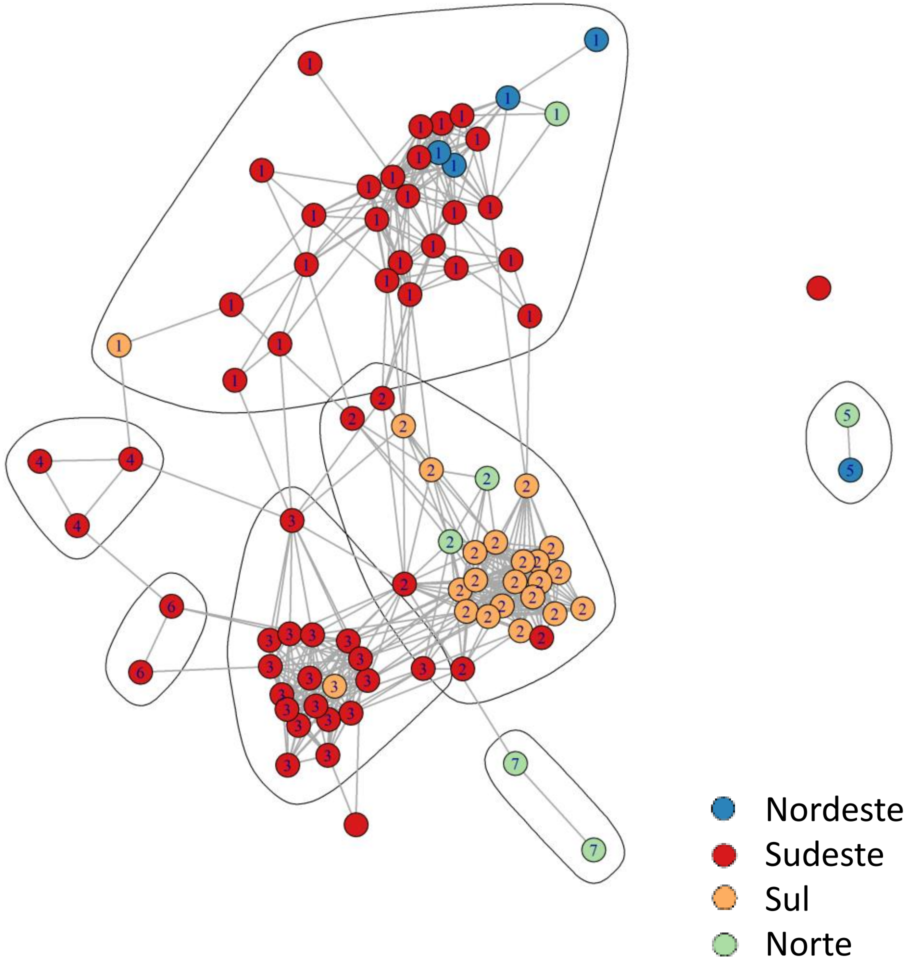



1964 – 1976

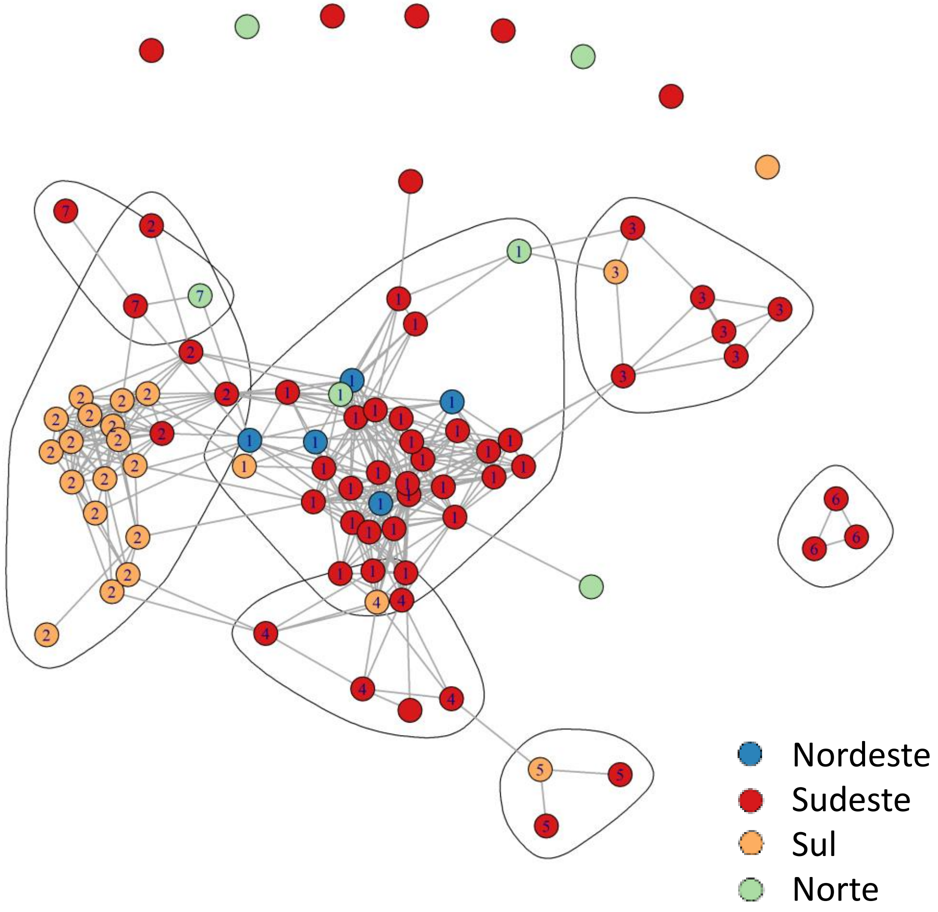


# INICIATIVA 2
## Redes Postos ONS

1977 – 1994




1995 – 2015



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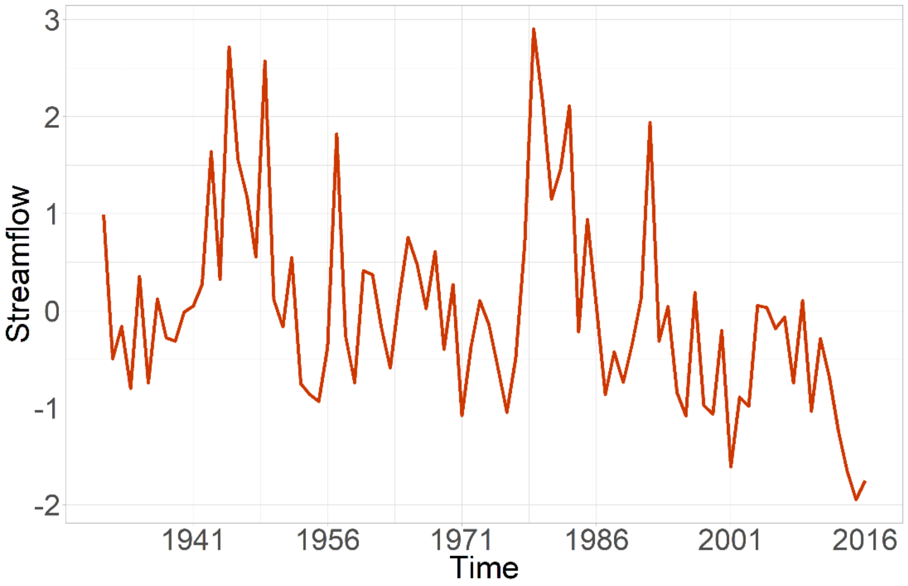
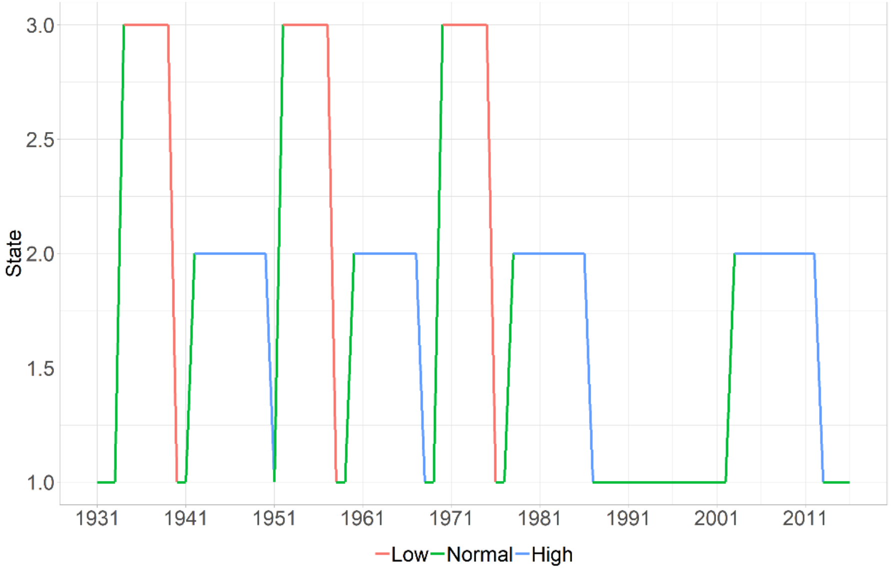
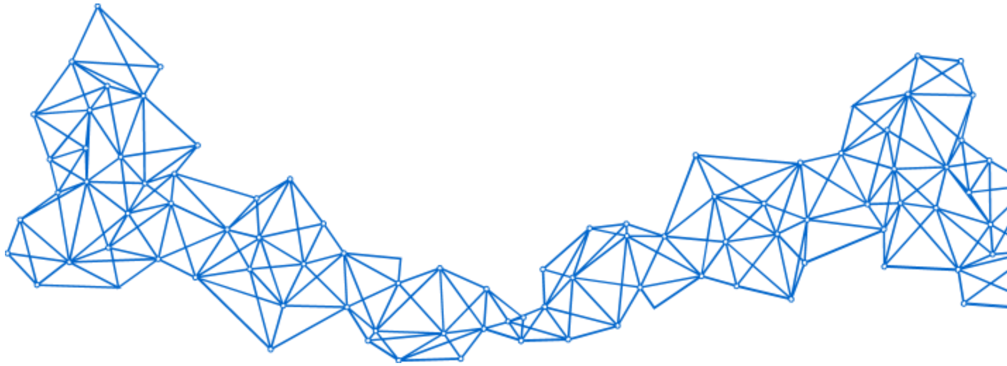
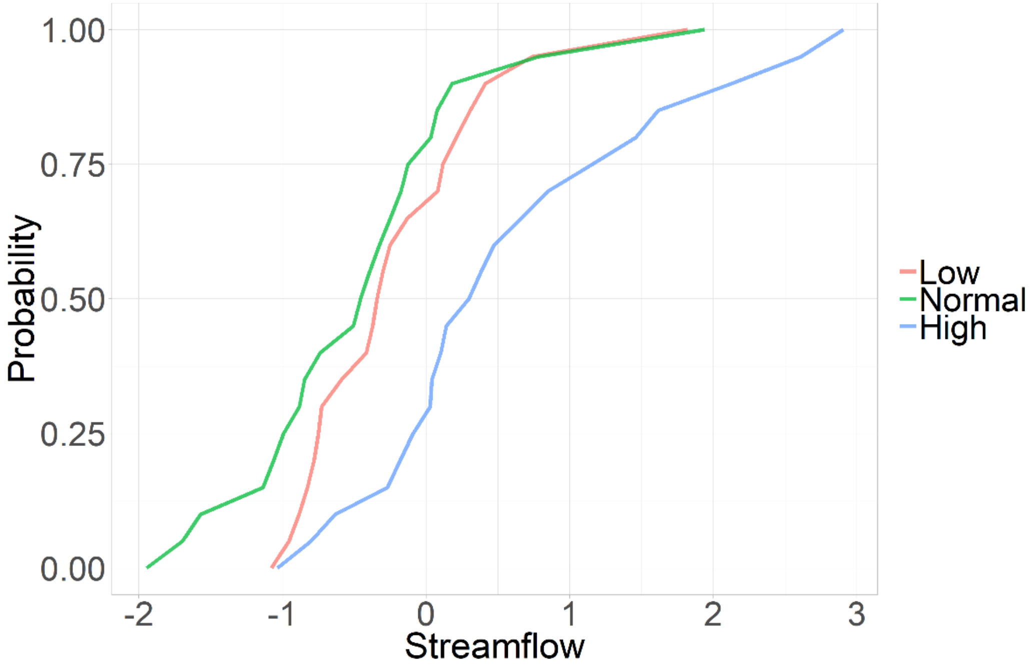


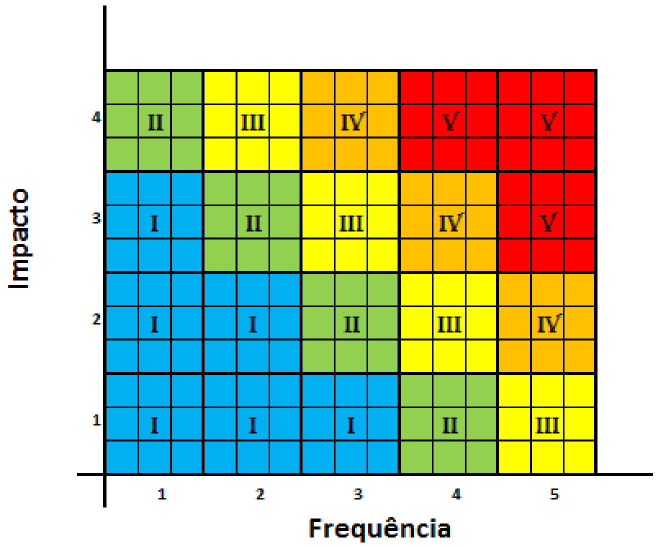


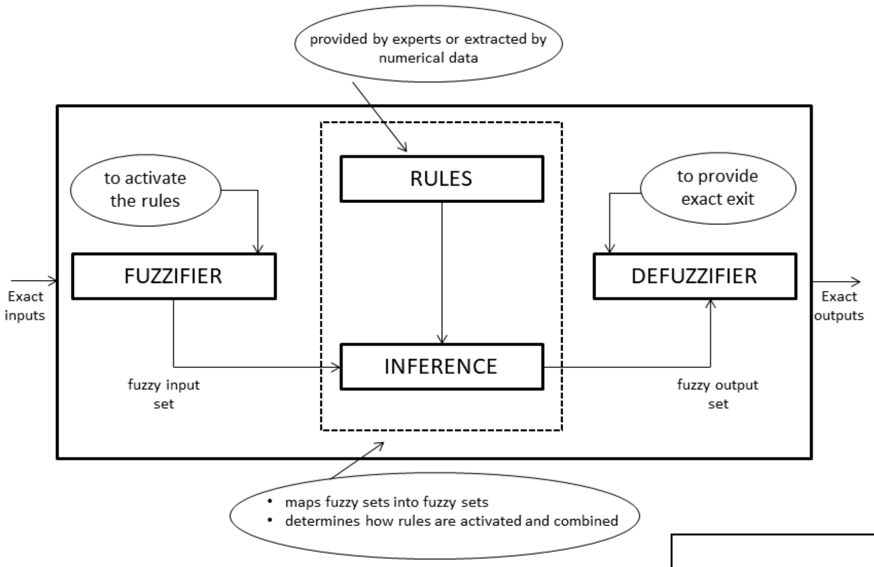

SÃO FRANCISCO - SOBRADINHO
Modelo HMM – Três Estágios
VAZÕES

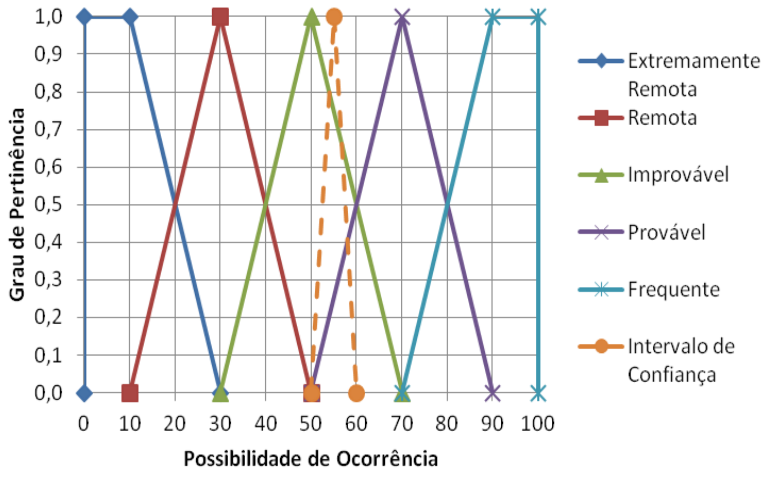
# INICIATIVA 4

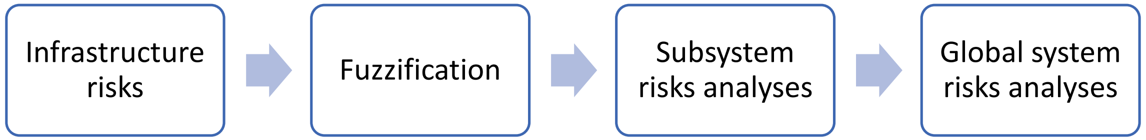
## Análise de Risco Sistêmico Utilizando Inferência Fuzzy

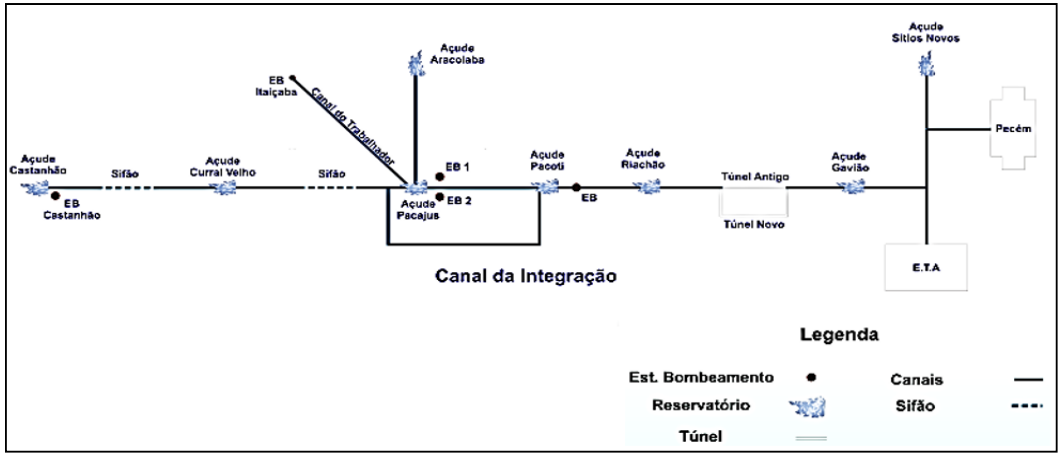
**Regiões de Risco**



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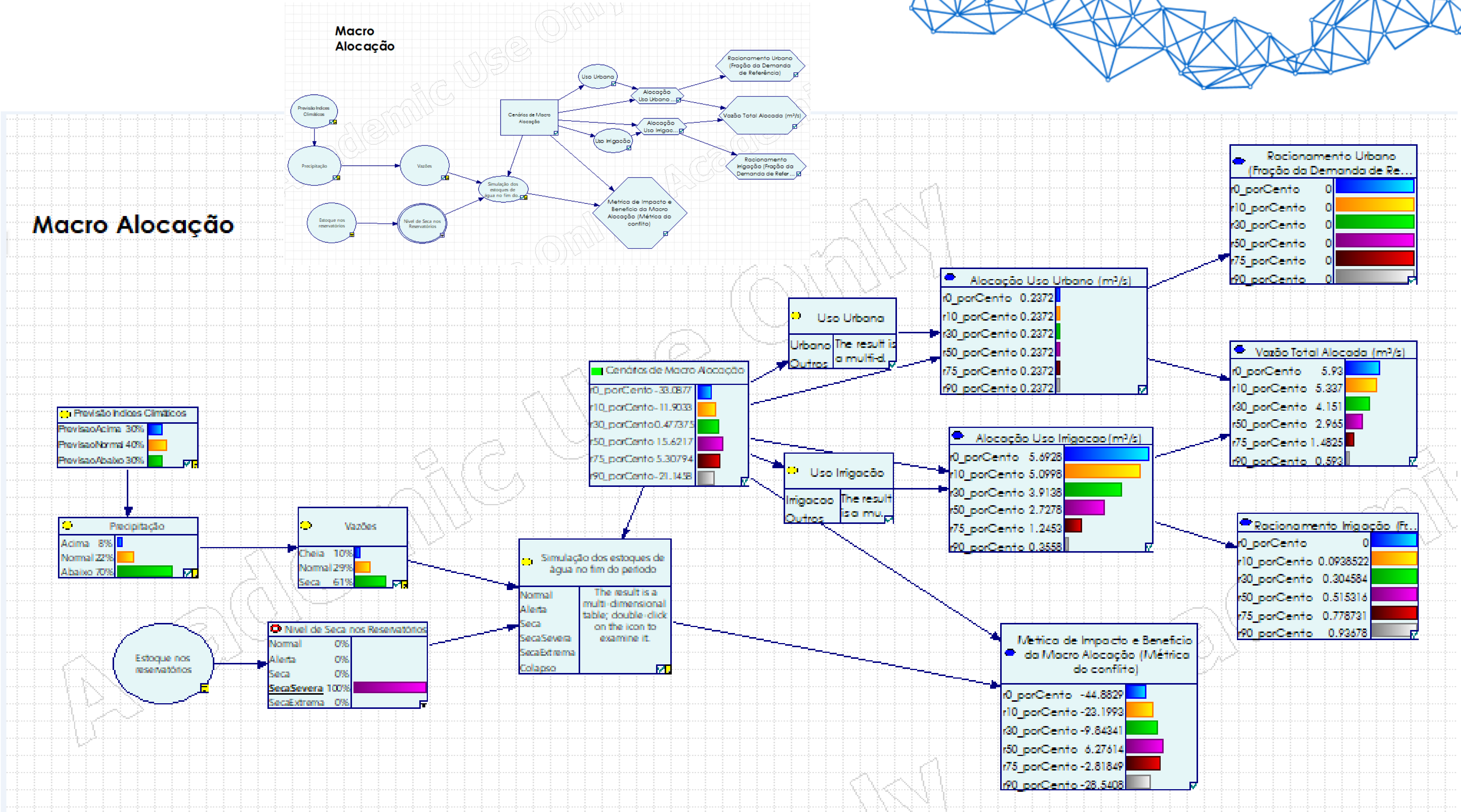

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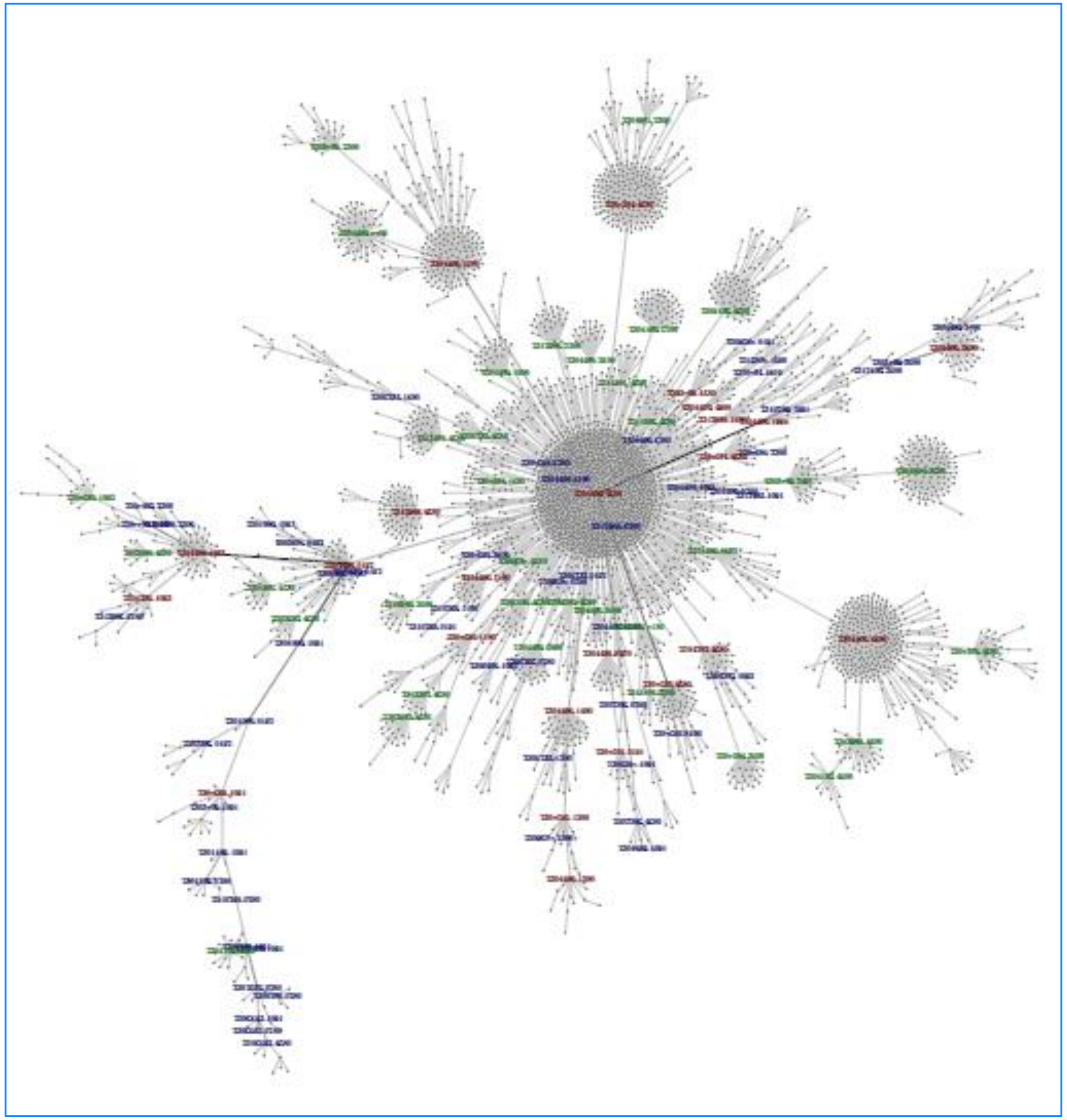

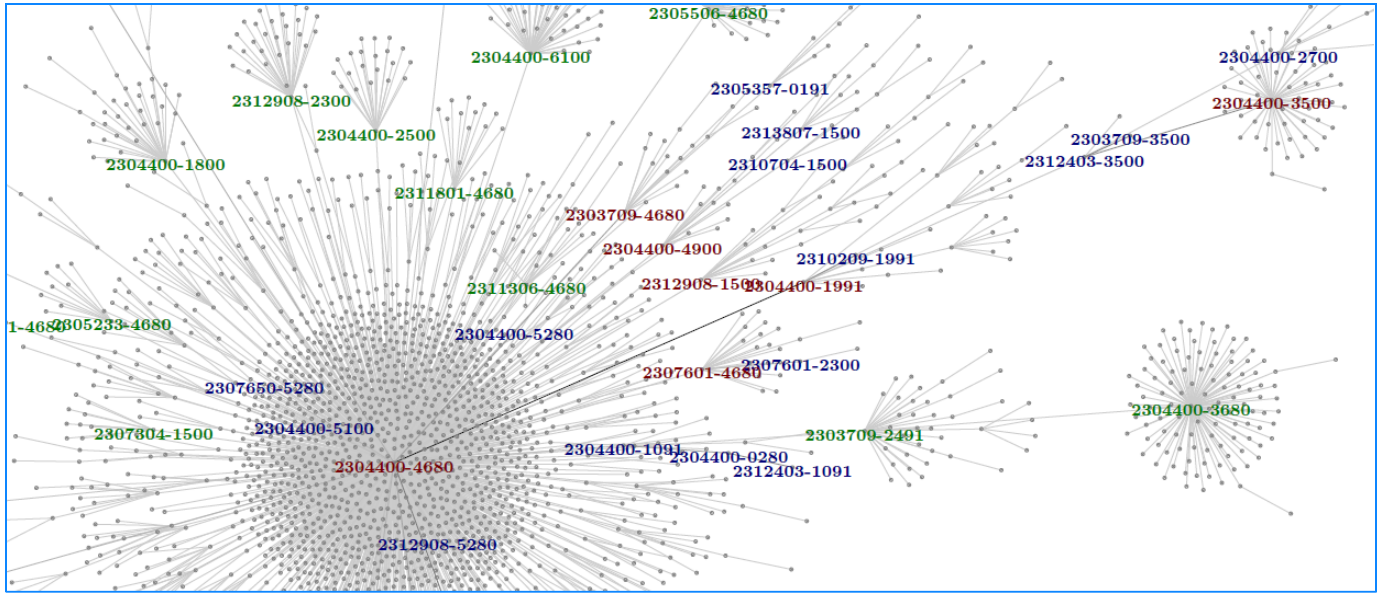

# SOCIEDADE HUMANA

# OBSERVAÇÕES **FINAIS**

# Dedico esta Fala ao
# **Prof. Ruben La Laina Porto**

# FIM

assis@ufc.br