An invited lecture at the
National Institute of Agronomy of Tunis (INAT)
Tunis – Tunisia, 3 October 2012

Re-establishing the link of hydrology with engineering

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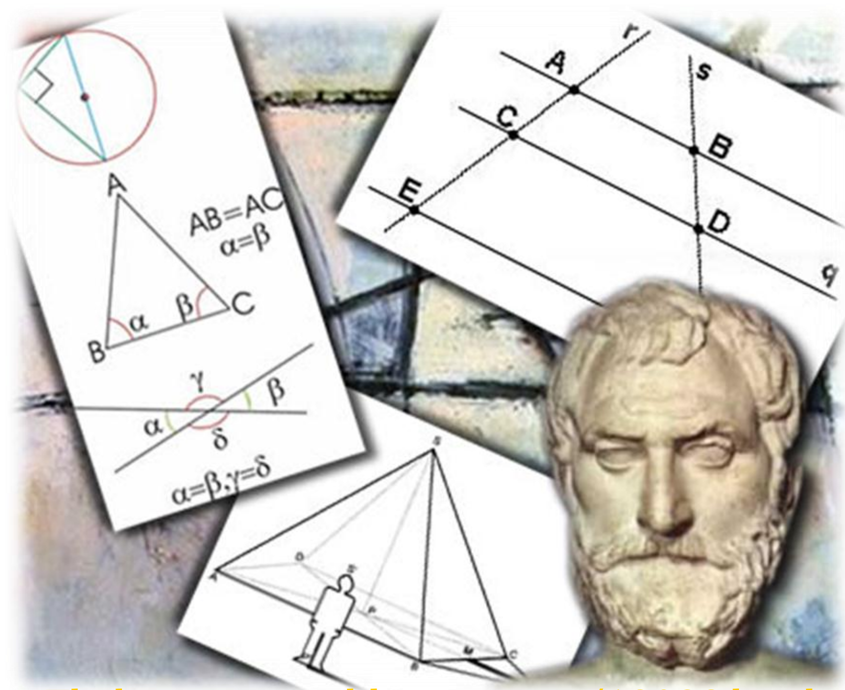
Presentation available online: itia.ntua.gr/1288/

The importance of hydrology in the antiquity

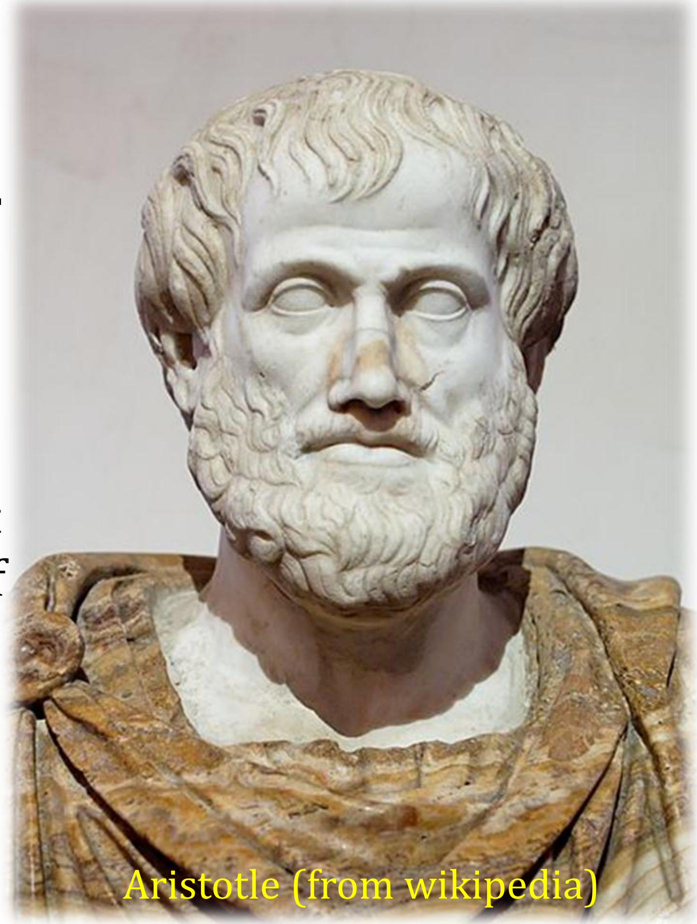
- The first scientific problems, put and studied as such, were about hydrological phenomena.
- The first geophysical problem formulated in scientific terms was the hydrological “paradox” of the Nile: flooding occurs in summer when rainfall in Egypt is very low to non-existent.
- Thanks to **Herodotus** (ca. 485-415 BC), we know that **Thales** of Miletus (640–546 BC; the father of philosophy and science), proposed an exegesis of this “paradox”.
- His attempt was followed by other Greek philosophers, including Herodotus.
- All exegeses during the classical antiquity were incorrect, but the important thing is that they were **physical** and thus **scientific**, contrary to the tradition of attributing natural phenomena to Gods’ action.



Thales: geramat.blogs.sapo.pt/18028.html

The emergence of the concept of hydrological cycle

- **Anaximander** from Miletus (ca. 610–547 BC) understood that rainfall is generated from evaporation.
- **Xenophanes** of Colophon (570-480 BC) conceptualized the whole hydrological cycle.
- **Aristotle** (384-328 BC) in his book "Meteorologica" recognized the principle of mass conservation within the hydrological cycle.
- It is clear in "Meteorologica" that the ancient Greek natural philosophers formed a view of the hydrological cycle, which was generally consistent with the modern one.
- It also included some incorrect elements (as happens in the development of scientific knowledge all the time).

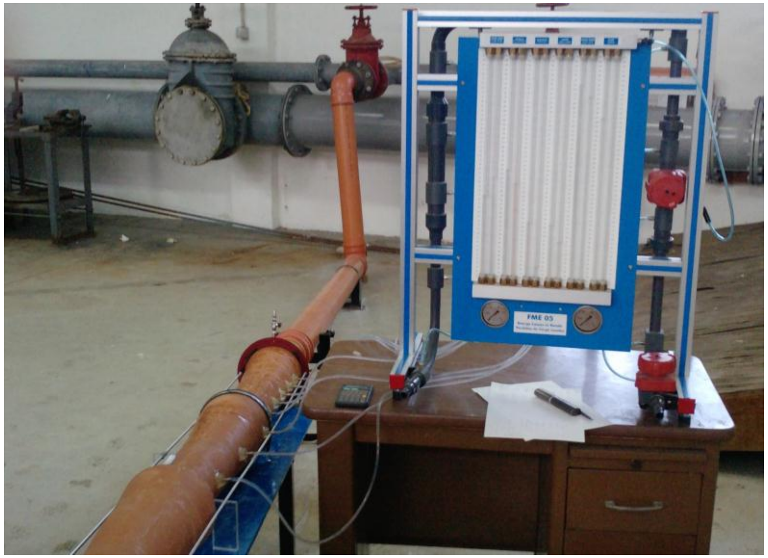


Aristotle (from wikipedia)

Technology before science

- Technological applications to solve practical problems preceded the development of scientific knowledge.
- Practical hydrological knowledge had its roots in human needs related to water storage, transfer and management.
- **Thales's** achievements include hydraulic engineering as he accomplished the diversion of the River Halys for military purposes.
- Nonetheless, hydraulic engineering achievements started in the prehistory, in several civilizations in Mesopotamia, Egypt, India and Greece (Mays et al., 2007).

Minoan pipes at Knossos and their study at the NTUA hydraulics laboratory (Angelakis et al., 2012)



Technology together with science

- The Hellenistic period marked the advancement of science, including hydrology (correct exegesis of Nile's flooding by **Eratosthenes**, 276–195 BC) and hydraulics (e.g. pressurized flow; **Hero of Alexandria**, ~150 BC).
- The Roman times are characterized by substantial progress in hydraulic engineering: the famous Roman aqueducts advanced in scale and spread all over Europe and beyond.

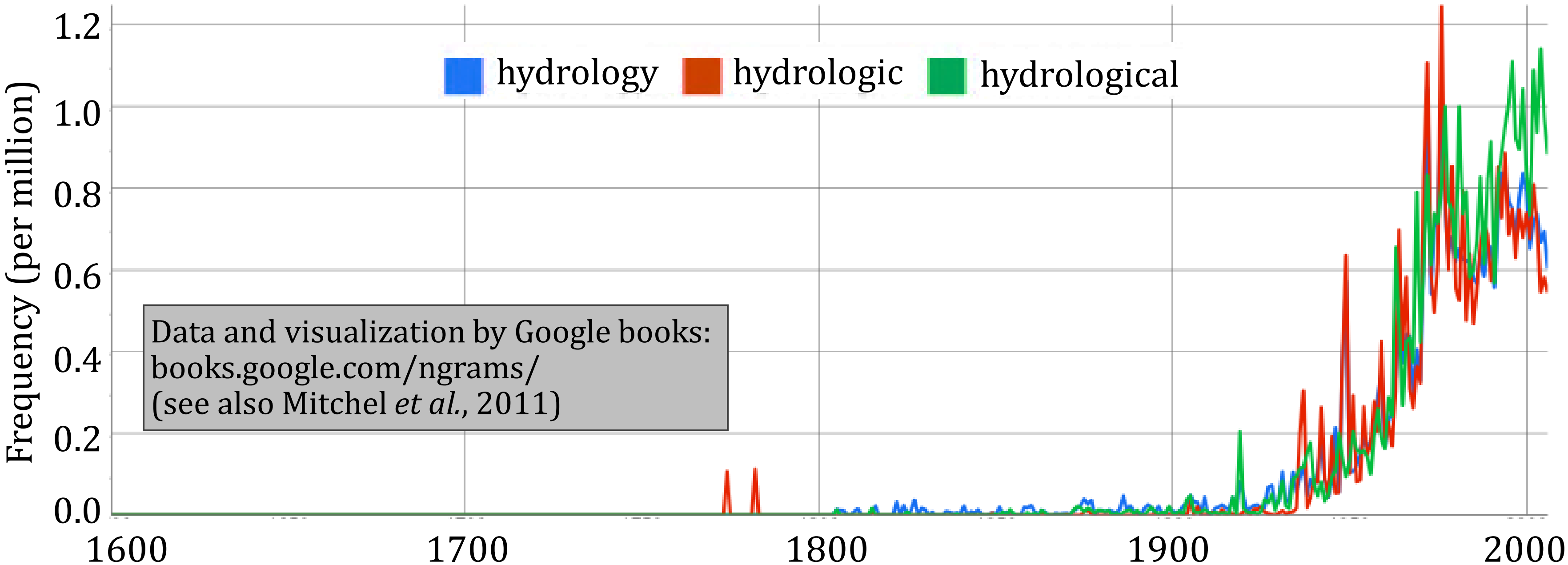
- New scientific progress had to wait until the Renaissance at Italy.
- The determinant breakthrough during the Renaissance was the recognition of the importance of the empirical basis (observations, measurements and experiments) in hydrological phenomena.
- In the 17th century, Benedetto Castelli installed a rain gauge in Perugia to provide a basis for estimating the variations in level of the Trasimeno Lake and control the discharge of its outlet.

Admittedly, as useful a matter as the motion of fluid and related sciences has always been an object of thought. Yet until this day neither our knowledge of pure mathematics nor our command of the mathematical principles of nature have permitted a successful treatment.

(Daniel Bernoulli, in a letter to J. D. Schöpflin, Sept. 1734)

History of the terms "hydraulic" and "hydrology"

- The term "hydraulic" (ὑδραυλικὸν) is used already in the Hellenistic period (by **Hero of Alexandria** in his "Pneumatica", a treatise on machines working on air, steam or water flow, and later by **Pliny**) and is related to "hydraulis" (ὕδραυλις), a hydraulic organ, invented by **Ctesibius**.
- However, the term "hydrology" (ὑδρολογία) did not exist in the classical literature and appeared only in the end of the eighteenth century.



Data and visualization by Google books: books.google.com/ngrams/
(see also Mitchel *et al.*, 2011)

Early uses of “hydrology”: Geography- and medicine-oriented

A TREATISE

ON

PHYSICAL GEOGRAPHY,

COMPRISING

HYDROLOGY, GEOGNOSY, GEOLOGY, METEOROLOGY,
BOTANY, ZOOLOGY, AND ANTHROPOLOGY.

BY A. BARRINGTON.

EDITED BY

CHARLES BURDETT,

AUTHOR OF "THE CONVICT'S CHILD;" "NEVER TOO LATE," ETC.

"The works of the Lord are great, sought out of all them that have pleasure therein."—*Book of Psalms.*

THIRD EDITION.

NEW YORK:
MARK H. NEWMAN & CO., 199 BROADWAY;
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AUBURN: J. C. IVISON & CO.; BOSTON: B. B. MUSSEY & CO.;
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FOR SALE BY ALL BOOKSELLERS.

1851.

46 SYMONS—PROCEEDINGS OF INTERNATIONAL CONGRESS AT BIARRITZ.

ON THE PROCEEDINGS OF THE

INTERNATIONAL CONGRESS OF HYDROLOGY AND CLIMATOLOGY AT BIARRITZ,

OCTOBER 1886.

BY G. J. SYMONS, F.R.S., F.R.MET.SOC., SECRETARY.

I. *Scientific Hydrology.*—Water analysis, micro-organisms, collection of mineral waters, geological influences, bathing apparatus, 34.
II. *Medical Hydrology.*—Physiological and medical questions, 40.
III. *Climatology, scientific and medical*, 35.

Early uses of “hydrology”: Engineering-oriented

MANUAL OF HYDROLOGY:

CONTAINING

I.—HYDRAULIC AND OTHER TABLES.

II.—RIVERS, FLOW OF WATER, SPRINGS, WELLS, AND PERCOLATION.

III.—TIDES, ESTUARIES, AND TIDAL RIVERS.

IV.—RAINFALL AND EVAPORATION.

BY

NATHANIEL BEARDMORE,

CIVIL ENGINEER.

London:

WATERLOW AND SONS, 49, PARLIAMENT STREET,

24, BIRCHIN LANE, AND 65 to 68, LONDON WALL.

1862.

WATER PIPES UNDER PRESSURE.—Tables 8a and 8b.

This will be seen upon reference to Mr. Leslie's paper “On the flow of water through pipes,” &c, before referred to, and the discussion which ensued thereupon. For very small pipes or flat rates of inclination, or waere a closer approximation to accuracy may be desired, somewhat better results may be obtained by using Du Buât's formula, viz.:—

$$\frac{307\,(\sqrt{r}-0.1)}{\sqrt{\frac{l}{h}}-\mathrm{L}\,(\sqrt{\frac{l}{h}+1.6})}-0.3\,(\sqrt{r}-0.1)=\text{Velocity in inches per second.}$$

$r=\frac{\text{dia}}{4}=$ “Mean radius” or Hydraulic mean depth in inches.

L = Hyperbolic Log. of the term to which it is prefixed.
Hyperbolic Log. = Common Log. × 2.30258. When reduced

TABLE OF HEIGHTS OF MAXIMUM FLOODS OF THE PO DURING THE NINETEENTH CENTURY,

As registered at various points on the river above summer low water, which at Piacenza is 132.3 feet above the sea level; at Cremona, 104.2 feet; at Isola Pescaroli, 89.2 feet; at Casalmaggiore, 74.8 feet.

Name of Station.	Dist. from the Sea.	1801 13th Nv.	1807 12th Dec	1812 15th Oct.	1823 16th Oct.	1827 13th My.	1839 20th Oct.	1839 8th Nv.	1840 6th Nv.	1841 31st Oct.	1846 20th My.	1846 20th Oct.	1855 1st Nv.	1857 Oct.
	Mls.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
Monticelli	210.0	23.0	...	21.9	...	...	23.9	17.8	23.0	21.8	25.6	26.9	25.5	28.7
Piacenza	196.3	24.9	...	...	...	...	26.4	23.1	24.4	24.6	26.2	27.3	26.2	28.0
Cremona	171.9	19.6	...	...	16.1	17.2	18.7	18.3	18.7	18.4	18.3	18.8	19.2	20.8
Isola Pescaroli	155.9	20.6	...	19.8	17.7	18.6	19.6	19.2	18.5	18.9	20.0	19.4	20.2	21.6
Casalmaggiore	141.8	21.3	...	19.1	18.1	20.6	21.1	21.1	20 0	21.2	21.2	21.8	21.1	22.5
Dosolo	125.4	26.9	25.7	...	24.6	...	25.4	26.2	25.5	26.1	25.6	26.1	26.8	...
Borgoforte	114.5	27.6	27.0	27.0	25.6	26.9	26.5	28.1	25.5	25.8	26.7	27.1	28.2	29.3
St. Benedetto	100.5	25.9	26.2	27.9	27.8	28.2	27.5	29.2	26.9	27.5	27.5	28.2	28.6	29.3
Ostiglia	88.4	28.4	29.2	30.1	29.9	29.7	29.8	31.3	28.8	29.7	29.9	30.3	30.7	31.7
Sermide	76.9	26.5	27.0	28.1	28.2	27.7	27.7	28.5	26.4	27.4	...	28.1	28.2	...
Quatrelle (Stellata)	66.5	26.4	27.4	28.6	28.4	28.1	28.0	29.0	27.2	27.6	28.1	28.5	28.2	29.7
Ponte Lagoscuro	53.9	25.2	26.0	26.8	26.6	26.8	27.3	28.1	27.1	26.5	26.6	26.8	26.9	28.1
Polesella	43.9	...	...	25.8	25.8	26.0	26.6	27.7	26.3	26.1	...	...	...	27.9
Crespino	36.1	...	...	24.2	24.2	24.6	24.6	25.5	25.0	24.5	...	...	...	25.6
Cavanelladi Po	19.1	...	...	17.9	18.0	18.4	18.8	19.6	18.6	18.5	...	...	...	...
Porto Scanarello	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.31

Historical links of hydrology with hydraulics and engineering

- From the 19th century up to the 1970s, the developed world had given priority in building public infrastructures.
- Hydraulics was a dominant and primary field in engineering to support the design of hydraulic structures such as dams, canals, pipelines and flood protection works.
- Hydrology was regarded as an appendage of hydraulic engineering (Yevjevich, 1968), to support the design of hydraulic structures (e.g. in estimating design discharges).
- The engineering aspect of hydrology was prominent also because it was part of the professional education in engineering schools.
- Hydrology made significant progress in developing a scientific approach to study natural variability and to tame uncertainty.
- It was its **close relationship with engineering that advanced hydrology into a modern quantitative scientific discipline**.

Important advances of hydrology for engineering purposes

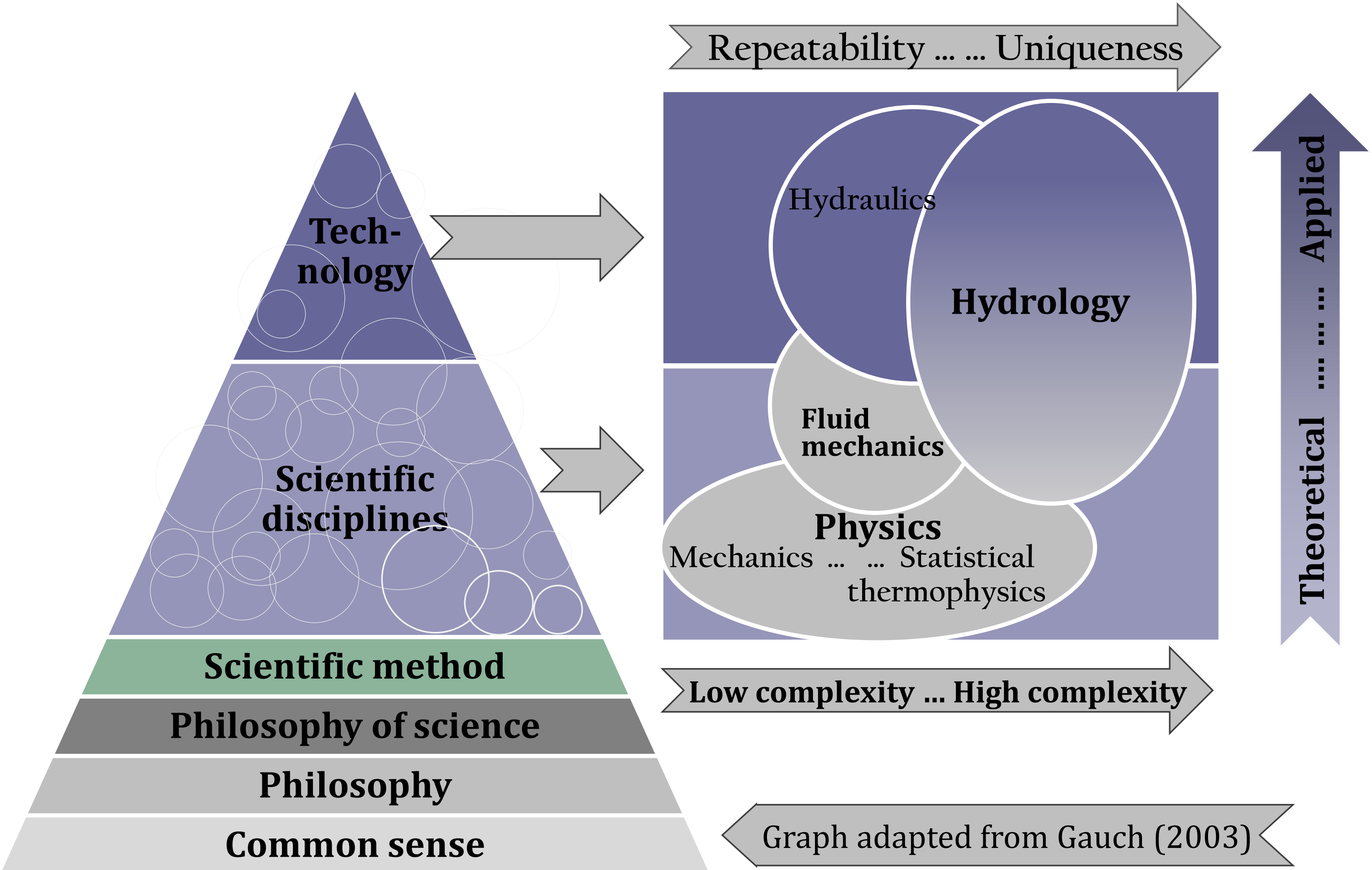
- Some of the advances are pertinent to both hydraulics and hydrology:
  - flow in aquifers and in unsaturated soils;
  - transport phenomena and the movement of sediments.
- Other advances are purely hydrological, yet with clear engineering orientation:
  - probabilistic and stochastic modelling of hydrological processes;
  - development of data analysis tools;
  - Monte Carlo simulation techniques;
  - reliability theory of reservoir storage;
  - linear systems approximations to flood routing (e.g. unit hydrograph; Muskingum method);
  - parameterization-optimization of the modelling of hydrological processes;
  - systems analysis techniques for water resource management.

Modern meaning of hydrology: the UNESCO definition—and some notes

- *"Hydrology is the science which deals with*
  the waters of the earth,
  their occurrence, circulation and distribution on the planet,
  their physical and chemical properties,
  and their interactions with the physical and biological environment,
  including their responses to human activity."

  (UNESCO, 1963, 1964)
- The UNESCO definition does not explicitly recognize its link with hydraulics and, more generally, with engineering.
- While the definition of "**hydrology**" is clear and elegant, other terms commonly used as synonyms are problematic.
- "**Hydrological science**" conceals the fact that hydrology is strongly linked with engineering and technology.
- "**Hydrological sciences**" (plural) has never been defined—in particular it was not explained which the constituent sciences are.

Hydrology in the pyramid of knowledge



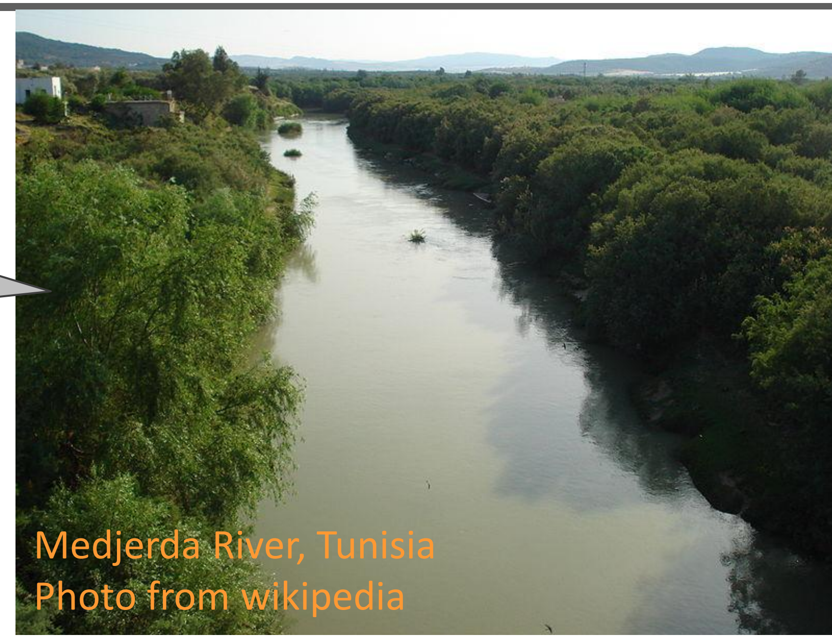
Graph adapted from Gauch (2003)

Visualized difference of hydraulics and hydrology

Hydrology: Complex and unique objects

Hydraulics: Typically simple and repeatable objects

Hydrology:
Domain: atmosphere, surface, subsurface
Phases: solid, liquid, gaseous

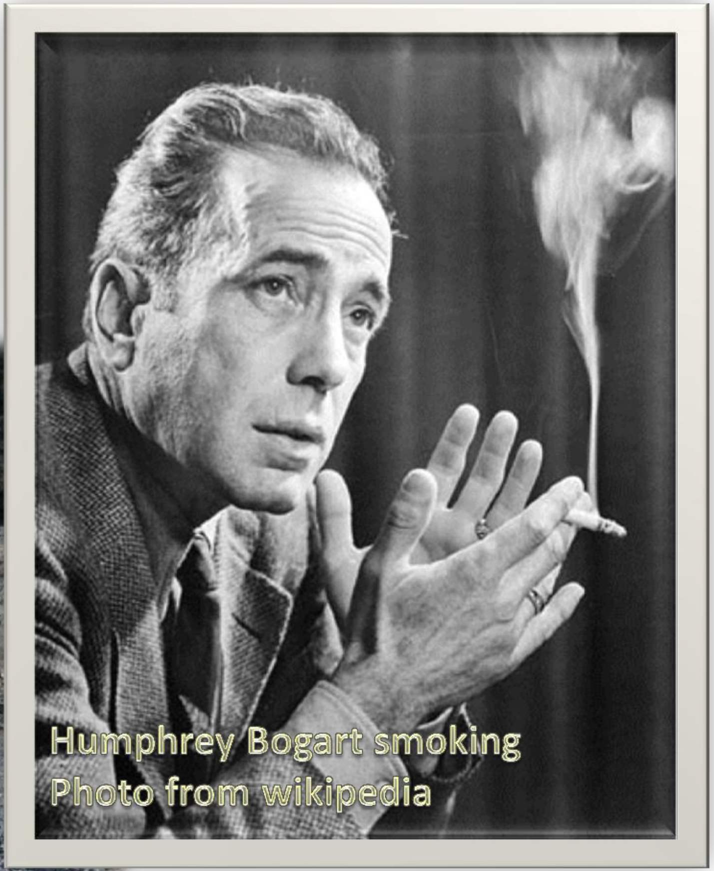

Medjerda River, Tunisia
Photo from wikipedia


Irrigation canal in Abu Simbel; photo from http://libya360.wordpress.com/2012/06/14/squeezing-africa-dry-behind-every-land-grab-is-a-water-grab/


Medjerda River, Tunisia
visibleearth.nasa.gov/view.php?id=55161

The grand intersection

Where physics, fluid mechanics, hydraulics and hydrology meet: **turbulence**



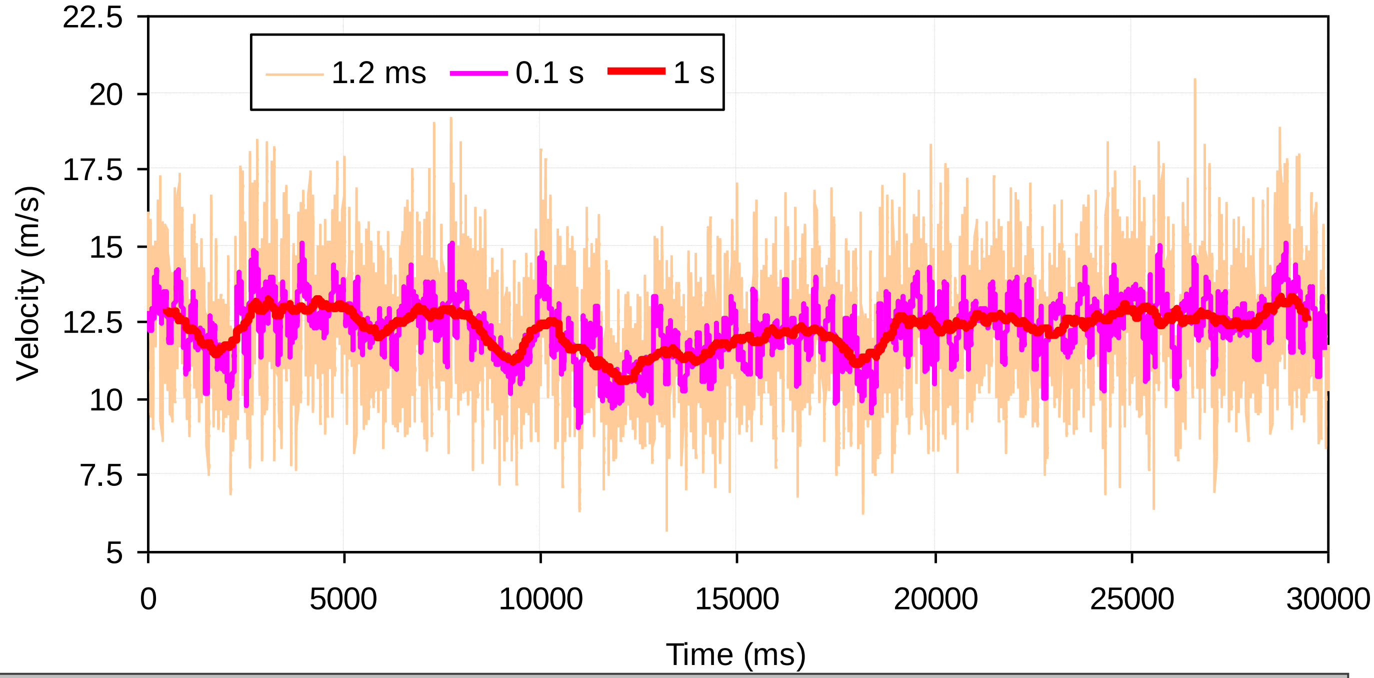
When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe He will have an answer for the first.

(attributed to Werner Heisenberg or, in different versions, to Albert Einstein or to Horace Lamb)

Turbulence: macroscopic motion at nanosecond scale

- Laboratory measurements of nearly isotropic turbulence in Corrsin Wind Tunnel (length 10 m; cross-section 1.22 m by 0.91 m) at a high-Reynolds-number (Kang *et al.*, 2003)

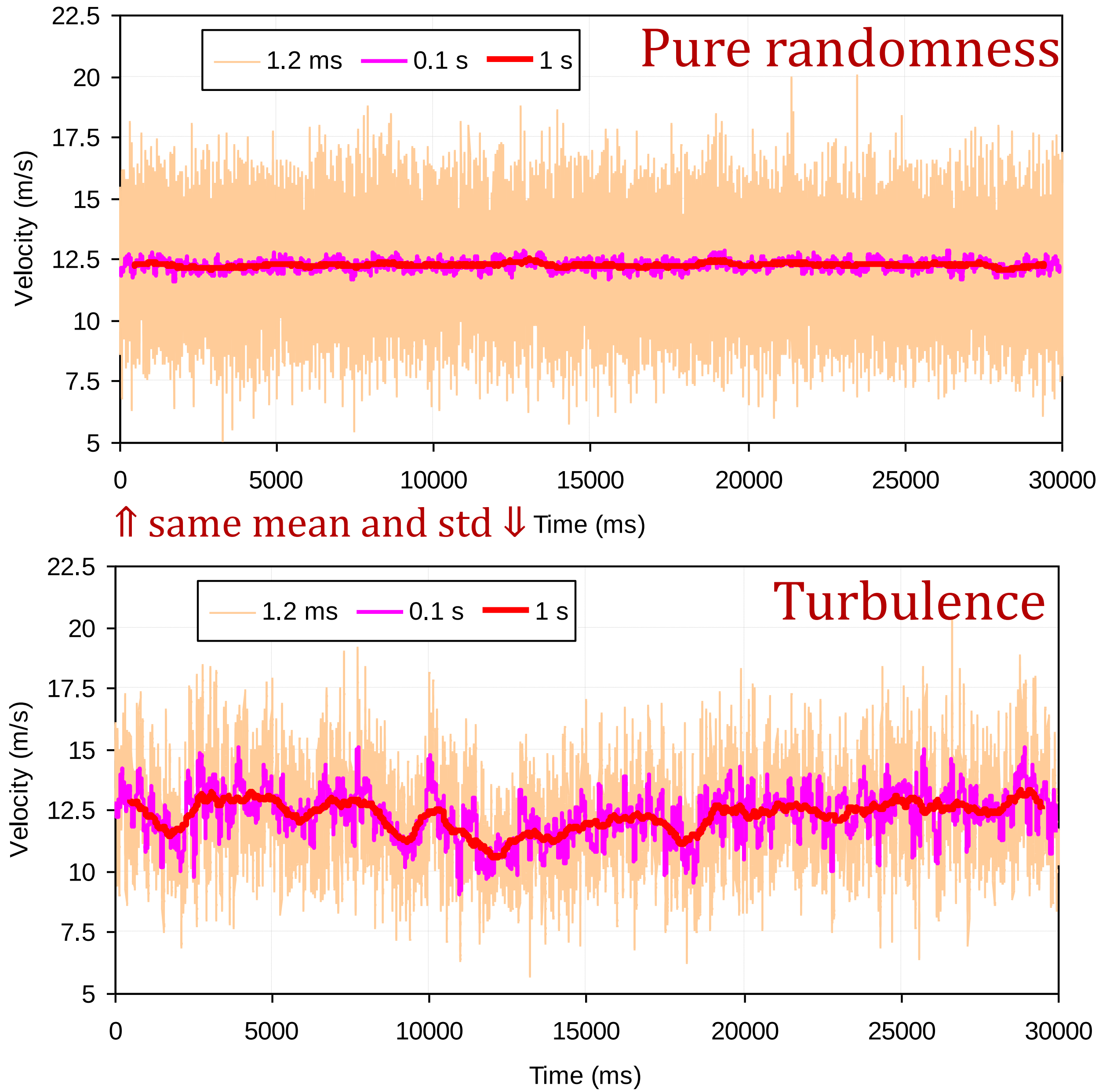
- Measurements by X-wire probes; sampling rate of 40 kHz (once per 25 ns; total length 900 s; here aggregated at the three scales shown)



Data downloaded from www.me.jhu.edu/meneveau/datasets/Activegrid/M20/H1/m20h1-01.zip

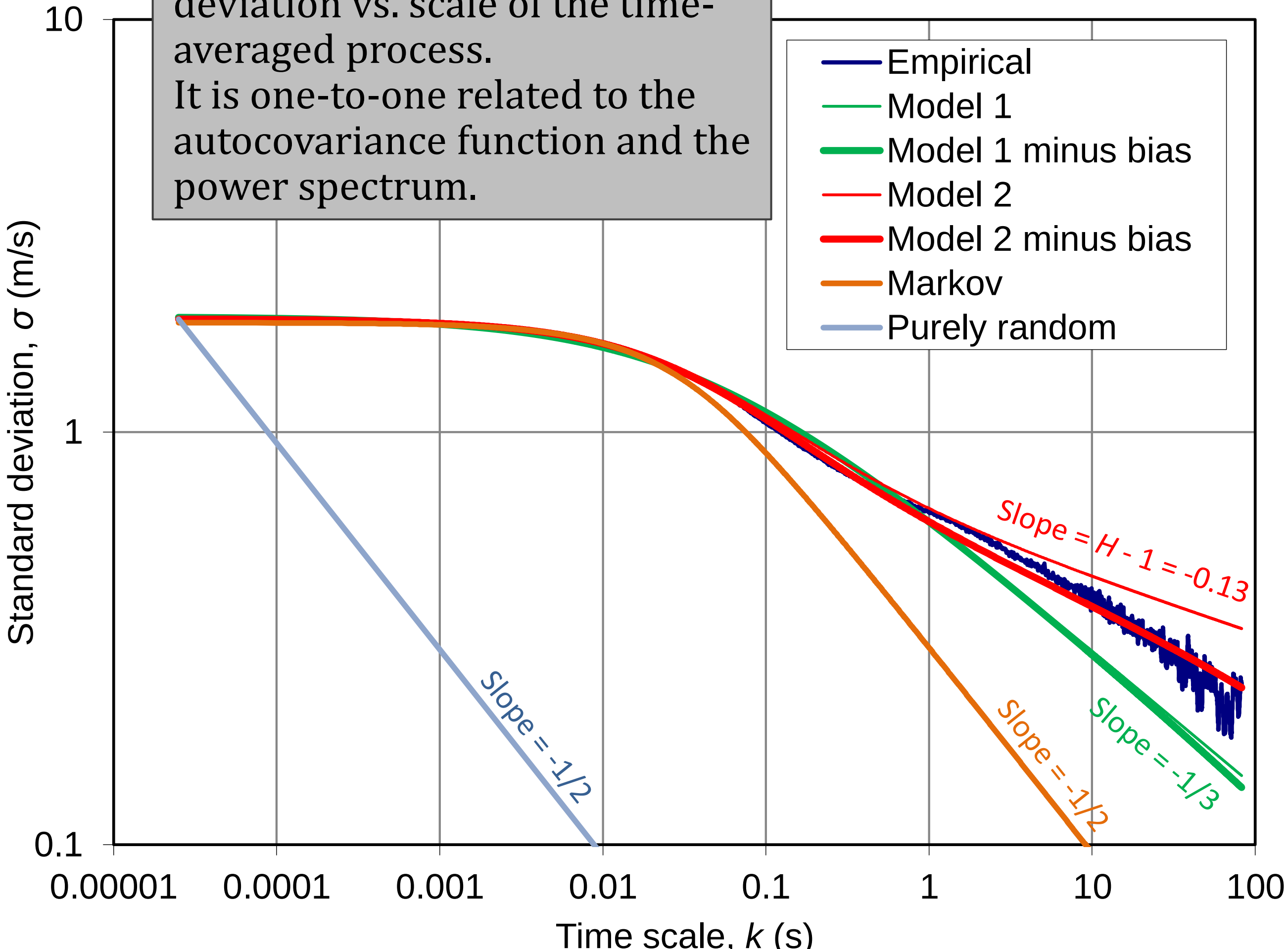
Pure randomness *vs*. turbulence

- Pure random processes, assuming independence in time (white noise), have been effective in modelling microscopic motion (e.g. in statistical thermodynamics).
- Macroscopic random motion is more complex.
- Pure randomness, gives a rather static average.
- In turbulence, change occurs at all scales.



Turbulence: A climacogram view

Climacogram: a plot of standard deviation vs. scale of the time-averaged process.
It is one-to-one related to the autocovariance function and the power spectrum.



Model 1

$$\sigma^2(k) = \frac{\lambda_1}{1+(k/\alpha_1)^{2/3}}$$

Model 2

$$\sigma^2(k) = \frac{\lambda_2}{\left(1+(k/a_2)^{2/3}\right)^{\frac{2-2H}{2/3}}} + \frac{\lambda_3}{1+k/a_3}$$

Markov

$$\sigma^2(k) = \frac{\lambda_4}{k/\alpha_4}\left(1 - \frac{1-e^{-k/\alpha_4}}{k/\alpha_4}\right)$$

Parameters

Hurst coefficient: $H = 0.87$

Time scale parameters (s): $\alpha_1 = 0.03831$; $\alpha_2 = 0.007346$; $\alpha_3 = 0.03518$; $\alpha_4 = 0.01347$.

Variance parameters (m^2/s^2) $\lambda_1 = 3.624$; $\lambda_2 = 1.283$; $\lambda_3 = 2.316$; $\lambda_4 = 6.776$.

Scales relevant to fluid mechanics and hydraulics

Scales relevant to hydrology

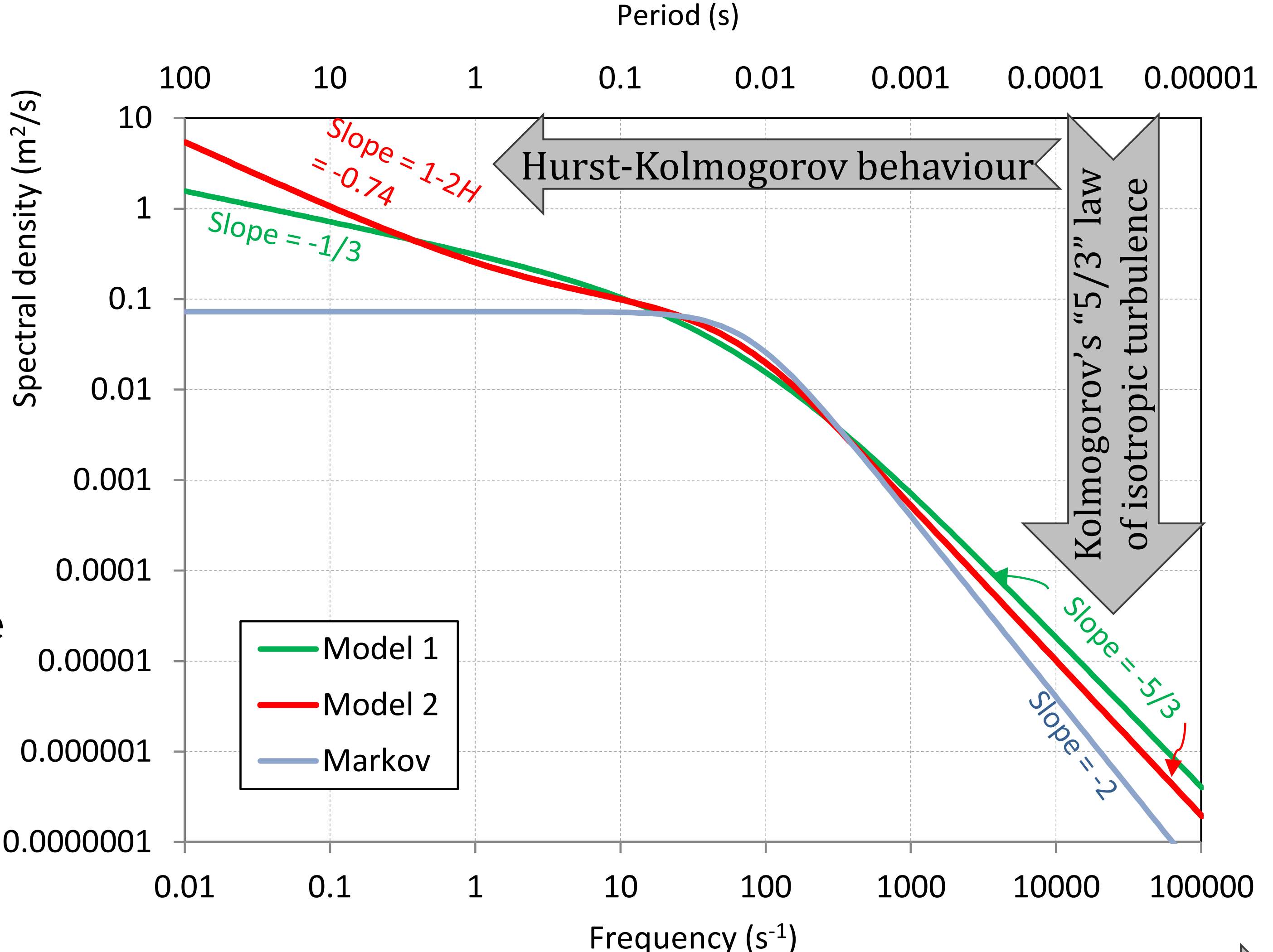
Turbulence: A spectral view

Notice the "break of scaling".

A typical slope for high frequencies is −5/3.

It can be proved that at small frequencies the asymptotic slope cannot be −5/3.

It is confined in (−1, 1).



Frequencies relevant to hydrology

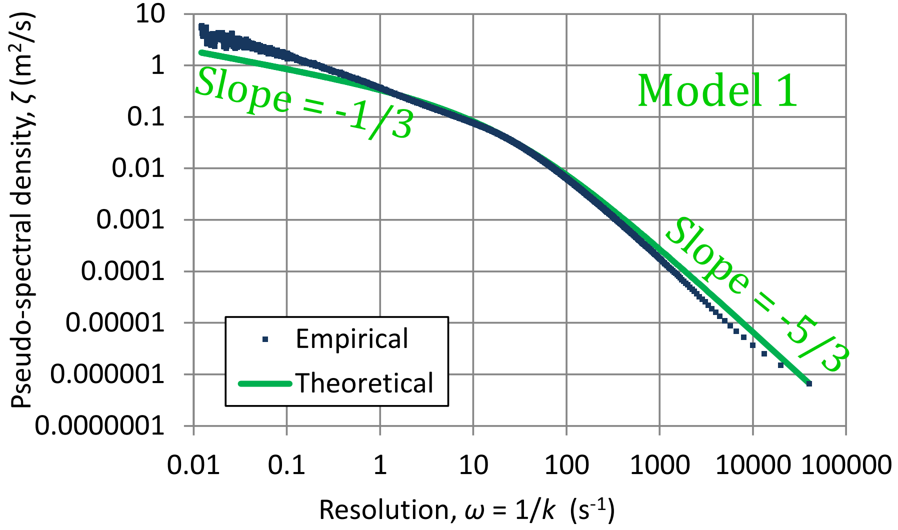
Frequencies relevant to fluid mechanics and hydraulics

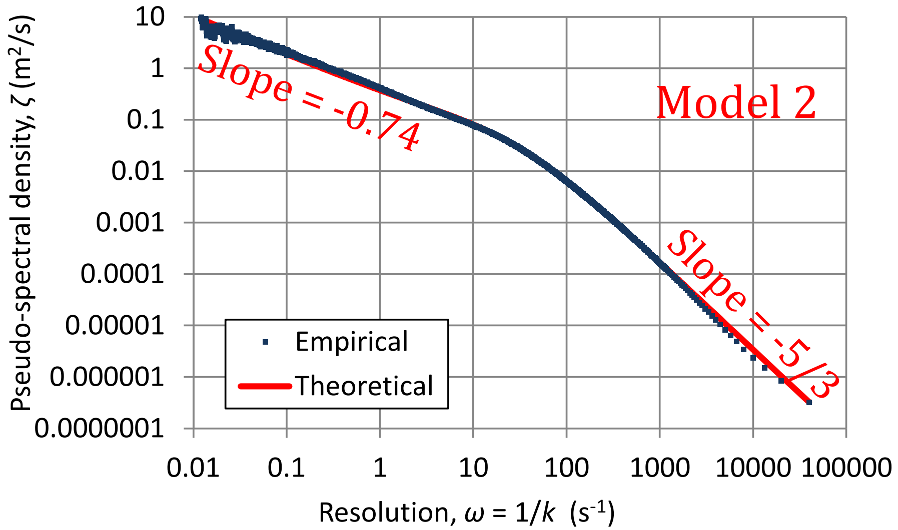
Model comparison via the pseudo-spectrum

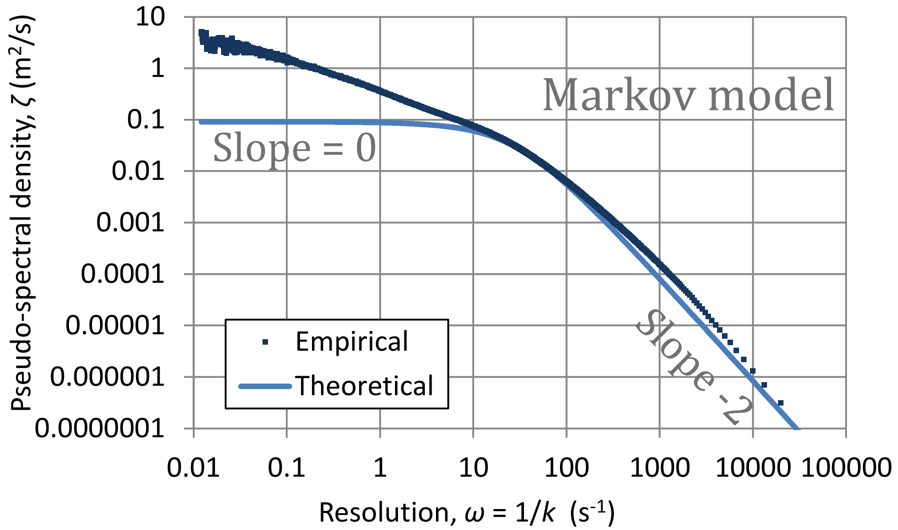
- Definition of pseudo-spectrum:

$$\zeta(\omega) \;\coloneqq \frac{\sigma^2(1/\omega)}{\omega}\left(1 - \frac{\sigma^2(1/\omega)}{\sigma^2(0)}\right)$$

- It resembles the power spectrum.
- In particular, its asymptotic slopes for resolutions $\omega \to 0$ and ∞ are identical with those of the power spectrum.
- The empirical $\zeta(\omega)$ is smooth (in contrast to the empirical periodogram).

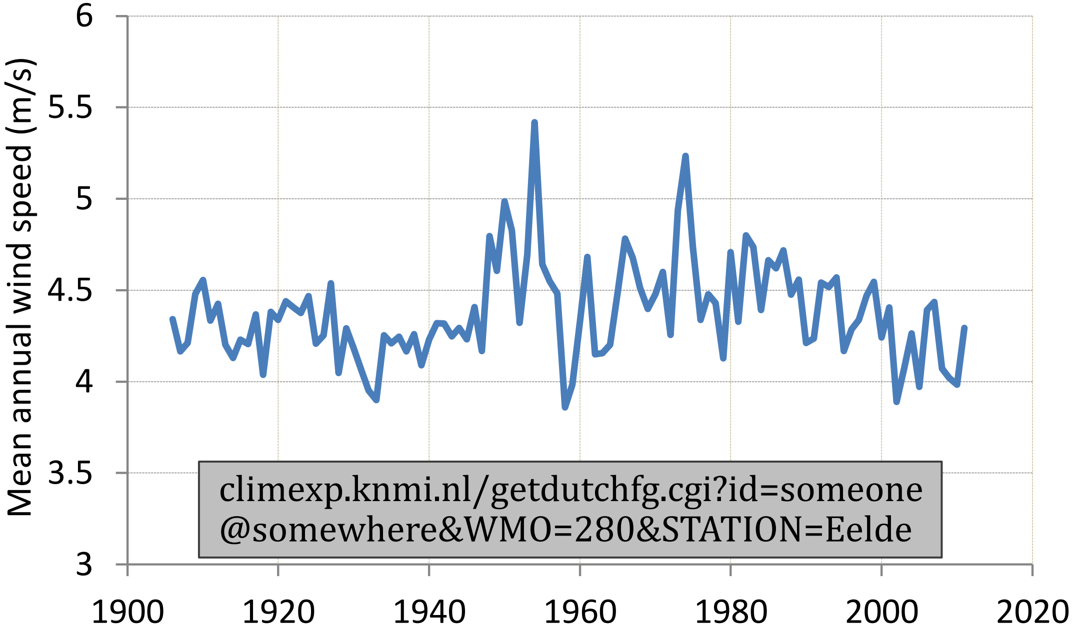


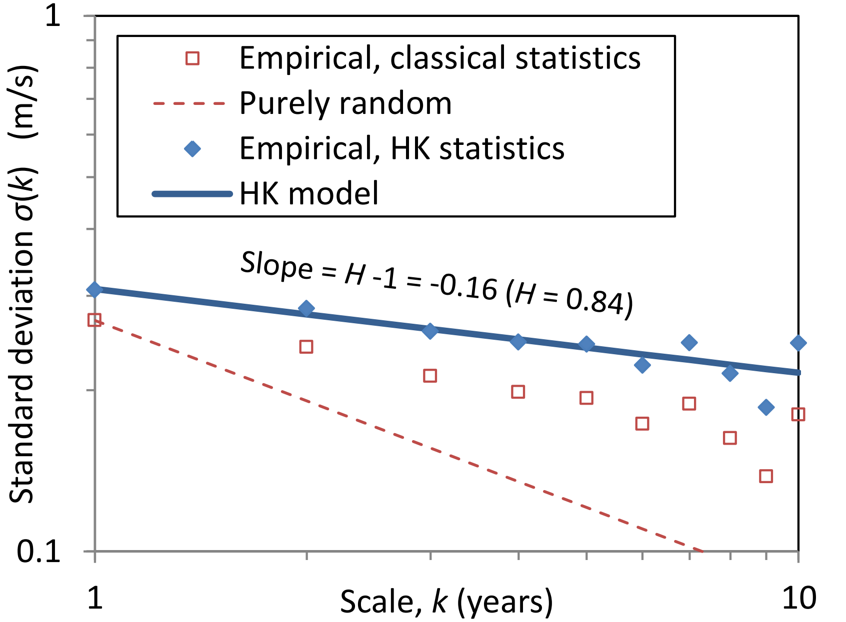




What happens with natural wind at large time scales?

- The data are from the Eelde station, The Netherlands (53.13 N, 6.58 E, 3.5 m), for the period 1906-2011 (106 years; available online by the Royal Netherlands Meteorological Institute).
- The data were homogenized for measuring height changes, as reported in station metadata (using a logarithmic velocity profile).
- The Hurst-Kolmogorov (HK) behaviour with high *H* (0.84) is evident.





Important lessons from the turbulence overview

- Natural processes are never Markovian—whether the observation scale is small or large.
- There is scaling but not simple scaling.
- Large scales, which are more relevant to hydrology, are characterized by Hurst-Kolmogorov scaling with large *H* (~0.8-0.9).
- This extends to even larger scales relevant to hydrology and climate, and makes hydroclimatic prediction difficult.
- Small scales, which are more relevant to fluid mechanics and hydraulics, are characterized by Kolmogorov's "5/3" scaling law.
  - In fluid mechanics the law can help the analytical and numerical modelling of turbulence.
  - In hydraulics, this law can yield Manning's equation for rectangular cross sections (Gioia and Bombardelli, 2002).

The character of Manning's equation

- In the first steps of modern hydraulics, complex equations were proposed such as Du Buat's equation of the 18th century (also shown in slide 10):

$$V = \frac{48.92(\sqrt{R}-0.016)}{\sqrt{1/i}-\ln\sqrt{1/i+1.6}} - 0.05(\sqrt{R}-0.016) \text{ [metric units]}$$

- At later stage more simplicity was found, as seen in Manning's equation:

$$V = \frac{1}{n}R^{2/3}i^{1/2}$$

- Note: In both equations, *V* is the **(areal and temporal) mean** velocity of the cross section, *n* is a roughness coefficient (not appearing in Du Buat's equation), *R* is the hydraulic radius and *i* is the energy slope.
- The Manning equation is:
  - **Macroscopic**: it does not describe the detailed velocity field;
  - **Statistical**: it involves areal and temporal averaging;
  - **Empirical**: it was essentially derived using laboratory and field data;
  - **Not exact**: error up to 28% for open flow in circular pipes;
  - **Not general**: adaptation needed for flow in composite cross-sections and for meandering channels (Chow, 1959);
  - **Physical**? Perhaps yes, if we accept statistics as part of physics.

From Manning's equation to hydrology

- The Manning equation is (per se) useful in hydrological applications (at river branches).
- It is even more useful in helping us perceive some characteristics and limitations of hydrology.
- Specifically, **hydrology**, with its much more complex, unique (not repeatable) objects should necessarily be:
  - **Macroscopic**: it cannot describe details;
  - **Statistical/stochastic**: it should use averages, standard deviations and probability distributions;
  - **Empirical**: it necessarily relies on field data;
  - **Not exact**: errors and **uncertainty** will never be eliminated;
  - **Not general**: different catchments need different treatment as similarities are too minor to allow accurate generalizations;
  - **Physical**? Perhaps yes, if we accept statistics as part of physics.

In a recent study Montanari and Koutsoyiannis (2012) outline a **blueprint for process-based modelling of uncertain hydrological systems**.

They contend that randomness and uncertainty are inherent in hydrological systems and propose a unification of hydrological modelling and uncertainty assessment.

Back to the relationship of hydrology and hydraulics within an engineering frame

- In engineering planning and design, prediction horizons are very long (several decades).
- In water management, prediction horizons can also be long because present decisions affect the future states of hydrosystems.
- In **long time horizons**, engineering constructions and hydrosystems are subject to **uncertain** loadings and are inescapably associated with **risk**.
- Long prediction horizons, uncertainty and risk are challenges for **hydrology and hydraulics**—and they are effectively dealt with.
- An impressive result of the combined effort of hydrology and hydraulics in an engineering frame is the **transformation**, through large-scale constructions, such as dams, reservoirs and hydropower plants, of **highly varying and uncertain natural flows** into **regular**, often constant, outflows that satisfy the water and energy **demands** of the society (see also Koutsoyiannis, 2011).

The modern change of perception in hydrology

- Up to the 1980s the engineering efforts had provided reliable, technology-enabled, water resources to the developed world and allowed a high-quality hygienic lifestyle.
- As the infrastructures were completed to a large extent in the developed world, engineering lost importance and hydraulics lost its primary role as a scientific and engineering field.
- Interestingly, at about the same time the link of hydrology with engineering was questioned.
- Moreover, it was emphatically asserted that **cutting the umbilical cord between hydrology and engineering** would be beneficial for both (Klemeš, 1986).

The developments in IAHS

- The change of perception was reflected in the discussions about the character of the International Association of Hydrological Sciences (IAHS) in the 1980s. The then president Vít Klemeš defined the focus of IAHS as:

  "the development of hydrology as a strong geophysical (earth) science and the promotion of sound applications of this science on solving practical problems."
- However, despite recognizing the importance of solving practical problems, he also asserted that water resources management is not a hydrological science and IAHS is not its professional home (Klemeš, 1987).
- Not surprisingly, his message instigated a strong debate from others (Shamir, 1988) who regarded water resource systems as an essential section of IAHS.

The developments in the USA and the "gospel" of modern hydrology

- A similar message was broadcast in the US, as manifested in a text by the US Committee on Opportunities in the Hydrologic Sciences (1992) that has been widely regarded as the "gospel" of modern hydrology.
- This gave the emphasis on "**understanding**" of hydrological processes and asserted that:

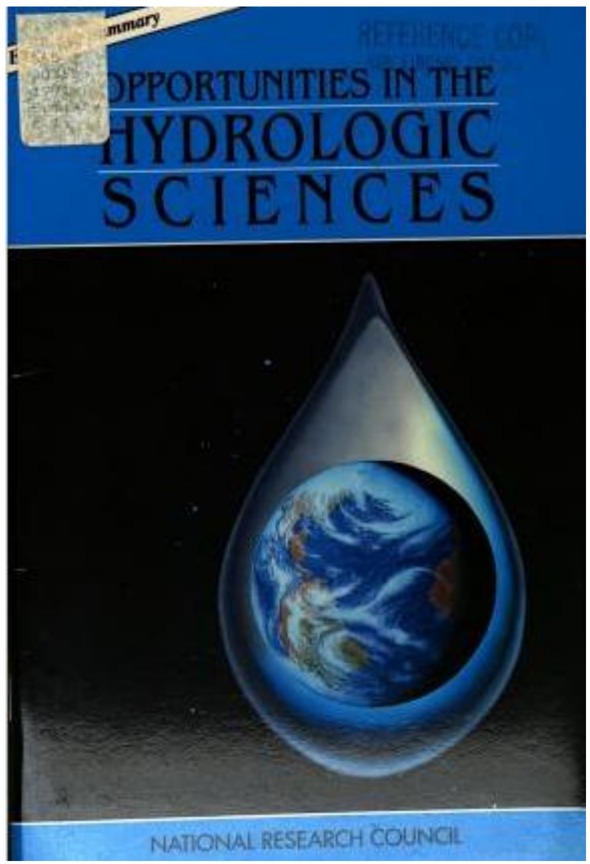
  "Development of hydrology as a science is vital to the current effort to understand the interactive behaviour of the earth system."

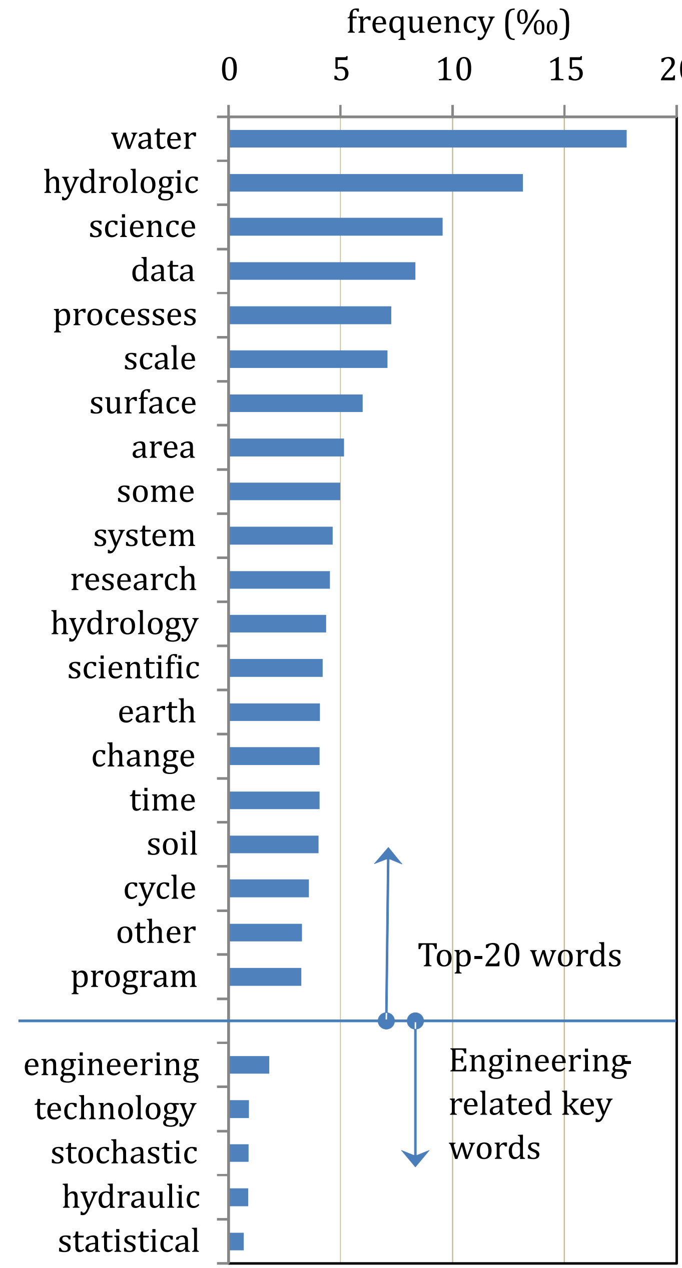
- It also concluded that:

  "graduate education in the hydrologic sciences should be pursued independently of civil engineering."

Some metrics in the "gospel" of modern hydrology

An analysis of word frequency in the book reveals depreciation of engineering-oriented aspects of hydrology.





A comparison with a more recent (2012) version of the book will be shown later.

The influence of ideological trends

- The new trend in hydrology was in line with a general change of perspective of the developed world societies, marked by a departure from a problem-solving approach and engineering solutions.
- By definition, engineering deals with real-world problems and aims to change, transform or control natural processes, and to provide solutions to these problems.
- Engineering solutions were also opposed during the last decades by the developing "green" ideology as well as by politico-economic agendas related to the "climate change" movement.
- The latter has determined the direction of research funding of national and international bodies in a manner that hydrology would not have any share except as an assistant in subjects dictated by the dominant political agendas (e.g. in studying hypothetical climate-related threats and impacts).
- Thus, hydrology, instead of becoming an autonomous science with a broader domain, as envisaged, developed new umbilical cords with politically driven agendas, and its role was narrowed.

The "soft water path"

- The change of perspective went further by proposing the so-called "**soft water path**" (Gleick, 2002), which,

  "by investing in decentralized facilities, efficient technologies and policies, and human capital […] will seek to improve overall productivity rather than to find new sources of supply [and] will deliver water services that are matched to the needs of end users, on both local and community scales."

- This has been promoted as a contrasting alterative to engineering solutions to problems that rely on infrastructure development, which Gleick (2002) calls the "hard path" and criticizes for:

  "spawning ecologically damaging, socially intrusive and capital-intensive projects that fail to deliver their promised benefits."

- Interestingly, the groups that project threats like bigger floods and droughts of greater duration due to climate change, and highlight the need for adaptation to climate change, are the same groups that discourage building new water projects and promote their "soft path" for developing nations.

From real world to virtual reality: a hypothetical “success story”

- As the new promoted “soft path” approach is weakly connected to the material world, it encouraged a new culture in research transactions.
- This could be exemplified by the following hypothetical story in developing a research programme:
  (a) We invent a problem that does not exist.
  (b) We coin a smart name to describe it (e.g. *metastatic urbanism*).
  (c) We get plenty of money to study it.
  (d) We organize brain-storming meetings to define the (non-existing) problem.
  (e) We fill forms and spreadsheets, and produce stereotypical deliverables to justify funding.

The “soft hydrological sciences”

- Several new areas, related to hydrology and consistent with the “soft path”, have recently emerged or been proposed:
  - **Biohydrology**: the study of the interactions between biological and hydrological systems (Feachem, 1974);
  - **Ecohydrology**: the study of the interactions between water and ecosystems within water bodies (Zalewski et al., 1997);
  - **Hydropsychology**: the study of the transactions between humans and water-related activities (Sivakumar, 2011);
  - **Sociohydrology**: the science of people and water, a new science that is aimed at understanding the dynamics and co-evolution of coupled human-water systems (Sivapalan et al., 2012).

The importance of the new knowledge acquired by these emerging fields is not questioned. Particularly, ecohydrology, by shedding light on the interactions and feedbacks between hydrologic processes and terrestrial ecosystems (Porporato and Rodriguez-Iturbe, 2002; D'Odorico et al., 2010) has indeed offered useful knowledge.

The reductionist approach

- One of the most characteristic failures of the "non-engineering hydrology" is the view that modelling may get rid of the necessity of field data.
- It was hoped that a complex system can be modelled without data, by
  - cutting it into small nearly-homogeneous pieces,
  - describing the natural processes in each piece using differential equations which implement "first principles", and
  - solving the differential equations numerically thanks to the ever increasing computer power.
- This reductionist philosophical view constituted the basis of the so-named "physically-based" hydrological modelling (e.g. Abbott et al., 1986) and was highly promoted in the initial document of the decade-long IAHS initiative for Prediction in Ungauged Basins (PUB; Sivapalan et al., 2003).
- However, pragmatism and experience may help us see that the more detailed an approach is, the more data it needs to calibrate.
- Also, common sense may help us understand that it is infeasible to estimate the evapotranspiration of a forested area by "cutting" the forest into trees and then each tree into individual leaves.

The parsimonious approach

- History of science teaches that feasible and convenient macroscopic descriptions can only be achieved using principles of probability theory like the law of large numbers and the principle of maximum entropy.
- There are several examples where simpler and more parsimonious models gave better fits and better predictions in complex hydrological systems.
- An interesting example is the modelling of a karstic basin in Bosnia and Herzegovina with a complex system of surface poljes and underground natural conduits (Makropoulos et al., 2008).
  - Three different research teams worked independently from each other adopting different approaches but using the same data.
  - One of the approaches was “physically-based”, one was based on a detailed conceptual description of the processes and the third was a “toy model”, lumping similar elements of the system into a single substitute element.
  - Naturally, the “toy model” performed best, while the “physically-based” model gave the worst predictions.

On understanding and misunderstanding

- "Understanding" seems to have become the Holy Grail of modern science, including hydrology, as testified by the frequent and emphatic use of this word in scientific papers.
- For example, a Google Scholar search reveals that out of 32 900 papers published since 2008 that contain the word "**hydrologic**" (as of August 2012), **62% also contain the word "understanding"**.
- This is an infelicitous development, because "understanding" is a vague and obscure term per se. In particular, "understanding" is a subjective cognitive procedure rather than anything objective.
- Perhaps a more relevant term is "**interpretation**", which is also subjective, but more **honest** in admitting the subjectivity: while fans of the term "understanding" would pretend to target a unique type of "understanding" (characterizing other views as "misunderstanding"), they would be less reluctant to allow multiple "interpretations" of a phenomenon as legitimate.
- In addition, as "understanding" is typically used within a deterministic point of view, it leaves out important targets as the "understanding" of randomness and uncertainty.

From understanding to overstanding

- In science, "understanding" is not a primary goal (cf. quantum physics).
- In engineering, "understanding" is clearly a secondary goal; the primary one is to solve a problem in a reliable manner.
- As history teaches, full understanding has not been a prerequisite to act.
- As "understanding" is typically associated with deterministic detailed descriptions of phenomena, it may lead to failure in constructing the big picture.
- For the latter, the term "overstanding" has been coined (Koutsoyiannis, 2010) which highlights the importance of macroscopic views of complex phenomena—the view of the forest than of the tree.

Credit for sketches: Demetris Jr. (from Koutsoyiannis, 2009).

A neat assessment of the current state of affairs

“[A] new infectious disease has sprung up—a WATER-BORN SCHIZOPHRENIA: on the one hand, we are daily inundated by the media with reports about water-caused disasters, from destructive droughts to even more destructive floods, and with complaints that ‘not enough is done’ to mitigate them and, on the other hand, attempts to do so by any ***engineering means—and so far no other similarly effective means are usually available****—are invariably denounced as ‘rape of nature’ (often by people with only the foggiest ideas about their functioning), and are opposed, prevented, or at least delayed by never ending ‘environmental assessments and reassessments’. In the present ‘green’ propaganda, all dams are evil by definition, ranking alongside Chernobyls, Exxon Valdezes, ‘rape of the environment’, AIDS, cancer and genocide”.*

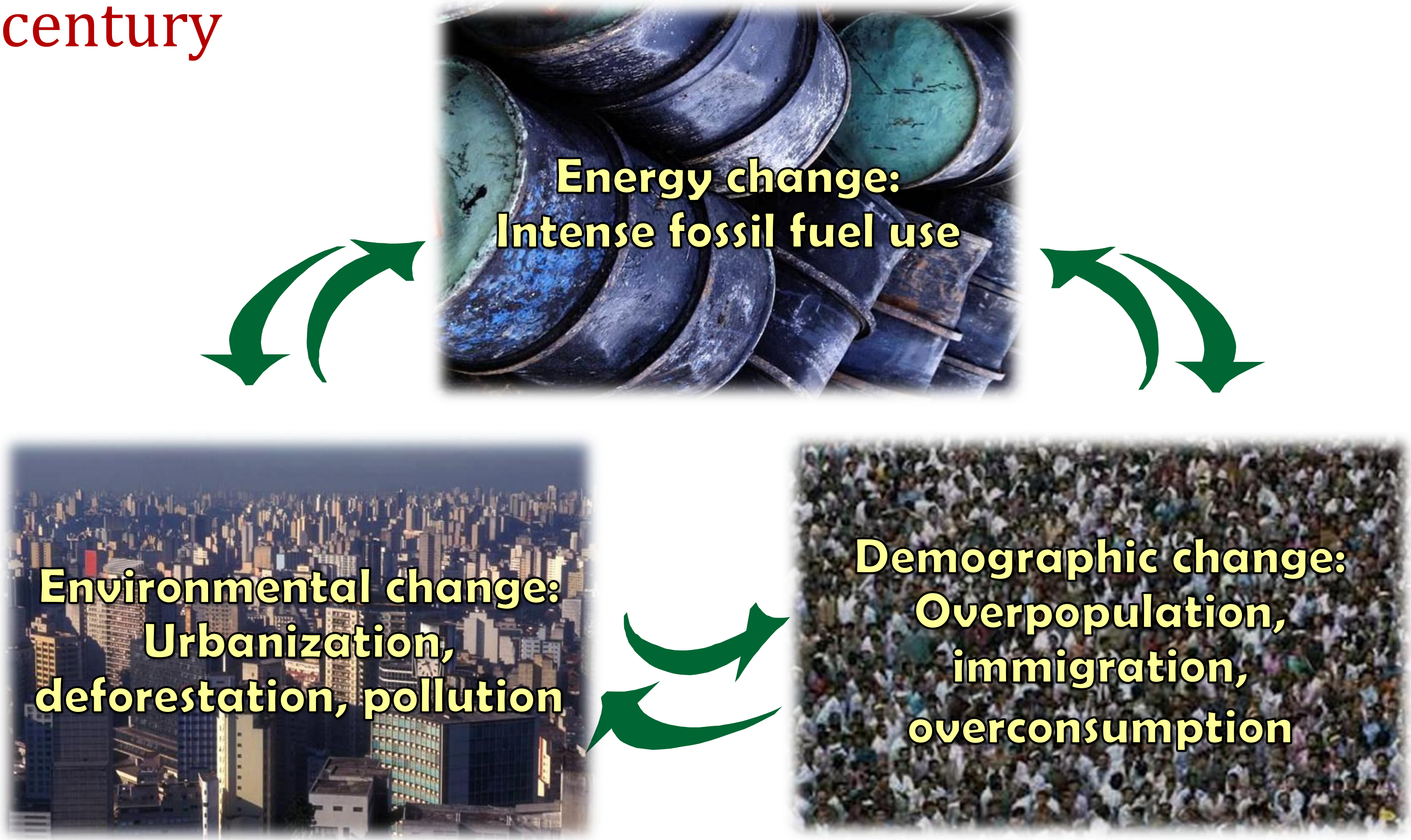
From one of the lasts talks of the late Vít Klemeš (2007; my emphasis), one of the pioneers of the mandate to make hydrology a science independent of engineering.

A neat assessment of the current state of affairs (contd.)

*"I shall close with a plea to all of you, **hydrologists and other water professionals, to stand up for water, hydrology and water resource engineering**, to restore their good name, unmask the demagoguery hiding behind the various 'green' slogans. As in any sphere of human activity, errors with adverse effects were and will be made in our profession as well (think of the human toll of errors made in the medical profession – and nobody is vilifying hospitals and advocating tearing down medical clinics). But, on the whole, our profession has nothing to be ashamed of—from the times of the ancient Mesopotamia, Greece and Rome to the present, it has done more good for mankind than all its critics combined."*

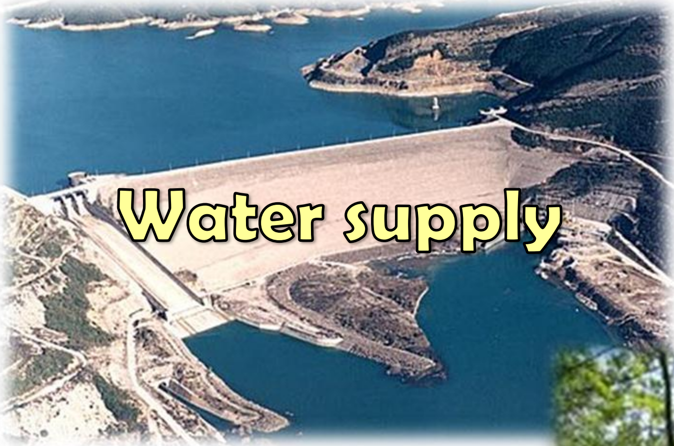
From one of the lasts talks of the late Vít Klemeš (2007; my emphasis), one of the pioneers of the mandate to make hydrology a science independent of engineering.

The real problems: the vicious circle of the 20th century



Adapted from Koutsoyiannis et al. (2009)

Major real challenges of the 21st century



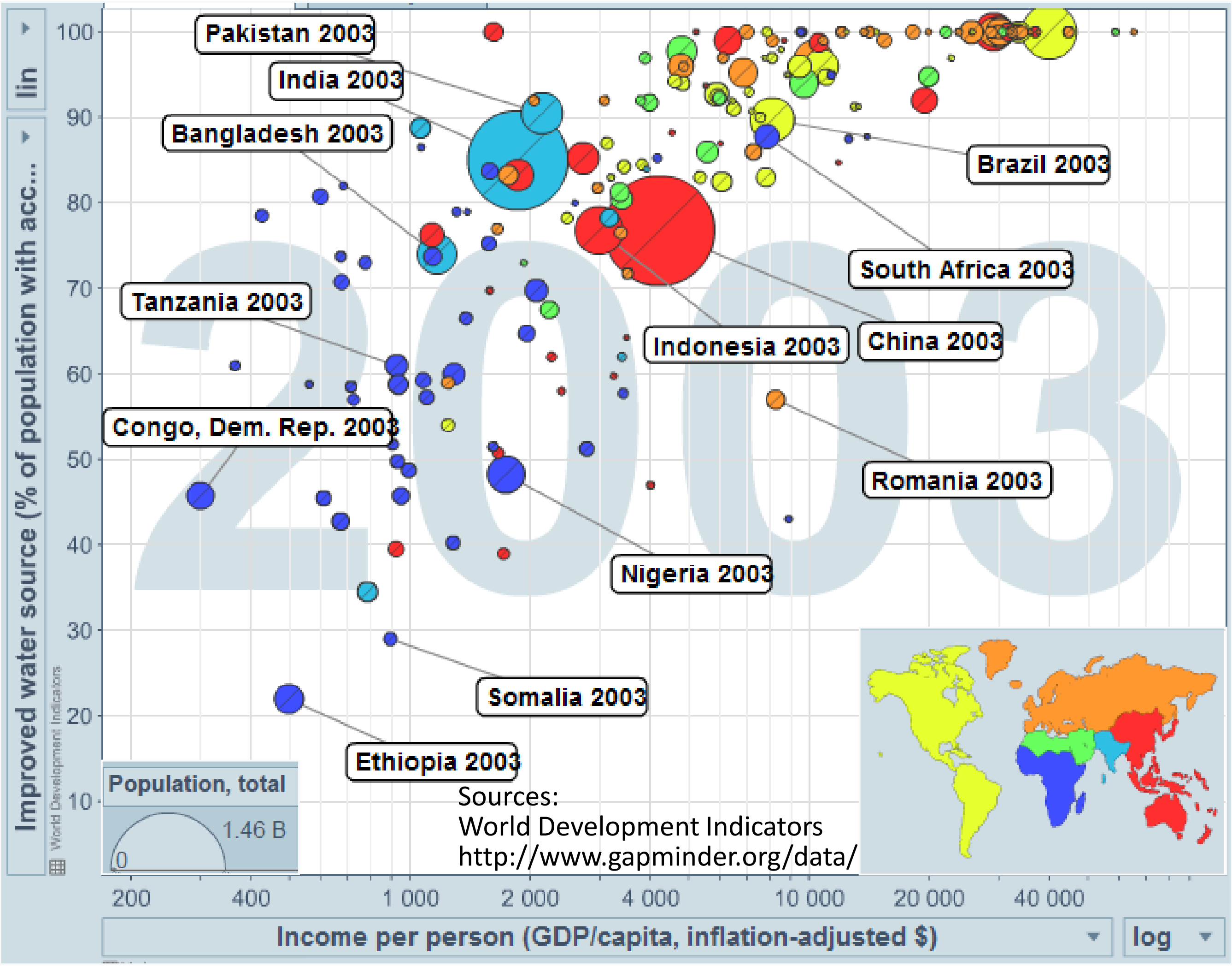
Problems—and misdiagnoses—about water supply

- Disparities in water supply among different areas in the globe are marked.
- In developed countries any person has water supply through house connections and consumes typically 150-200 L/d and in some cases up to 1000 L/d.
- In developing countries it constitutes only a target to provide 'reasonable access' to water: 20 L/d per capita at a distance of less than 1 km.
- 18% of the world population (> 1 billion) do not meet this 'standard' (Howard and Bartram, 2003).
- Comparison with standards in the Athens of the 7th century BC (2 × 20 L/d, 740 m according to Solon's legislation; Koutsoyiannis *et al.*, 2008b) indicates a stagnancy, or even regression, over 27 centuries.
- In addition, an astonishing misunderstanding of hydrological processes and the real nature of water problems is typically demonstrated, as, e.g., in the so-called **European Declaration for a New Water Culture**:

  "*We live in times of crisis in which the international community must pause to reflect and decide which model of* ***global governance*** *we must take on board for the 21st century. We must face up to the* ***ever worsening crisis of social and environmental unsustainability in the world****. With reference to water resources,* ***the systematic destruction and degradation of water ecosystems and aquifers has already led to dramatic social repercussions. 1 100 million people with no guaranteed access to drinking water, and the breakdown of the hydraulic cycle*** *and health of rivers, lakes and wetlands are two* ***consequences of this crisis***".
  (www.unizar.es/fnca/euwater/index2.php?idioma=en)

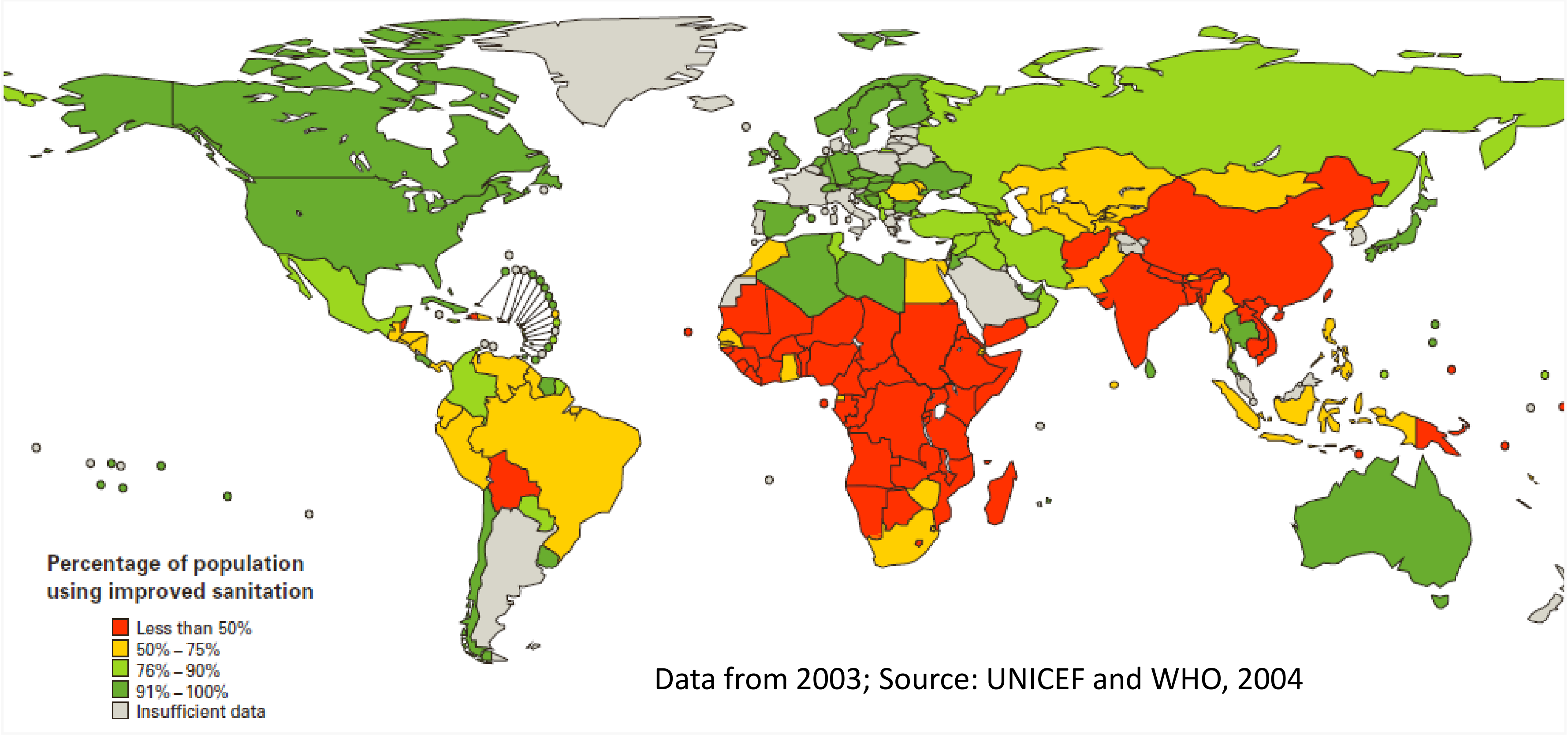
Disparities in water supply among different areas

- In developed countries, 100% of the population has proper water supply.
- In developing countries, this percentage depends on the income (GDP).
- This percentage is very low in African countries.



More on disparities and their consequences on health

Half of the urban population in Africa, Asia, and Latin America suffers from diseases associated with inadequate water and sanitation (Vörösmarty *et al.*, 2005).

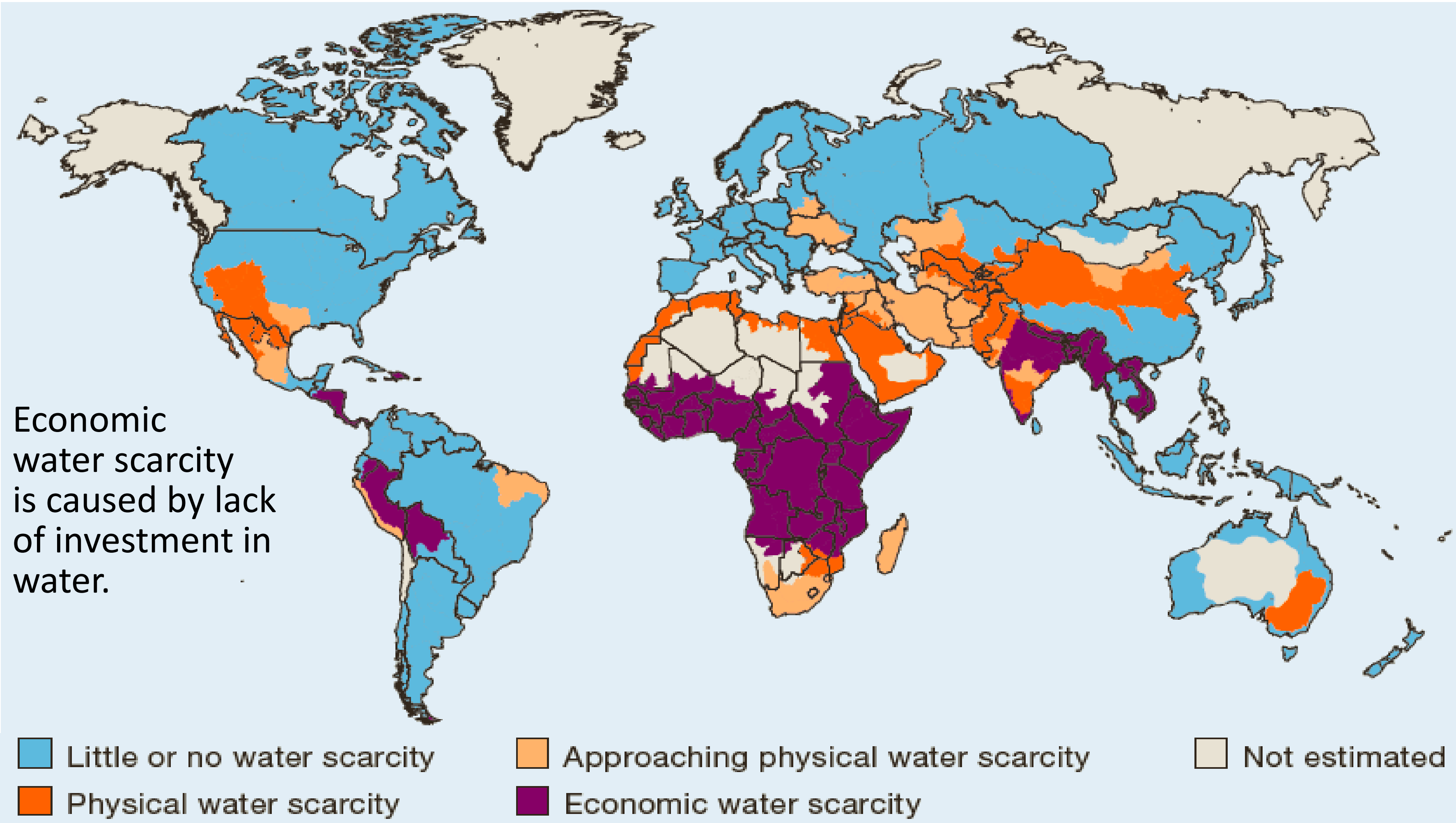


Data from 2003; Source: UNICEF and WHO, 2004

Water scarcity is economically driven*

*except for desert areas

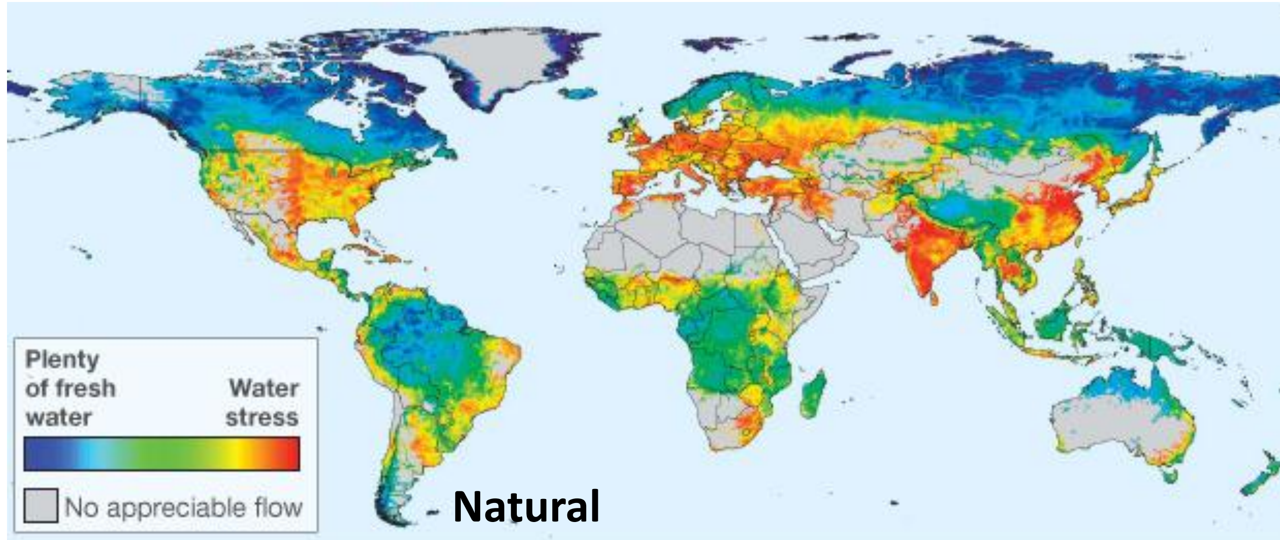
Economic water scarcity is caused by lack of investment in water.

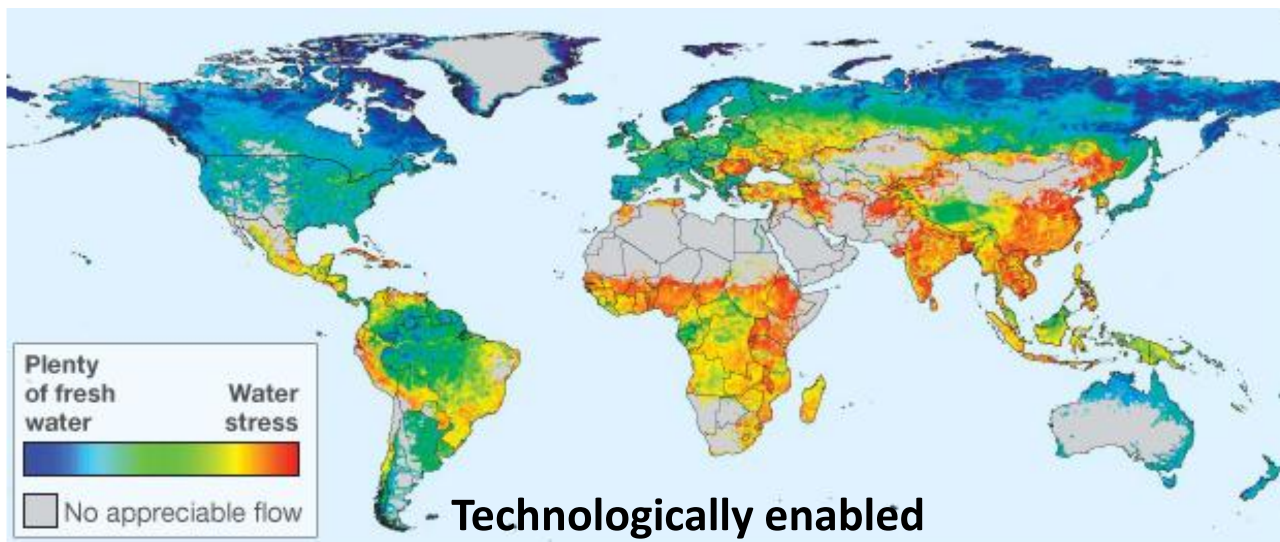


Source: Comprehensive Assessment of Water Management in Agriculture (2007)

Water scarcity = lack of water infrastructure

- Vörösmarty *et al.* (2010), who constructed these graphs, advocate, for developing countries, "*integrated water resource management that expressly balances the needs of humans and nature*".
- However, they do not suggest technological means different from those already used in developed countries.

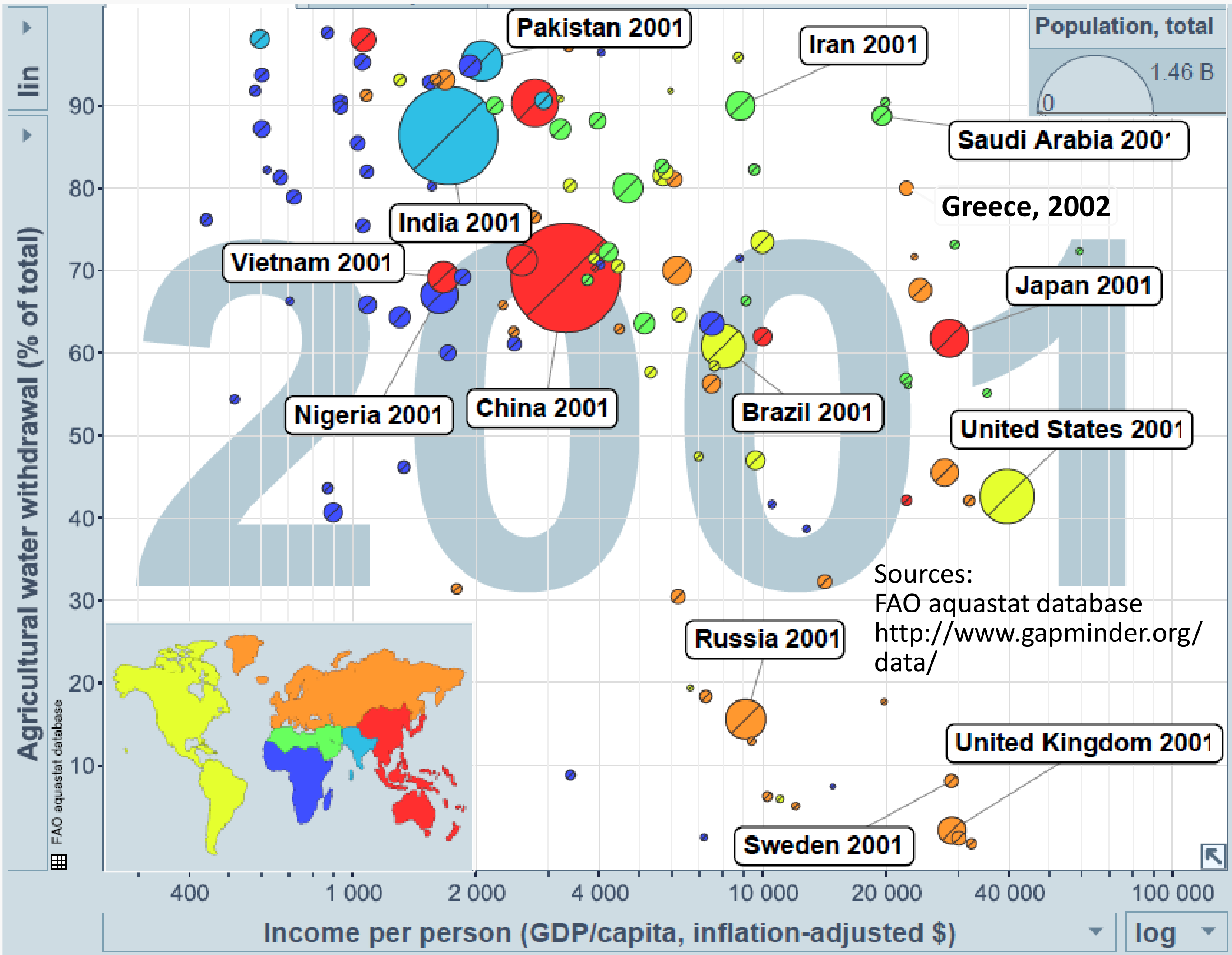




Source: Vörösmarty *et al.* (2010) as adapted in www.bbc.co.uk/news/science-environment-11435522

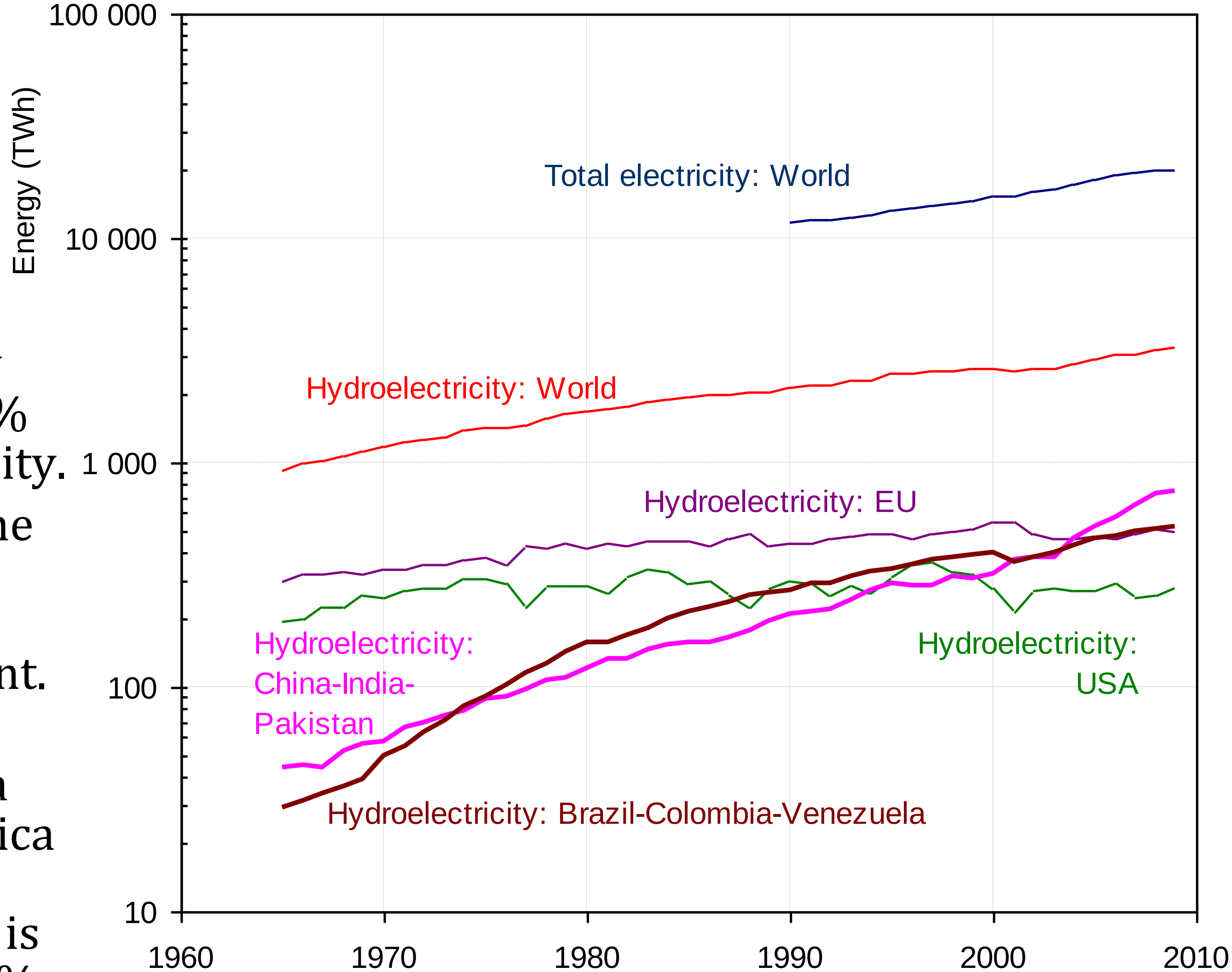
Water for food

- Most of water consumed worldwide goes to irrigation.
- The portion of agricultural water use depends on climate—not on income.



Water for energy

- Electricity and hydro-electricity increase by 3% and 2.6% per year, respectively.
- Hydroelectricity represents ~16% of world electricity.
- In Europe and the USA hydroelectricity has been stagnant.
- In several countries in Asia and South America the increase of hydroelectricity is spectacular (> 6% per year).



Data source: www.bp.com/productlanding.do?categoryId=6929&contentId=7044622

Is there potential for hydroelectric development worldwide?

Continent	Economically feasible hydro potential (% of world)	Exploitation percentage (%)
Europe	10	75
North & Central America	13	75
South America	20	30
Asia	45	25
Africa	12	8

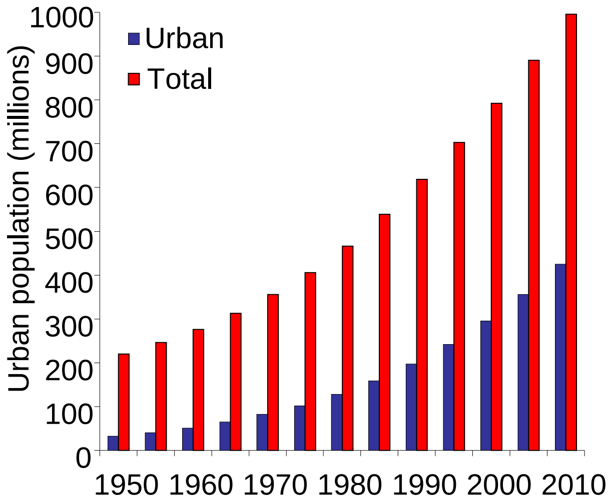
Source: Leckscheidt and Tjaroko (2003)

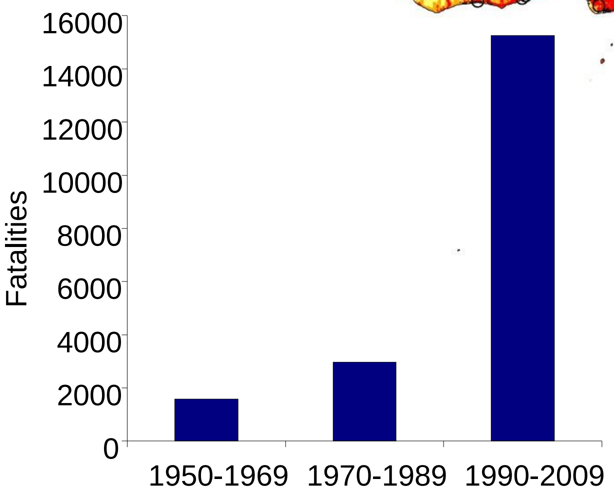
Additional needs for hydropower:
As the importance of renewable energy becomes higher—and because wind and solar energy are highly variable and unpredictable—**energy storage** becomes absolutely necessary.
The only available technology for large-scale storage of energy is provided by reversible hydropower plants.

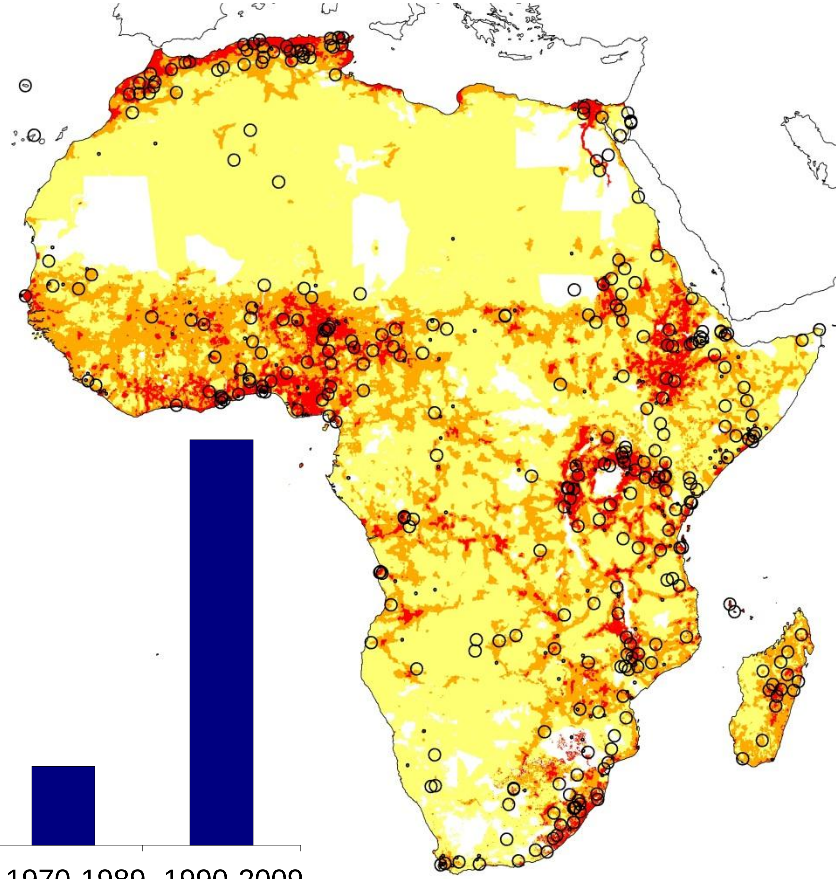
Protection from floods

- When urbanization is not combined with urban water infrastructure, the results are tragic.
- Engineering infrastructure should include flood protection works and urban planning

Population growth in the period 1960-2000 in Africa: yellow, less than 100 inhabitants per cell (2.5'); orange, 100-1000; red, more than 1000. The figure also shows the location of floods (dots) and deadly floods (large circles) in the period 1985-2009 (Di Baltassare et al., 2010).







Protection from droughts and "food availability decline" (famines)

Period	Area	Fatalities (million)	Fatalities (% of world population)
1876-1879	India China Brazil Africa Total	10 20 1 ? >30	>2.2%
1896-1902	India China Brazil Total	20 10 ? >30	>1.9%
1921-1922	Soviet Union	9	0.5%
1929	China	2	0.1%
1983-1985	Ethiopia	≤1	0.02%

Sources: de Marsily (2008); Devereux (2000)

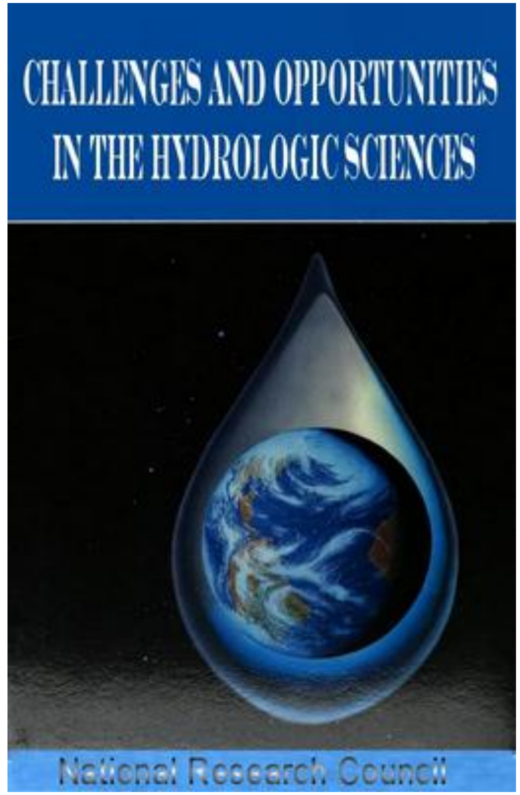
- Long-lasting droughts of large extent are intrinsic to climate (cf. Hurst-Kolmogorov dynamics).
- Such droughts may have dramatic consequences, even to human lives, as shown in the table, which refers to drought-related historical famines.
- Large-scale water infrastructure, which enables multi-year regulation of flows, is a weapon against droughts and famines.
- As shown in table, famines and their consequences have been alleviated through the years owing to improving water infrastructure and international collaboration.

Relevance of hydrology for 21st century challenges

- Creation or modernization of **urban water supply systems** demands engineering means and hydrology has certainly a big role to play in this.
- **Food security** is more vulnerable in areas with high evapotranspiration, which necessitates irrigated agriculture; some of the controlling factors (water resources availability, irrigation efficiency) are related to engineering hydrology.
- Engineering hydrology, with its particular experience in studying and managing natural variability can substantially help in the development of technology for large-scale **storage of energy** (reversible hydropower plants) and in the more reliable management of **hydropower**.
- Hydrology and hydraulics are the scientific fields most pertinent to the study and management of the **flood risk** both in real time and in planning and design time horizons.
- **Environmental problems** associated with the creation of infrastructure and with industrial activities demand appropriate technologies and engineering solutions, in which hydrology has an important role to play.

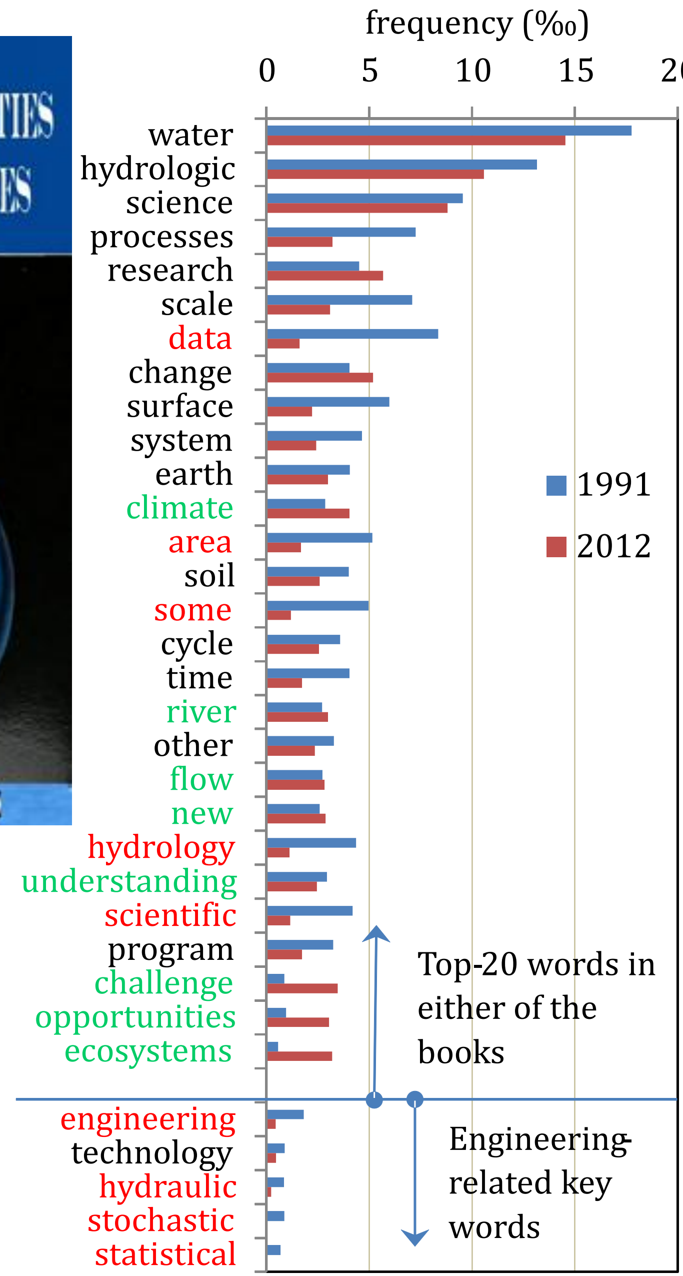
Do current trends allow optimism?

- Will hydrology ignore these challenges and keep on walking on the trails formed in the last three decades?
- It is very probable, given the inertia of the scientific community (**cf. the new version of the 1992 “gospel”**; US Committee ..., 2012), the targets of the classe politique and the related socio-economic interests.



Words loosing frequency in the 2012 book (in comparison to the 1992 book) by more than 100%

Words entering the top-20 list in the 2012 book or gaining frequency by more than 100%



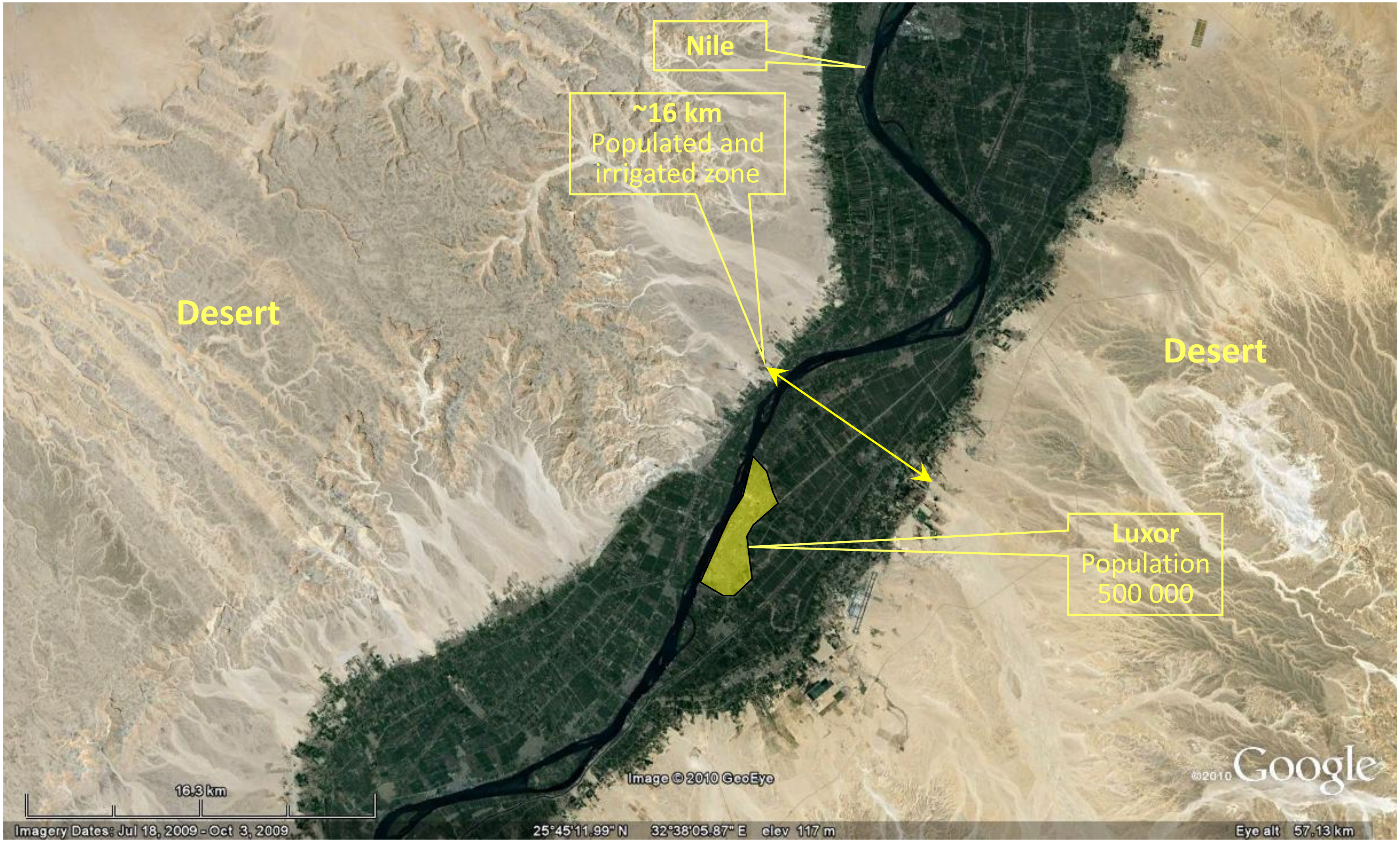
Conditions for a better future of hydrology

- If it revisited its strong technological and engineering roots.
- If it took advantage from the historical fact that it is the scientific discipline that has studied natural uncertainty better and in greater depth than any other discipline.
- If it recognized again that change, uncertainty and risk are intrinsic and interrelated properties of this world and are not eliminable, but are quantifiable and manageable.
- If it appreciated that parsimonious macroscopic descriptions are more powerful than inflationary detailed ones and that holistic approaches are more effective than reductionist ones.
- If it identified its role within the real and challenging problems of the contemporary world.

Concluding remarks

- Re-establishing the disturbed link of hydrology with engineering could help hydrology to land again from the virtual reality into the real world,
  - where data and facts are more important than models,
  - where predictions are tested against empirical evidence,
  - where life is in continuous dialogue with uncertainty and risk.
- In the real world, change is the rule, rather than an adverse property that should be opposed, and, therefore, engineering, as a means of planned and sophisticated change, is essential for progress and evolution.
- Thus, the study of change, natural and engineered, as well as the implied uncertainty and risk, can constitute a fertilizing field of mutual integration of hydrology and engineering.

“*Nothing can be green without water – except ‘green’ politics*” (Vít Klemeš)



⇩ **To Aswan dam** (hydroelectricity, storage of irrigation water, flood control)

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