



**IDRA 2012 – XXXIII Conference of Hydraulics
and Hydraulic Engineering
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Reconciling hydrology with engineering



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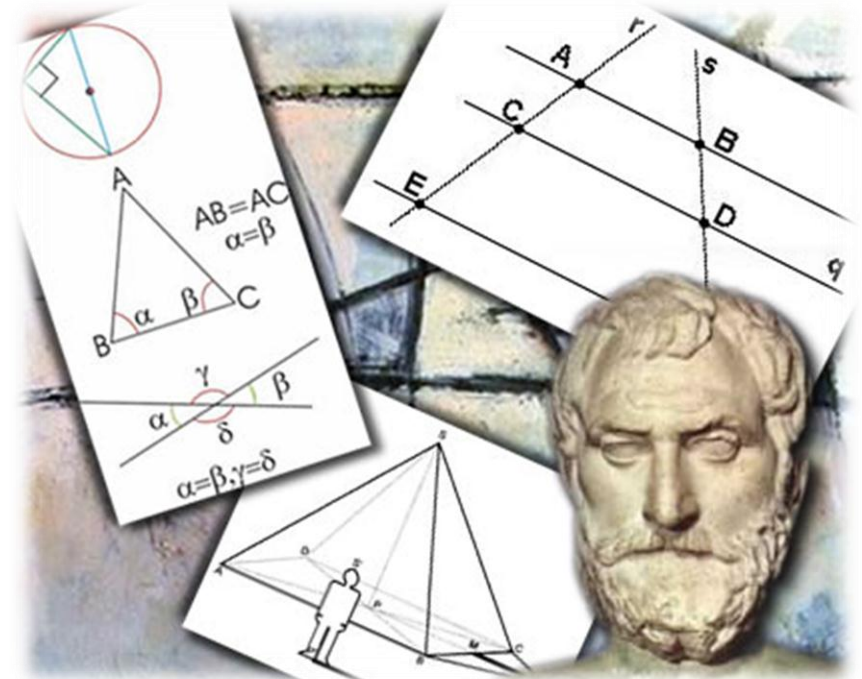
Presentation available online: itia.ntua.gr/1235/

The philosophers have only **interpreted
the world, in various ways;
the point, however, is to **change** it.**

Karl Marx; Theses on Feuerbach, 1845

The importance of hydrology in the antiquity

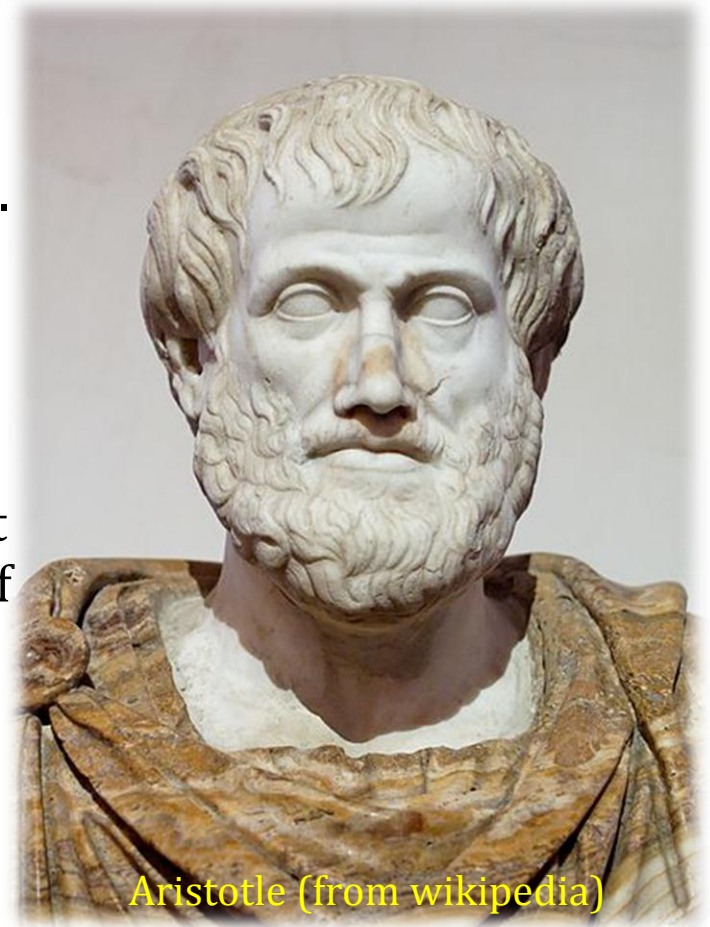
- The first scientific problems, put and studied as such, were about hydrological phenomena.
- The first geophysical problem formulated in scientific terms was the hydrological “paradox” of the Nile: flooding occurs in summer when rainfall in Egypt is very low to non-existent.
- Thanks to **Herodotus** (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).

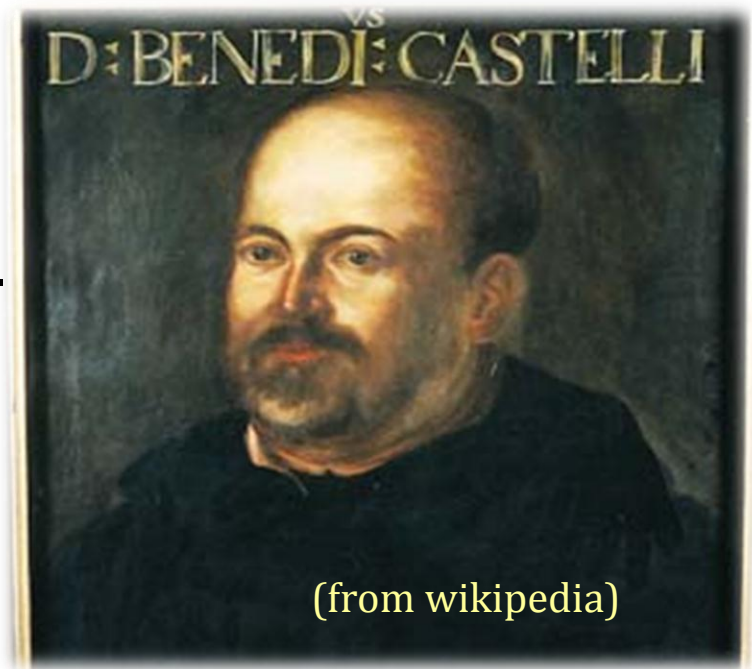


Minoan pipes at Knossos and their study at the NTUA hydraulics laboratory (Angelakis et al., 2012)



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.
- **Benedetto Castelli**, as explained in his book “Della misura delle acque correnti” (1628), 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.

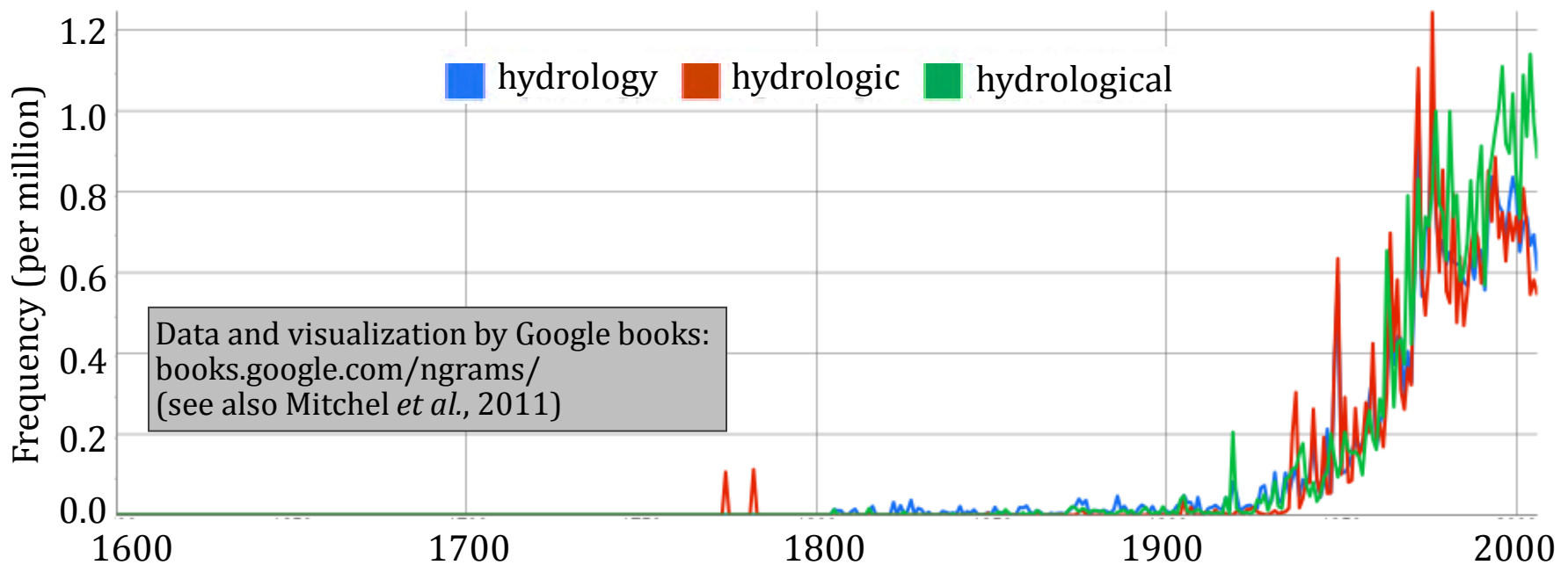


Admittedly, as useful a matter as the **motion of fluid** and related sciences has always been an object of thought. Yet **until this day neither our knowledge** of pure mathematics nor our command of the mathematical principles of nature **have permitted a successful treatment.**

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

History of the terms “hydraulic” and “hydrology”

- The term “hydraulic” (ὕδραυλικὸν) 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” (ὕδρολογία) did not exist in the classical literature and appeared only in the end of the eighteenth century.



A TREATISE
..
PHYSICAL GEOGRAPHY,

COMPRISING

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

BY A. BARRINGTON.

EDITED BY

CHARLES BURDETT,

AUTHOR OF "THE CROCK'S CHILD;" "DEFER 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., 109 BROADWAY;
CINCINNATI: W. H. MOORE & CO.; CHICAGO: S. C. GRIGG & CO.;
AUBURN: J. C. IVISON & CO.; BOSTON: H. E. MURPHY & CO.;
PHILADELPHIA: LEITCHSCOTT, GRAMER, & CO.; AND
FOR SALE BY ALL BOOKSELLERS.

1851.

Early uses of "hydrology": Geography- and medicine-oriented

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 where a closer approximation to accuracy may be desired, somewhat better results may be obtained by using Du Buat's formula, viz. :—

$$\frac{307 (\sqrt{r} - 0.1)}{\sqrt{\frac{1}{h}} - L (\sqrt{\frac{1}{h}} + 1.6)} - 0.3 (\sqrt{r} - 0.1) = \text{Velocity in inches per second.}$$

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

L = Hyperbolic Log. of the term to which it is prefixed.

Hyperbolic Log. = Common Log. \times 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	1807	1812	1823	1827	1839	1839	1840	1841	1846	1846	1855	1857
		13th Nv.	12th Dec.	15th Oct.	16th Oct.	13th My.	20th Oct.	8th Nv.	6th Nv.	31st Oct.	20th My.	20th Oct.	1st Nv.	1st Oct.
Monticelli	Mls. 210.0	ft. 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
Serride	76.9	26.5	27.0	28.1	28.2	27.7	27.7	28.5	26.4	27.4	...	28.1	28.2	...
Quattrole (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

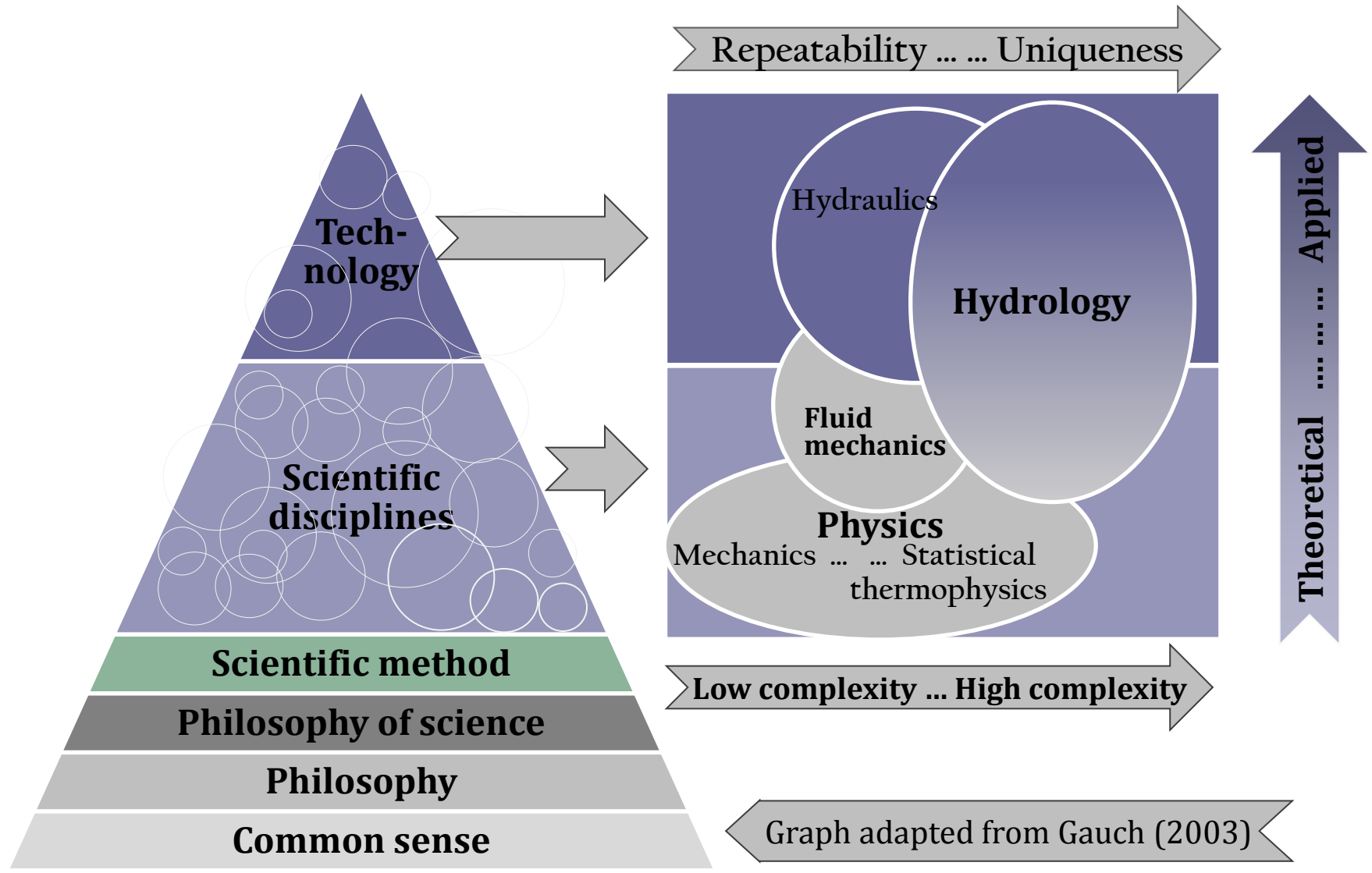
- Some of the advances are pertinent to both hydraulics and hydrology:
 - flow in aquifers and in unsaturated soils;
 - transport phenomena and the movement of sediments.
- Other advances are purely hydrological, yet with clear engineering orientation:
 - probabilistic and stochastic modelling of hydrological 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

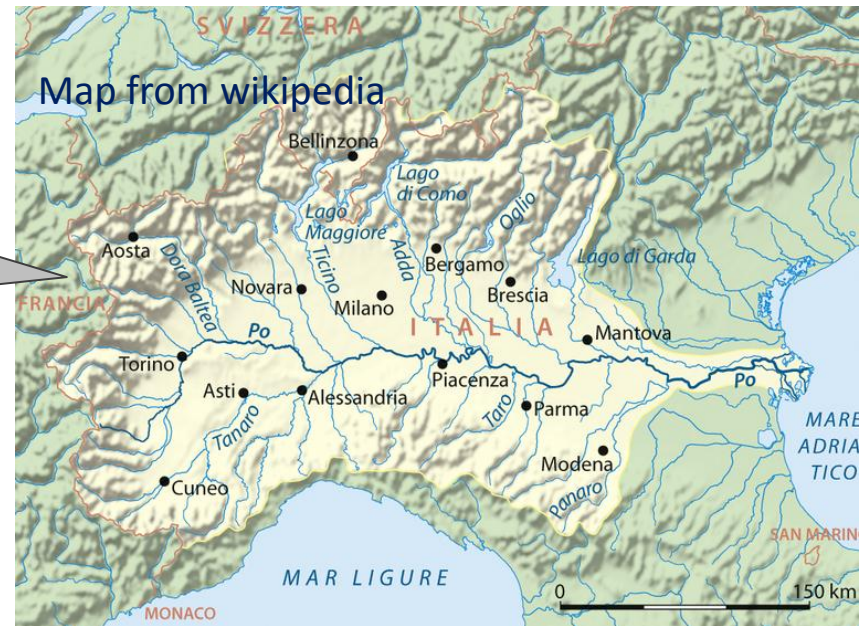


Visualized difference of hydraulics and hydrology

Hydraulics:
Typically simple and repeatable objects

Hydrology: Complex and unique objects

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

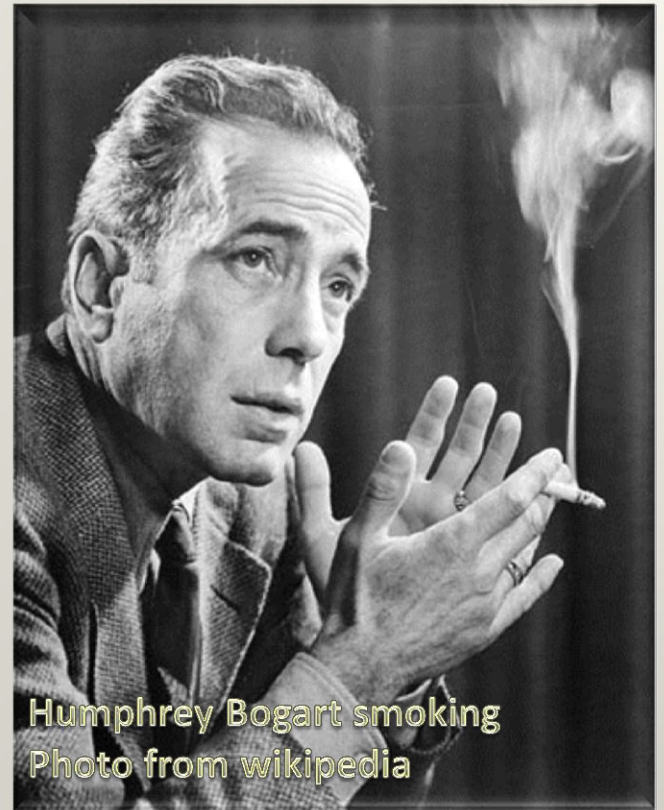


The grand intersection

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



Karpenisiotis river at Acheloos river-basin
Photo by author



Humphrey Bogart smoking
Photo from wikipedia

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.**

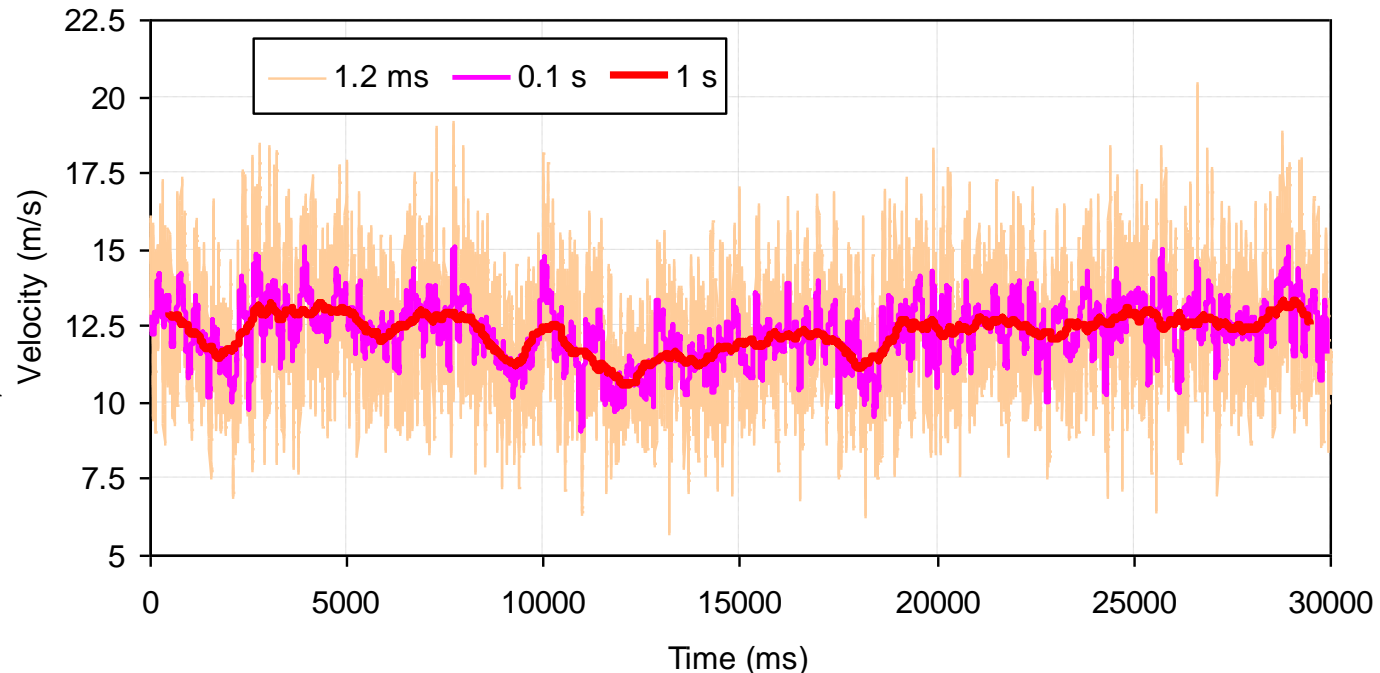
(attributed to Werner Heisenberg or, in different versions, to Albert Einstein or to Horace Lamb)

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)



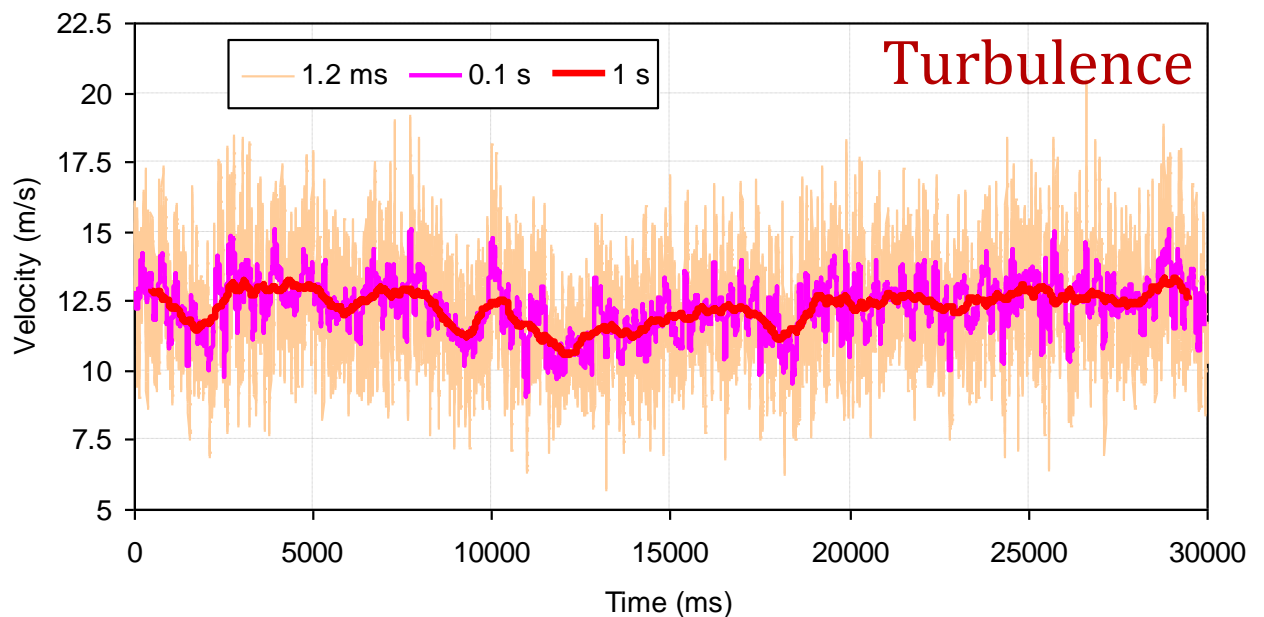
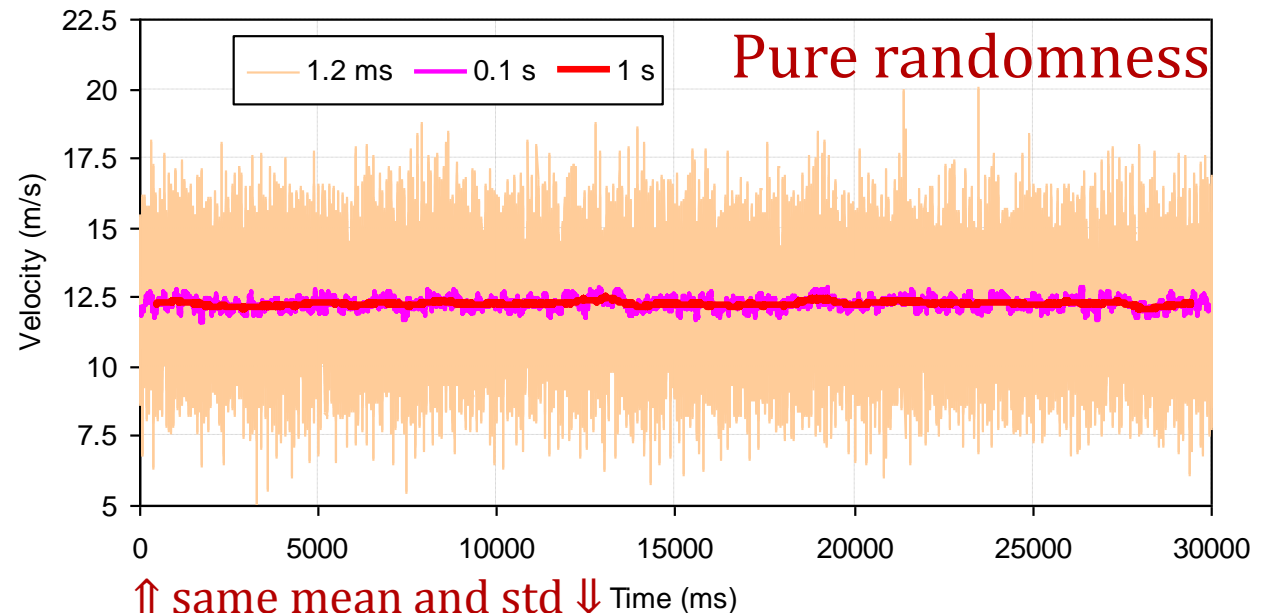
- Measurements by X-wire probes; sampling rate of 40 kHz (once per 25 ns; total length 900 s; here aggregated at the three scales shown)



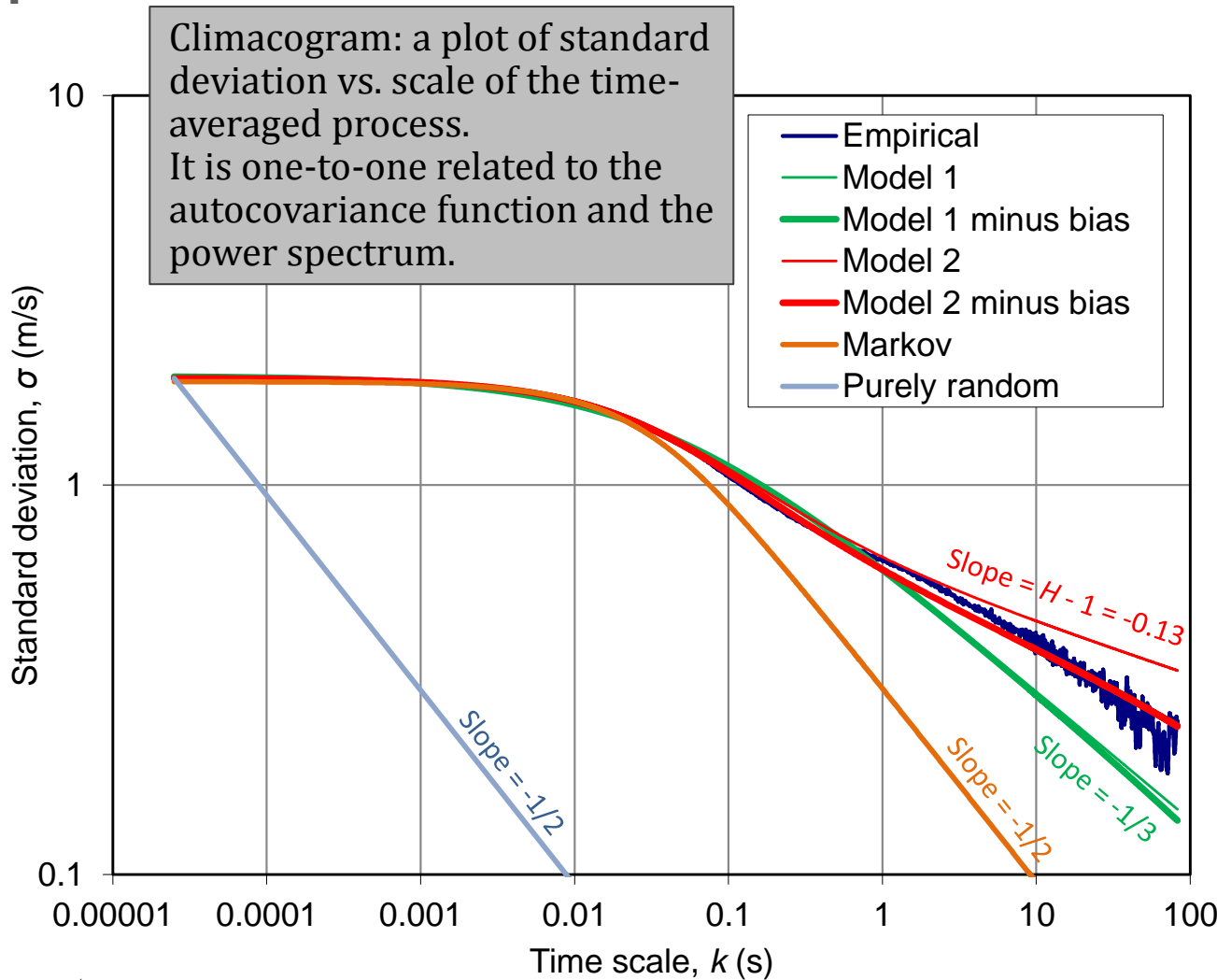
Data downloaded from www.me.jhu.edu/meneveau/datasets/Activegrid/M20/H1/m20h1-01.zip

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



Model 1

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

Model 2

$$\sigma^2(k) = \frac{\lambda_2}{(1+(k/\alpha_2)^{2/3})^{2/3}} + \frac{\lambda_3}{1+k/\alpha_3}$$

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

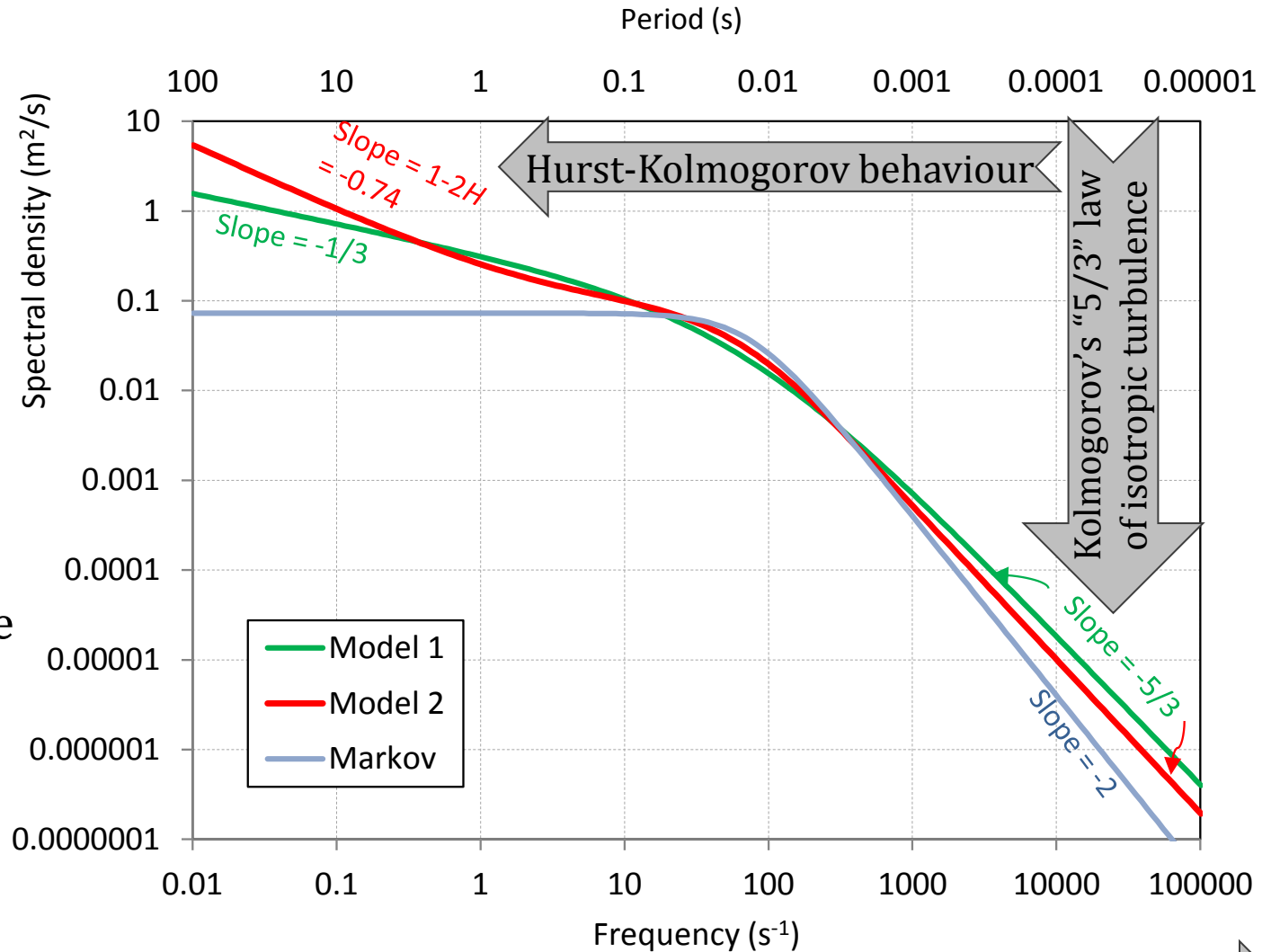
Turbulence: A spectral view

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

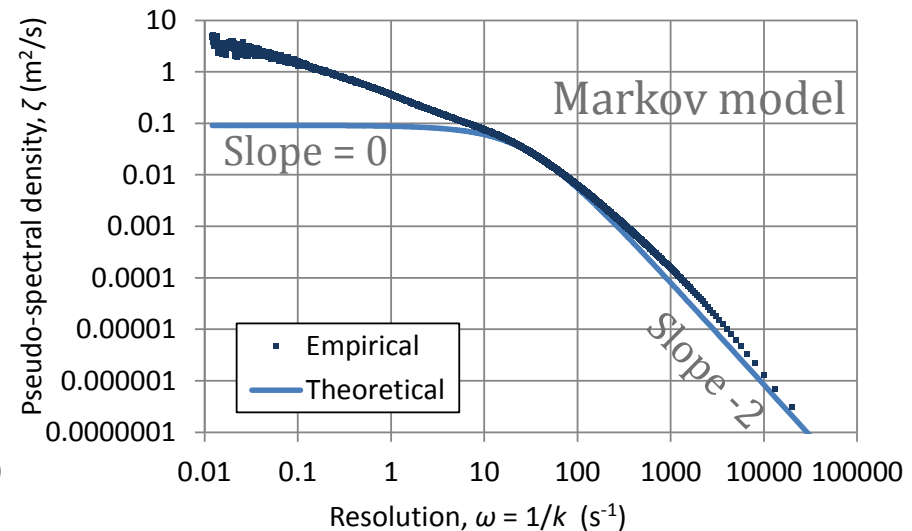
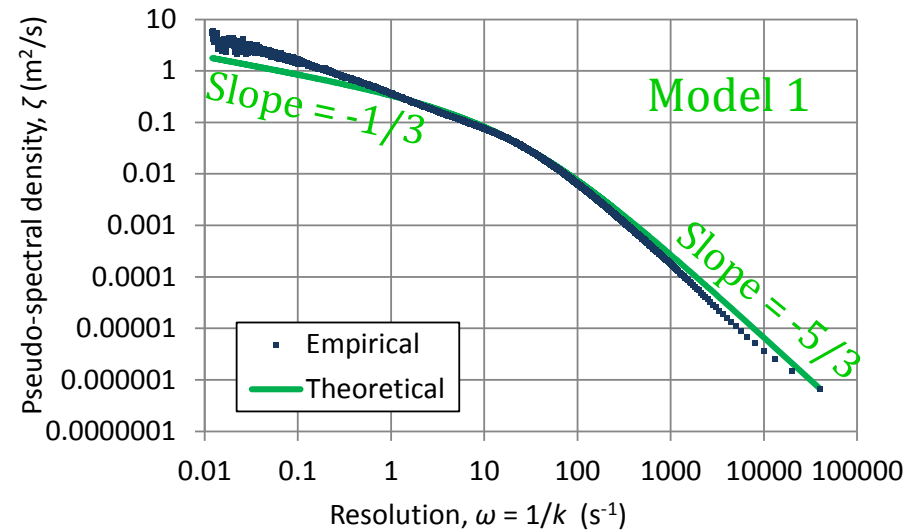
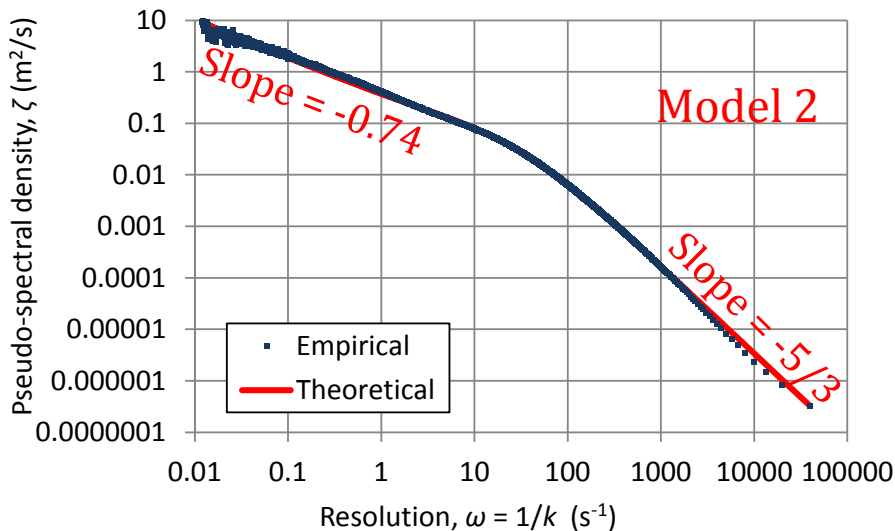
Frequencies relevant to fluid mechanics and hydraulics

Model comparison via the pseudo-spectrum

- Definition of pseudo-spectrum:

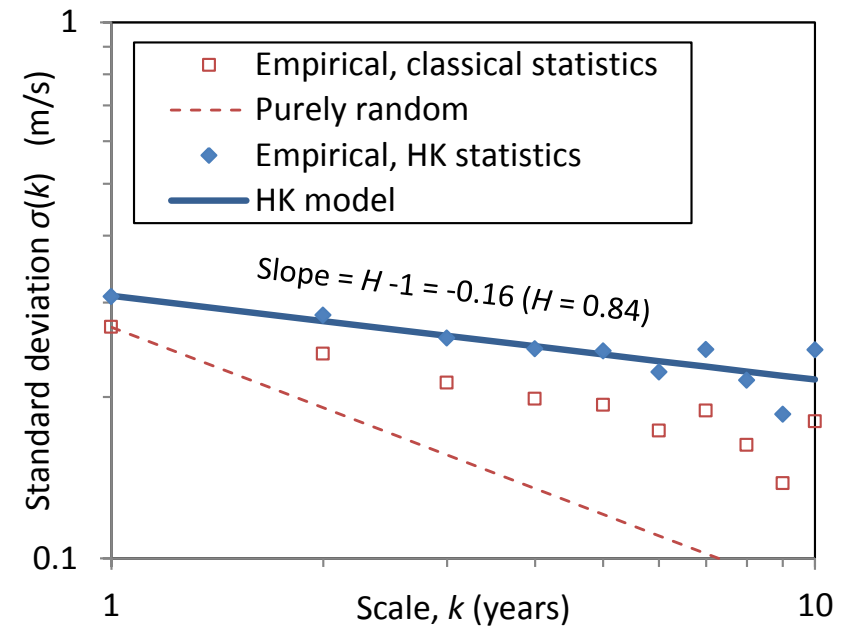
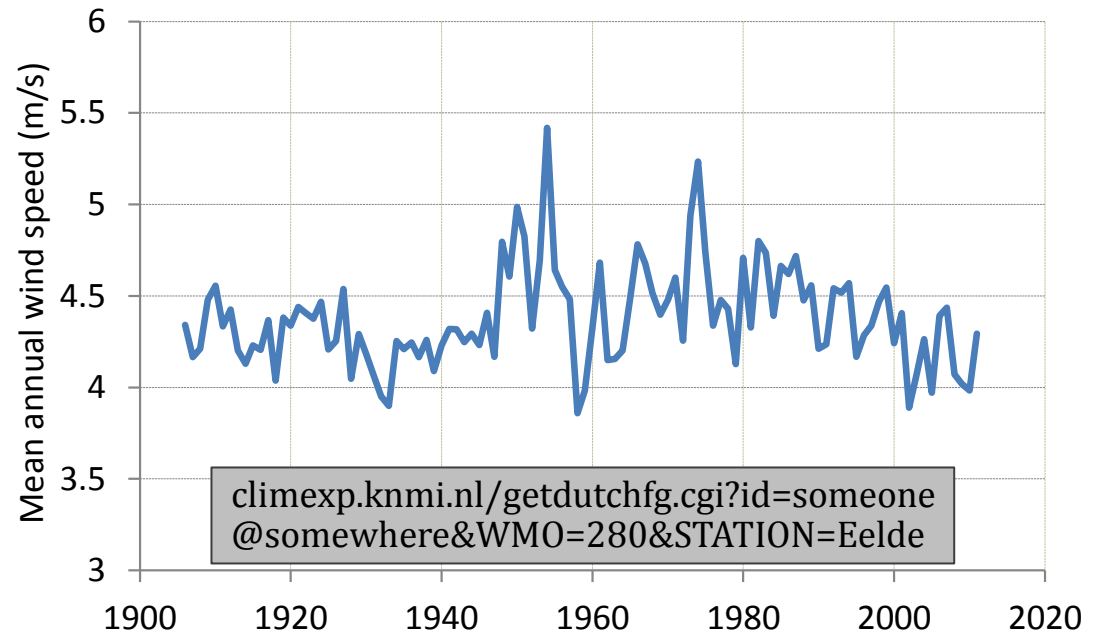
$$\zeta(\omega) := \frac{\sigma^2(1/\omega)}{\omega} \left(1 - \frac{\sigma^2(1/\omega)}{\sigma^2(0)} \right)$$

- It resembles the power spectrum.
- In particular, its asymptotic slopes for resolutions $\omega \rightarrow 0$ 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 ($\sim 0.8-0.9$).
- 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

- The simplicity of Manning's equation:

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

is revealed if we compare it with Du Buat's equation of the 18th century (also shown in slide 10):

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

- 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 (2012a, b) 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:

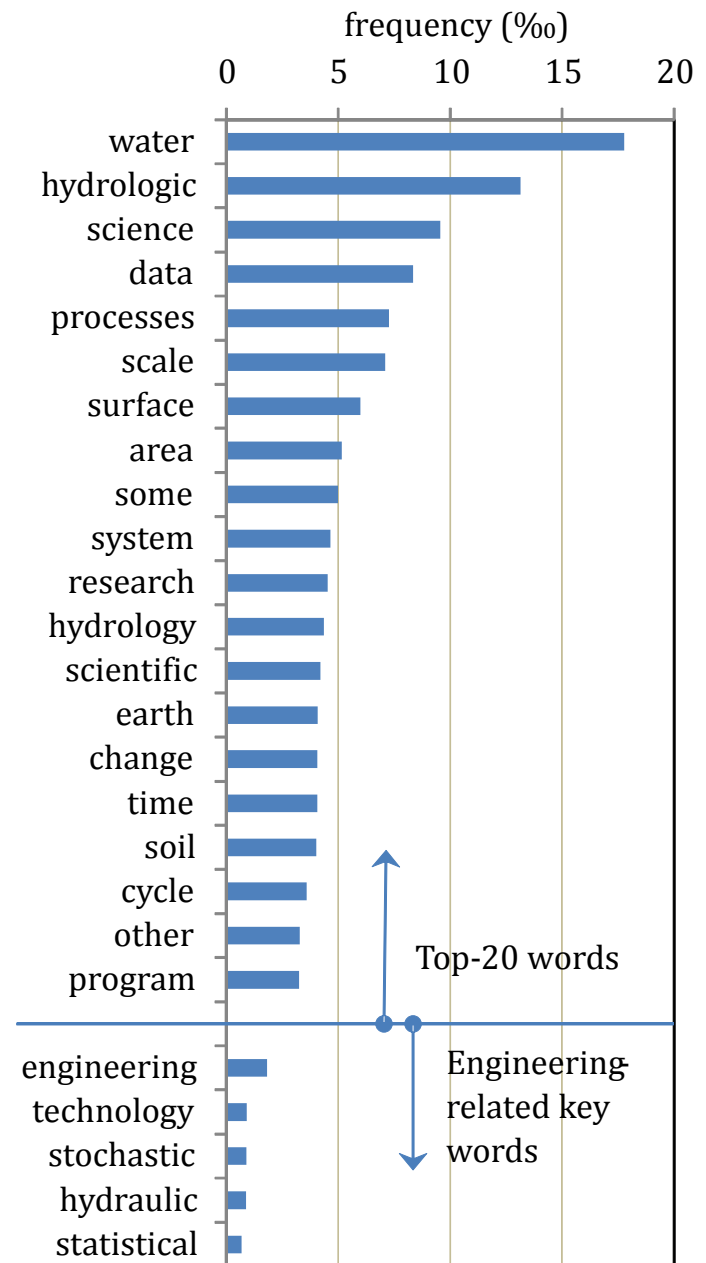
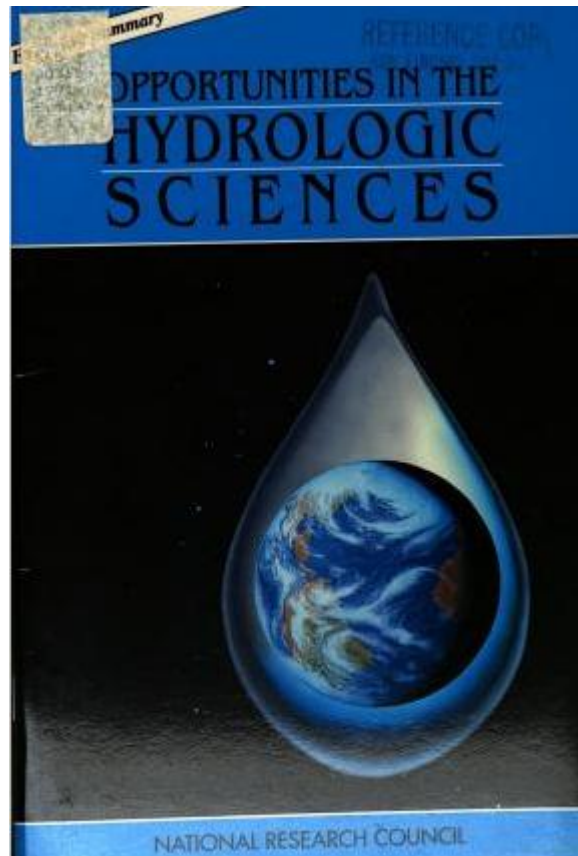
“Development of hydrology as a science is vital to the current effort to understand the interactive behaviour of the earth system.”
- It also concluded that:

“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 alternative 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”.*

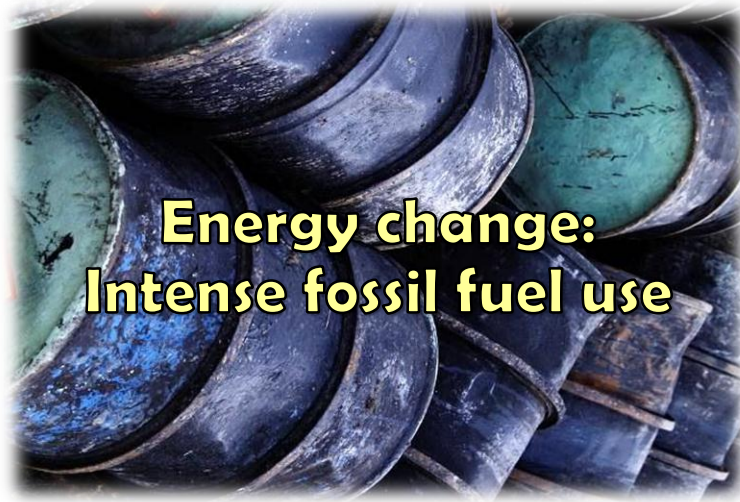
From one of the last talks of the late Vít Klemeš (2007; my emphasis), one of the pioneers of the mandate to make hydrology a science independent of engineering.

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.”*

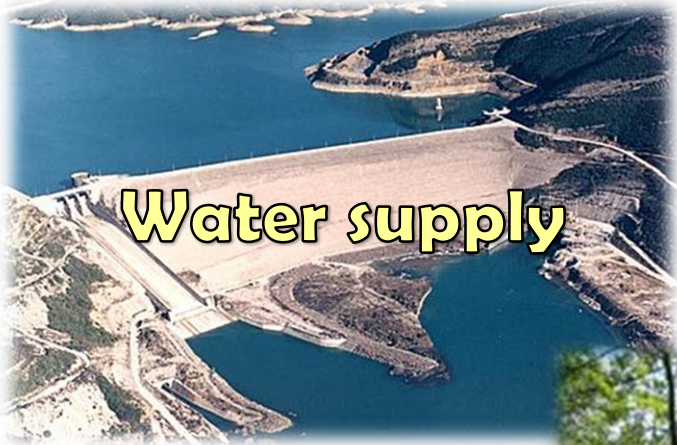
From one of the last talks of the late Vít Klemeš (2007; my emphasis), one of the pioneers of the mandate to make hydrology a science independent of engineering.

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



Adapted from Koutsoyiannis et al. (2009)

Major real challenges of the 21st century

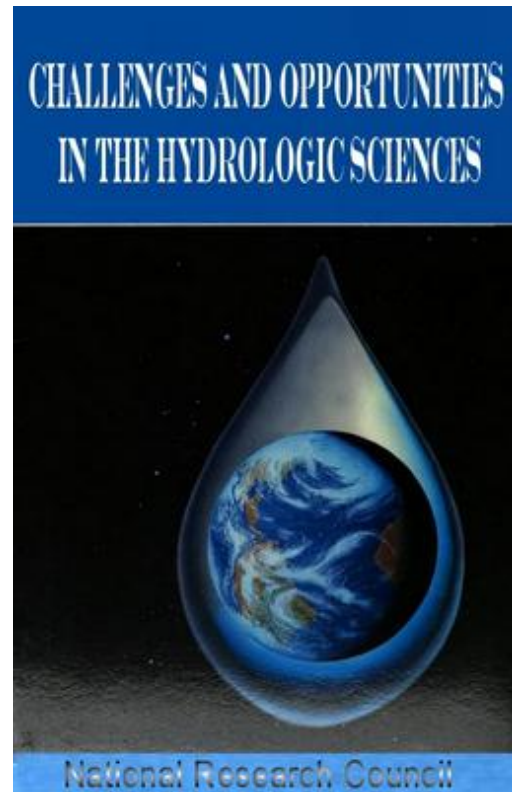


Relevance of hydrology for these challenges

- 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.
- 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; engineering hydrology, with its particular experience in studying and managing natural variability can substantially help.
- 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.

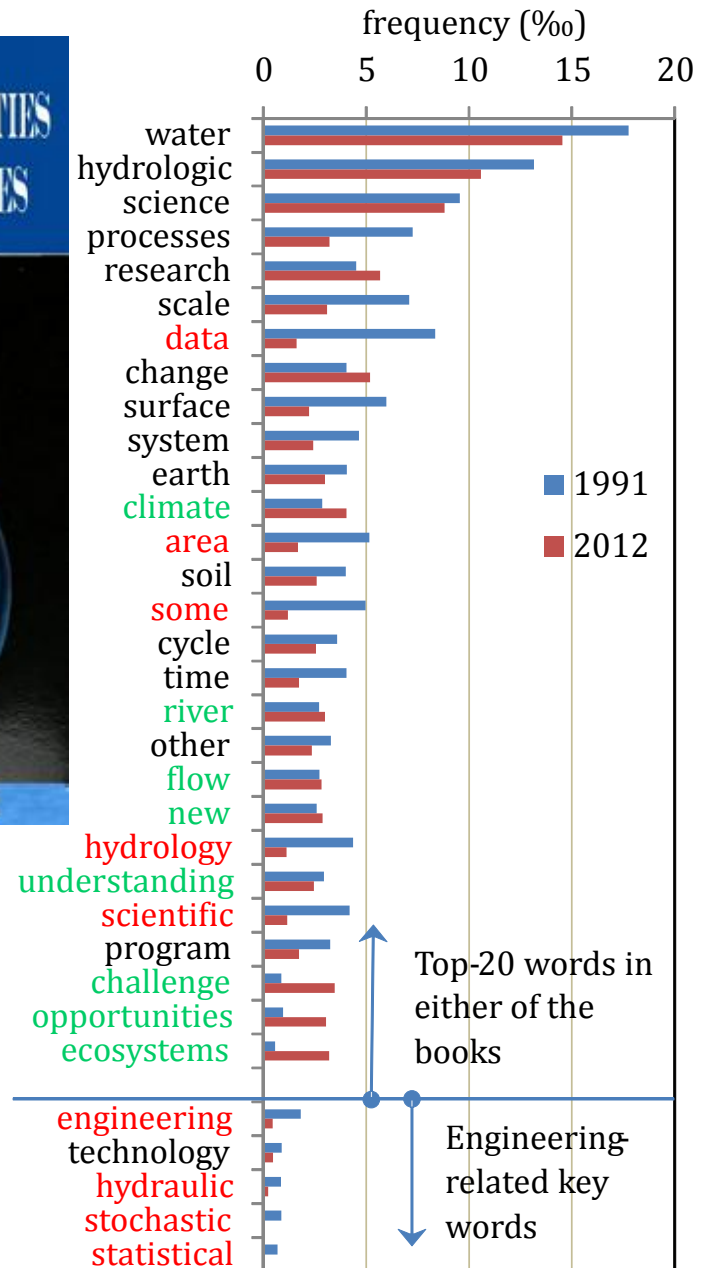
Do current trends allow optimism?

- 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 losing 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

- Reconciling 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.

References

- Abbott, M. B., J. C. Bathurst, J. A. Cunge, P. E. O'Connell and J. Rasmussen, J., An introduction to the European Hydrological System – Systeme Hydrologique Europeen “SHE”, 1, History and philosophy of a physically-based, distributed modelling system, *Journal of Hydrology*, 87(1-2), 45-59, 1986.
- Angelakis, A. N., D. Koutsoyiannis, and P. Papanicolaou, On the geometry of the Minoan water conduits, *3rd IWA Specialized Conference on Water & Wastewater Technologies in Ancient Civilizations*, Istanbul, Turkey, 172-177, International Water Association, 2012.
- Chow, V. T., *Open-Channel Hydraulics*, McGraw-Hill, 1959.
- D’Odorico, P., F. Laio, A. Porporato, L. Ridolfi, A. Rinaldo and I. Rodriguez-Iturbe, Ecohydrology of terrestrial ecosystems, *BioScience*, 60 (11), 898-907, 2010.
- Feachem, R., Faecal coliforms and faecal streptococci in streams in the new guinea highlands, *Water Research*, 8 (6), 367-374, 1974.
- Gauch, H.G. Jr., *Scientific Method in Practice*, Cambridge, 2003.
- Gleick, P. H., Soft water paths, *Nature*, 418, 373, 2002.
- Gioia, G., and F. A. Bombardelli, Scaling and similarity in rough channel flows, *Physical Review Letters*, 88 (1), 014501.1-4, 2002.
- Kang, H. S., S. Chester and C. Meneveau, Decaying turbulence in an active-grid-generated flow and comparisons with large-eddy simulation, *J. Fluid Mech.*, 480, 129-160, 2003
- Klemeš, V., Dilettantism in hydrology: Transition or destiny?, *Water Resources Research*, 22 (9S), 177S-188S, 1986.
- Klemeš, V., President’s page, IAHS Newsletter No 31, 5-6, 1987 (iahs.info/news_frm.htm).
- Klemeš, V., 20 years later: What has changed - and what hasn’t, XXIV General Assembly of the International Union of Geodesy and Geophysics, Perugia, International Union of Geodesy and Geophysics, International Association of Hydrological Sciences, 2007 (itia.ntua.gr/831/).
- Koutsoyiannis, D., A random walk on water (Henry Darcy Medal Lecture), *European Geosciences Union General Assembly 2009, Geophysical Research Abstracts, Vol. 11*, Vienna, 14033, European Geosciences Union, 2009.
- Koutsoyiannis, D., HESS Opinions “A random walk on water”, *Hydrology and Earth System Sciences*, 14, 585-601, 2010.
- Koutsoyiannis, D., Scale of water resources development and sustainability: Small is beautiful, large is great, *Hydrological Sciences Journal*, 56 (4), 553-575, 2011.
- Makropoulos, C., D. Koutsoyiannis, M. Stanic, S. Djordevic, D. Prodanovic, T. Dasic, S. Prohaska, C. Maksimovic, and H. S. Wheater, A multi-model approach to the simulation of large scale karst flows, *Journal of Hydrology*, 348 (3-4), 412-424, 2008.
- Mays, L. W., D. Koutsoyiannis, and A. N. Angelakis, A brief history of urban water supply in antiquity, *Water Science and Technology: Water Supply*, 7 (1), 1-12, 2007.

References (contd.)

- Michel J.-B., Y. K. Shen, A. P. Aiden, A. Veres, M. K. Gray, The Google Books Team, J. P. Pickett, D. Hoiberg, D. Clancy, P. Norvig, J. Orwant, S. Pinker, M. A. Nowak and E. L. Aiden, Quantitative analysis of culture using millions of digitized books, *Science*, 331 (6014), 176-182, 2011.
- Montanari, A., and D. Koutsoyiannis, A blueprint for process-based modeling of uncertain hydrological systems, *Water Resources Research*, 2012a (in press).
- Montanari and Koutsoyiannis, Un'impostazione teorica per la modellazione matematica di processi idrologici in presenza di incertezza, *IDRA 2012 – XXXIII Conference of Hydraulics and Hydraulic Engineering*, Brescia, Italy, 2012b.
- Porporato A., and I. Rodriguez-Iturbe, Ecohydrology – a challenging multidisciplinary research perspective, *Hydrological Sciences Journal*, 47 (5), 811-821, 2002.
- Shamir, U., View from the ICWRS President, IAHS Newsletter No 31, 4, 1988 (iahs.info/news_frm.htm).
- Sivakumar, B., Hydropsychology: the human side of water research, *Hydrological Sciences Journal* 56 (4), 719-732, 2011.
- Sivapalan, M., H. H. G. Savenije and G. Blöschl, Socio-hydrology: A new science of people and water, *Hydrological Processes*, 26 (8), 1270-1276, 2012.
- Sivapalan, M., K. Takeuchi, S. W. Franks, V. K. Gupta, H. Karambiri, V. Lakshmi, X. Liang, J. J. McDonnell, E. M. Mendiondo, P. E. O'Connell, T. Oki, J. W. Pomeroy, D. Schertzer, S. Uhlenbrook and E. Zehe, IAHS Decade on Predictions in Un-gauged Basins (PUB), 2003-2012: Shaping an exciting future for the hydrological sciences, *Hydrological Sciences Journal*, 48(6), 857-880, 2003.
- UNESCO (United Nations Educational, Scientific and Cultural Organization), *Report, Preparatory Meeting on the Long-Term Programme of Research in Scientific Hydrology*, UNESCO House, Paris, UNESCO/NS/181, 1963 (unesdoc.unesco.org/images/0001/000173/017325EB.pdf).
- UNESCO (United Nations Educational, Scientific and Cultural Organization), *Final Report, International Hydrological Decade, Intergovernmental Meeting of Experts*, UNESCO House, Paris, UNESCO/NS/188, 1964 (unesdoc.unesco.org/images/0001/000170/017099EB.pdf).
- US Committee on Opportunities in the Hydrologic Sciences, *Opportunities in the Hydrologic Sciences*, ed. by P. S. Eagleson, National Academy Press, Washington DC, USA, 1992 (www.nap.edu/catalog.php?record_id=1543 and books.google.gr/books?id=ADorAAAAYAAJ).
- US Committee on Challenges and Opportunities in the Hydrologic Sciences, *Challenges and Opportunities in the Hydrologic Sciences*, National Academies Press (ed. by G. Hornberger et al, 2012.
- Yevjevich, V., Misconceptions in hydrology and their consequences, *Water Resources Research*, 4 (2), 225-232, 1968.
- Zalewski, M., G. A. Janauer and G. Jolankai, Ecohydrology, A new paradigm for the sustainable use of aquatic resources, *UNESCO IHP Technical Document in Hydrology No. 7. IHP - V Projects 2.3/2.4*, UNESCO Paris, 60 pp. 1997.