Principal Investigator: Demetris Koutsoyiannis

Institution: National Technical University of Athens

Proposal title

Climate, Hydrology, Energy, Water: the Conversion of Uncertainty Domination and Risk Into Sustainable Evolution

Acronym

CHEWTHECUDANDRISE

Project duration: 60 months

Abstract

Since 1990 extensive funds have been spent on research in climate change. Although Earth Sciences, including climatology and hydrology, have benefited significantly, progress has proved incommensurate with the effort and funds, perhaps because these disciplines were perceived as “tools” subservient to the needs of the climate change enterprise rather than autonomous sciences. At the same time, research was misleadingly focused more on the “symptom”, i.e. the emission of GHGs, than on the “illness”, i.e. the unsustainability of fossil fuel-based energy production. There is a real risk of severe socioeconomic crisis in the not-too-distant future, unless energy saving and use of renewables become the norm. We propose a framework for drastic change, in which water plays a central role, due to its unique link to all forms of renewable energy, from production (hydro, wave) to storage (for time-varying wind and solar sources), to biofuel production (irrigation). The expanded role of water will be considered in parallel to usual roles in domestic, agricultural and industrial use. Hydrology, the science of water on Earth, must reinvent itself within this new paradigm and radically rethink its fundaments (chewing-the-cud), which are unjustifiably trapped in the 19th-century myths of deterministic theories and the zeal to eliminate uncertainty. Guidance is offered by modern statistical and quantum physics, revealing the intrinsic character of uncertainty/entropy in nature, thus advancing towards a new understanding and modelling of physical processes, which is fundamental for the effective use of renewable energy and water resources. Our target is to deconstruct pervasive myths in the areas of hydrology and climate and propose a new consistent approach. We will further explore the impact of this new approach on renewable energy and water resources planning and management, and unravel its implications towards a real (in lieu of the current “mythical”) sustainable development.

A research proposal submitted for the ERC Advanced Grant

February 2008

Section 1

1a. The Principal Investigator

1a.1 Curriculum Vitae (CV)

Name:	Demetris Koutsoyiannis
Birth info:	Village of Mesounta, Province of Arta, Epirus, Greece, 27 April 1955
Nationality:	Greek
Family status	Married, one son, one grandson
Professional Certification:	Civil Engineer, Dr. Engineer
Employment:	Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens (NTUA)
Position:	Associate Professor, Analysis and modelling of hydrological processes and hydrosystems
Other national positions:	Professor of hydraulics in the Hellenic Army's Postgraduate School of Technical Education of Officers Engineers Board of Directors of the Organization for the Management and Restoration of the Kephisos River and its Tributaries
International positions:	Deputy Editor, *Hydrological Sciences Journal* Editor, *Hydrology and Earth System Sciences* Associate Editor, *Water Resources Research* and *Journal of Hydrology* Chair, *Precipitation and Climate* of *Hydrological Sciences Division* in the *European Geosciences Union*
Academic visitor:	Imperial College, London (1999-2000), Hydrologic Research Center, San Diego (2005), Georgia Tech (2005-06), University of Bologna (2006).

My birthplace, a small village in Epirus, where I lived in a traditional agrarian state, up to the age of 12 (1955-1967) and completed the elementary school, offered me important knowledge that I would lack, had I been born in a city, and that is the compass of my work even to this day. Being constantly in touch with water, abundant in Epirus, helped me understand *hydraulic and hydrological behaviours*. I realized the importance of *water quality* by the fact that not all of this abundant water was good to drink. In fact, as a child I had an everyday duty to bring drinking water from the nearest (1 km) spring to my house. As my family run a traditional water mill, I had the chance to actively engage *hydropower* and understand the energy transformation from potential to kinetic and production of work. I also acquired an experiential feeling of what we would call today *sustainable use of resources*: full recycling of material sources (zero waste production), and minimal use of energy in agriculture and transportation (animal power), heating (wood) and lighting (oil – no electricity).

From the years of my study in the high school in Athens (10th public Gymnasium of Athens, 1967-1973) I learned the value of adapting to new environments and of taking responsibility for my actions (because I lived on my own since 1970). This allowed me to unfold and develop my skills, and achieve top performance in school. One of the most remarkable things of this period was the contrast between, on one hand, reason, ethical virtues, freedom, democracy, participation, that were taught in school based on classical Greek texts and, on the other hand, the irrationality of a tough military dictatorship in power in Greece at the time, which, unfortunately, relied on the tolerance of a scared public majority.

In my first month (Nov. 1973) in the university (School of Civil Engineering, NTUA, 1973-78) I participated in the uprising against the dictatorship. After three days of occupation of the university quarters, I found myself opposite to a tank that invaded the university to suppress the uprising. This was a valuable lesson on the importance and worthiness of overcoming fears and resisting against irrationality – and that such a struggle can be effective as this uprising was the first step to overthrow Greece's dictatorship a few months later. Thus, I continued my studies in a free university. I received state scholarships for top performance throughout my university years. I followed the hydraulic engineering option (which I found natural due to my early familiarity with water and its flow!) and received my Diploma in 1978, graduating top of my class among more than 300 students, with 3 university and state awards for high achievements.

I then started my career in engineering as a consultant for private constructions as well as in hydrologic, structural and surveying engineering projects. I was a founding member of three engineering companies (Polytechnike Co., METER Ltd, BIOMETER Ltd) but left them five years later to dedicate myself to academia, which I had never left since I maintained a part time employment as a research assistant even during my years in industry. On the other hand, I never lost touch with industry and I still participate as a consultant in hydrologic and water resources engineering projects. I have successfully completed more than 60 engineering studies, 12 of which on hydrologic design of dams throughout Greece (for hydro-electric energy, water supply and irrigation).

I studied for my PhD in the same School (1983-88) under the supervision of Prof. Th. Xanthopoulos (later Rector of NTUA and currently Vice Minister for Public Works). While working on my thesis (“*A disaggregation model of point rainfall*”) I studied probability and stochastic processes and realized their power in better understanding natural behaviours and constructing mathematical models of natural processes. I also gained expertise in computer programming. My PhD work continued uninterrupted throughout my 25-month military service (seaman in the Hellenic Navy, 1984-86) and I received my PhD in 1988.

My academic employment includes my positions as lecturer (1990-95), assistant professor (1995-2003), and associate professor (2003-today) in the Department of Water Resources and Environmental Engineering of NTUA. Currently, I am candidate for full professor. I have taught undergraduate courses in *Engineering hydrology*, *Stochastic hydrology*, *Urban hydraulic works* and *Sediment transport*, and postgraduate courses in *Hydrometeorology*, *Advanced hydrology*, *Water resource systems optimization* and *Water resource management*. I have supervised 70 diploma and postgraduate theses and 6 doctoral theses.

I have gained a reputation in the water sector in Greece as someone who is able to solve real-world problems using advanced scientific methods. My reputation is also enhanced by my numerous students, which have appreciated the effort and time I invest in creating and keeping my courses up to date. This reputation encouraged generous funding from Greek authorities, including the *General Secretariat of Research and Technology – GSRT* (Hydroscope: Creation of a National Databank for Hydrological and Meteorological Information, 1992-93, 1.60 M€; Odysseus: Integrated Management of Hydrosystems in Conjunction with an Advanced Information System, 2003-06, 0.81 M€), the *Ministry of Environment, Planning and Public Works – MEPPW* (Evaluation of Management of the Water Resources of Sterea Hellas, Phases 1,2,3, 1990-2000, 1.18 M€) and the *Water Supply and Sewerage Company of Athens – EYDAP* (Modernization of the Supervision and Management of the Water Resource System of Athens, 1999-2003, 0.71 M€). I also undertook a number of smaller projects from these or other authorities, some of which, despite their small budget, were scientifically stimulating (e.g., *Support on the Compilation of the National Programme for Water Resources Management and Preservation*, *MEPPW*, 2007-08, 0.05 M€). These projects (15, amounting to a total budget of 3.28 M€ in 1992-2007, not including 26 projects in which I participated with a role other than project leader) aimed to solve demanding real-life problems (e.g. the management of the Athens water supply system in view of the Athens 2004 Olympics) and produce operational software tools. All projects were concluded successfully and their practical objectives were fulfilled. At the same time, I was able to perform scientific generalization, extension, abstract representation and groundbreaking in-depth penetration, and produce high quality research papers motivated by these practical problems. Several of these papers study fundamental scientific questions and include elements beyond the state of the art (section 1a.3), even though they were outcomes of “applied” research projects or in some cases results of unfunded research and independent academic activity.

Most of these national projects (those by GSRT and EYDAP) were co-funded by the EU. Earlier, I had an experience with EU research in an EPOCH project (*AFORISM, A comprehensive forecasting system for flood risk mitigation and control*, 1991-94), of which I was the key investigator for the Greek team (budget 0.08 M€). At the international level, I also participated in two UK projects (in collaboration with Imperial College and University College London, 1999-2001), in two projects in the USA (in collaboration with the Hydrologic Research Center and Georgia Tech, 2005-06), and in a Greek-Ethiopian expedition project. Other EU related research activities are my participation in COST action 22 on urban flood management (2005-08) and in the INTERREG-CADSES project “Educate!” (2006-08). I have participated in several research proposals to the EU, some of which passed all evaluation criteria but were, unfortunately, not funded. I would like to believe that my research profile and academic and publishing track record would have justified more support from EU research funds, but up to now funding priorities and consortium-building processes within the framework programmes have not seemed to favour my ideas. It appears to me however that ERC’s aims, placing “scientific excellence as the sole criterion for funding” irrespective of research area to support “investigator-driven” “frontier research” may be an ideal (and up to recently missing) funding body for my research work.

Nevertheless, the funding I have received so far allowed me to create and maintain continuously for more than 20 years, the research team *Itia* (Greek for willow tree – not an acronym), currently comprised of 20, highly qualified, research and academic staff. Without these collaborators I would not have been able to elaborate the above research. Itia has its own *open access* digital library which contains our papers, reports, books, educational notes, software, etc., as well as project data and information (www.itia.ntua.gr/dk/).

1a.2 Scientific Leadership Profile

My relationship with the international scientific community was built around my research publications in peer-reviewed journals. Since a significant part of my work is, arguably, breakthrough research challenging established beliefs, getting my papers to be published initially required persistence, even challenging editors' decisions. I now know that rejection is a very likely outcome of the review process for novel and innovative research (cf. Miller, 2007). A key focus of my work has always been to dispel well-established myths that hinder science, and attempt to go beyond the state of the art. In section 1a.3, I describe the main topics that I have challenged or advanced with my research. My current scientific publishing record (also detailed in Itia's digital library) comprises the following categories:

Categories	Total number	Since 1997
Publications in peer-reviewed scientific journals	64	54
Book chapters and fully evaluated conference publications	47	38
Publications and conference presentations with evaluation of abstract	70	55
Conference and workshop publications and presentations without evaluation	55	35
Books	3	3
Miscellaneous publications	36	27
Lecture note series	21	16
Academic theses	2	-
Research reports and monographs	83	34
Engineering reports	81	28
Total	**462**	**293**

In 31% of my 64 journal publications I was the only author; in another 42% I was the only or the first senior author, in 22% I was one of the senior authors and in 5% I was a junior author. This distribution suggests I am competent in both pursuing independent research on my own as well as leading small or large research teams.

Published research challenging existing beliefs tends to be ignored by other researchers, unless it can be proved to be mistaken. However, there has never been any publication reporting errors in my work, despite the fact that I always challenge reviewers, who suggest rejection of my papers, to publish their opinion. Ignoring challenging publications is an easier path, and perhaps this is the reason why my research findings were not quoted as much initially. It is indicative that my first paper published in an international journal (Koutsoyiannis & Xanthopoulos, On the parametric approach to unit hydrograph identification, *Water Resour. Manag.*, 3(2), 107-128, 1989) was cited for the first time 11 years after its publication in an article from a different discipline (Seifi et al., 2000 – see below); since then it continues to be cited regularly. Perhaps an entry in January 2006 on the weblog "Climate Audit" (2007 award winning as best science blog) entitled "Demetris Koutsoyiannis" by S. McIntyre (www.climateaudit.org/?p=483) increased the visibility of my research. Thus, in 2006 and 2007 the citations to my work approached 100 per year. The current (2008/01/27) bibliometric data for my publications, which give an indication of the impact of my studies, are shown in the following table:

Source	Number of registered publications	Number of cited publications	Number of citations	H-index
ISI Web of Science	46	93	443	14
Google Scholar	183	114	686	15
Scopus (publications of all years)	61	47	427	14
Scopus, excl. self citations	61	45	300	11
Itia's repository, excl. self citations	462	90	475	12

Some of these citations originate from disciplines other than hydrology, water and climate, including citations in fields such as mathematics, operations research, economics and archaeology; some examples are included below:

1. Seifi, A., K. Ponnambalam & J. Vlach, Maximization of manufacturing yield of systems with arbitrary distributions of component values, *Ann. Oper. Res.*, 99, 373-383, 2000.
2. Gneiting, T., & M. Schlather, Stochastic models that separate fractal dimension and the Hurst effect, *Society for Industrial and Applied Mathematics Review*, 46(2), 269-282, 2004.
3. Gorokhovich, Y., Abandonment of Minoan palaces on Crete in relation to the earthquake induced changes in groundwater supply, *Journal of Archaeological Science*, 32(2), 217-222, 2005
4. Ellis, C., & C. Hudson, Scale-adjusted volatility and the Dow Jones index, *Physica A: Statistical Mechanics and its Applications*, 378(2), 374-386, 2007.
5. Hultman, N.E., J.G. Koomey & D.M. Kammen, What history can teach us about the future costs of U.S. nuclear

power, *Environmental Science & Technology*, 41(7), 2087 - 2094, 2007.

An additional indication of the wider impact of my research can be seen in the following table, which gives the rank assigned to my publications by "Google Search" (among, literally, thousand of documents) as sources of information for the subject indicated by the keywords (note that these subjects are fairly general and central to the hydroclimatic discipline, which indicates broad recognition beyond some specialized academic niche; results as of 2007/01/27):

Google keywords	My publication identified by Google	Type of item	Google rank	Total Google results
Hurst phenomenon	Climate change, the Hurst phenomenon, and hydrological statistics	Journal paper	1	575 000
engineering hydrology	Engineering Hydrology	Book	1	209 000
ancient Greece engineering	Urban water engineering and management in ancient Greece	Book chapter	1	207 000
rainfall disaggregation	Rainfall disaggregation methods: Theory and applications	Article in conference proceedings	1	160 000
Gumbel distribution	On the appropriateness of the Gumbel distribution for modelling extreme rainfall	Article in conference proceedings	12	26 700

The statistics of visits in Itia's repository indicate that my most popular papers are those on ancient water technologies and management practices (items 17 and 18 in section 1a.3 below), as well those on climate (item 3 in 1a.3) and Hurst/scaling (item 6 in 1a.3). These particular fields have also triggered conference sessions. My co-author A. Angelakis and I have pioneered the research on the former topic and also organized the *1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations* in 2006, whose follow-up is currently being organized in Italy for 2009. For the latter two fields, two interdisciplinary sessions in the 2008 Assembly of the European Geosciences Union are organized, entitled: *IS23 - Climatic and hydrological perspectives on long-term changes* and *IS40 - Geophysical Extremes: scaling versus nonstationarity*.

My contribution to the scientific community is also reflected in over 200 reviews that I have prepared for articles submitted to 29 different scientific journals (plus 31 articles in books and conference proceedings, and 37 research proposals and projects). Since 1998, *all* my reviews are *eponymous* and since 2004 I am actively promoting the idea that a shift from anonymous to eponymous reviewing would help the scientific community to be more cooperative, democratic, equitable, ethical, productive and responsible. Editors have appreciated, in general, my eponymous reviews and have invited me to take more active roles in their journals. Thus, in 2000 I received the Editor's Citation for Excellence in Refereeing in *Water Resources Research*. Currently, I am the Deputy Editor of *Hydrological Sciences Journal* (since 2006; I was also Associate Editor since 2003), Editor in *Hydrology and Earth System Sciences* (since 2007), Associate Editor in *Journal of Hydrology* (since 2000) and in *Water Resources Research* (since 2007). These four are top journals in the field of hydrology and water resources, with the highest impact factors. I have also been a Guest Editor in two journals (*Water Science and Technology: Water Supply*: special issue on Insights into Water Management: Lessons from Water and Wastewater Technologies in Ancient Civilizations, 2007; *Physics and Chemistry of the Earth*: special issue on Time Series Analysis in Hydrology, 2006).

Furthermore, my contribution is manifested by my participation in 16 national and international scientific organizations and professional committees. Recognition for my contribution is reflected, *inter alia*: (1) in NTUA, by my election as member of the Senate (2004-05; associate member in 1993-94 and 2002-03) and member of the Inter-departmental Committee of the postgraduate programme *Water Resources Science and Technology*, responsible for the managerial and economic issues for the creation and operation of the programme (1997-2004); (2) in Greece, as a Member of the Board of Directors of the Organization for the Management and Restoration of the Kephisos River and its Tributaries (since 2003); (3) internationally, by my position as Chair of the *Sub-Division on Precipitation & Climate* of the *Division on Hydrological Sciences* of the *European Geosciences Union - EGU* (since 2006). Since my appointment, the participation on the activities organized by the Sub-Division was enhanced, as indicated by the number of scientific abstracts submitted in related EGU conference sessions, which were doubled in the *EGU General Assembly 2007* and then quadrupled in *EGU General Assembly 2008*.

I regard these national and international positions, particularly in top journals, as my best "awards", despite their demanding nature and required commitment. Recognition is being extended to other current or former members of the Itia team, four of which (Drs. P. Papanicolaou, I. Nalbantis, N. Mamassis, C. Makropoulos) are now academic staff, four (A. Efstratiadis, D. Zarris, E. Rozos, A. Langousis) have or are expected to receive their PhD this year (the last one from MIT), and all of which have already impressive publication track records of their own.

1a.3 Ten-year track record

My 10-year research and publications fall in the following ten categories. In each category I list a sample of two publications (the asterisk at the beginning indicates a publication also listed in the Administrative Submission Forms and a parenthesis at the end gives the number of the citations by other authors). I also summarize the questions addressed and provide a remark on the novelty of research.

I. Nature of hydrological and geophysical processes

1*. Koutsoyiannis, D., Uncertainty, entropy, scaling and hydrological stochastics, 2, Time dependence of hydrological processes and time scaling, *Hydrol. Sci. J.*, 50(3), 405-426, 2005. (6)

2*. Koutsoyiannis, D., An entropic-stochastic representation of rainfall intermittency: The origin of clustering and persistence, *Water Resour. Res.*, 42(1), W01401, 2006. (4)

Questions addressed: Why hydrological processes (and often other geophysical and technological processes) exhibit peculiar behaviours, such as long-term persistence, fluctuations on large scales, clustering, state and time scaling, and heavy distribution tails?

Remark: This research, highlighting entropy as a driving force of natural processes and suggesting that maximum entropy, i.e. maximum uncertainty, can explain observed large-scale behaviours, is novel, innovative and breakthrough. These results are challenging mainstream research and there are no similar publications in literature. The fundamental (type "why") questions addressed in this work have significant implications on the very understanding of natural behaviour.

II. Climate

3*. Koutsoyiannis, D., Climate change, the Hurst phenomenon, and hydrological statistics, *Hydrol. Sci. J.*, 48(1), 3-24, 2003. (10)

4. Koutsoyiannis, D., A. Efstratiadis & K. Georgakakos, Uncertainty assessment of future hydroclimatic predictions: A comparison of probabilistic and scenario-based approaches, *J. Hydrometeorol.*, 8(3), 261-281, 2007. (1)

Questions addressed: Are notorious future climate projections reliable and do they provide grounds to assess impacts in hydrological processes? What is the relationship of climate research with statistics?

Remark: This research shows that mainstream climate research is fundamentally flawed due to misrepresentation of the notion of climate (which by definition is a statistical concept) and suggests possible remedies.

III. Hurst phenomenon and scaling

5*. Koutsoyiannis, D., The Hurst phenomenon and fractional Gaussian noise made easy, *Hydrol. Sci. J.*, 47(4), 573-595, 2002. (10)

6. Koutsoyiannis, D., Nonstationarity versus scaling in hydrology, *J. Hydrol.*, 324, 239-254, 2006. (2)

Questions addressed: What are the main characteristics and implications of the Hurst phenomenon (also known as the Joseph effect, scaling, long-term persistence, long-range dependence, long memory)?

Remark: The research suggests that the Hurst phenomenon is not a puzzle, as regarded for half a century, but a regular, general natural behaviour, manifesting multi-scale fluctuation and highlighting uncertainty domination.

IV. Hydrological extremes

7*. Koutsoyiannis, D., Statistics of extremes and estimation of extreme rainfall, 1, Theoretical investigation, *Hydrol. Sci. J.*, 49(4), 575-590, 2004. (14)

8*. Koutsoyiannis, D., D. Kozonis & A. Manetas, A mathematical framework for studying rainfall intensity-duration-frequency relationships, *J. Hydrol.*, 206(1-2), 118-135, 1998. (33)

Questions addressed: How can we effectively and consistently describe the behaviour of extreme rainfall and flood? Are hydrological practices for estimation of extremes correct?

Remark: The research shows that the prevailing hydrological methodology for extremes, largely based on the Gumbel (or extreme value type 1) distribution is inappropriate and underestimates extremes significantly.

V. Chaotic vs. stochastic description of hydrological processes

9. Koutsoyiannis, D., On the quest for chaotic attractors in hydrological processes, *Hydrol. Sci. J.*, 51(6), 1065-1091, 2006. (-)

10. Koutsoyiannis, D., H. Yao & A. Georgakakos, Medium-range flow prediction for the Nile: a comparison of stochastic and deterministic methods, *Hydrol. Sci. J.*, 53(1), 142-164, 2008. (-)

Questions addressed: Do hydrological processes reveal deterministic chaos? Do they exhibit deterministic trends? Or can they be better modelled as stochastic processes?

Remark: The research reveals that the numerous recent studies that have detected chaotic deterministic behaviour in hydrological processes with low-dimensional attractors are fundamentally flawed, locates the errors made and suggests that stochastic descriptions are more effective and provide better forecasts.

VI. Stochastic modelling of hydrological processes

11*. Koutsoyiannis, D., Optimal decomposition of covariance matrices for multivariate stochastic models in hydrology, *Water Resour. Res.*, 35(4), 1219-1229, 1999. (6)

12*. Koutsoyiannis, D., A generalized mathematical framework for stochastic simulation and forecast of hydrologic time series, *Water Resour. Res.*, 36(6), 1519-1533, 2000. (11)

Questions addressed: How can we build stochastic models of hydrological processes effectively describing the natural behaviours and peculiarities? How can these behaviours be modelled in a multivariate setting?

Remark: The research proposes novel formalism and algorithms for multivariate stochastic simulation, much more parsimonious (small number of parameters), general (short- and long-range dependence) and powerful (with analytical solutions for internal parameters of the generation schemes) than the common ARMA models.

VII. Scales and disaggregation

13*. Koutsoyiannis, D., Coupling stochastic models of different time scales, *Water Resour. Res.*, 37(2), 379-392, 2001. (12)

14*. Koutsoyiannis, D. & C. Onof, Rainfall disaggregation using adjusting procedures on a Poisson cluster model, *J. Hydrol.*, 246, 109-122, 2001. (17)

Questions addressed: How can we disaggregate hydrological data? How can we couple stochastic models of different time scales?

Remark: The research proposes a novel and theoretically consistent methodology for disaggregation of data from coarser to finer time scales, radically different from existing ones, and applies it in the most demanding problems such as rainfall disaggregation of fine time scales.

VIII. Hydrosystems modelling and management

15. Nalbantis, I., & D. Koutsoyiannis, A parametric rule for planning and management of multiple reservoir systems, *Water Resour. Res.*, 33(9), 2165-2177, 1997. (13)

16. Koutsoyiannis, D., & A. Economou, Evaluation of the parameterization-simulation-optimization approach for the control of reservoir systems, *Water Resour. Res.*, 39(6), 1170, 1-17, 2003. (4)

Questions addressed: How can we effectively model and manage large hydrosystems? Can we combine simulation and optimization techniques? How many decision variables do we need in the management of a large hydrosystem? How can we perform global optimization of hydrosystems?

Remark: The research proposes a radically novel approach for hydrosystem management, which is parsimonious in decision variables (parameterization), and combines Monte Carlo simulation and global nonlinear optimization, totally replacing existing oversimplifying linear or dynamic programming methods.

IX. Ancient technologies and water management practices

17. Angelakis, A. N., D. Koutsoyiannis & G. Tchobanoglous, Urban wastewater and stormwater technologies in ancient Greece, *Water Res.*, 39(1), 210-220, 2005. (9)

18. Koutsoyiannis, D., N. Zarkadoulas, A. N. Angelakis & G. Tchobanoglous, Urban water management in Ancient Greece: Legacies and lessons, *J. Water Resour. Plan. Manag.*, 134(1), 45-54, 2008. (1)

Questions addressed: How recent are the modern technologies and management practices in water supply, wastewater, and agricultural water use?

Remark: This research shows that the most important breakthroughs in hydraulic technology and water management have been achieved as early as 2000-4000 years ago in Ancient Greece and earlier civilizations.

X. Publishing and evaluation systems in hydrological community

19. Kundzewicz, Z. W., & D. Koutsoyiannis, Editorial - The peer-review system: prospects and challenges, *Hydrol. Sci. J.*, 50(4), 577-590, 2005. (4)

20. Koutsoyiannis, D., & Z. W. Kundzewicz, Editorial - Quantifying the impact of hydrological studies, *Hydrol. Sci. J.*, 52(1), 3-17, 2007. (1)

Questions addressed: What are the pathologies of the scientific publishing system and how can it be improved?

Remark: It is proposed that there is a positive feedback between the review system and the academic ethics and behaviours, and that any improvement in either of the two will positively influence the other.

The above synopsis was deliberately based on journal publications, which more accurately reflect my research achievements. Due to space limitations, I am not providing details of other activities. Statistics of my entire publication record are given in section 1a.2 above. Lists of books and monographs, invited lectures, as well as contributions to the organization of international conferences (5 representative out of a total of 15, to which another 14 Greek conferences should be added) are given in the administration forms.

1b. Extended Synopsis

Αἰών παῖς ἐστι παίζων πεσσεύων (Ηράκλειτος)

Time is a child playing, playing dice (Heraclitus; ca. 540-480 BC)

The intense and unsustainable use of fossil fuels was the background of the explosive population growth in the 20th century (from 1.65 billion in 1900 to 6.6 billion currently). Cheap energy and the implied change of social and economic conditions resulted in sprawling urbanization (Vlachos and Braga, 2001), with increasing environmental impacts and consequences. The increased human population, economic development, and energy exploitation had global environmental effects, which were so prominent that geologists coined the term "Anthropocene" to refer to a new geological epoch, successor of Holocene, dominated by human activity (Zalasiewicz *et al.*, 2008).

One of the consequences of these developments was the emission of carbon dioxide and other greenhouse gases into the atmosphere, which may have an effect on climate. While many have claimed that this effect has been already detected or is "more likely than not" (IPCC, 2001, 2007), others have argued that such detections are a result of misuse of statistics and that existing data analysed with correct statistics do not support such conclusions (Cohn and Lins, 2005; Koutsoyiannis & Montanari, 2007). It is then puzzling how the ambiguous and still debatable concept of "*climate change*" has dominated the scientific vocabulary over the more defendable terms of *"environmental change"* and *"demographic change"*. The unfortunate implication of the domination of this term on scientific thought is that carbon dioxide emissions, a by-product ("symptom") of unsustainable energy policies and practices, have been given a tremendous research priority. Science and technology are currently focusing on the study and remedy of a "symptom" of a major "illness", instead on the "illness" itself and its causes.

At the heart of this reversal between cause and effect, lies the (alluring) myth of a deterministically predictable future climate, which underestimates the intrinsic uncertainty in nature. This myth has given rise to erroneous diversions of scientific attention in the recent past, including for example the concept of "global cooling", which was a prevailing concept in 1970s (Ponte, 1976), alarmingly similar to the current "global warming". Since 1990, funds running to billions of euro have been spent worldwide in trying to deterministically project climate, understand its impacts and resolve possible vulnerabilities based on these projections. It should not be surprising that progress proved incommensurate with the effort and funds: the enormous complexity of the Earth's climate system and the geophysical systems interacting with it, in which uncertainty is intrinsic, necessitate a drastically different, probabilistic approach. Arguably, attempts of deterministic predictions of climate for horizons of 100 years may be "more an exercise in prophecy than prediction" (quoting Beven, 1993, for a similar situation).

This deterministic approach to climate need not be surprising in view of the equally deterministic thinking that has thus far governed the crucial (and arguably more central to the environmental change debate) issue of energy production. Fossil fuels gave us the luxury of a controllable and deterministically manageable energy production, with the flip of a switch. However, their use is unsustainable and short-lived. Industry and economic growth are intimately connected to energy production and within the current paradigm, ultimately bound by the quantity of (limited) fossil fuels. Their extraction rates will unavoidably have a peak (Hubbert, 1956, 1982; Grove, 1974, van der Veen, 2000; Hirsch, 2005; Kerr & Service, 2005).

There is hence a growing realization that the use of renewable energy sources needs to be drastically increased (e.g. the EU Renewables Directive target of 22% till 2010) to avoid severe socioeconomic crisis in the not-too-distant future (Duncan, 2001, 2005-2006). However, although technology has increased the efficiency and lowered the cost of renewable sources of usable energy, a drastic change from fossil fuels to renewable sources is still difficult to implement: Renewable sources of energy, such as wind and solar, are highly variable, and their efficient use implies an energy management paradigm that recognizes and exploits the intrinsic uncertainty of natural processes. The radically different nature of renewables as compared to fossil fuels calls for a paradigm shift in energy technology and management, which embraces uncertainty as a dominant natural behaviour and converts it into an element boosting, rather than hindering, sustainable development and evolution. Besides, nature itself provides many hints that randomness, chaos and uncertainty are necessary prerequisites for evolution.

We argue for abandoning the deterministic myth of the 19th century, which promises to eliminate uncertainty, and propose here a research program that will *develop a consistent mathematical and methodological framework for the description and management of randomness and uncertainty in natural systems behaviour and will investigate its implication for integrated management of renewable and, hence, variable resources with an emphasis on the role of water in sustainable energy production and management under uncertainty*.

The integrative role of water

Managing uncertain resources requires regulation through storage. For example, exploitation of wind and solar energy, which are highly variable, dependent on atmospheric conditions (wind speed, sunshine), irregularly varying and unavailable at the time of demand, should be necessarily combined with technologies for energy storage. In their state of the art review, Crabtree & Lewis (2007) classify the cost-effective storage of electricity well beyond any present technology. Nonetheless, we claim that, at least for electricity production applications, the proven method of pumped storage (pumping of water to an upstream location consuming available energy, to be retrieved later as hydropower) is an efficient method, representing best available technology since: 1) it does not emit any by-products to the environment, 2) it is cost efficient, with efficiency ratios exceeding 90% and 3) hydroelectric energy production does not consume water (only convert its dynamic energy), and thus can be combined with other water uses: domestic, agricultural and industrial. To this extent, a technological paradigm where natural elements such as water, wind and sunshine are the sources of energy, with water in an additional integrative and regulating role, becomes plausible and desirable. Hydrology, the science of water on the Earth, and its interface with atmospheric sciences and energy technologies, have thus a prominent role to play in this new paradigm.

Towards a novel and concrete mathematical framework to quantify uncertainty in nature

Engineering hydrologists understood early that the design of engineering projects based on deterministic projections is a hopeless task and appreciated the usefulness of probabilistic approaches. However, during the last two decades hydrology changed perspective and invested its hopes in deterministic descriptions and models, harmonizing itself with a more general trend in geophysical disciplines and particularly in climatology. The trend towards the so-called "physically based models" signifies this change of perspective. The concept behind these models is that modern computational means would allow the full description of the physics of the hydrological cycle using mechanistic model structures and "first principles" such as Newton's laws and their particular formulations in fluid mechanics (i.e. Navier-Stokes equations). From the first steps of these modelling attempts, it was argued that there are fundamental problems in their application for practical prediction in hydrology, which result from limitations of the model equations relative to a heterogeneous reality; see e.g. Beven (1989). Nonetheless, the aspiration of achieving pure deterministic modelling still dominates, and the relative myth has been "officially" formulated in the framework of the IAHS Decade on Prediction in Ungauged Basins (PUB; Sivapalan *et al.*, 2003) promising that the "cacophony" of theories and models existing prior to 2003 (the beginning of the PUB initiative), which need calibration, will be replaced by a "melodious harmony" of new innovative models based on increased understanding that do not require calibration. We argue that such goals are not feasible and that the claim of "convergence of a plurality of approaches towards the single objective of reducing predictive uncertainty" is misleading within a deterministic context.

This direction in hydrology reflects a general philosophical and scientific view, in which determinism is almighty and uncertainty is a subjective element that could be, in principle, eliminated with better understanding of mechanisms that are regarded to follow a "sharp" causality. This general view fails to recognize the radical advances in physics and mathematics of the twentieth century such as: (a) dynamical systems theory, which shows that uncertainty can emerge even from pure, simple and completely known deterministic (chaotic) dynamics and, hence, cannot be eliminated; (b) quantum theory, which emphasizes the intrinsic character of uncertainty and the necessity of a probabilistic description of nature; (c) statistical physics, which use the purely probabilistic concept of entropy (which is nothing other than a quantified measure of uncertainty defined within the probability theory) to explain fundamental physical laws (notably the Second Law of Thermodynamics), thus leading to a new understanding of natural behaviours and to powerful predictions of macroscopic phenomena; and (d) Gödel's incompleteness theorem in mathematical logic, which challenged the almightiness of deduction (inference by mathematical proof) thus paving the road to inductive inference from data.

Arguably, the state-of-the-art in hydroclimatic research is far from satisfactory, perhaps because the hydro-climatic research community remains attached to pervasive myths that prohibit incorporation of the above radical advances in physics and mathematics. Scientific progress has been ever related to the dispelling of the fog of myths. Therefore, our initial research activities intend to:

Deconstruct myths currently prevailing in hydroclimatic research (*Activity A*), by demonstrating that:

1) climate and the impacts of climate change cannot be deterministically predicted;
2) deterministic approaches may be obstacles in hydrological sciences and water resources technologies; and
3) classical statistics and stochastics are insufficient to describe complex hydroclimatic processes.

Develop a *new hydroclimatic theory* (*Activity B*), which recognizes the structural character of uncertainty in natural processes and builds upon it, using the advances in physics and mathematics of the twentieth century. This activity includes:

1) the study of entropy as a concept for understanding and quantifying uncertainty with respect to hydro-climatic processes and as a driving mechanism of these processes;
2) the study of the nature of geophysical processes based on observed long time series, with particular emphasis on extremes and time dependence structure; and
3) the streamlining of a stochastic theory of hydroclimatic processes.

Activities A and B will provide the foundations for scientific progress, including rigorous definitions of concepts and useful interpretations of behaviours. Currently the emphasis has been given on the construction of algorithms and models and the concepts themselves have been left unclear. Therefore the proposed scientific framework, which will provide clear definitions of concepts, is a breakthrough that will boost future research. The notion of entropy and the principle of maximum entropy as a tool for logical inference (Jaynes, 2003), understanding of natural phenomena (Stowe, 2007) and effective modelling thereof, can be implemented to hydroclimatic systems (Koutsoyiannis, 200a,b) to provide a sound theoretical basis for hydroclimatology, which is currently missing.

Knowledge discovery from past information on water, climate and socio-economic development

A rigorous analysis of the past has always proved to be an unsurpassable tool for science to formulate and test scientific hypotheses and avoid misconceptions. For example the recent myth that anthropogenic CO_2 emissions could lead Earth to end up like Venus with temperature rises of several hundreds degrees and sulfuric acid rain (suggested by none other than Stephen Hawking), could have been avoided by considering that during relatively recent geological eras the atmospheric CO_2 concentration had often been 10-20 times higher than the current value (Figure 3.2 in IPCC, 2001; Figure 6.1 in Jansen *et al.*, 2007) resulting in productive ecosystems rather than disappearance of the water cycle and life. Recent advances in dynamical systems and chaos have highlighted the importance of quantified historical information for prediction: the method of analogues (a local nonlinear chaotic method) has proved efficient in analysing, learning and predicting from similar system states in the recorded past.

To assist the deconstruction of myths and strengthen the development of a consistent and concrete theory for hydroclimatic processes, our *Activity C* focuses on organizing historical information on climate, water, energy, their interconnections and their relationship to socioeconomic development. Specifically, we plan to:

1) process documented historical and paleoclimatic (proxy data) information as a means of (a) understanding historical climatic changes, and (b) constructing quantified time series for statistical analysis;
2) relate past socio-economic development with (a) the extent of the climatic variation at specific locations, (b) the prevailing practices in society related to resources use (water consumption, exploitation of solar and wind energy), and (c) the ability of different societies to manage natural sources (construction of works, sustainable management practices, etc.) in an unstable environment; and
3) investigate the different conditions and models of energy use in developed and developing countries, with respect to interactions with population growth, agriculture and food production, transportation, water use and lifestyle.

Activity C will provide invaluable insights on both historical factors relevant to the understanding of future uncertainty and the interplay between resource consumption, energy and sustainable development.

Coupling water, renewable energy and sustainability

The new approach towards understanding, analysis and modelling of water and climate, developed in activities A and B and supported by the historical evidence and socio-economic implications examined in activity C, will give rise to a new framework for describing, quantifying and ultimately managing renewable water and energy resources. *Activity D* of our programme focuses on developing comprehensive tools for long-term water-energy management both at local and global scales. Specifically, we intend to:

1) quantify the interdependencies between water availability and climatic conditions required for efficient long-term exploitation of renewable energy resources (including, hydropower, wind, solar, wave and bio-fuels);
2) understand and model the variability of renewable water-energy resources, using the new hydro-climatic knowledge and models from activities A and B;
3) develop methods and tools for long-term, strategic planning for the integrated exploitation of renewable water-energy resources; and
4) integrate hydrometeorological models for short term prediction of wind and sunshine and link their results to the management of renewable energy production.

The above research will explore the key role of water in sustainable energy management and develop strategic planning and real time management methodologies for integrated exploitation of renewable energies. The development of these methodologies combined with the understanding and modelling of short-term (daily to monthly scales) and long-term (annual to overannual scales) variability of natural sources of energy, will provide the vocabulary for developing an operational framework that drastically improves the potential of renewable energy management, and directly supports the move from finite fossils fuel dependency to sustainable energy production.

Proof of concept

The potential of the developed theoretical and technological framework for renewable energy management will be tested in real-world conditions (*Activity E*). A unique large-scale hydrosystem extended in two major river basins interconnected through diversion projects will be explored. Importantly, the chosen sensitive socio-economic area lacks fossil fuels and is strongly dependent on external energy sources, despite its substantial hydropower potential. Hence, its sustainable development requires drastic change of the present over-consumptive socio-economical model and the development of local renewable energy resources. In this, it presents an ideal case, highly transferable to other areas of the EU and the world.

The proposed case study, which will test the applicability of the developed framework and also investigate the sustainable development potential of the study area, includes:

1) analysis of the current energy use and management;
2) investigation of the potential of sustainable energy development;
3) development of future energy scenarios;
4) long-term simulations for the development of a strategic renewable energy plan;
5) short-term simulations to demonstrate the reliability and robustness of the proposed plan; and
6) investigation of the transferability of lessons learned in the case study to other cases around the world.

An open knowledge approach

Science requires verifiability and falsifiability, which, in turn, imply ease of access to all underlying information. To enable the scientific community to reproduce experiments and the public to monitor the progress of publicly funded research, our final *Activity F* aims at:

1) organizing all hydrometeorological and energy data using an advanced open source database system;
2) storing the developed open-source application software on a publicly available repository; and
3) developing a project-oriented web site that will provide news and documentation and point to all sources of relevant information.

The spirit of openness and the idea that true open access and discussion is the best way for scientific research, will allow the scientific community to verify (or even challenge) our findings and, hence, advance research in multiple directions yielding further results.

Activities, outcomes and indicators of progress

The technological means to efficiently transform renewable sources into usable energy, largely exist already and significant improvements are expected in the near future in specific technologies (e.g. conversion of solar energy), which are the subject of ongoing research in the EU and globally. But the shift from finite (fossil fuels) to renewable resources requires more than specialized technologies. It requires a global (conceptual, scientific, technological and economical) paradigm shift towards integrated management energy production and use under uncertainty. This type of uncertainty is yet unknown to “classic” modes of energy production. We propose to contribute to the establishment of this new paradigm and the formulation of its theoretical and methodological basis, in a research programme which includes six activities, A to F, as described above and summarized in the following schematic:

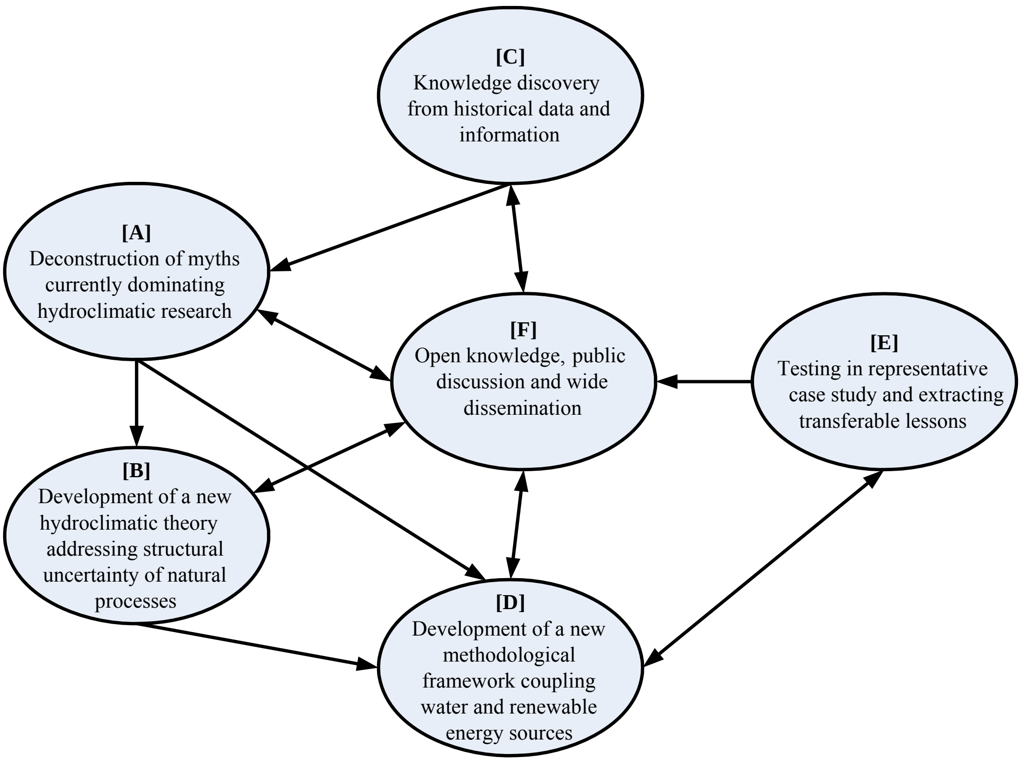

Figure 1 Schematic of programme structure

The research will be conducted in the National Technical University of Athens by the Itia research team, currently consisting of 20 scientists, lead by D. Koutsoyiannis. Three new researchers with complementary expertise will be added to Itia to support the needs of this work. The team will be complemented by short, targeted visits by key experts as well as by longer visits (during sabbatical leaves) of four prominent European scientists, who currently work in the USA.

The research programme will be tightly connected to *educational processes*, through the involvement of postgraduate students in research activities and workshops, the elaboration of PhD, MSc and diploma theses, and the adaption of relevant postgraduate courses to encompass knowledge produced within the programme.

Outcomes of this research are envisaged to include:

1. a rigorous scientific analysis, with philosophical connotation, of the dominant myths on natural processes and their cross-disciplinary implications, leading to their deconstruction;
2. an extensive (open access) historical knowledge base related to climate, water and energy use;
3. a new scientific framework for understanding natural behaviours recognizing their inherent uncertainty;
4. an entropic-stochastic theory of uncertainty and risk;
5. a novel tested methodology for modelling hydroclimatic processes;
6. a new methodological approach for the sustainable coupling of water and renewable energy;
7. a proof of concept of integrated renewable resource management in the form of a case study;
8. a set of recommendations and transferable lessons learned, as a basis for innovative applications;
9. a structuring of knowledge gained, for incorporation into educational processes.

We anticipate the following *measurable indicators* of progress of the *research* and its links with *education*:

- 35+ publications in peer-reviewed journals, in the form of research and opinion papers, and commentaries;
- 50+ presentations in widely respected international conferences;
- 1 book on Hydrologic Stochastics and 2 monographs on Sustainable Water and Energy;
- an *open access* database with long-term hydroclimatic information and energy data;
- a toolkit with software implementation of all models developed, provided as *open source*;
- a content management system with all information related to the project, including a weblog;
- 5 workshops designed to bring together experts on relevant fields to foster further discussion;
- 8 short visits and 4 long visits of international experts;
- 4 PhD and 15+ MSc and diploma theses produced within the research programme;
- 2 postgraduate-level courses (hydrometeorology, stochastic water resources technology) on an e-learning platform, adapted to encompass knowledge produced within the research programme.

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