Five Easy Pieces on Water

Essentials of Water Science
explained by an Engineering Scholar

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Fresh drinking water is an issue of primary importance, since it is indispensable for human life and for supporting terrestrial and aquatic ecosystems. Sources of freshwater are necessary for health care, agriculture, and industry. Water supplies used to be relatively constant, but now in many places demand exceeds the sustainable supply, with dramatic consequences in the short and long term.

Encyclical Letter Laudato si'
of the Holy Father Francis, 2015

To Donatella,
to mother Aria,
to the two Riccardo in my life,
and to our unforgettable Rufus.

Preface

Water is the most essential substance for life on Earth. Water is a common good, a shared resource, a treasure trove of humanity. From a knowledge standpoint, water is not exclusive to engineers, physicists, mathematicians, or architects. The scholars of business administration, political or social sciences cannot claim a primacy on water. Not even the philosophers, although they were the first to investigate its nature. Water is the most shared natural resource of all living organisms and represents both the material and cultural legacy of humanity.

Having devoted my academic career to the study of water, I hope to leave behind a legacy that is kind, pleasant, and approachable while maintaining the highest standards of scientific rigor. In recent years, my classes have included not just aspiring engineers, but also architects, urban planners, landscape designers, and occasionally, art historians. Most of them were curious and passionate students without the mathematical toolkit of a physicist. In introducing them to the wonders of science, the mysteries, and the beauty of water, I had to forego formal mathematics. I have found that qualitative discussions, especially when bolstered by historical context, can elucidate numerous properties and behaviors of water on our planet. This even encompasses several fundamental principles that support our understanding of water.

Professional divisions undoubtedly serve practical purposes, yet they are not inscribed on the tablets of any natural or divine decree. The pursuit of understanding of water knows no bounds, as Vitruvius recognized. He was the father of all 'water masons', as a distinguished professor at the University of Padua used to call the hydraulic engineering scholars. Over the centuries, specialization has expanded humanity's technological repertoire significantly.

However, if reductionism becomes the sole approach to knowledge, our ability to truly observe nature diminishes to a mere glimmer.

The handouts in this booklet record five core lectures on water as delivered to the students of the Landscape Hydrology Studio at the Master in Landscape Architecture and Land Landscape Heritage of the Politecnico di Milano. In the transcript, I also took advantage of dialogues in the context of educational laboratories and flipped classrooms. Since the primary emphasis of these lectures was on the topic of water in its simplest form, I was freed from any strict disciplinary framework. A comprehensive grasp of water's fundamentals serves as a valuable resource intended for dissemination across rigorous scientific fields, practical technology applications, as well as social and human sciences domains.

The title of the booklet draws on the legacy of one of the most fascinating scientific works of the last century. I am speaking of Richard Feynman's *Six Easy Pieces*, published posthumously in 1994. A title perhaps chosen in association with *Five Easy Pieces*, the collection of four-handed piano pieces by the Russian composer Igor Stravinsky, published during World War I. The work of Feynman, one of the greatest physics scholars of the twentieth century, deals with classical lectures that bring the reader with the lightness of a balloon toward understanding fundamental topics such as the atom, basic physics, energy, gravitation, and the relationship of physics with other sciences. Indeed, they are the papers of the lectures that Feynman taught Caltech students from 1961 to 1963. He had imparted these essential concepts in a very straightforward manner, using primarily qualitative explanations and little formal mathematics.

I should have said at the outset that we are now mainly discussing freshwater. I hope, for the time being at least, that the inexperienced but inquisitive reader would peruse this book's pages objectively and with forgiveness. And I expect the knowledgeable reader to be kind and understanding.

Eugenio Pugliese Caratelli deserves my gratitude for his comprehensive discussion on many aspects of this book. I also thank Giovanni Vannucchi for suggesting incorporating key drawings and other amenities. Solomon Vimal shared his storytelling about Robert Horton, Paolo Frisi, and other pillars of water knowledge with me. David Butler is gratefully acknowledged for his help in improving my poor writing style in a foreign language.

Milan, Italy Renzo Rosso

Acknowledgments

I am grateful to all my students, especially those who openly challenged me and those who quietly criticized my lectures. I have received far more from them than I could have ever imagined and much less than I could offer them, since even the harshest criticism aids us in thinking critically, understanding, and growing.

Introduction

I fulfilled my graduation in hydraulic engineering in two steps, a review essay and a research dissertation. First I presented a short review of *The limits to Growth,*[1] a book that greatly influenced my professional life. Then, I discussed my work on extreme value prediction in hydrology.

There was significant debate regarding the graduation panel's consideration of a novel subject in civil engineering, but it was settled peacefully. The core was the research dissertation on flood hydrology, which involved a significant amount of effort to advance probability theory by an infinitesimal amount. Its application to the statistical prediction of flood discharge in the Magra River, a minor creek in northwestern Italy, did not exactly excite the panel, which was between bored and skeptical.

At the time, hydrology was viewed as a sort of hydraulics for beginners, or even worse. A distinguished English scholar dubbed a hydrology textbook that was recently released by an Irish colleague as "Hydraulics for Dummies." Throughout the 1970s, the most popular saying among Italian and European academics was "hydrology is to hydraulics like astrology is to astronomy."

Everything has changed. After fifty years, Hydraulics is not nearly as popular, or practiced in colleges and research facilities worldwide as Hydrology. Hydrologists were among the first to take the issue of global warming and its climatic effects seriously because the water cycle is the transmission belt of weather and climate. Currently, hydrology serves as the professional domain of choice for those working in engineering, planning, management, and water

[1] Meadows, D. H., Meadows, D. L., Randers, J., & Beherens III, W. W. (1972). *The limits to growth*. Fall Church: Potomac Associates.

economics. To the point that some malicious hydrologists consider hydraulics to be one of the numerous subfields of hydrological sciences.

Is it worth distinguishing? Does the knowledge of water still make sense if it is reduced, fragmented, or contained? Do watertight compartments still make sense if we acknowledge that we are all viewing water in all of its facets through the diverse lenses of our unique, both different and complementary mindsets?

"No" is my answer.

I concur with Edgar Morin that we must rediscover the significance of the qualitative approach in addition to the quantitative one. To this effect, we must connect rather than separate, integrate rather than reduce.[2]

This book aims to simplify things, although unfortunately, they are often a little more complicated than they seem at first glance. I have spent a significant portion of my life complicating problems, sometimes simple ones, and sometimes only to satisfy the craving for the beautiful mathematical form of knowledge. Therefore, I follow here the traditional method that aligns with the legacy of Leonardo da Vinci, who first observed nature before theorizing.

This book does not ignore complexity. We should never forget that oversimplifications and false assertions must be out-lawed, as claimed by Archimedes of Syracuse, the man who gave the Western world its first knowledge of water and, unbeknownst to him, a hydraulic engineer.

> Those who claim to discover everything but produce no proofs of the same may be confuted as having actually pretended to discover the impossible.[3]

No discipline or scholar is a master of the science of water, despite the fact that many academics in today's highly fragmented university fight for supremacy. Even though water is arguably the most studied scientific topic during the past three millennia, everyone should help expand on the many aspects that are yet unknown. Professional issues make sense in many practical situations, but they should not mask the transdisciplinary nature of water knowledge. Water knowledge is a field that has no bounds in its quest for knowledge.

The path of those who study the water cycle and those who design water turbines was divided by disciplinary fragmentation beginning in the second half of the nineteenth century. The fates of scholars who grasp theories and sophisticated calculus have gradually diverged from those of engineers who build aqueducts and sewers. Let alone the forking paths taken by the experts in water governance and the water architects.

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[2] Morin, E. (1986). *La méthode III. La connaissance de la connaissance*. Paris: Seuil (*The method III. Knowledge of knowledge*, in French).

[3] Archimedes, *On spirals*, around 225 BC (as translated by T.L. Heath, The Works of Archimedes, Cambridge: At the University Press, 1897).

Reductionism has had a significant impact on science, engineering, and architecture. Although it sparked a lot of advances in human knowledge, it is not the sole method for investigating nature or fostering innovation. A river network is greater than the sum of its creeks, as well as the forest is greater than the sum of its trees,[4] because each creek or tree contributes to river or forest health just as every member of society contributes to the well-being of their communities.

Theory and practice can go together. For instance, Luis van Wittel, born in Naples, is regarded as one of the finest architects of the eighteenth century. The world's most exquisite buildings and gardens, the Royal Palace of Caserta, is his creation. But we also owe him one of the most significant aqueducts of the contemporary era. The magnificent Carolino Aqueduct was opened in 1762 to supply a huge amount of water to the Palace and its surrounding gardens. It features bridges that cross mountain ridges, tracking the proper slope for water conveyance, as well as the first iron ducts made in Calabrian foundries. It is no accident that the elderly Vanvitelli was summoned to Genoa in 1771 to resolve a long-standing political and economic conflict around the 1000-year-old Genoa civic aqueduct.[5]

Why am I calling upon the past?

Models and data have exact bounds. A colleague who devoted his life to hydrological measurements once whispered that "no one believes in models except those who implemented them; and everyone believes in data except the one who measured them." Using only the power of poetry, no data nor computations, Dante expertly describes the crucial processes in the Arno River that produce flood hazard in Florence, as well as the city's vulnerability.[6]

The paradigm of knowledge has been almost entirely quantitative over the past 200 years. The numbers pretty much say it all. The remainder is anarchy. Although as is frequently the case, I concur with Edgar Morin again when he states that

> calculation (statistics, surveys, GDP growth rate) conquers everything. Quantity drives out quality. Humanism is in regression under the technical-economic pressure.[7]

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[4] Wohlleben, P. (2016). *The hidden life of trees: What they feel, how they communicate.* Vancouver: Greystone Book.

[5] Podestà, F. (1879). (*L'acquedotto di Genova 1071–1879*, Genova: Tipografia del Regio Istituto Sordo-Muti (*The Genoa aqueduct from 1071 to 1879*, in Italian).

[6] Dante Alighieri, *Divina Commedia, Purgatorio*, Canto V, 116–123.

[7] Morin, E. (2014). *Einseigner à vivre. Manifeste pour changer l'éducation*. Paris: Actes Sud/Play Bac.

I have no doubts that humanity needs to reevaluate the worth of qualitative knowledge relative to quantitative knowledge.[8] In keeping with this, I arranged here the handouts of five basic lectures that I delivered to my students according to the approach by Guelfo Pulci Doria who pioneered the now rediscovered need of understanding science via history and integrating human science with STEM knowledge.[9]

It is true that there is a big gap between creating knowledge and getting it out to the public, yet closing this gap is essential to society's progress. In the seventeenth and eighteenth centuries, during the Enlightenment, the idea of public science started to take shape. Knowledge was no longer only the purview of elites or privileged institutions, but rather was valued as a public good. Prominent scholars including Francis Bacon, Galileo Galilei, and Isaac Newton promoted the sharing of scientific information with the general public. Because of their conviction that the growth of research should benefit all people, organizations like scientific societies and universities were founded with the goal of encouraging public participation with science.

This concept changed over time, inspiring the creation of procedures and policies that support inclusivity, openness, and transparency in scientific research and public outreach. But this also made the distance between knowledge and its application wider. Many academics these days do not give a damn when it comes to giving simple lectures, speaking to the public in person, or utilizing cryptic language, ignoring direct communication in science. The waning confidence and interest in science in the third millennium is not unrelated to this mindset.

Public and scientific confidence can be increased through effective science communication. Researchers can fight disinformation and improve the credibility of their work by openly disclosing their techniques and findings. These lectures aim to close the knowledge gap between public science and various fields and stakeholders using water. They also provide basic information to a wider audience of individuals who are interested in learning more about water and bridging the gap between theory and practice.

Water is an essential but multiform substance. It is complex in its apparent simplicity, an odd mix of order, disorder and organization. The majority of real-world applications appear simple and intuitive, yet as formal knowledge has advanced, many water processes can only be explained by rather hard, non-linear mathematical principles. Mankind has been aware of this for

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[8] Rosso, R. (2019). *The decline and renaissance of universities: Moving from the big brother university to the slow university*. Heidelberg: Springer.

[9] Pulci Doria, G. (2005). *Il corso di idraulica a partire dallo sviluppo storico-sociale della disciplina*, Napoli: Cuen (*A treaty of hydraulics moving from the historical and social developments of the discipline*. in Italian).

2300 years, since Archimedes of Syracuse pioneered the mechanical approach along with introducing surprising inventions such as the hydraulic screw and the water clock. He always used mathematics to prove his discoveries. In the realm of water, things are not always easy. Speaking of water, nothing is ever too easy.

I chose the book's contents to provide a short but comprehensive survey of water knowledge. This includes encouraging human sciences exploration among STEM students and piquing the interest of students in social, economic, and human sciences toward mysterious STEM fields. For mankind, comprehending *the nature of water* has been a constant challenge. The first step to exploring the water world is to describe the behavior of *water at rest*. Even though people have observed running water and have been moving water for thousands of years, there are still a number of unsolved problems with *water in motion*. Investigating climate and ecosystems, as well as designing and carrying out civil engineering projects, requires a thorough understanding of *the water cycle*. In the twenty-first century, one of the main barriers to humanity's peaceful coexistence and cooperation will be *the governance of water*.

Contents

1

The Nature of Water

Water is H_2O, hydrogen two parts, oxygen one,
but there is also a third thing, that makes it water
and nobody knows what it is.
David Herbert Lawrence, The third thing, in: Painses*, 1929.*

"Cooking acts like a capricious nymph—often leading to despair. Yet, it also brings joy, for when you master a dish or conquer a challenge, you revel in the taste of victory." Pellegrino Artusi introduces his culinary masterpiece with this blend of irony, presenting it as the most captivating recipe book ever written.[1] The same introduction could describe water: very useful and humble and precious and chaste, echoing St. Francis of Assisi's teachings. However, water also possesses a mischievous nature when one delves into its characteristics, because the only common substance that can exist in the Earth's surface at the comparatively narrow range of temperatures and pressures as a gas, liquid, or solid naturally is water. At times, like in the case of some wintertime geyser explosions in Island, all three stages can even exist at the same location and time.

[1] Artusi, P. (1891). *La scienza in cucina e l'arte di mangiar bene*. Florence: Salvatore Landi (*Science of cooking and the art of good eating*, in Italian).

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