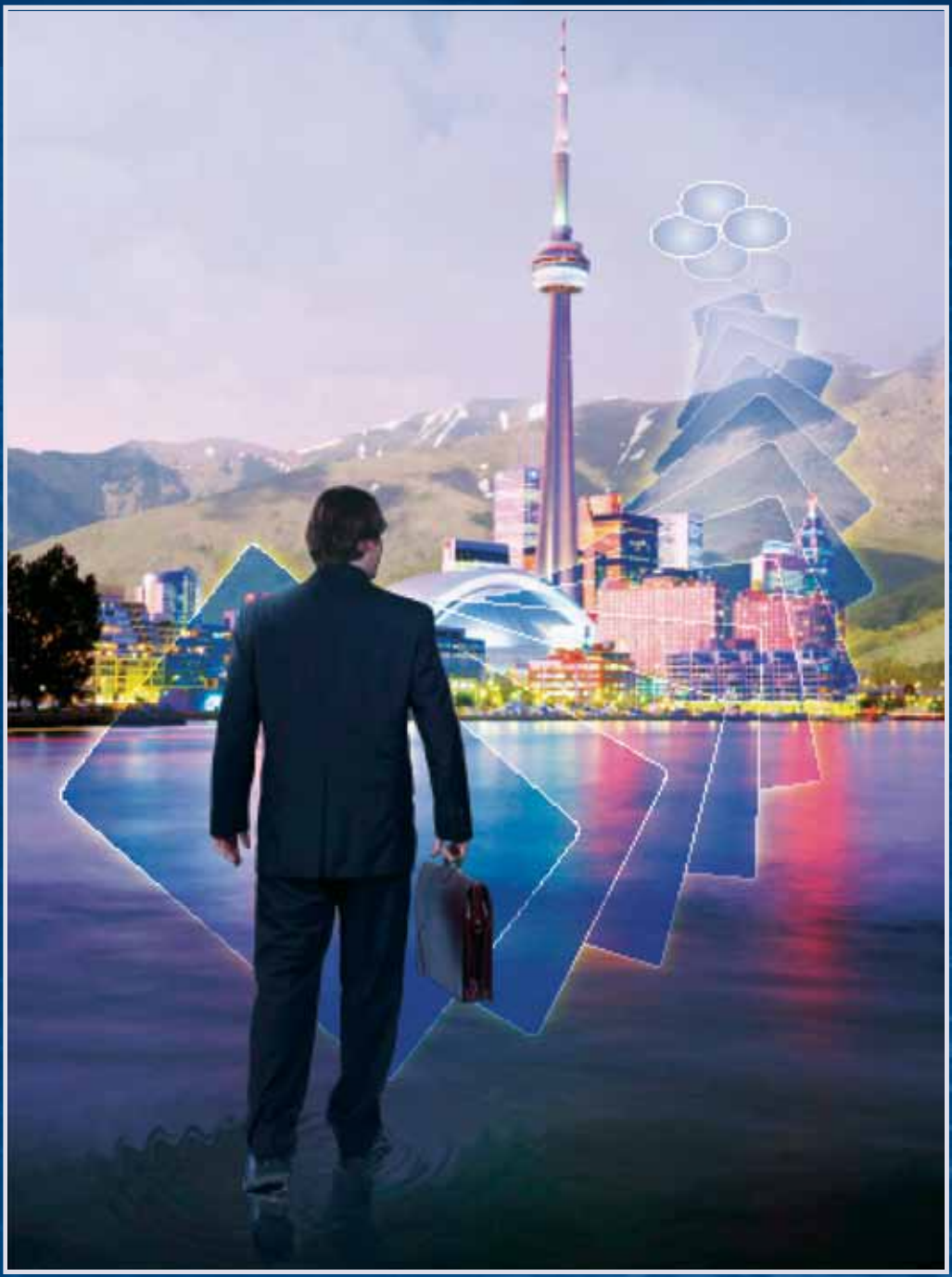
Cities as Forces for Good
in the Environment
Sustainability *in the Water Sector*



Sustainability Concepts Paper

M Bruce Beck

Sustainability Concepts Paper

CITIES AS FORCES FOR GOOD IN THE ENVIRONMENT:

SUSTAINABILITY IN THE WATER SECTOR

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Abstract

What was unprecedented about the final decade or so of the 20th Century was not so much the pace of change in technology — which supposedly is always "unprecedented" — but our collective willingness to question whether Man had got his relationship with the Environment "about right". It was as though the rarity of the approach of a new millennium had evoked just as uncommon and profound a questioning, no less so for water professionals and environmental engineers than for people from all manner of other walks of life. This *Sustainability Concepts Paper* is marked by that experience. Having become used to decades of the water-based paradigm, for removing the biological residuals of the city's metabolism and returning them to the aquatic environment, we had ceased to question what might otherwise have been — had the water closet not been so successful at some critical juncture in the competitive technological stakes of the mid-19th Century. The *Paper* takes this experience of the "great sustainability debate" of the 1990s, first to record the role of customary environmental engineering therein — almost its fall from grace by default — and, second, to set out a vision and challenge for it.

As we proceed thus into the early decades of the 21st Century:

> How can the built infrastructure of the city be re-engineered to restore the natural capital and ecosystem services of the nature that inhabited the land before the city arrived there, in "geological time"?
>
> How can this infrastructure be re-engineered to enable the city to act as a force for good, to compensate deliberately and positively for the ills of the rest of Man's interventions in Nature?

The *Paper* is about responding to such challenges: of our becoming less unsustainable in the setting of Integrated Urban Water Management (IUWM) nested within Integrated Water Resources Management (IWRM) over a watershed.

Triple Bottom Line (TBL) accounting was born of the 1990s. Sustainability will be judged the greater for those actions, decisions, policies, businesses, and technologies that embody {social legitimacy}, {economic feasibility}, and {environmental benignity} to a greater degree. In that order this *Paper* discusses the concepts and attributes of these three emboldened line items, of what it might mean to be moving forward towards sustainability in the water sector.[1] While the great sustainability debate may have been prompted by the perception of Man bumping up against the limits of Environment — a sense of poor performance in respect of {environmental benignity} — the *Paper* acknowledges the labyrinthine complexity of {social legitimacy} as *primus inter pares*, first among the equals of the three bottom lines. {Economic feasibility} enfolds the grandest of socio-economic programs as much as the bluntest of practical, visceral, necessities of life. Given the myriad elemental notions comprising {social legitimacy} and {economic feasibility}, the *Paper* relates {environmental benignity} as a succession of steps in engineering a platform on which to proceed to meet the foregoing challenges and embrace their vision — indeed, to change it as time passes.

On this account, it turns out that the old — and now much denigrated — water-based paradigm with its infrastructure of "end-of-pipe treatment" may not be quite as comprehensively "broken" and in need of wholesale "fixing" as we might once have been persuaded. Yet the argument of this *Concepts Paper* is surely no advocacy of the comfort of maintaining the *status quo*. Adaptive management is almost as popular a catch-phrase as is sustainability itself. And so it should be, when understood and enacted as originally intended: through policies designed expressly to steer and probe the system at one and the same time, deliberately to reduce uncertainties, if not vagueness, and to promote learning. Yet something more, somewhat beyond adaptive management, is needed. As if to jolt and jar us out of our comfort zone, the *Paper* discusses a search for clumsiness — neither elegance nor necessarily efficiency — in the institutional structures of governance that will be enabling (or disabling) of progress towards less unsustainability of IUWM within IWRM. We venture to label this a kind of "adaptive community learning", something in which the maxim of "Always Learning; Never Getting It Right" is deeply ingrained. Sustainability will be no

[1] And they are sufficiently important to the organizational structure of this *Concepts Paper* to merit the distinction of their enclosure in parentheses {...}.

more ever hereafter "right" than will the next grand idea to subsume it — or sweep it entirely away.

For all of this being a *Concepts Paper*, its closure is about stepping out in the harsh world of *practice*, thereby determinedly to re-fashion the TBL as we account for it today (TBL_{now}) into how we currently imagine it might be gauged generations hence (as TBL_{future}).

A *Concepts Paper* cannot be left without a parting thought, however. It is this: if we were to be supremely successful in sustaining IUWM within IWRM, we might then be left but to contemplate IU*Nutrient*M within I*Nutrient*RM. This *Concepts Paper* bears the sub-title "Sustainability in the Water Sector". Yet re-engineering the city so that it may become a force for good in the environment defies such familiar compartmentalization. An intervention in the water sector has ramifications for the energy sector, the food sector, the waste-handling sector — and *vice versa* — and so on, and on (endlessly).

Preface

My first attempt at writing this *Paper* was in 2002, in anticipation of the First Leading-Edge Symposium on Sustainability of the International Water Association (IWA) in Venice, Italy (November, 2002). That first attempt was circulated as the Background Paper to the Symposium. The notion of its being, or becoming, a *Sustainability Concepts Paper* had not surfaced.

Shortly after the Venice Symposium, Andrew Speers (then Programs Manager, IWA Secretariat) established two Committees charged with steering and leading the "Sustainability Initiative" within IWA. Andrew was of the view that IWA needed to generate a "*Concepts Paper*"; and the Committees agreed with him. So it was that during 2003 Andrew drafted the first version of the beginnings of such a Paper. I agreed to take up the baton, to re-draft that Paper, thus engaging in my second attempt at a *Concepts Paper*, sporadically over the course of 2004. To assist me in making better progress, Andrew made a second assault on his task in 2005, trying to simplify and consolidate an extensive, perhaps rambling, text. Taken, mesmerized, absorbed by the challenges of my own second attempt, I began a third time, throughout the Fall of 2005. And there things languished, as the Leading-Edge Symposia of the IWA Sustainability Initiative transmogrified into the present-day IWA Specialist Group on Sustainability in the Water Sector.

In the Spring of 2007, prompted by Keith Robertson (now Programs Manager, IWA Secretariat), I was persuaded to release part of the third attempt for "public" consumption, through a presentation made by Paul Jeffrey to IWA's Strategic Council. Having not been present myself at the Council's meeting, which may have been a blessing, I asked for a report from Keith on how things had gone. I read between the lines and concluded "not well".

Later in that same year, Professor Cedo Maksimovic (of Imperial College London) asked me to write a paper on the concepts of sustainability for a book he was preparing (under the Urban Water Management Program of UNESCO's International Hydrological Program). By the close of 2008, I had undertaken a fourth (comprehensive) revision of the *Concepts Paper*; and I had written an entirely separate text for Cedo. I believed I had succeeded in my task. I was wrong. It was obvious I had captured little of the sense of eternal *change* about what it might mean for things to be sustainable and my *Concepts Paper* was lacking any calibration against contemporary practice.

What you are reading is the completion, at last, of a second re-drafting of my fourth attempt at this *Concepts Paper* — six attempts in all, then.

Without knowing it initially, Cedo's request in 2007 was liberating, for I abandoned the (vain) attempt at writing on behalf of others, a committee, or an entire Association. I have written simply as me, M B Beck: Sustainability as seen from my perspective.

And that — crucially — is exactly how this Concepts Paper should be read.

I make no claim to represent here anyone other than myself.

In retrospect, having now written this, I find it even more difficult to grasp how any such *Concepts Paper* could be written by a committee, or as an expression of views reflecting the consolidated posture of an entire Association. From exchanges around the Management Board of the IWA Specialist Group on Sustainability, as much as from the reported views of the Strategic Council meeting of April, 2007, I recognize a diversity of strongly held views on whether one should ever write something that is itself fundamentally defined by having to recognize the inevitability of a diversity of just as strongly held other viewpoints. Which viewpoints should — and certainly are — hotly debated. That is a cause for celebration, not exasperation.

Exasperation there surely has been in my writing this *Concepts Paper*. Towards the end, when I had to confront my own challenge — of moving forward in the face of vagueness — I found myself in danger of being sucked into a never-ending downward vortex, of acknowledging the impossibility of expressing what seemed to have been called for: a "Manual of Practice for All of Life".

So let me close this Preface with a strictly personal statement. All my career, from 1970 onwards, I have shunned use of the first-person singular — the *I* — in all that I have written. I fully recognize the transformation scientific and technical writing is undergoing: like the (debatable) fall from grace of the technocracy of the last century, from the objective and passive "it" to the subjective and active "I". Yet it has always seemed to me unattractively arrogant to write, as some have in their technical documents, "I discovered ...". I am by nature much more taken by the "we", gathering in you the reader, and having you accompany me on the journey.

This *Concepts Paper* has brought me down, however. I have had to use the "I" word in one or two places — which yet seems only fitting.[2]

[2] Nevertheless, I have tried to confine the "I" word to footnotes!

Omissions

This is not a slim volume. Yet the water and nutrient metabolisms of *industry* in the city and its adjacent watershed, as well as the sustainability of urban *drainage* systems, are given somewhat short shrift in it. How has this happened?

This is not especially a matter of logic (or sheer exhaustion). I am aware of both subjects, of course. Much about the notion of the City as a Force for Good (CFG) was originally inspired by the book *Remaking the Way We Make Things* (McDonough and Braungart, 2002). And a good deal of engineering for the greater sustainability of urban drainage infrastructure has to do with re-arranging the spectrum of the system's hydrological variations, a specific instance of the notion of spectrum that has been pivotal in conceiving of a CFG to begin with. So much of my labor has been spent in looking outwards, to things often well beyond the customary water sector. But in all my reading, learning, and pondering — eventually to express this *Sustainability Concepts Paper* as you now find it — I was simply never driven to thread the flow of my arguments through either of the two subjects to any marked extent. It was not my intent to be comprehensive in my review of the domain-specific literatures. It was to convey the generic concepts underpinning CFG and sustainability, somewhat detached from some of those particular domains.

Perhaps I should put these omissions down to prejudice, to the ideas I first brought to the subject all those years ago. If so, I am duly humbled. And I am deafened now by the maxim, to which I attach such importance, ringing in my ears: "Always Learning; Never Getting It Right"!

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Executive Summary

This is as it is named: a paper about *Concepts* — concepts of what it may mean to become less unsustainable in the context of cities and their infrastructures (primarily water). It is written from the perspective of Engineering, by an engineer. Yet no operational definition of sustainability will be presented. In that alone, the *Paper* may be judged contrarian. It is in any case contrarian by design, the intent being to give the reader pause for thought. In the absence of an operational definition of sustainability, how might we yet go forward in spite of vagueness, in deed, by our actions, deliberately *to* spite it?

Contrarian Stance

Two contrarian positions are adopted from the outset: first, that there should be no convergence to conformity or singularity of perspective on sustainability in the water sector; and, second, that the long view inherent to sustainability, yet so often conspicuous by its absence, must be center-stage in our thinking — and when it is so, we cannot escape the truth of "change being the only constant in life".

The Water Sector

Sustainability in the water sector will be understood herein as Integrated Urban Water Management (IUWM; in the city) nested within Integrated Water Resources Management (IWRM; in the watershed). These two scales alone, however, do not encapsulate a subject that penetrates down to the very local and quintessentially personal, while reaching up to changes and the cycling of materials literally on a global scale.

Fall From Grace

During the 1990s, with the approach of the new millennium, the voice of Engineering in the "great sustainability debate" was not as loud or as audible or as articulate as those of Ecology and Economics. Environmental engineers, in particular, were confronted with the realization of their *not* self-evidently doing good by the environment. The "old" water-based paradigm of centralized wastewater infrastructure, with its "end-of-pipe" treatment, was accused of being broken and in need of fixing. In the eyes of some, if not many, the esteemed image of environmental engineering fell with the general descent of the modern technocracy of the second half of the 20th Century. The epitome of an engineering turn of mind — the mathematical program for optimizing engineering designs — may too have come to look as something from a bygone age of inanimate clockwork mechanisms. Yet paradoxically, it might now not seem this anachronism to some, but instead an algorithmic framework perfectly attuned to satisfying the newly minted constraints of Triple Bottom Line accountancy: of {environmental benignity}, {economic feasibility}, and {social legitimacy}.

The Challenges

This *Sustainability Concepts Paper* argues we face something of a supreme challenge, for infrastructures as a whole. In this resides a vision to be shaped by responding to the following kinds of questions:

How can the built infrastructure of the city be re-engineered to restore the natural capital and ecosystem services of the nature that inhabited the land before the city arrived there, in "geological time"?

How can this infrastructure be re-engineered to enable the city to act as a force for good, to compensate deliberately and positively for the ills of the rest of Man's interventions in Nature?

How can cities of the Global South avoid adopting the same technological trajectory as those of the Global North? Can they, as it were, "leap-frog" the Global North by forgoing the entire human-waste-into-the-water-cycle phase, thereby ending up one step ahead?

More profoundly, how can the engineering of city infrastructure be deployed expressly so that those at the bottom of the pyramid of dignified human development may be brought to a level where they care to engage in a debate over such a grand challenge for this century — of cities as forces for good — beyond their desperate needs of survival for just today and tomorrow?

Line by line, the *Paper* builds its response to these questions, introducing successively the concepts and needs of achieving {social legitimacy}, {economic feasibility}, and {environmental benignity} of action, policy, or development initiative.

This *Paper*, therefore, is a first over-arching response to the challenges set out in the essay on "Cities", reprinted here as Box ES1. It is also a manifesto for the ongoing research program on Cities as Forces for Good in the Environment — or CFG for short (www.cfgnet.org).

Deeply Engrained Cultural Diversity and Plural Wisdoms: Social Legitimacy

What is essential about {social legitimacy} is acknowledgment of the plurality of perspectives on the Man-Environment relationship amidst the mind-boggling cultural diversity that is the rich social mosaic of our world.

Ecologist Holling's several Myths of Nature can be mapped one-to-one onto anthropologist Thompson's several archetypes of social groupings and their respective outlooks on the world (*Weltanschauungen*). Each is associated with different hopes and fears for the distant, inter-generational future, different strategic styles of management and governance, and, we argue, different preferences for the type of technological path to be adopted for moving away from unsustainability towards sustainability, even in the water sector. Along with legal expert Coglianese, this *Concepts Paper* challenges what he has called the contemporary craving for consensus — the attainment of a shared vision before embarking on a given course of action. Endless, but punctuated, contestation — played out amongst the enduring plurality of perspectives, wisdoms, diagnoses, policy prescriptions, and technological alternatives — might rather be the essence of what is needed. And in this, the allusion is to the continuing refurbishment of political theorist Dahl's original ideas regarding pluralist democracy.

There is a deeply rooted moral and ethical role for engineers in societies. In his book *The Existential Pleasures of Engineering*, Samuel Florman reminds us of the moral cause that engineers once attached to Engineering: to install works that would lift the ordinary people out of the drudgery of their daily existence. So great was their commitment to this vision that, in the early 20th Century, engineer Gantt founded an association called the "New Machine" in order to pursue his vision of what society should be. Things change across the generations. A century on, in the long view, we can look back aghast at Gantt's vision; recognize too some of its later manifestations in the technocracy of the past 50-60 years; and apprehend something of how our grandchildren might come to view what we shall have done in the utterly dedicated contemporary pursuit of sustainable development.

Things change fundamentally: from phosphorus as pollutant and eutrophy as bad, to phosphorus as resource and oligotrophy as not necessarily so good. Recognizing this inevitable flux in cultural norms, customs, and outlooks over the generations is just as essential, to what will constitute {social legitimacy}, as is the constancy of there always being cultural diversity and plurality of perspective.

Business and Grand Social Programs: Economic Feasibility

Picturing the environment in terms of natural capital, ecosystem services, and service providers — adding the images and words of a kind of "business speak" to those of the Triple Bottom Line — may be anathema to some. For they, from their perspective, consider Man as essentially caring and sharing, not self-seeking and market-oriented. But this, nonetheless, is how we begin our account of the bottom line of {economic feasibility}. An engineer's caricature of the four "*E*"s of Economics is set out. It recognizes four styles (or tastes) in economics, in ever widening purviews beyond the "fence line" of the business enterprise: from Engineering, through (conventional) Economics and Environmental, to Ecological economics. We can lift up our horizons, from the capital expenditures and operational expenditures of water-infrastructure assets (their "capex" and "opex") to ecologist Kremen's tabulation of the role of biodiversity in the service providers of the global *Millennium Ecosystem Assessment*.

Descending back down from these dizzying heights, we can see how the humble, hum-drum unit process of activated sludge treatment of sewage (in the inner spaces of IUWM) might be re-engineered to provide "designed" ecosystem services for the outer space of IWRM (in the watershed). As if just from the words of this business speak, we can discern too how such ecosystem services might be metered in a simulation model — as can the consumption of electricity — evaluated, and added to the (discounted) total annual economic costs of capex and opex over the life-time of a treatment plant.

That, of course, is {economic feasibility} gauged primarily across ever-widening spatial scales, under which ever more of the economic externalities may be gathered in as "internalities". Just as there is a temporal

BOX ES1

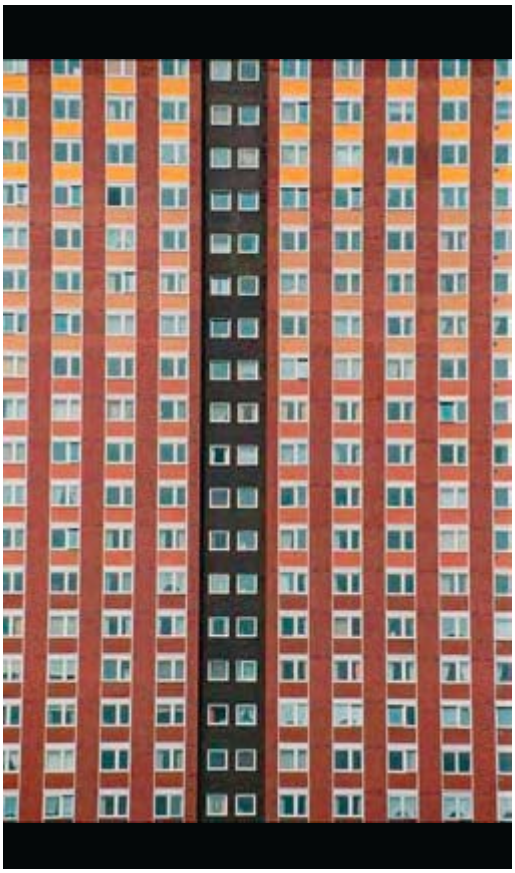
CITIES

Grand challenges for engineering

Turning cities into forces for good in the environment

The world is becoming ever more populous and urbanized. Cities are inherently unmitigated environmental "evils"; with no extenuating circumstances; like bulls in china shops. Man's burden on the environment—woe, that it is—will continue to be piled upon woe. So runs the popular mind-set.

Yet things do not have to be this way, no matter how hard it may be today to conceive of cities as forces for good in the environment. Far from infrastructures having to take on the burden of compensating for the ills of cities, the two should "act" deliberately to contribute positively to enhancement of the environment around them. That is our grand challenge for engineering; and this is how we might begin to think of responding to the challenge.



In introducing their concept of the "urban ecological footprint"—massive, of course, for cities such as Paris, New York, and so on—William Rees and Mathis Wackernagel invite us to conceive of the city as a "large animal grazing in its pasture." We imagine that animal to be a bull. The "bull" of intense social and economic activity in the city is to be shod, we suggest, with the "padded athletic trainers" of re-engineered infrastructures and imbued with a technological deftness and intelligence sufficient for restoring the business of running the environmental "china shop" in which it charges about—indeed, profitably expanding the shop's operations.

The city, continuing the large grazing animal analogy, takes in its daily grass and daily water, while we, for readily understandable but increasingly unsustainable reasons, have engineered the return of the residuals of this metabolism to the air, water, and land environments surrounding the city. In the Global North, a good deal of the city's daily water is used to remove the residuals of its daily grass as wastewater so that citizens can lead healthy and productive lives. And much technological effort has been invested in treating that wastewater, not always to the better of the air, missing an opportunity to benefit the land, while not being a wholly unmitigated good for the water environment. In short, wastewater treatment in the Global North can end up shunting nitrogen into the atmosphere, to avoid fertilizing the aquatic environment, while we labor awfully energetically with the Haber-Bosch process to pull that nitrogen out of the atmosphere to produce industrial fertilizer.

How, then, can the built infrastructure be re-engineered to restore the natural capital and ecosystem services of the nature that inhabited the land before the city arrived there; how can it be re-engineered to enable the city to act as a force for good, to deliberately and positively compensate for the ills of the rest of man's interventions in nature? And how can cities of the Global South avoid adopting the same technological trajectory? Can they, as it were, "leapfrog" the Global North by foregoing the entire human-waste-into-the-water-cycle phase, and thereby end up one step ahead?

More profoundly, how can the engineering of city infrastructure be deployed expressly so that those at the bottom of the pyramid of dignified human development may be brought to a level where they care to engage in a debate over such a grand challenge for the next century—of cities as forces for good—beyond their desperate needs of survival for just today and tomorrow? ■

Further information This essay is part of a project by the US National Academy of Engineering to determine the Grand Challenges for Engineering during the next 100 years: www.engineeringchallenges.org

Professor Paul Crutzen (Nobel Prize for Chemistry), **Professor M. Bruce Beck**, and **Dr. Michael Thompson** are all Institute Scholars at IIASA. They also research at the Max Planck Institute for Chemistry, University of Georgia, and University of Oxford, respectively.

dimension to the contents of {social legitimacy} — to complement the spatial dimension over which such considerations are spread out — so too there is a well known, and thoroughly vexed, temporal dimension to assessing the {economic feasibility} of alternative technological paths leading away from unsustainability. Ecologists Sumaila and Walters have recently proposed an attractive escape from some of the intellectual impasses of inter-generational discounting. It acknowledges, year on year, the rise of future cohorts of the population to the age of majority and, therefore, their entry into a voting democracy. But it assigns to everyone — old or young, current or future generation — a single, invariant perspective on the Man-Environment relationship.

Rising again to the heights of grand social and moral programs, economist Solow talks of "bequests to future generations". What should each and every one of us write into our "last environmental wills and testaments"?

What, instead, asks engineer Mara, should a poverty-stricken villager in India invest in: a costly resource-recovering ecosan toilet or a cheap resource-wasting single-pit pour-flush toilet? Through this visceral question for the dispossessed, our feet have been planted firmly back on the ground.

Responding to the Challenge: Environmental Benignity

We have the ecosystems we saw in rivers prior to the arrival of Man and the city in the watershed because they evolved in *tandem* with all the variety of natural perturbations to which those rivers were subject: over seconds, minutes, hours, days, years, decades, centuries, millennia, and so on. The watershed had a certain spectrum of perturbations to which it was subject. Constructed wetlands, or the "environmental flows" prescribed by stream ecologists for restoring the prosperity of fish assemblages, are policies of the electrical engineer's spectrum manipulation — manipulation of the "pulse" of the city-watershed couple — intended to restore the pace and spread of variations in pre-city conditions to the watershed. Environmental engineers should see it as manifest in the principle of low-impact urban development.

The metaphor of the "large animal grazing in its pasture", introduced by ecological economists Rees and Wackernagel, has brought us the simple, yet powerful, concept of ecological footprint. To this measure of the city's impact on the (global) environment can be added, first, the metabolism of the city and, second, the pulse of the city-watershed couple. Imagine Paris as the "bull" in the "china shop" of the restored, yet increasingly vulnerable, Seine watershed. Through the three criteria of appetite (footprint), metabolism, and pulse, the biological metaphor is employed in this *Paper* to respond to the challenges set out above.

A conjecture is offered, entirely in line with a *Concepts Paper*: that intelligence and metaphorical deftness of movement might be bestowed upon the bull of the city, such that with its infrastructure re-engineered across the generations it might act as a force for good in the watershed. Whereas ecologists prescribe environmental flows for improving the health of the watershed's aquatic ecosystem, this *Paper* commends the conceptual possibility of the city issuing "nutrient supplements" to benefit the river — and it grounds this commendation in a computational simulation of the city of Atlanta within the Upper Chattahoochee watershed. What agriculture and hydropower-generation in the watershed may not be able to do for themselves in mitigating their impacts, the smart and deft city might do for them instead.

Appetite and metabolism invite eco-efficiency and "belt-tightening" as policy and technology responses. In their book *Remaking the Way We Make Things*, architect McDonough and chemist Braungart argue that our becoming "less bad" is not the same as our becoming "good". Their alternative of eco-effectiveness is the complement of eco-efficiency. In this *Concepts Paper*, it is also the inspiration for turning entities that may seem (to some) intrinsic environmental "bads", such as cities, into environmental "goods". It is the expansive vision of cities as forces for good in their dispensing nutrient supplements. It is the sheer *joie de vivre* in conceiving of how to re-engineer the city's infrastructure to that end. The old technocratic, centralized paradigm is *not* entirely broken.

If the city tightened its water belt to enclose but a shrunken, pencil-thin urban water metabolism — and almost vanishingly so — what would we water professionals then do by way of gainful employment? Author and journalist Fred Pearce has written a book: *When the Rivers Run Dry*. Journalist and writer Michael Specter has penned an article about *The Last Drop*. What if that last drop were never reached, nor did the rivers ever run dry; what should we write of then to attract the attention of Society?

The *Concepts Paper* has a suggestion: a book chronicling "When the Soils (do not) Starve", predicated upon IU*Nutrient*M nested within I*Nutrient*RM and in response to the challenge of re-engineering the city's nutrient-return infrastructure.

Forward in the Face of Vagueness: Backwards in the Big Picture

In a healthy democracy of stakeholders, all manner of hopes and fears — aspirations, convictions — can be imagined for the distant, inter-generational future: five such visions are shown in Figure ES1, as the green oval domains towards its upper right corner. Taking the hull of the current wastewater infrastructure of cities of the Global North and re-engineering it, step by step into the future, to produce a "Perfect Fertilizer" (and a by-product of clean water), is one of them. It is exploited throughout to anchor the lofty, airy "thought experiments" of this *Concepts Paper* in hard, engineering specificity. Yet it does not have the authenticity or {social legitimacy} of being born of those holding much more than a mere conceptual stake in *their* city becoming a less unsustainable entity in *their* watershed — at *their* expense, *their* personal sacrifice, or *their* commitment to changing *their* household plumbing and *their* dietary choices.

Such multiple, *authentic* visions of the distant future are the essential starting point. If at all there are to be formal, quantitative indicators of sustainable development, such as the Human Development Index (HDI), political theorist Boulanger would have them deployed as *active* instruments for cultivating such people-conditioned preferences. And the task — of going forward in the face of vagueness about what

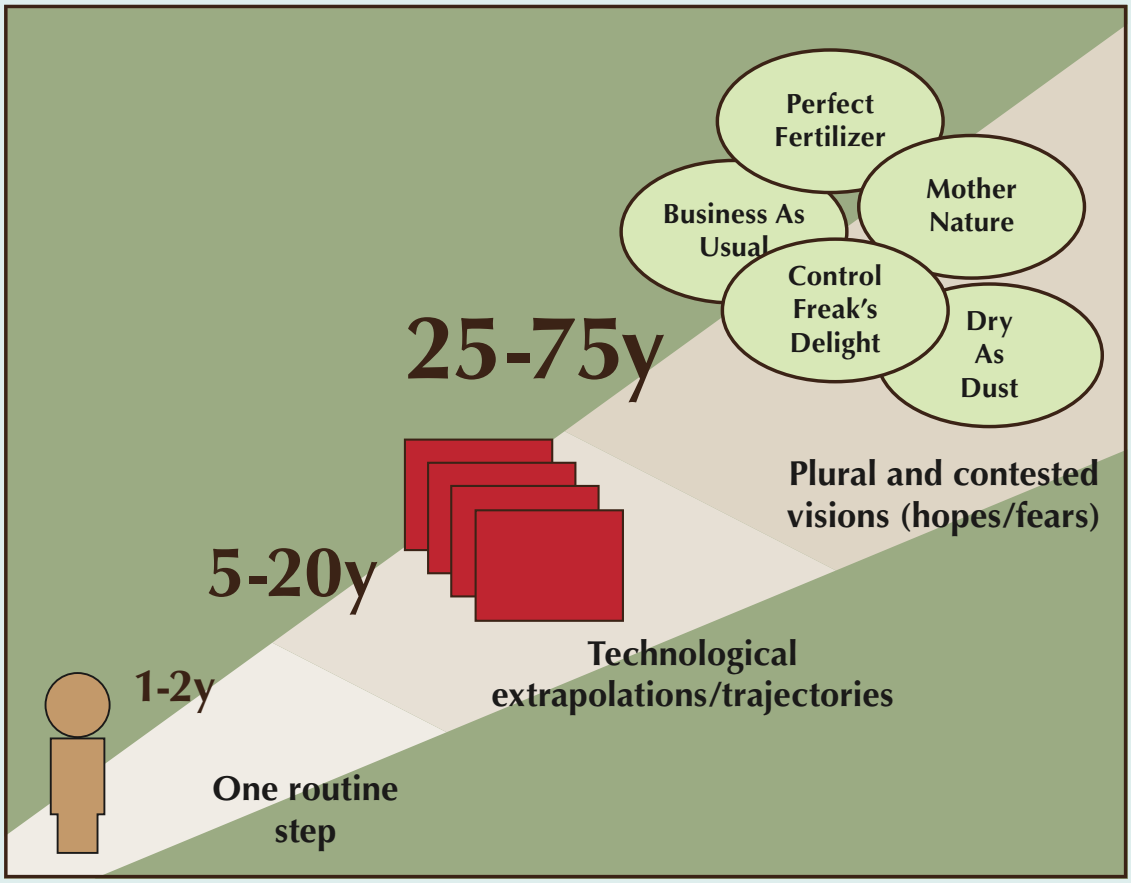


Figure ES1:
Framing the "big picture" of how the city might evolve to become a force for good in its environment with, first, the plural (and contested) visions of the distant, inter-generational futures for the city's water infrastructure (green oval domains), second, the technological alternatives (red rectangles) as possible paths towards those futures from, third, the determination and implementation of one routine step "tomorrow".

"sustainability" is — is to get back from the plurality of those distant, dissonant, unshared, target futures to fashion just the "one routine step" tomorrow, at the origin on the left-hand side of Figure ES1.

Engineering and engineers contribute to undertaking this task in two significant — and uniquely distinctive — ways. For it is they who are responsible for inventing and shaping the alternative technological paths (the red rectangles, center-span in Figure ES1) to take us to the distant green ovals from tomorrow's one routine step. It is in the destiny of engineers too to be part of the great adventure in computational simulation, on its way towards the ever-receding virtual reality. To engineers fall therefore the privilege and responsibility to probe, explore, and assess the reachability of the distant targets, under huge, gross uncertainty and vagueness, should we place our foot this way or that as we step out tomorrow, on one or the other path of innovation and re-engineering. Engineers may even need to be persuasive artists: in the sense of commanding the art of communicating their professional opinions to the public at large, while yet being members of that self-same community, with feelings and emotions, and where some of this artistry and artfulness will reside in the virtual reality itself.

All of this entangled, riotous variety must be narrowed back into the singularity of the decision at the origin in the lower left corner of Figure ES1: there to express from the big picture *the* course of action to be pursued. It would be that one routine step tomorrow, conditioned upon the *prior* expressions of what the people want, in their own *several* voices, as their green ovals of the distant future. From each perspective, it should give "us" more of what "we" want, less of what "we" do not want (for that would be more of what "they" want), under the inevitable *plurality* of "we's". Such plurality — as in the policy benefitting accordingly from a plurality of the wisdoms of the "we's" — is to be celebrated. If, from "our" perspective, the decision does not give "us" much of what we want, "we" might go along grudgingly *for a while* — noisy dissonance and disagreement not eliminated, merely biding their time, before resurfacing.

Enabling or Disabling Governance: Around and About the Framing of the Picture

There is not just one routine step, of course, determined now, once and for all, once for ever. There is the picture of Figure ES1 at time t_k. And given the decision, and its unfolding consequences, there will come a time t_{k+1} for the next step, with another picture, with re-arranged and re-expressed green and red icons for the community's aspirations and the alternative technological paths. After a while, it will be time too to re-air grudges, grievances, dissatisfactions, and satisfactions.

Governance — bestowing {social legitimacy} on the entire iterative process, or not (as the case may be) — is the surrounding frame of the picture (of Figure ES1): entry *via* expression of the green oval domains, exit at the origin of the one routine step, and then re-entry, and so on. What form of governance is enabling, and what disabling, of the process: of coming successively back to tomorrow's policy step, conditioned upon considerations of the evolving distant aspirations of greater sustainability and the evolving possibilities of technological paths towards them? Between t_k and t_{k+1}, how might we engage in acquiring more of the enabling structure of governance and shedding some of the disabling? Can the one routine policy step tomorrow be designed *deliberately* to experiment with forms of governance over the period t_k to t_{k+1}?

The words "adaptive management" are today almost as ubiquitous as "sustainable development". As originally expressed by Holling, policy within adaptive management had two purposes: to steer the behavior of the environment in some desired direction; and to probe the environment, so as to reduce the uncertainty in understanding its behavior, i.e., to learn something about that behavior. Could each successive policy step be designed to probe in addition not only the community's understanding of its interaction with the environment (Man interacting with Environment), but also that community's understanding of its own behavior (Man with Man), hence appreciation of the advantages and disadvantages of its institutional structures of governance? We should call this adaptive community learning.

In all the extensive discussion of the "global water crisis" as a crisis of governance, no-one appears to have pointed to the advantages of metropolitan governance for enabling progressively less unsustainability of IUWM within IWRM. We, the community of water professionals, may not be casting a covetous eye on such promising forms of governance. Others are, however. Ecological economist Gatzweiler wishes to borrow from them in order to organize a "Public Ecosystem Service Economy for Sustaining Biodiversity" in the cultivation of natural strains of coffee in the highlands of Ethiopia. It is the scope

for experimentation and learning that he prizes (amongst other attributes) in metropolitan governance. Economist Paul Romer sees cities as being deliberately designed as forces for social good. Cities with enabling rules of governance, he says, should be built to secure sustainability where the surrounding (national) economic and political environments are otherwise not conducive to such.

Change: the Only Constant in Life

Everything changes over the generations: science bases, technologies, and institutional structures of governance; our appreciation of {social legitimacy}, our valuations of {economic feasibility}, and schools of thought on {environmental benignity}; in short, our ways of judging what constitutes sustainability. And we dare to conjecture on charting the course of this change: a conjecture sufficient for refutation or corroboration, in the fullness of time and in the light of the experience of practice. If all else around us is changing, why should we expect the criteria for assessing sustainability to remain invariant? We have a view of the current contents of Triple Bottom Line (TBL) accounting. Label it TBL_{now} for short. In this *Concepts Paper* we move towards closure — for the time being — with an expression of its possible future contents, i.e., a candidate TBL_{future}. Iteration around Figure ES1 between t_k and t_{k+1} can seem as but the smallness of one brief, routine step within the grander embrace of migrating from TBL_{now} towards TBL_{future}.

Stepping Out in Practice: The Essential Top Line

All of this is fine, in concept. No apology is made for this having been the purpose: to provide pause for thought. Yet what should be said of putting concept into practice and, every bit as much, enabling practical experience continually to re-shape concept, by design, including any future edition of this *Concepts Paper*?

Scanning across the outermost reaches of practical experiences in implementing our arrangement of the elements of the TBL in the "real world", we can assemble a practical $TBL_{frontier}$. Done in the final re-draft of the *Paper*, when all of the preamble culminating in expression of the conceptual TBL_{future} had become seemingly immutable (and now beneficially so), the $TBL_{frontier}$ is the empirical "posterior" to the theoretical "prior" of the TBL_{future}. The result is telling: of where elements of the TBL_{future} lead their counterparts of the $TBL_{frontier}$, specifically, in some of the grander notions of {economic feasibility}; and of where they lag, notably in some joined-up thinking about {environmental benignity}.

We know the aphorism of "Thinking Globally, Acting Locally". In this *Concepts Paper* we see its complement, in:

Engineers "Acting Most Locally" to engender a community eager to engage in "Thinking Globally"

Leading to Learn

Thus it is that the entirety of this *Concepts Paper* can be distilled down to its essence in Table ES1: from things as we conceive of them today (TBL_{now}; the second column of the table), stepping out in practice at the cutting edge of concept (the $TBL_{frontier}$ in the third column of the table), to shape and re-shape what might become our concepts of the distant future (TBL_{future}; fourth column). Fourteen line items, crowned by a fifteenth, at the top of the table:

Always Learning; Never Getting it Right

For this, the "self-transforming mind that leads to learn" — in the words of psychologists Kegan and Lahey (from their book *Immunity to Change: How to Overcome It and Unlock Potential in Yourself and Your Organization*) — would seem to have arrived not a moment too soon

Such compression — into the single page of Table ES1 (eventual outcome); the single diagram of Figure ES1 (the means to fashion an actionable step); and the single page of Box ES1 (original challenge) — entails massive encryption of concepts, hence the need to read this *Concepts Paper* in full, and to disagree with its perspective and its contrariness.

LINE ITEM	TBL_{now}	STEPPING OUT IN PRACTICE ($TBL_{frontier}$)	TBL_{future}
(T0) ORGANIZATIONAL LEARNING		Yarra Valley Water seeks change through organizational learning	"Always Learning, Never Getting It Right"; in pursuit of the self-transforming mind, which "leads to learn"; entertaining self-contradiction, including abandoning a line item, even "sustainability" itself
(T1) Personal Aspirations	Health and hygiene	Sulabh Sanitation & Social Reform Movement elevates women scavengers to the fashion catwalk at UN Headquarters	Towards a well-being sufficient for self-reflexive apprehension of the "big picture"
(T2) Citizen Participation	Individuals empowered to acquire and employ expertise and "know-how"	San Francisco Public Utilities Commission (SFPUC) is accountable to stakeholders from "cradle-to-cradle" in its planning processes	Deliberative democracy
(T3) Social Bonds	"Cultural acceptance", as in adoption of a given style of device or technology	Clean Water Services, Ostara, and the Clean Water Institute have evolved a tripartite, institutional synergy amongst public-, private-, not-for-profit sectors	Benefitting from multiple (four) wisdoms on how to live with one another and nature
(T4) Quality in Governance	Presence of institutional-regulatory framework *per se*	Nepal Water Conservation Foundation is pursuing a clumsy institutional process for restoring the Kathmandu-Bagmati system	Refurbished pluralist democracy of Dahl; adaptive community learning
(T5) Ethics and Equity		Sydney Water employs inter-generational equity as a matter of routine in screening projects	Variety of standpoints on the consequences of inappropriate behavior in man-to-man, man-to-nature, individual-to-group, present-to-future generation, seller-to-buyer, and other relationships
(T6) Valuation	Engineering economics; user/service fees/revenues	Over 300 Water Health Centers signal private-sector business-model success for Water Health International	Plurality of what counts economically; bequests to the future ("final environmental wills and testaments")
(T7) Environment Within the Language of Business	Biodiversity		Natural capital, ecosystem services, and service providers; risks to "business as usual" through loss of biodiversity
(T8) Supply-Value Chains	None beyond "factory (treatment plant) fence-line"	50 cities committed to UN Global Compact; CH2MHill, Halcrow and other water businesses are signatories of Global Compact's CEO Water Mandate	Exercise of power ever further along ever more extended and intricately interwoven chains of commercial relationships
(T9) Commercial Sectors	Water ... alone	Veolia Water UK as "Multi-utility Services Company" (MUSCO)	Water sector ... and nutrient and energy sectors ... and more
(T10) Space	IUWM or IWRM; rarely both	DHV Group (Consulting Engineers) re-engineers Soerendonk Sewage Treatment Plant to blur distinction between sewage treatment and river habitat	From Earth Systems Analysis to individual agency (e.g., dietary preferences)
(T11) Life Cycle and Time	Expenditures and revenue streams over time	The Natural Step has worked with Yarra Valley Water on Life Cycle Analyses	From cradle to cradle analyses
(T12) Function	Adaptability; durability; robustness-vulnerability; reliability	Within IBM's Smarter Planet and Smarter City portfolio, Galway, Ireland is acquiring a SmartBay	Ecological resilience and biomedical self-repair
(T13) Gauging Environmental Benignity	Environmental degradation: pollution syndromes; eco-efficiency	Ostara, Clean Water Services and British Columbia Conservation Foundation partner to issue nutrient supplements to restore declining salmon stocks	Biomimicry: appetite; metabolism; pulse
(T14) Cycling of Materials	Man's appropriation/ consumption of resources (water, nutrients, energy, and land area)	Severn Trent plc acknowledges water-cycle and carbon-cycle policy antagonisms; Resources Centres on Urban Agriculture & Food Security (RUAF) promote Sustainable Urban Nutrient Management	Natural nutrient cycles and technical nutrient cycles; dematerialization; eco-effectiveness

Table ES1 Triple Bottom Line (TBL) accounting for sustainability: a summary of contemporary usage (TBL_{now}), elements of water-sector practice in the vanguard ($TBL_{frontier}$), and what might be conceived of for the future (TBL_{future}).

Acknowledgments

I have learned a very great deal indeed in writing this *Sustainability Concepts Paper.* Above all, I have enjoyed the privilege and good fortune to rub shoulders with Michael Thompson for the past several years. Not only have I learned so much from Mike, I have rarely laughed so heartily when entertained by him. I am profoundly indebted to Mike. For those who fear my captivity in Cultural Theory, allow me to reassure you: I believe there is never one key to unlocking better understanding — of the workings of Society, by an engineer, in this case. I look forward to being handed other designs of keys to other insights; even their being thrust at me in response to this *Concepts Paper.*

I owe Andrew Speers a vote of sincere thanks, and an apology. I am sorry I have been unable to deliver these goods in the manner in which they were originally intended. To Cedo Maksimovic, I am indebted for release from what I came to see, in retrospect, as the burden of writing on behalf of a collective, shared perspective.

For the paper I *did* eventually write for Cedo, I am grateful to Bruce Rittman for inviting me to speak as the keynote at the 5th IWA Leading-Edge Technology Symposium in Zürich (June, 2008). In particular, I am indebted — as always — to my graduate students (Rodrigo Villarroel Walker, Feng Jiang, and Shi Feng, in this instance) for undertaking the computational work that reined in my conceptual excesses, if that is what they were. The benefit of their influence is apparent in this *Concepts Paper*, in particular, in its discussion of {environmental benignity} in Chapters 3.3 and 3.4. From time to time, Charles van der Haegen puts an altogether different style of thought-provoking material before me, on this occasion notably the book of Kegan-Lahey, to which the culmination of Chapter 5.2 is entirely devoted.

To have been the Wheatley-Georgia Research Alliance Professor and Eminent Scholar in the Warnell School of Forestry and Natural Resources at the University of Georgia (UGA) has been an honor. To those who contributed to the making of this, I am for ever indebted. Special thanks are also due to Jenny Yearwood, Program Coordinator for Water Resources, in my office at UGA, as well as J P Bond and Elizabeth Hagin, who were responsible for the graphics and design of this *Paper.*

I have long enjoyed watching — and participating in (if I might presume so) — the growth of the International Water Association (IWA), and by leaps and bounds. My prosperity in that organization has benefitted from its "openness to new ideas" and "lack of suffocating bureaucracy". These traits are to be treasured by any organization and never to be ceded, no matter how large and influential the organization might become. It has accordingly been a pleasure to work with my several fellow water professionals on the Management Board of the IWA Specialist Group on Sustainability in the Water Sector. I am especially indebted to Paul Jeffrey and George Crawford, who installed the IWA Prizes for Sustainability in the Water Sector, obliging me thereby to review all the details of all the submissions for those awards in their inaugural year (2008). It was a privileged insight into the "state-of-the-art". Cheryl Davis, Saburo Matsui, Steve Kenway, and Eric Rosenblum deserve my thanks for helping me with their various insights. Cheryl's distinctive contribution to the human (and lyrical) dimension of sustainability is liberally quoted in Chapter 6. It has also been a pleasure to have worked alongside Keith Robertson and Adrian Puigarnau, and to watch them grow in stature with the organization. Thank you also, Keith and Adrian, for badgering me about this *Concepts Paper*, these past (too many) years.

My continuing and long-standing association with Imperial College is palpable in the visual material of this *Concepts Paper*, in particular. It dates back to October, 2004, when I hosted a Seminar at Imperial on "Sustainability: Never Mind the Engineering Principles — Just Deal with the People, Politics, and Public Relations". I am grateful to a member of the academic staff of the Department of Civil and Environmental Engineering who accused me (on that day) of having done nothing more than re-discover that there was a Society "out there" (with which engineers have to deal).

And then there is the International Institute for Applied Systems Analysis (IIASA) to thank. If I achieve anything in furthering inter-disciplinary work, I owe this achievement to my long-standing association with IIASA. That is how I came to know Michael Thompson, as well as write the short essay on Cities with Mike (Anthropologist) and Paul Crutzen (Atmospheric Chemist) for the US National Academy of Engineering. The Challenges of the foregoing *Executive Summary* are taken from that essay. My current program of research on "Cities as Forces for Good in the Environment" originates in all of this.

A decade ago I made a strictly personal dedication of the book *Environmental Foresight and Models: A Manifesto* to members of my family. Confident in the knowledge they remain unaware of it, I make another:

Thank you, again. I really do do what you always imagined was my work.

M B Beck

Athens, Georgia
August, 2011

Chapter 1: Introduction

> "Without an operational definition of sustainability with which to work, we shall not make any progress in this project."

Such remains the common refrain, more than twenty years on from 1987, the year we now generally mark as the beginning of the global movement towards sustainable development.

People speak of an "industry" of indicator-generation that has since sprung up. There is convincing evidence of this. "Assessment Frameworks, Indicators, and Metrics", merits a two-volume special issue of the journal of *Engineering Sustainability* of the UK Institution of Civil Engineers (Fenner, 2008). Even alternative procedures (Cobiac, 2006) have arisen — amongst which we must choose — for choosing the indicators, which will subsequently be applied for the purpose of evaluating policies and progress towards sustainability. Or should we be thinking in terms of "unsustainability", defining it instead, and reaching for indicators for gauging movement away from it? It is as though we have been driven back, through lack of success in defining what was originally the object of interest, to defining a lengthening succession of increasingly subsidiary objects, with which then to remount our attack on the original matter of concern.

The absence of a sufficiently satisfying definition or indicator set is surely not for want of trying. A host of definitions of sustainability and sustainable development has become available to us in these past twenty years and more: definitions in respect of development around the globe; for the world community and economy, in general; as much as for the water sector, in particular (for example, Loucks and Gladwell, 1998). Sustainability fully deserves such attention. It is undeniably a BIG idea. It should not be anything less, given the scale of the problems to which it is addressed.

It is also frustratingly vague and imprecise, remarkably resistant to any better definition than that first coined (to paraphrase):

> Doing well now by the biosphere and the stock of natural capital and flow of services therefrom entails doing at least as well generations hence.

It is unquestionably about the long view into our future. And when we "do", what we do must be judged — by those who will bear the brunt of the doing — to be socially acceptable, economically feasible, and environmentally benign (Elkington, 1998).

The primary purpose of this *Sustainability Concepts Paper* is not to contribute to yet another operational definition or indicator set, for what it might mean to have sustainability in the water sector, or more precisely, sustainability in the pursuit of Integrated Urban Water Management (IUWM) nested within Integrated Water Resources Management (IWRM). Rather, this is a *Concepts* paper: a discussion resonant with the notion of sustainability as a big *idea*, written from the perspective of Engineering and the Engineer.

In setting out thus some concepts of what "IUWM within IWRM" could be, and how we can move from where we are now to where these aspirations might lead, part of our purpose initially is to act as a counterpoint to the copious attempts at definition, precision, reproducibility, standardization, codification, procedural systematization, and so forth. This does not mean any tightness of logic is to be sacrificed. On the contrary, it will become especially vital in charting the changes in the way we assess sustainability in Chapters 5 and 6.

If, however, the contrarian stance provokes debate and protest, that indeed will be a measure of its success. So let us start by seeking to be contentious, and on two accounts.

Wrong-headed Convergence Towards Conformity and Singularity

In the midst of discomforting imprecision, vagueness, and uncertainty — when *surely* there should instead be clarity in what the problem is, specificity in what our aspiration is, and prescription in the path to the solution — the urge to converge on

Getting it right; finding *the* unique solution; hence moving measurably forward

can become almost overwhelming. It should be resisted, of course! William Rees, co-author of the ecological footprint, has berated the successful LEED program for promoting green buildings with the following words (Rees, 2009):

> Consistent with Heidegger's lament, the LEED programme has been accepted uncritically (i.e., almost thoughtlessly) as a sustainability solution with little consideration to whether it is actually addressing the fundamental problem of global overshoot and rarely any adjustment to vastly differing local conditions and requirements.
>
> LEED is a reform at the margin that would deliver a more energy- and material-efficient version of the otherwise status quo.

Once was the time when we could indeed have imagined there was just *one* way of becoming less unsustainable in the water sector, a seeming singularity. This was more apparent than real, however. For it depended upon listening to but one of the several players on the global water scene, each of whom tended to assert that it — and it alone — possessed *the* "answer" to becoming sustainable. Given the crowded field of many such players, what one was actually witnessing was more the advocacy of a plurality, if not plethora, of seeming certitudes, even mutually contradictory certitudes (Thompson, 1985).[1]

Engineering education perhaps unwittingly aids and abets the urge towards the singularities of conformity, with all its protocols, procedures, standards, codes of practice, and the like. This we fully appreciate and respect. It has to do with minimizing the risk of failure. But what might constitute "failure" in the context of engineering for sustainable development? Should students of Engineering, like those of History or Philosophy, be taught that there is more than one school of thought; more than one basic style of building a water purification plant, for example; more than a single set of fundamental principles — to be very provocative — for that particular branch of engineering design?

We should not be surprised by there being disagreement over the essential matter of this *Paper*. The plurality of schools of thought on the nature of that essence, moreover, can surely be held to be valid at one and the same time. The approaches of both Ashley *et al* (200) and Starkl *et al* (2009) have been lauded: as recipients of the Award for Excellence in achieving theoretical progress in Sustainability in the Water Sector (inaugurated by the International Water Association (IWA) in 2008). The one (Ashley *et al*, 2008) acknowledges (but largely dismisses) the other's refutation of generic criteria for assessing sustainability, for they (Starkl *et al*, 2009) argue thus:

> In implementing such ambitious policies, one needs to distinguish case sensitive objectives (they are to be defined for each problem, depending upon the applicable regulations) from generic ones (they are prescribed for all cases). The solidification of case sensitive objectives gives the local decision-makers (developers, planners, authorities) a certain amount of autonomy. However, it may introduce uncertainty (court appeals, project delays, cost excesses), where different persons think about the same issue in different ways. ... This form of case sensitivity barely matters for the objectives of class A (cost minimization) [subject to the constraints of environmental regulations], it may matter for B1 [seek an environmentally best alternative in the case of similar costs of the alternatives], and it is highly relevant to B2 (optimization of ecological efficiency) and C (maximization of overall benefits) [in the context of sustainability].

The deeper one delves into what it may mean to become less unsustainable, the more the disagreement matters. Counter-intuitively, disagreement and conflict might matter in ways that (up to a point) are to be constructively harnessed.

Plurality of perspective reigns supreme. There is no simplicity to be wrung from an irreducible complexity.

How then should we proceed in the absence of a shared, consensual, singular, complete definition of a "sustainable IUWM within IWRM", especially when achieving such singularity and conformity runs against

[1] This jostling for position may yet apply. In their recent theoretical exploration of global governance for water, Pahl-Wostl *et al* (2008), contend that "[t]he various global initiatives developed to date appear to compete for influence rather than move toward coordination".

the deep grain of the mind-boggling cultural diversity so evident around the world?

The Essential Long View: Conspicuous By Its Absence

Sustainability is nothing, if it is not about taking the long view and being mindful of what will, what might, and what must, change from one generation to the next. We have to look up from our day-to-day routine — each day — to recall and re-shape the vision of sustainability. And there can be no question: the world in so many places needs now, not tomorrow, the engineered infrastructures for providing life-giving potable water and health-preserving sanitation. Yet those infrastructures must just as much be conceived of as a first step along a path evolving towards greater sustainability a generation hence.

All too often, the long view is conspicuous by its absence from many discussions with "Sustainability" prominent in their titles. Either that, or the sheer urgency arising from looking back at an enduring, unmet historic need — provision of safe water and sanitation for all — may induce myopia when looking in the other direction, towards the distant future.

How too then should we proceed when adoption of the very long view is the one *distinguishing* — if not *defining*! — feature of being less unsustainable, not least when Society's views on what constitutes a "good thing" are bound to change, and change substantially? For all their current command of the global attention, sustainability and sustainable development will themselves just as surely be swept away in due course by the next yet better "solution".

We acknowledge then that we are proceeding in the spirit of "Always Learning; Never Getting it Right". Change is the only constant in life.

Forward in the Face of Vagueness

This *Concepts Paper* is therefore about setting out a framework for thoughtful guidance of actions today in respect of achieving less unsustainable forms of IUWM within IWRM, without our losing sight of the inter-generational consequences of these actions. And it is just as much about preparing this philosophical framework itself for change and evolution — a few years from now — as we continue to learn from our everyday actions.

Nor can what is to be said be confined and packaged merely as succinctly expressed insights, although it can in the end be tabulated cryptically, as a set of line items within the context of Triple Bottom Line (TBL) accounting (Elkington, 1998). Instead, the reader will be confronted with a lengthy discourse, in which insights and messages are intricately interwoven, if not densely entangled, at several levels of interpretation.[2] What is to be said, moreover, must necessarily be written from one perspective, i.e., one particular disciplinary perspective, given which this *Paper* is bound to be biased, inadequate, and quite incomplete in the face of the massively multi-disciplinary nature of sustainability and its framing around the Triple Bottom Line.

We shall set out in Chapter 2, therefore, a challenge and a vision. These are motivated by a metaphor, of the city as a "large animal grazing in its pasture" (Rees and Wackernagel, 1996). They are conditioned upon some of the relevant history of the past century, especially the two decades since the 1980s. Above all, they are perhaps uncommon, even preposterous, in their intent: of re-engineering urban water infrastructure so as to make the city a force for good in its watershed (Beck *et al*, 2010a). This challenge and vision could even come to be viewed as yet another contrarian element of this *Paper*. They are essential, however, in keeping our discussion focused, as it threads its way through the labyrinth of the three bottom lines in Chapter 3: first, of {social legitimacy}, wherein plurality of perspective is everywhere to be found (and faced); second, of {economic feasibility}, with its high-minded principles unmistakably cast within the long view; and third, of {environmental benignity}, throughout which our

[2] In defense of this, and in spite of one's best endeavors, over several years and through several drafts, the present lengthy text is not entirely out of line with other similar documents, such as the highly influential report of the Global Water Partnership on Integrated Water Resources Management (GWP, 2000a) and the SIWI-IWMI (2004) policy-position paper *More Nutrition Per Drop*. Here too, in this footnote, I — the author; the "one" cited in the previous sentence — should address an issue of style. I shall occasionally resort to such use of the first-person singular (I), when I want to make a personal attribution especially clear. "The author" sounds stiff, impersonal, and perhaps out of keeping with the contemporary idiom. Otherwise, I tend to write as "we", a form I like because of its hint of gathering the reader with me into some joint endeavor.

metaphor may be pushed to its limit in constructing a response to the challenge and vision.[3]

That biological metaphor, of the city as a large animal interpreted as a bull, which then elides into the image of an athlete, is not some silly play on words. It is a powerful means of conceiving of what sustainable forms of IUWM within IWRM could be, without jettisoning the companion metaphor of the clockwork mechanism as the epitome of engineering design and innovation.

When all is said and done, our predicament remains: of how to move forward under vagueness. This is the subject of Chapter 4. Yet vagueness is not necessarily a bar on discerning how, specifically, to proceed. History encourages us in the view that the original Brundtland expression of sustainability, for all its vagueness (indeed perhaps precisely because of it), may have the power to inspire, motivate, and innovate *in practice* — just as did Aldo Leopold's land ethic of six and more decades ago (Leopold, 1949). Leopold's inspiration was expressed thus: "a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community". No matter how vague this may be, almost tautological, the evidence shows it has motivated many over the years to restore and treasure landscapes and environments in palpable ways (Meine and Knight, 1999), including expressly the IUWM within IWRM now before us (Rosenblum, 2005).

Preparing for Change

Change is indeed the only constant in life and wrestling with it still is how we shall close this *Concepts Paper*. Chapter 5 charts the eternal change and flux, from how we have conceived currently of the Triple Bottom Line, i.e., the TBL_{now}, to how we might imagine concepts for assessing sustainability in the future (a TBL_{future}). Chapter 6 calibrates this TBL_{future} against what is presently being achieved in the forward-most reaches of practice, at the $TBL_{frontier}$.

Cheryl Davis of the San Francisco Public Utilities Commission has quoted an insight of Aldo Leopold towards the close of her essay on "Ethical Dilemmas in Water Recycling" (Davis, 2008):

> Let no man jump to the conclusion that [the ordinary man] must take his Ph.D. in ecology before he can 'see' his country. On the contrary, the Ph.D. may be as callous as an undertaker to the mysteries at which he officiates.

A *Concepts Paper* should be mindful of this Leopoldian "Ph.D." In the *practice* of the $TBL_{frontier}$, hence in Chapter 6 also, resides the engine of yet further change to our concepts of sustainability and its assessment. And so the saga will continue:

Always Learning; Never Getting It Right.

[3] Wherever emphasis is to be placed on any of the triple bottom lines, so the device of placing the phrase within parentheses {...} will be employed.

Chapter 2: Engineering, Water, and Sustainability

> In proposing a new model of watershed management for the 21st Century, ecologists have rejected the "quick engineering fix" of the 20th Century (Poff *et al,* 2003).

Looking back over twenty years of the Ganga Action Plan, Crandall Hollick relates the sad tale of a technocracy bent on cleaning up that river through centralized wastewater treatment systems, as in the city of Kanpur (in *Ganga: A Journey Down the Ganges River*; Crandall Hollick, 2007). Funds were available for planning, design, and construction, in rapid succession, but *not* beyond: *not* for the lengthy, drawn-out operational stage in an infrastructure's life cycle.

That there might at project conception be such short-sightedness in the "quick engineering fix" has long been well known. The case of Kanpur would seem to have played out on a grand scale what had become recognized by the late 1970s as the stunted conceptual life-cycle of most of the then civil and environmental engineering projects (Beck, 1981; compare with Beck, 2005). If the fixation on operations of Beck (1981) could be deemed prescient with hindsight — or simply an alternative, minority school of thought (as eventually set out in Box 1 and, in more detail, in Box 3) — we should derive no joy whatsoever from what has unfolded since in the Ganga Action Plan.

One of the defining features of sustainability has become that of providing the dogged, determined, compensatory focus on the distant future — on the long view. At times it will be discomforting, and should be.

2.1 Integrated Water Resources Management and Integrated Urban Water Management

Much has been said of Integrated Water Resources Management (IWRM), since the concept was brought back to the center-stage of our thinking and further elaborated by the Technical Advisory Committee of the Global Water Partnership (GWP) in 2000 (GWP, 2000; Giupponi *et al*, 2006; UCOWR, 2006; Jeffrey and Geary, 2006). Some of what has been said of it, moreover, has been to this effect: that IWRM has been practised in various successively less rudimentary forms for more than a century in the modern era (Beck, 2005), most notably in the industrial watersheds of northern Germany (see, for example, the Emschergenossenschaft; Raasch and Schüler, 2007).

Not for the first time, IWRM has become the well-spring for conceiving of how to steward water, infrastructure, and land use within a watershed — now in "sustainable ways", in contemporary parlance. Integration here has several dimensions to it, along each of which the purview of our thinking is being enlarged, to embrace a more balanced spectrum of disciplines and to erase unhelpful and entrenched divides amongst the parts[4] (Beck, 2005): over time, as in thinking across the various stages in a project's life cycle; in space; in respect of surface and sub-surface waters, and likewise aquatic and terrestrial environments; in what is to be counted (literally) in the economics of providing water and sanitation services; amongst fragmented institutional units for managing each component of the infrastructure; amongst the perspectives of individuals, communities, and local, regional, and central governments; and between the lay member of society, on the one hand, and professionals and experts on the other.

Falkenmark (2005) has summed up the gathering social orientation of IWRM in her phrase "hydro-solidarity". She has since extended this to embrace "ecohydrosolidarity" (Falkenmark, 2009).

With the "I" of IWRM (and IUWM) comes the recipe for ever greater complexity in assessing the sustainability of an engineering intervention or a policy. Intuitively, we appreciate the spreading scope of sustainability: the shared exhortation, both to attain the whole perspective of Earth Systems Analysis, and to reflect on the most intimate of personal choices and ethics. In short, as in the deceptively trite aphorism, we are to:

> "Think (ever more) globally, while continuing to act (very) locally".

[4] And the number of those constituent parts can only but increase the broader the purview becomes.

From the Global Appropriation of Water for Agriculture ...

We know the enormity of the impact of agriculture on water resources and water quality in the watershed. With book titles such as *When The Rivers Run Dry*, we can be left in little doubt as to the dominant role of agriculture in the way in which regions and countries "burn up" their natural, geographical endowments of water in producing food (Pearce, 2006). An article in the *New Yorker* of the same year seeks similarly to grab the general public's attention with its title *The Last Drop* (Specter, 2006).

Cities and urban communities, in contrast, are the focus of the most intense social and economic activities within a watershed. Witness, for example, the recent accounts of a comprehensive study of the interplay over the centuries between the city of Paris and the Seine watershed (Billen *et al*, 2007a,b). People across the world continue to migrate from rural to urban areas, today in ever larger numbers. There, in the city, they may move along the poverty-affluence continuum, with accompanying changing choices over diet (Tilman *et al,* 2002). Thus will derive changing market signals sent out from consumers in cities in respect of the preferred foodstuffs to be produced in the rural hinterlands (SIWI-IWMI, 2004).

While no-one could doubt the magnitude of the impact of cities on their environments, there *is* nevertheless a tenable proposition: that when viewed globally within the context of water resources, savings on water consumption in cities may be of but marginal significance, relative to "doing something about agriculture". Yet very personal and local choices within the city, and very many of them, all regarding food, *not* water, can have significant consequences for agriculture.

Agriculture, as if we needed reminding, is primarily about putting nutrients in our mouths — *More Nutrition Per Drop* (SIWI-IWMI, 2004)[5] — albeit with massive, secondary implications for water. With food in our mouths, with the flux of nutrients into the city, what then is the fate of these nutrients thereafter, other than sequestration in the standing stock of city dwellers? What, even though this is a paper about sustainability in the water sector, is the impact of the city not merely on water resources (and allied energy resources), but also on the nutrient-resources sector, and its allied part of the energy sector?

Huge quantities of water and nutrients may be pushed through the rural systems of agriculture and livestock production. Increasingly, however, personal preferences and market signals as to what should be produced in those systems, if not how this "daily bread"[6] is produced, will emanate from urban communities, as the motor of that "pushing" (SIWI-IWMI, 2004). Modernity, industrialization, and technocracy, focused on urbanization and cities (often creatively so; van Noorden, 2010; Glaeser, 2011), are collectively the driving forces today. They are the unseen, but far from insignificant, forces driving what become manifest as "water crises" in the rural landscape. In that sense, the social and economic activities of cities are primary drivers of the movement of materials around the globe. The history of Paris within the Seine watershed, and the city's symbiotic relationship with its rural surroundings in respect of their common "nutrient metabolism", especially during the 1800s, is exceptionally well recounted in Barles (2007a,b), Billen *et al* (2007a,b), and their accompanying papers (in a special issue of *Science of the Total Environment*).

... To the Local and Personal Appropriation of Water for Urban Sanitation

Those same social and economic activities of cities, driving (in part) Man's appropriation of water across the agricultural landscape, are themselves enabled, if not powered, by Man's appropriation of water in systems of sanitation for maintaining public health in cities. McGreevey *et al* (2009) observe this:

> Until there could be a solution of child death from water-borne infections, the [industrial] revolution that began with science and invention decades even centuries earlier would remain incomplete.
>
> Ill health in cities before 1870 created a barrier and a bottleneck inhibiting the growth possibilities deriving from propinquity. The barrier, once broken, allowed urban agglomeration to flourish, producing conditions that accelerated information exchange, invention, innovation, and economic growth.

[5] As an advance on the preceding slogan of "more crop per drop".

[6] Or whatever is the culturally appropriate staple of one's diet.

The same relationship, between public health and the economic success of cities, has contributed to economist Glaeser (2011) nominating cities as mankind's greatest invention.

What happens in cities is profoundly affected by Man's *local* appropriation of water from its natural cycle (for sanitation) and profoundly important for his *global* appropriation of water (for the production of food and fiber) — and every bit as important for the local removal of nutrients from cities and their return into the global cycling of nutrients.

The concept of Integrated Urban Water Management (IUWM) seeks much the same benefits as does the concept of IWRM. These are benefits to flow from integrating considerations over all of the physical and engineered features of the urban water infrastructure: abstraction of water from the environment; its treatment; distribution through the potable supply network; the sewer network; the wastewater treatment plant; urban surface water; urban groundwater; and so on. When nested within the wider perspective of IWRM, however, such features may often pale into insignificance. Worse still, yet other features of vital importance can appear to have been overlooked altogether, even in the very best of contemporary studies (see Beck *et al*, 2009).

Consider what for many epitomizes the role of Engineering as a provider of solutions: the computational, or mathematical, model (***M***). Its assembly and deployment in the service of IUWM (within IWRM) are especially revealing, of what is to be counted (and what not) in the associated thinking and analysis. For all their other successes, the Paris-Seine studies convey this impression (Billen *et al*, 2007a). The vast and intense social and economic activities of 10,000,000 agents — people, that is, behaving as consumers, citizens, enfranchised stakeholders, adopters of technologies, holding a plurality of cultural perspectives on sustainability, having a growing interest in Man's relationship with the Environment, perhaps even contemplating Gibbons' (1999) suggestion of Science being in need of a new contract with Society — are compressed into but a single, inanimate vector of time-invariant boundary conditions of the watershed model (***M***). All this is compressed down to a point, as in a point-source discharge of treated wastewater.

People, of course, should be highly prominent in the account of the city. Without such, IUWM does not deserve to be credited with the quality of being "Integrated". It is thus the citizens, their diets, their tele-connections to the wider global system of food production, and their local connection to a system of sanitation, that should appear in the picture — and be counted. People as farmers, after all, are in sharp contrast frequently acknowledged and accounted for expressly as simulated agents in the simulated landscapes of watershed analyses (Janssen and Carpenter, 1999), in support of IWRM. The difference is as stark as the prominence given to the agency of the lone farmer in the landscape and the insignificance accorded to the *individual* agencies of 10,000,000 inanimate, urban, pollution generators.

If one conceives of what passes through the individual, the individual household, garden, back yard, street, office complex, industry, or any other water- and nutrient-processing entity in the city, and then thinks through the literally global ramifications of the engineering and management of the infrastructure required to secure the health and prosperity of those entities, within the city, within its watershed — then that is Integrated Urban Water Management (IUWM), embedded within IWRM.

2.2 Cities of the Global North: Infrastructure and Technological Lock-in

> "Wastewater treatment plants would work fine, if only people would eat just salads in winter and just goulash in the summer" (Watts, 1993)

Most discussions of IUWM equate the generic "Urban" with what happens specifically in cities of the Global North, with their paradigm of using water to convey the residuals of the metabolisms of the city and its citizens, from within the core of the city's confined spaces, back into its surrounding environment. Some mischievous reader of Barles' (2007a) historical analysis of Paris in respect of "feeding the city"— taking advantage of well-known cultural diversities — might ruefully argue that introduction from the late 1800s onwards of the British invention of the water closet (WC) caused Paris to become an unappealing "bull" in the "china shop" of the Seine watershed.

From the invention of the WC, historically pivotal in the genesis of the infrastructure required to secure public health in the city, hence debatably economic

growth (McGreevey *et al*, 2009), can now be seen to have flowed — with the benefit of substantial hindsight — three less-than-positive consequences:

(i) The symbiosis of the urban-rural *nutrient* metabolisms, so prominent in the case of Paris, was severed, as meticulously revealed in Barles (2007b) and echoed likewise in Neset *et al* (2008);[7]

(ii) Nutrients, and subsequently other (polluting) substances, were diverted into the aquatic environment, where they would not "normally" have been headed; and

(iii) The inexorable migration was set in motion, towards the rigid technological lock-in of the current paradigm of comprehensively muddled water and nutrient metabolisms of the city.

Thus we have the lock-in of Figure 1(a), but not everywhere. Cities of the Global North are not *all* of the cities in the world.

The infrastructure of the city of the Global North has been arranged such that the city (in Figure 1) can receive its daily water and daily bread as a matter of stable routine, largely free of the risks and threats arising previously from the vagaries of the weather, principally precipitation. Drought is a continuing clear and present threat to our daily water, of course. To our daily bread, however, it is these days but a remote, if nevertheless economic, threat (for many of us in the Global North, that is). It has become one of those tele-connections we can take for granted, as the sources of foodstuffs are switched amongst the variety of globally distributed food-producing regions, any one of which (though not all at once) may be suffering from some form of precipitation-related damage or elimination. Flooding of the urban environment remains just as much a risk to public health as always, through either the presence of combined sewerage, or the literal overwhelming and debilitation of the normal services of low-lying water and wastewater treatment facilities by extreme events, such as hurricanes in the south-eastern USA (Burkholder *et al*, 2004). The threat of flooding — from precipitation (as opposed to sea-level rise) — may itself be heightened by the processes of urbanization themselves (Shepherd *et al*, 2010, 2011).

Unsurprisingly, city infrastructure in the Global North has altogether been arranged to our liking (our social lock-in): to concentrate on conducting our lives according to the daily routines and weekly rhythms we favor; and largely to ignore the mere inconveniences of fluctuations in the natural order of things — droughts over months and years, storms lasting hours and minutes.

The archetypal city of the Global North is intimately connected to the "big picture" of Earth Systems Analysis (Hall and O'Connell, 2007), of "thinking globally": of the global trading, *ergo* movement, of the "virtual water" embodied in producing foodstuffs (Allan, 2003; SIWI-IWMI, 2004), as much as of the global movement of the nutrients embodied in those foods (Grote *et al*, 2005). For every kg of beef eaten, 15 metric tonnes of water have been "burned up" in its production, 2 metric tonnes for each kg of cereal (wheat) consumed (Mekkonen and Hoekstra, 2010). Of all the nitrogen (N) applied to the land in fertilizers, roughly 35% of it will reach our mouths in those cereals (Ladha *et al*, 2005), but only 1.5% in any meat eaten (van den Hoek, 1998). Choices over diet have a significant impact on the big picture (Tilman *et al*, 2002; Kytzia *et al*, 2004; Duchin, 2005; Neset *et al*, 2008). Each of us is thereby connected as an individual into the grand scheme of things and, just as much, into the personal and intimate ways of "acting very locally". Would I, we, or you, dear reader, choose a diet in the interests of generating a "designer sewage" (Henze, 1997) — as Watts (1993), quoted above, so amusingly entreats us?[8]

Whereas the city of Figure 1(b) pulls in from afar the virtual water and actual nutrients of its upstream daily bread, so it has its tele-connections with the distant downstream environment. The rise and fall over the centuries of Paris's discharge of nutrients to the Seine River are mirrored in the (inferred) historic changes in what has been the limiting nutrient of algal growth in the distant coastal Seine Bight (nitrogen, phosphorus, or silicon) and in the occurrence or otherwise of harmful marine algal blooms (Billen *et al*, 2007b). More generally, nutrients are depleted in the soils

[7] Barles' analysis was of the N metabolism of Paris (1790-1970); that of Neset and colleagues was of the P metabolism of the city of Linköping in Sweden (1870-2000).

[8] Lord Stern, author of the "The Stern Review Report: the Economics of Climate Change" (2006), created something of stir in October, 2009, when he suggested — and very publicly so — that we should stop eating meat. It is unlikely he had a designer sewage in mind, however.

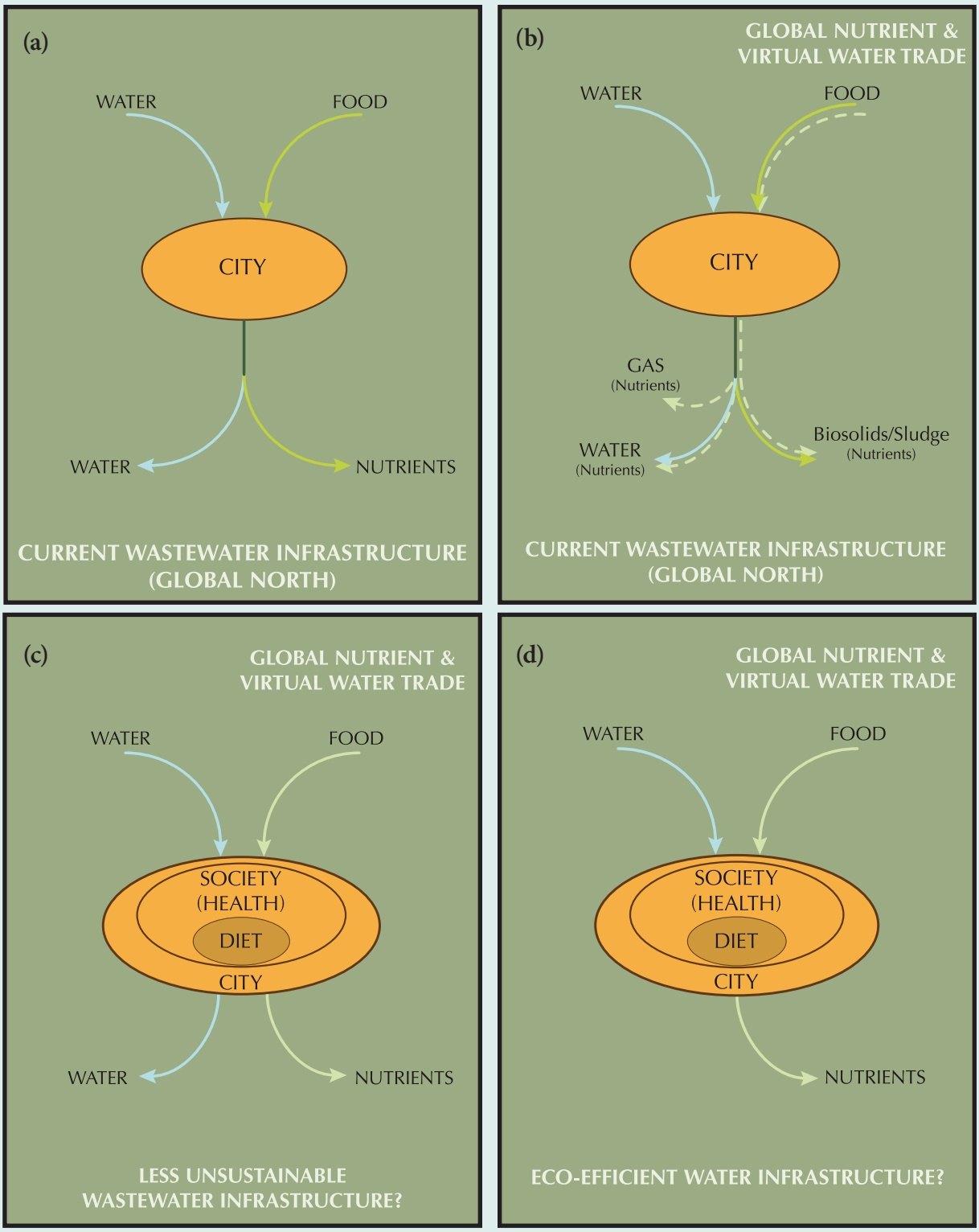


Figure 1
Schematic of the city, its daily water and daily bread, its metabolism, and its water and nutrient return infrastructures: (a) current water-based wastewater infrastructure of cities of the Global North (comprehensively coupled return infrastructures); (b) the current paradigm of (a) bent to some other purpose, e.g., the recovery of resources from the solids (sludge) stream, with yet resource losses to the water and atmospheric media; (c) future vision of uncoupled water and nutrient return infrastructures, with people, their health and their dietary choices in the picture; (d) the logical limit of a maximally eco-efficient city water metabolism, i.e., a dry sanitation system.

of food-exporting countries only to end up fueling eutrophication along the coasts of food-importing countries, through their excess in the residuals of the metabolisms of the cities located by those coasts (Grote *et al*, 2005). Erisman *et al* (2008), for instance, suggest that the transfer of reactive nitrogen from terrestrial to coastal systems has doubled since pre-industrial times.

Thus is the following well worth contemplating. In the desperate and urgent struggle to provide citizens with their daily water, desalination can today be fairly described as a "hot technology" (Frenkel and Lee, 2011). Perhaps this very innovation will be capable of accelerating the migration of people to coastal cities. However, given then that installing infrastructure for dealing with the metabolic residuals of the city's daily bread — through wastewater treatment, that is — always lags behind the provision of infrastructure for supplying the city's daily water, one could mount the argument that broad-scale innovation of desalination will lead to wholesale coastal eutrophication and consequent distortions of marine foodwebs and ecosystems beyond (Jackson *et al*, 2001).[9] And such a downside is conceivable, without even considering the carbon emissions of desalination and the larger number of citizens exposed, ultimately through this technological innovation, to threats of flooding from sea-level rise, possibly exacerbated by the changing intensities of extreme meteorological events.

Context, place, the onlooker's perspective, and how this changes with time, all matter with respect to what is a sustainable technology and its sustainable application in cities.

What might have been, we can but speculate, had an Air (Vacuum) Closet (VC) or Earth Closet (EC) achieved popular adoption ahead of the Water Closet. Would we today be instead concerned about the airborne propagation of disease (from the VC) and the wholesale pollution of urban groundwater systems (from the EC) — "come wind or come rain", respectively — had cities of the Global North spent a century and more locking onto an infrastructure of dry sanitation?

[9] McGreevey *et al* (2009) observe in passing that the lag referred to here is about 20 years. Other evidence generally supporting some of the threads of the overall conjecture regarding the innovation of desalination can be found in Grimm *et al* (2008).

2.3 Breaking the Paradigm: the Approach of the Millennium

Everywhere is the biological metaphor appropriated. That projects and products have life-cycles is a commonplace. We pointed to the stunted conception of the life-cycle of centralized sewerage and wastewater treatment for the city of Kanpur, under the Ganga Action Plan. For there, in the conceptual scheme of things, i.e.,

planning — design — construction [— operation — disassembly & recycle — {reincarnation}]

adequate forethought had not been given to any of those stages in the life-cycle beyond construction, hence the fixation of Beck (1981). An inter-generational long view, in effect, was absent. All life bracketed within [...] above should somehow take care of itself.

Having emerged in the late 1960s, life-cycle assessment (Frankl and Rubik, 2000) sees itself as addressing a form of cradle-to-grave analysis, which in turn can be extended to the concept of "cradle-to-cradle" analysis (Stahel, 1997; McDonough and Braungart, 2002; WWAP, 2006), wherein the metaphor of {reincarnation} might be brought to mind. Much vaunted too is the notion of biomimicry, with its proposed access to the vast store of intellectual seed-corn for the technological innovations of the Second Industrial Revolution (Benyus, 1997). Industrial Ecology has been formally in place as an academic subject for two decades (Ayres and Ayres, 2002). The *Journal of Industrial Ecology* was first published in 1996. In 2007, noting that "[c]ities have not been major units of analysis in industrial ecology", it produced a special issue on *Industrial Ecology and the Global Impacts of Cities* (Bai, 2007a). The city can be conceived of as having an ecological footprint, an appetite, a metabolism, a pulse, and so on (Wolman, 1965; Beck, 2005; Barles, 2007a,b).

In 1996, as the new millennium approached, Rees and Wackernagel invited us to imagine the city as a large animal grazing in its pasture, as a means of engaging us in conceiving of the rather successful innovation of the urban ecological footprint — massive, of course, for cities such as Paris, New York, and the like (Rees and Wackernagel, 1996). Viewed thus as an organism, the city takes in its daily bread and daily water (as Figure 1 shows), together with life-sustaining "breath". And we have engineered the return of the residuals of this

metabolism to the air, water, and land environments surrounding the city. In the Global North, a good deal of the city's daily water is used to convey the residuals of its daily bread — as wastewater — away from the confines of the urban space, so that citizens can lead healthy and productive lives. Much technological effort has been invested in treating that wastewater, not always to the good of the air, missing an opportunity to benefit the land, while not being a wholly unmitigated good for the water environment.

Consider the global N cycle (Galloway *et al*, 2003; Boyer *et al*, 2006) and place conceptually within it the metabolism of the city, connected to its surrounding watershed. To deal, on the one hand, with the deleterious consequences for the aquatic environment of employing water-based conveyance in removing from the city the metabolic residuals of its daily bread, great effort and cost are invested in accelerated biological nitrification and denitrification of sewage during wastewater treatment. On the downside of the city, therefore, N is deliberately shunted into the atmosphere (as now in Figure 1(b)) — in order to avoid historic problems of water pollution — whence it must then, also with great effort and cost, be fixed through the Haber-Bosch process for incorporation back into the production of artificial fertilizer, for application to the land, on the upside of the city. Roughly two-thirds of the N "removed" in this manner from urban wastewater during treatment, across the whole of Finland, is vented as gaseous emissions to the atmosphere (Sokka *et al*, 2004).

To a degree, the paradigm of urban wastewater infrastructure into which cities of the Global North have become locked can be bent towards other purposes (as in Figure 1(b)), most obviously the recovery of water, nutrient, and energy resources (Guest *et al*, 2009). But this does not seem a sympathetic way of organizing the metabolism of the city and its compensatory wastewater infrastructure; of enabling the city to sit more comfortably within its surrounding environment and the web of global material cycles in which its metabolism participates (Beck, 2005).

What was novel about the approach of the new millennium was not so much the unprecedented pace of change in technology, the economy, and society, but the unprecedented willingness to ask, at a fundamental level, and without fear of overturning long held and much cherished habits of mind: has Man got his relationship with the Environment about right? And in the ensuing reflection it was claimed that the water-based paradigm of wastewater infrastructure in the archetypal city of the Global North was not only "broken" but sore in need of "fixing". In particular, a retreat was to be beaten from the modern technocracy of environmental engineering to a renaissance of manipulating the more natural systems (of ecology) of earlier times (Niemcynowicz, 1993).

This, in fact, was to be a retreat from the modern technocracy itself (Barraqué *et al*, 2006). Experts and professionals — engineers included (presumably) — have been put on probation (Massarutto, 2006):

> Increased corporatization (if not privatization) of water service operation implies a loss of control and a strong delegation of power to professionals and 'water experts', whose faithfulness to the general interest of the community has to be proven.

2.4 Challenge and Vision

> Once the public health of city-dwellers has been secured, the purpose of the urban wastewater infrastructure is to keep the soil fertile (Otterpohl *et al*, 1999).

About 50% of the world's population is now (2011) classified as urban. Much of the built environment can be equated with infrastructure for sustaining the city's metabolism. The intellectual argument may well be:

> that "footprints depict negative impacts of cities without accounting for the probable efficiency of dense urban living" (Kaye *et al*, 2006);
>
> that we should hope for cities to become "hot spots for solutions as well as problems" (Grimm *et al*, 2008; likewise, Sassen (2009), van Noorden (2010), Rosenzweig *et al* (2010), Glaeser, 2011); or even
>
> that at the risk of lionizing slums, they "Can Save the Planet" (Brand, 2010), since the squatter cities resulting from the mass rural-urban migration in developing countries "can teach us much about future urban living" (Brand, 2010).

The visceral reaction might be quite otherwise: cities and the built environment are most likely viewed (in the popular mind-set) as inherent environmental "bads", with no extenuating circumstances. And that view has in turn its intellectual argument: "parasitic" ecosystems is how systems ecologist Eugene Odum (1989) perceived them, living at the expense of other systems.

Things do not have to be this way, no matter how hard it may today be to conceive of cities as forces for good in the environment. Far from the burden of infrastructures having to compensate for the ills of cities, the two should "act" deliberately to contribute positively to enhancement of the environment about them.

Let us take the metaphor of Rees and Wackernagel (1996), therefore, with its obvious basis in ecology, and see just how far it can be pushed to serve the purposes of an engineering turn of mind. Imagine their animal as a bull, as already suggested in the case of Paris. The "bull" of intense social and economic activity in the city might be shod in the future with the "padded athletic trainers" of re-engineered infrastructures and imbued with a technological deftness and intelligence sufficient for restoring the business of running the environmental "china shop" in which it charges about. Pushing the metaphor yet further, the city might even profitably expand the shop's operations, by becoming a net contributor to some of the watershed's ecosystem services. Projections show that, by the compliance date (2015) of the EU Water Framework Directive, Paris might well look like the bull in the restored but vulnerable china-shop of the Seine watershed (Billen *et al*, 2007a,b; Even *et al*, 2007), yet not at all self-evidently shod with padded trainers, nor necessarily in possession of the technological deftness required for expanding the shop's operations.

Thinking in terms of the attributes of an organism and of the manner in which that organism lives and prospers harmoniously within its environment is, we now appreciate, a powerful metaphor for engineering and industrial design. It augments the image of the clockwork mechanism as the earlier epitome of the same, manifest itself indeed in the caricature of a mathematical program to be set out shortly below. Courtesy of the biological metaphor, therefore, we can compose the following set of challenges, all geared to realizing the vision of "Cities as Forces for Good" (CFG, for short) in the watershed and the wider environment (Crutzen *et al*, 2007; Beck *et al*, 2010a,b).

Broadly, we ask:

> How can the city's water infrastructure be re-engineered to restore the natural capital and ecosystem services of the Nature that occupied the land before the city?
>
> How can urban infrastructure be re-engineered to enable the city to act as a force for good, deliberately to compensate for the ills of the rest of Man's interventions in Nature, such as, for example, the non-urban structures of dams and irrigation diversions?

More specifically, rising stepwise up from the scale of the intensely local aspects of household plumbing to matters global, we ask herein:

> What trajectories of technological innovations towards alternative, future metropolitan water infrastructures might:
>
> (a) Secure public health and enhance well-being in the city [local and community scales];
>
> (b) Uncouple the water and nutrient metabolisms of the city [city scale];
>
> (c) Enable the city-infrastructure couple to be a net contributor to ecosystem services [watershed scale];
>
> (d) Lower the global nutrient and virtual water metabolisms, i.e., uncouple human/economic development from industrial N fixation [global]; and
>
> (e) Be robust and resilient — in particular, in an ecological sense (Holling, 1986) — under climate change (Beck *et al*, 2010a)?

The key is implied in the transitions from the arrangements *and* perceptions of Figures 1(a) and (b) to those of Figure 1(c), where the "nutrients" are somehow to be separated from the "water" on the downside of the city. The goal would eventually be to prize apart the water and food-nutrient cycles in which the city and its dwellers participate. The future strategic aspiration — one among several possibilities — might be to achieve thereby an urban wastewater infrastructure that

generates a perfect fertilizer product and, incidentally, a very clean by-product, i.e., water (Beck and Chen, 1999; Jiang and Beck, 2007; Beck *et al*, 2011a).

The essential thrust of all of this, of course, is towards accounting predominantly for the bottom line of our achieving {environmental benignity}, through becoming less unsustainable. We make no apology for this. In the approach to the new millennium dawned the realization of our collectively bumping up against the boundaries of the biosphere. Whatever form of less unsustainable styles of IUWM nested within IWRM are chosen, their genesis should be inspired, first and foremost, by their perceived contributions to sustaining the biosphere, neither the economy, nor society.

Significantly, throughout those most healthy and liberating debates of the 1990s — over the worthiness of the goals and styles of environmental engineering — no radically different alternative emerged for the kind of infrastructure that would supply the city with its daily water. On the upside of the city in any of the panels of Figure 1, nothing structurally is changing. Infrastructure for getting water to our mouths may indeed be as "old as the hills", as some have bluntly put it. It continues to co-evolve incrementally, of course, in tandem with suppressing the propagation of an ever-evolving array of contaminants. The water-based paradigm of nineteenth-century sanitation cut the short feedback loop of pathogens returning to the mouth; on the downside of the city, it conveyed them well away from our personal living spaces. As our individual status moves back and forth along the continuum of health and well-being, we shed not only pathogens, but metabolites of the medications (pharmaceuticals) we take to recover from and avoid ill-health, as well as residuals from the personal-care products that enhance our sense of well-being. These too will be unwelcome constituents in the daily water of those downstream of us (and the nature in between), no matter the distance of their city from ours — and irrespective of the fact of our sharing the planet ever more intimately with more than 7 billion others. But still our daily water reaches the city as it always has done (Figure 1).

Wherever there was radicalism in those sustainability debates of some twenty years ago, it was focused on casting off the straitjacket of the wastewater infrastructure on the downside of the city of Figures 1(a) or 1(b). Thus was revealed the notion of what we shall now call the city's *nutrient infrastructure* — its means to deal primarily with the residuals from the metabolism of the city's daily bread.

2.5 Engineering for Sustainable Development: Triple Bottom Line — Just Another Mathematical Program?

We — members of the predominant school of thought in environmental engineering of the second half of the twentieth century — have had a couple of decades to become accustomed to realizing we are not self-evidently doing good by the biosphere, precisely because of the apparent radicalism of Niemcynowicz (1993) and others.

A paper such as this, focusing essentially on concepts (of sustainability) and setting out the elements of constructing a vision of a more distant future for IUWM within IWRM, should provoke the possibility of our putting aside some of the old, much cherished, habits of thinking. And we can all recognize these traits in ourselves. Those of us interested in the "hi-tech" of control and dynamic systems theory, which gave us the fixation on the operational stage of an infrastructure life-cycle (as in Beck (1981), for example), may be persuaded to mount an argument against decentralized, local, self-organized, ecological, non-technocratic forms of IUWM, because they do not appear to call for much of our favored theory. This is not necessarily unhealthy, for we shall in due course advocate a plurality of schools and styles of engineering thought (below in Box 1 of Chapter 3). It might indeed be quite creative (as in due course we shall see in Box 3); but it is as well to admit its occurrence.

Others amongst us, acknowledging the systematic and quantitative style of analysis that is defining of the Engineering tradition, might welcome with keen anticipation the evolution in thinking over these past fifteen years, towards the Triple Bottom Line (Elkington, 1998). The unabashed allusion of the Triple Bottom Line to a quantitative accounting procedure of business — albeit cast within the context of its moral imperative — might present too attractive an opportunity not to draw ever more of the human dimension into our tradition of engineering analysis. After all, subjecting our paraphrasing of the original exhortation of sustainability to the strictures of the three components of the Triple Bottom Line, yields something of a caricature of the classical

optimization problem of mathematical programming (which underpins, formally or informally, so much of "objective" engineering design and decision-making). Thus we have:

> {Doing well now by the biosphere and the stock of natural capital and flow of services therefrom entails doing at least as well generations hence}
>
> Subject to attainment of this objective of "doing well" being witnessed by all the stakeholders to satisfy the properties of
>
> {environmental benignity}
> {economic feasibility}
> &
> {social legitimacy}

There will indeed be those kinds of community water problems that are amenable to being addressed and resolved using quantitative methods from the traditional engineering toolkit, in which case the fine line separating this form of technical analysis from public debate and democracy might well be able to penetrate deep into the property of {social legitimacy}.

In others, it will be decidedly inappropriate, with that line barely able to penetrate the property of {environmental benignity}. There may even be no common ground for formal agreement amongst the various groupings of stakeholders on the science underpinning projections of what constitutes "doing well" by the biosphere, let alone on the form of democracy, debate, and governance through which the "doing well" can be witnessed by most, if not "all", as about to be done.

As engineers, we have been drawn on by the appeal of being "objective". Yet as the following reveals with some obvious discomfort, we know that attainment of complete objectivity in assessing sustainability is beyond our grasp. This is taken from the work of another awardee of the inaugural (2008) IWA Prize for Sustainability in the Water Sector (Sharma *et al*, 2009):

> Which is the 'best' water servicing scenario? This is a complex, multi-dimensional question. No matter how much modelling is undertaken, some degree of subjective value judgement is required by the decision maker(s). Morse *et al* (2001) also indicated that an element of qualitative integration incorporating value judgement and subjectivity is inevitable with a concept like sustainability. The sustainability assessment framework presented in this paper reduces the subjectivity and increases the objectivity in the decision making process, but none the less, a subjective value judgement is still required.

As goes Science (Nowotny *et al*, 2001), so may need to go Engineering for the purposes of achieving IUWM within IWRM: towards a style we might call "socially robust engineering", similar in spirit, but not content, to the original engineering of water infrastructures a century and more ago.

With this shifting line in mind — with its accompanying implication of tailoring appropriate, but different, styles of water engineering to different problems — we now embark on setting out the elements of the framework of the Triple Bottom Line, placing that of {social legitimacy} firmly in the first rank, as "first amongst equals" (*primus inter pares*). We may have come upon the Triple Bottom Line through confronting the problems of sustaining the biosphere. Any approaches to overcoming the problem, however, will surely have to be socially and politically legitimate, as a priority. Chapter 3.1 must therefore address the labyrinthine complexity of the interaction between Society and our notion of IUWM within IWRM.

The second of the bottom lines, that of {economic feasibility}, is treated in Chapter 3.2, there to reveal, if anything, the size of the intellectual gap between some high-minded principles of economics and ecosystems theory and the practical needs of engineering urban water infrastructure.

The struggle to achieve {environmental benignity} in that engineering will be examined in Chapters 3.3 and 3.4, starting from the global perspective of Earth Systems Analysis and in response to the challenge and vision just set out above in Chapter 2.4.

All these elements of the framework for a less unsustainable IUWM within IWRM, emerging from Chapter 3 (and then Chapter 4), will eventually be gathered together and tabulated in cryptic form (in Chapters 5 and 6).

Chapter 3: The Triple Bottom Line

> "[W]hat is sound about the idea of a Triple Bottom Line is not novel ... and ... what is novel is not sound" (Norman and MacDonald, 2004).

To each and every force, such as that propelling our discussion strategically towards the merits of the Triple Bottom Line, there is an equal and opposite reaction. Such healthy skepticism is just as apparent in respect of IWRM (Jeffrey and Geary, 2006). That likewise there could be archly opposed schools of thought on the engineering of IUWM, however, has essentially been anathema to our profession in modern times, at least until the "revolutions" of the 1990s already noted. A multiplicity of alternative, even controversial, technological paths leading away from unsustainability may abound, as much as a discomforting multiplicity of inter-generational community aspirations, towards which distant futures those paths should broadly be heading.

Our journey through the Triple Bottom Line may therefore be bewildering for some readers, especially in the now approaching first stage of considering what might constitute {social legitimacy}. For this will not be the stuff of everyday practice in environmental engineering. But we shall still need to take every opportunity to ponder how our ensuring there is optimal flocculation in the clarifier of a potable water treatment facility, for example, fits into this bigger picture.

Plurality: The Absence of Conformity and Convergence to a Singularity

To guide us on our journey, let us consider Figure 2 and, for the moment, confine our discussion of it to just the following, stretching out first to the distant future and subsequently returning in two steps to the present.

Where Society wishes to be generations hence (25-75 years from today) is expressed in Figure 2 as the green oval domains to the upper right of the picture. They are plural, of course. And it would be surprising indeed were the situation to be anything other than this. In a healthy society, with good governance, such expressions of people's aspirations for the longer-term futures of their cherished facets of their environments are highly unlikely to converge on the singularity of a consensus, or shared vision. Significantly too, these aspirations for the distant future should unmistakably be here the views of the lay stakeholders in the given community or city: that which *they* imagine, in *their* terms, to be what we technical experts are calling "IUWM nested within IWRM". Achieving social legitimacy would seem to call for nothing less than that the several distant aspirations of Figure 2 be recognized as "owned" by the different solidarities amongst the stakeholders, bearing thereby the authenticity of *their* authorship, untainted by any signs of manipulation as a result of some carefully crafted process orchestrated by professional experts.[10]

Developing the alternative technological trajectories enabling policy to attain society's more distant aspirations is very much the responsibility of Engineering and engineers. These various paths are symbolized by the red rectangles in Figure 2. Courtesy of the paradigm-breaking thinking provoked by the approach of the new millennium, they too are decidedly multiple. They will not be confined solely to that "business-as-usual" which dominated affairs for the final several decades of the twentieth century. A second school of thought, for example, was hammered out in the very struggle to break — or break free from — that paradigm (Hunt, 2010). It is recognized today as ecological engineering (McCutcheon *et al*, 1994; Odum, 1994), hence distinguished from (traditional) environmental engineering, if not also from Green Chemistry, itself arguably a third relevant school of thought, which also emerged in the early 1990s (Anastas and Warner, 1998; Wikipedia, accessed 8 November, 2008; Warner Babcock Institute for Green Chemistry; www.warnerbabcock.com; accessed 10

[10] However, the green oval domains of Figure 2 spring from my imagination — I, the technical expert writing this *Concepts Paper* — and those of my professional colleagues (for instance, Beck and Chen, 1999; Beck *et al*, 2011a). If things are thus tainted and unauthentic, alas, so must be it for the purposes of this *Paper*. Nevertheless, I am a stakeholder and a member of Society, not some detached value-free agent, somehow set well apart from Society, as my own personal experience with the origins of what is to come later in Box 4 (of Chapter 4) has clearly shown me (Hare *et al*, 2006).

March, 2010) and subsequently broadened to enfold Green Engineering (Anastas and Zimmerman, 2003).

Extrapolations of future infrastructure components — from whatever school of thought — might reasonably extend anywhere between 5 and 20 years ahead in time.

Taking now a second step back from the distant future to the present, at the lower left in Figure 2, to within the next couple of years or so, some socially legitimate institution or process is obliged to fashion "one routine step" into the future; which step must be most mindful of both the plurality of distant future aspirations and of stimulating expansion in the palette of alternative technological trajectories. In moving from the locked-in initial conditions of the paradigm of water infrastructure in cities of the Global North (those of Figures 1(a) and 1(b)), each routine, incremental technological change should promote a burgeoning of options for subsequent, incremental adaptation.

But how are we to fashion that first, one routine step, for tomorrow? How should we move forward under all the plurality of Figure 2?

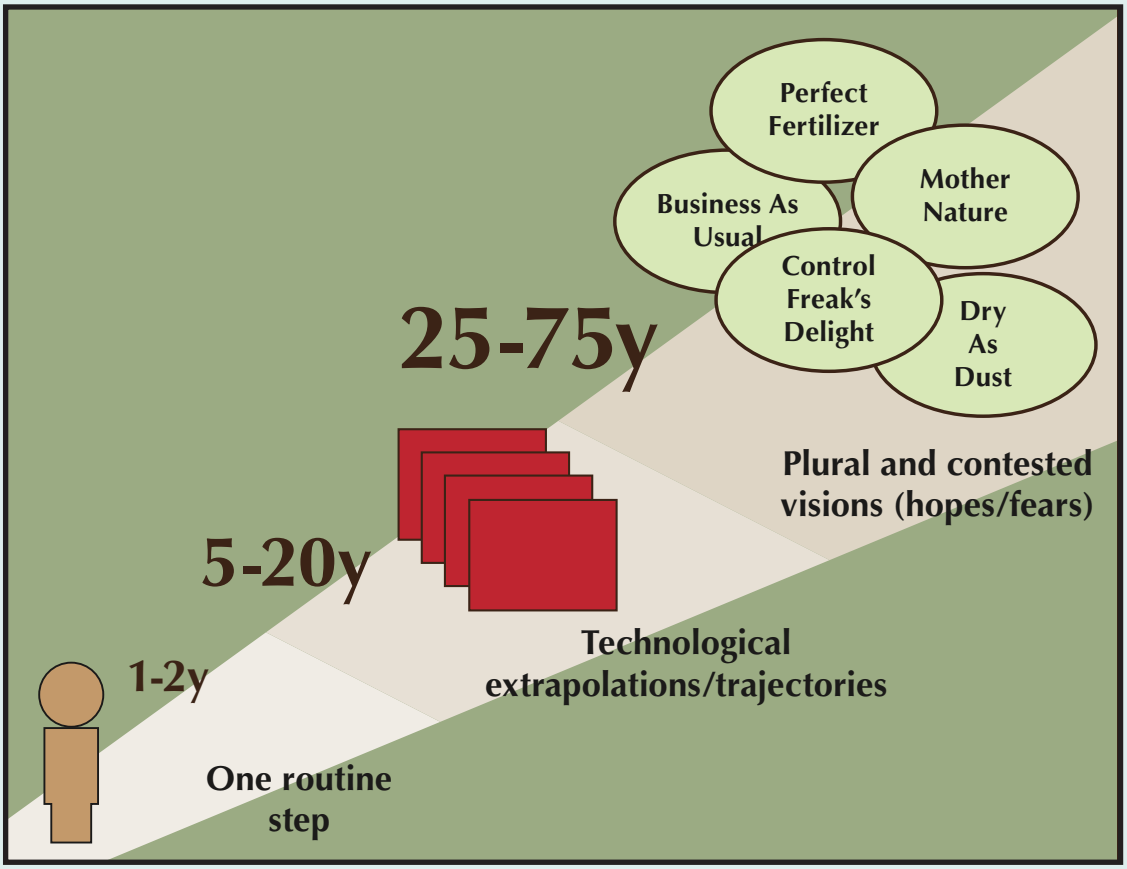


Figure 2:
Framing the "big picture" of how the city might evolve to become a force for good in its environment with, first, the plural (and contested) visions of the distant, inter-generational futures for the city's water infrastructure (green oval domains), second, the technological alternatives (red rectangles) as possible paths towards those futures from, third, the determination and implementation of one routine step "tomorrow".

3.1 Social and Political Legitimacy

> If the challenges we face today — of too great an unsustainability in the water sector — were ones of engineering and technology, they would already have been fixed, years ago. Today's problems are those of achieving good governance.

Simply and succinctly put, we assume governance has everything to do with the healthy debate surrounding the plurality of perspectives held by various stakeholders on any issue of environmental stewardship affecting and within their community. We need to understand something about how this plurality can arise, hence be expressed as the alternative green oval domains in Figure 2, and how the tortuous complexity of community politics and negotiations — as they surround the formation of policy/action — can be grasped through the workings of a relatively uncomplicated typology.

Myths of Nature and Social Bonds

In *Sustainable Development of the Biosphere* (Clark and Munn, 1986), Holling posited four "Myths of Nature" (Holling, 1986; and Figure 3).

Let us begin with his myth of "Nature benign", in the lower left panel of Figure 3. In that outlook, though subject to all manner of insults and injury, Nature is imagined supremely resilient, able to return to the "equilibrium" Man has come to know and cherish over the generations. The state of nature — as the ball-bearing on the basin-shaped potential surface in Figure 3, or as the state variable ($\boldsymbol{x}$) in a mathematical model ($\boldsymbol{M}$) — may be buffeted this way and that, but will always come to rest at the bottom of the basin.

The myth of "Nature tolerant but perverse" (upper right panel; Figure 3), holds instead that — up to a point — Nature will indeed return to the favored equilibrium following disturbance by Man, but if struck too forcefully may be dislodged into quite another equilibrium, and one that may not be at all to Man's liking.

Then there is the myth of "Nature ephemeral" (lower right panel; Figure 3). Those who adhere to this view believe that any perturbation, no matter how small, may cause the behavior of Nature to descend into unmitigated disaster.

For many — and here is the rub, for so many of the world's poor and disadvantaged — Nature must appear as "Nature capricious", behaving without rhyme or reason, beyond their conception of what counts to survive in life (the fourth, upper left panel of Figure 3).

Onto these Myths of Nature can be mapped characteristics of the social solidarities of Cultural Theory (Thompson *et al*, 1990). These are characteristics of how individuals bind one to another to form like-minded groups, with a shared outlook, in particular on the Man-Environment or Man-Nature relationship. Their mapping onto Figure 3 is literally so (Thompson, 2002)[11].

For upholders of the individualist solidarity, typically associated with markets and corporations, Man is regarded as inherently self-seeking and atomistic, while Nature is well able to recover from any exploitation, in other words, "Nature benign". Here, in the lower left quadrant of Figure 3, competition between individuals tends towards being unfettered.

Members of the egalitarian solidarity, for whom Nature is almost the exact opposite — "Nature ephemeral", fragile, and intricately inter-connected — consider Man as essentially caring and sharing (in the lower right quadrant of Figure 3). To them, unfettered competition in the affairs of Man (if not Nature) has very little appeal indeed.

A third social grouping, the hierarchist solidarity, aligns itself with the myth of "Nature tolerant but perverse", in the upper right quadrant of Figure 3. It stands somewhere between the individualists and egalitarians and their favored myths of Nature. For it views Man as malleable, deeply flawed, but redeemable by firm, long-lasting and trustworthy institutions. Egalitarians, being themselves in a rightward quadrant of Figure 3, sympathize with the fettering of competition implied by the hierarchy, but abhor the layered forms of social interactions and differences of unequal status, the very essence of which hierarchy comprises.

[11] We offer this particular anthropological perspective not because we believe it fits all social contexts, but because it offers the most straightforward insights. These insights, moreover, are especially well suited to the setting of water and engineering (see, for example, Dixit, 2002; Gyawali, 2004).

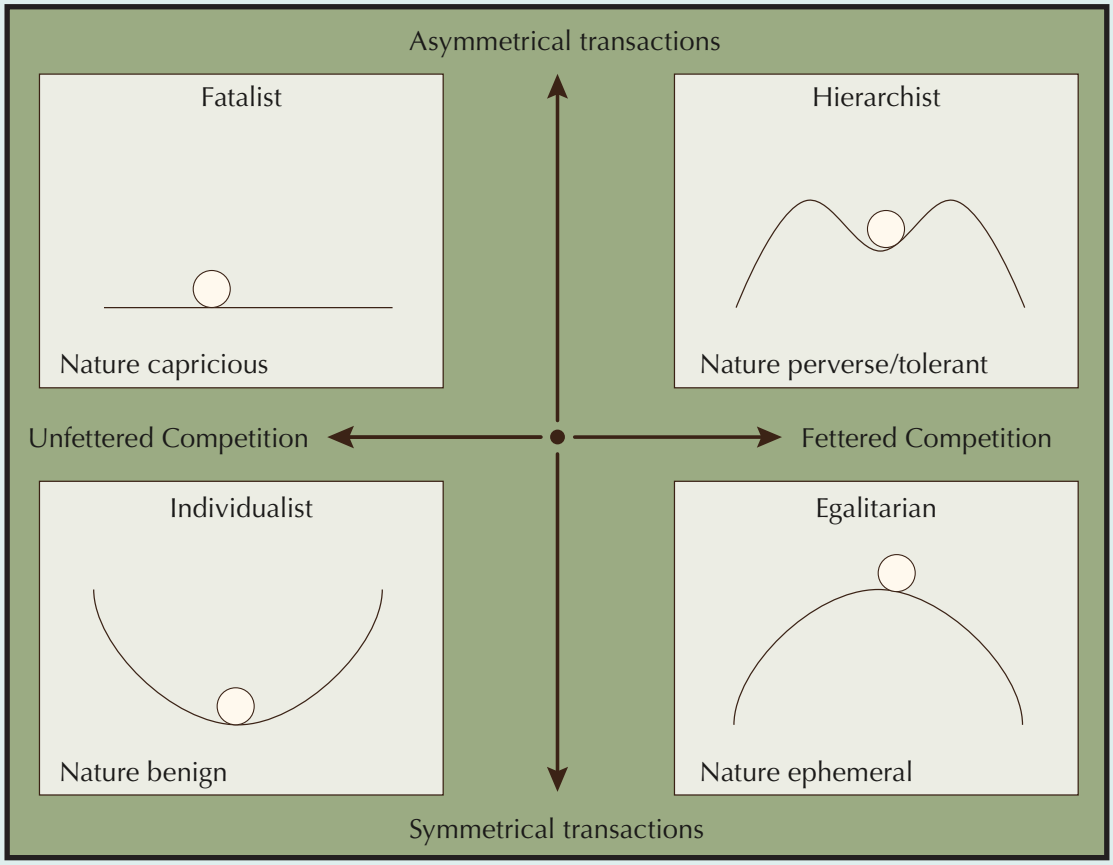


Figure 3:
Thompson's "solidarities", and their respective Myths of Nature (from Holling). The metaphor is that of a ball-bearing (the state of the system) rolling about on a surface (of potential energy), where local stability and stasis are defined by any points on the surface with (locally) a zero gradient (from Thompson, 2002; redrawn).

Standing apart from social and community governance, in the upper left quadrant of Figure 3, the fatalist solidarity gathers around the myth of "Nature capricious", for it knows that Man is fickle and untrustworthy. No member of this solidarity has power or influence in the affairs of Man and Society — why bother to vote, the government is always elected!

Viewed through the prism of this typology of social solidarities, it could be argued that sustainable development is itself essentially an outlook of the hierarchists alone, and one which risks excluding the other "voices" in society: those of the individualist, for whom all development is sustainable; the egalitarian, for whom no development is sustainable; and the fatalist, for whom nothing makes much difference at all.

Styles of Management

Of the five social solidarities recognized in Cultural Theory,[12] but three — individualist, egalitarian, and hierarchist (for the fatalist has, by definition, no voice) — reaffirm the essence of democracy in the affairs of Man and Environment, through their contestation in the policy debate (Thompson, 2000):

> [T]hough each solidarity has its distinctive model of democracy (and is thus able to claim that its solution will strengthen democracy, and that those professed by the others will weaken it) no one of them has the "right" model ...

[12] A fifth solidarity is recognized beyond the four of Figure 3: that of the hermit, who lives out an autonomous existence (Thompson *et al*, 1990).

The three comprise an irreducible, triangular policy space, defined at its vertices by the three policy prescriptions of the three solidarities for solving the ills of the world — a three-legged "contested terrain", as pictured by Gyawali (2004). An orthodox insistence on there having to be a *single agreed* definition of the problem, and the struggles then to decide which policy prescription and attaching model of democracy are right, may not in fact be helpful. Endless, but punctuated, contestation, played out amongst the *enduring plurality* of perspectives, diagnoses, and prescriptions, might rather be the essence of the democracy that is needed.

For the individualist solidarity, therefore, managing institutions that work "with the grain of the market", free of environmentally harmful subsidies, for instance, are what are needed. This is the voice in the debate that calls for de-regulation, for the freedom to innovate and take risks, and for the internalization of environmental costs so as to "get the prices right".

We must all tread lightly on the Earth, argue egalitarians. Trust and leveling go hand-in-hand, while institutions that distribute unequally are distrusted. This is the voice in the debate for whom voluntary simplicity is the only solution to our environmental problems, with the "precautionary principle" being strictly enforced on those who are tempted not to share the simple life. It argues for zero-growth and calls urgently for major shifts in our behavior, so as to bring our profligate consumption down within the limits that have been set by Mother Nature.

Environmental management requires certified experts — assert the hierarchists in contrast — not least because determining the precise locations of Nature's limits, hence statutory regulation, calls for a good scientific grasp of where the boundaries of stability lie in their myth of Nature (in the upper right quadrant of Figure 3). All economic activity must then be kept within those limits. Fair distribution is by rank and station. Theirs is the voice that talks of "global stewardship".

Fatalist actors do not really have a voice in the debate. If they had, they would not be fatalistic! Nevertheless, since time and money that are spent on something about which nothing can be done is time and money wasted, there is some wisdom here that should not be ignored.

Such sentiments — of a constructively contested space of sharply juxtaposed outlooks and prognoses, which essentially should not be rendered down to just a single prescription for managing from one perspective — are widespread in the contemporary sustainability debate. They appear in the *Local Politics of Global Sustainability* (of Prugh *et al*, 2000), the *Panarchy* of Gunderson and Holling (2002), the design space of *Remaking the Way We Make Things* (McDonough and Braungart, 2002), the Public-Government-Science Trialogue of Ashton *et al* (2006), the four world views essential to growing the successful businesses of *The Next Industrial Revolution* (Hawken *et al*, 1999), and the five strategic "rationales" for the restoration of ecosystems (Clewell and Aronson, 2006). Their point is to crystallize out the pluralism of perspective necessary for the birth of policies and designs respectful of diversity — and thereby having a greater potential to succeed.

Styles of Environmental Science, Engineering, and Technology

Gyawali (2001) has argued that success in the future for Nepali water science will *only* be achieved providing the democratic debate is framed by a plurality of culturally conditioned styles for that science, which entail differing attitudes towards risk: market science, which is of an innovative and risk-taking nature; government science, born of a regulatory and risk-managing background; and voluntary science, dominated by precaution, skepticism (about technology), and risk-avoidance. Engineers and scientists working in a given context — government department, private-sector consultancy, voluntary organization — will generally tend to frame the "problem", hence the nature of the "solution", in ways sympathetic to the capabilities and influence of that context. This would be no surprise to the authors of IWA's *Sanitation 21* document (IWA, 2006).[13] It was Gyawali's experience too, fired in the crucible of having been Minister for Water Resources in Nepal (Gyawali, 2004):

> The very sciences of different solidarities, their framing of problems, the questions they ask and the areas they look into for answers are different.

[13] And Boxes 2 and 4 will make this quite apparent in due course.

There can, and arguably should, be a plurality of environmental sciences *and*, we add here (again), a plurality of schools of thought on IUWM nested within IWRM. They are set out in Box 1.

In matters of re-engineering and technological innovation, the archetypal hierarchist actor favors high-tech virtuosity and large-scale engineering projects, whereas the egalitarian would celebrate "small is beautiful", as well as small being frugal, empowering, and environmentally benign (Thompson and Gyawali, 2001). The egalitarian ignores any economies of scale, in contrast to the hierarchist, who overlooks any dis-economies of scale, such that big is always best. At a scale somewhere in between, where the minimum of the curve of net economic production lies, the individualist will plump for (economically) appropriate technologies — as "cheap and cheerful" as possible. The individualist's challenge, however, is that the minimum is inherently both uncertain and shifting, hence the need for careful judgement and risk-taking. The fatalist instead simply has better things to worry about, such as "getting by from day to day", so that economic productivity is diversified, but not in any systematic or strategically reasoned way — "very cheap, but not so cheerful".

Yet it seems that any murmurs about the merits of engineering and technology innovations in IUWM within IWRM are being drowned out by the calls for "good governance".

Governance Over Technology: The Urge Towards Participation

> The Global Water Partnership (GWP, 2000b, 2002) and the UN's World Water Assessment Program (WWAP, 2006) recognize the current water crisis as a crisis of water governance.

Indeed, we should all doubtless want better governance. And surely a very great deal has been written and discussed of such better governance in the water sector (GWP, 2000b, 2002; EC, 2000, 2001; Barreira, 2003; WWAP, 2006; Ashton *et al*, 2006; Mostert, 2006a; Pahl-Wostl *et al*, 2007a,b, 2008; Pahl-Wostl and Toonen, 2009; Termeer, 2009; Franks and Cleaver, 2009). From this derives that sense of engineering and technology being cast aside, that they are not the issue: a kind of hegemony of "governance over technology", in other words. But how might we now understand governance through the lens of the foregoing discussion of plural Myths of Nature, styles of management, styles of engineering for sustainable development, and so on? For of great concern eventually will be to have a sound appreciation of which elements of governance are enabling (and which disabling) of the kinds of re-engineering interventions and technological innovations deemed attractive for attaining CFG (our challenge from Chapter 2.4; Beck *et al*, 2011b).

History records that most developed nations introduced urban water and sewerage services in the mid-1800s through privately owned companies or private operators. It was not long, however, before these utilities were taken into public (municipal) ownership, with the notable exception of those in France (Juuti and Katko, 2005). The public-sector voice comes across with clarity in the moniker "social municipalism", even reinforced in the accusation — presumably from opposed former private-sector actors — of this being "water and gas socialism" (Barraqué *et al*, 2006). Hooper (2006) tends towards endorsing the same, since he interprets the GWP's call for good governance as emphasizing the involvement and leadership of public-sector actors.

Mondello (2006) appears otherwise convinced, and for reasons likely to confirm those fears persuading Massarutto (2006) to place professionals, experts, and engineers "on probation" (as already observed). Mondello's vision is of the General Agreement on Trade and Services (GATS) of the World Trade Organization (WTO) ushering in more privatization of water services, including in the urban sector of greatest interest to us herein.

Yet others, in particular Mostert (2006a), note the significance of civil-society (non-governmental) actors. If public participation is a very good thing, it would culminate according to Mostert (2006a) in "self control" at the top of Arnstein's (1969) "ladder of citizen participation", wherein "the public performs tasks independently, for example, through water users' associations". Western-style public participation, Mostert goes on to note, has been articulated by government. In promoting and achieving such participation elsewhere, however, non-governmental users' associations have been prominent (and

BOX 1

Schools of Thought: Styles of Engineering Sustainability

Center-span in Figure 2 is a portfolio of several red rectangles. It symbolizes the set of alternative paths of technological transitions, leading away from the current unsustainable pattern of urban water infrastructure (today) towards something judged more sustainable (generations hence). These options for re-engineering the city, we assert, may also reflect alternative schools of engineering thought, or alternative styles of engineering sustainability into an unsustainable system.

We set out these alternatives herein. Our sketches of them are inevitably colored by the subjective perspective of a life-time's experience.[1] History, appropriately therefore, provides both context and a starting point.

S1: 20th-Century Technocratic Paradigm (20CTP)

This is essentially the style of Civil Engineering, with hitherto a modicum of input from Chemical Engineering and, more recently, from Green Chemistry and contemporary, hi-tech Biomolecular and Biochemical Engineering. By reflection — in the eyes of ecologists, in particular — this is all about shovels, bulldozers, earth-moving, bricks, concrete, steel and so on: men, materials, and intrusive engineering structures. "Big is best." It is the infrastructure we have predominantly in cities of the Global North. This is how we have come to know the basic structural configuration of Figure 1(a) for the city's intimately coupled water and nutrient infrastructures. Its future, one might suppose, may continue along much the same lines, as Figure 1(b), with increasing rates of innovation from disciplines other than traditional Civil Engineering.

From the standpoint of Control Engineering, the 20th-Century Technocratic Paradigm would not be described as impressively hi-tech, but rather mid-tech. It struggles to exploit Information and Communications Technologies (ICT) to the full. Its style of re-engineering over the generations can be caricatured as one instinctively of "100% reconstruction": build, demolish, and build entirely anew. The style has a high propensity for technological (and institutional) lock-in, according to Collingridge's four technical indicators of inflexibility in technological systems (Collingridge, 1981; Thompson, 1996): large scale (of the production unit); long lead time; capital intensity; and major infrastructure needs, for example, where a large, remotely located dam (water infrastructure) requires yet other infrastructure as a pre-requisite, such as transport for access (Gyawali, 2004).

The risk of failure is self-evidently low. By definition, 20CTP uses tried-and-tested technologies; it is the custom we have come to expect. In the unfolding of this paradigm over the decades, nonetheless, the system of urban wastewater infrastructure — and the watershed whose integrity it is intended to protect — can be argued to have become ever more fragile and vulnerable (Beck, 2005; Beck *et al*, 2010a). In the absence of ICT, there is no capacity to detect and respond to significant, fast disturbances in real, operational time. The deleterious consequences of any associated upsets will appear all the more amplified, the more the watershed has been restored towards a pre-city status — by the very introduction of this customary (20CTP) sewerage and wastewater treatment in the first place.

[1] Lest there be any doubt, I declare myself to have been steeped in what will come to be described as the outlook of Dynamics and Control (D&C).

BOX 1

S2: Dynamics and Control (D&C)

Anything having an operational stage in its life-cycle should be the subject of Dynamics and Control. D&C supposes a world in which there has been wholesale incorporation of ICT into engineering systems. "Very smart indeed", its proponents would say. In this ideal world, such thoroughgoing application of ICT would enable full advantage to be taken of the (theoretical) sophistication of Control Engineering — a generic style of engineering, yet not generally taught to Civil Engineers (alone amongst all the primary branches of Engineering). Under D&C, operational management in real-time of each of the constituent unit processes of any of the structural arrangements of Figure 1 ought to be highly responsive to any untoward disturbance or change of operational objective. Pushing this to its logical limit, D&C should be the epitome of a strategy of "0% reconstruction" for re-engineering of the city's infrastructure so that it may become a force for good (a CFG). In the sense of constructive, argumentative debate, D&C could be set to oppose 20CTP (as indeed it is, in Box 3). It should exemplify the spirit of adapting the existing built environment to the maximum extent possible. It is all about sensors, electronics, communication, the internet, computers, buttons, switches, actuators, touch screens, and so on. To the professional engineer, D&C could appear as the "soft" alternative to the "hard" path of 20CTP. To the ecologist it could be seen as his/her nemesis, the apotheosis of all that s/he abhors in the engineering turn of mind: Man's supreme control of Nature; his dominion over it.

D&C looks as if it ought to be low risk. It is merely a matter of applying ICT to otherwise tried-and-tested Civil Engineering works. It should fare well in respect of minimizing operational failure, being fully capable of swift, quasi-subliminal reactions in suppressing damage propagation and accelerating system recovery in the event of any process upset or failure. And yet there is the well-known argument (rehearsed in Beck, 2005): that increasing any system's reliance on ICT merely makes that system even more vulnerable to failure in the supervisory ICT sub-system itself. Altogether "Too clever by half" might be the view of those who are suspicious of D&C's style. D&C, moreover, would be precisely that school of engineering thought promoting Holling's "brittleness" of behavior in any technological system (Holling, 1996). For it is largely born of a belief in being able to control the system according to the Myth of "Nature benign" (in Figure 3; lower left panel). In this view, devoting ever more ICT and automation to confining movement of the ball-bearing of Figure 3 to an ever narrower trough on the potential surface, renders the system ever more prone to abrupt failure — worse still, with no means of maintaining any kind of useful service under the then ensuing radically changed operating conditions.

At its core, the Control Engineering of D&C is about re-engineering the dynamics of a system's behavior. It is about changing the spectrum of perturbations and variations to which our lives should otherwise naturally be subject, through our participation in the water and nutrient metabolisms of the city, so that they might become more to our liking and comfort. But what is liked and comfortable for one individual or solidarity may be very different from that for another, exactly as conceived of in Figure 3.

S3: Ecological Engineering with Self-Organizing Systems (SOS)

To the extent that any specific realization of any of the basic arrangements of Figure 1 is intrinsically lower-tech (in the mind of the archetypal engineer), so SOS will be pre-disposed towards application thereto. This might primarily be the case for Figure 1(c), where aquatic ecosystems may predominate,

or Figure 1(d) in which terrestrial ecosystems may be better attuned to an infrastructure gathered around the technologies of dry sanitation.

For those who view D&C as the culmination of the heavy-handed, technocratic paradigm of Engineering — surpassing even 20CTP in its most extreme form — SOS would have none of all that ICT. It would have none of any *externally* imposed control. Control should much rather be encouraged to derive from within the system, as it does *par excellence* in the self-organization of natural ecosystems. Advocates of SOS, therefore, argue for a system of urban wastewater infrastructure thoroughly rid of the controlling, un-natural hand of the engineer. They argue for the natural-ness of flora, fauna, soils, and the unit processes of wetlands, reed-ponds and so on — not the manufactured-ness of steel and concrete, nor the engineered intensity of the unit processes contained within the structures made of such materials. SOS is Ecological Engineering writ large, in spite of a recognition of this very title being (highly) debatably an oxymoron (Hunt, 2010).

SOS suffers from two strategic difficulties. First, it is difficult to make the unit processes of SOS work intensively in the compressed and confined spaces of dense cities. Second, because of their intrinsic *self*-organization and nonlinear ecological complexity — *and* our inevitably substantial lack of understanding thereof — their behavior must be replete with latent "tipping points", hence full of "systemic risks". Just as much as control and stability derive from *within* the self-organizing system, so may the seeds of its instability, with no apparent, *external*, causative disturbance. We may not know well on which potential surface of Figure 3 things are operating. Furthermore, the system itself may be evolving, or re-organizing internally the way it organizes itself. The shape of the potential surface is migrating, in effect, through the four archetypes of Figure 3, such that the previously innocuous, minor, external perturbation may push the system's dynamics over the edge into instability. If we imagine technologies to have life-cycles, these processes of Ecological Engineering — when somehow softly re-engineered to work more intensively in cities — could "grow up" to be the "wayward teenagers" we all know of only too well. Absent ICT, moreover, we would have no idea of passage past the latent tipping points, until there was teenage messiness all over the place.

When city-focused, therefore, SOS should be considered potentially high-risk. Yet being tried and tested, hence low-risk, is precisely what SOS could be claimed to be. For there are decades and centuries of experience of SOS designs in the rural and pre-industrial societies of China and Indo-China. But here too lurk significant latent risks. SOS's origins in the intensely close cycling of the excreta of humans, pigs, ducks, and fish amongst the houses, pens, and ponds of south-east Asia might make it a most effective engine of pathogen evolution and propagation. Perhaps SOS seeks to realize just a bit too much of the mantra of eco-effectiveness, of "waste equals food" (McDonough and Braungart, 2002).

S4: Decentralization: Small is Beautiful (SiB)

This, now, strikes one as a most democratic style of engineering sustainability. SiB's inspiration is that of placing "control" back in the hands of the ordinary people in the local street. Things will become beautiful through the increasing smallness wrought by systematic decentralization of the currently massively centralized — *ergo* brutal — configuration of 20CTP. Small could be beautiful for any of the structural arrangements of Figures 1(a), (c), or (d): from the residuals of our daily bread and water being utterly mixed, to their separation respectively under wet and dry sanitation systems. Imagine thousands of miniature replicates of these arrangements of Figure 1 eventually blooming across the

city. With the beauty of such local empowerment comes responsibility for technical failure. As the form of infrastructure migrates away from the single, centralized wastewater treatment plant, owned and operated by the municipal government (or private utility), logic would require responsibility to rest increasingly in the hands of the individual head-of-household.[2]

SiB bears a risk. Its logical thrust is that of returning the water and nutrient infrastructures of the city to where they were, in their close spatial proximity, prior to the invention and introduction of the WC. The risk is therefore that of undermining the security of urban public health. "Small" might be too "intimate". The lesson has been comprehensively learned: the supply of drinking water should remain technically remote from the disposal of human excreta. In the denseness of the cities of the Global North, and in the light of increasingly innovative approaches to urban agriculture at various scales (Dagerskog *et al*, 2010; Drechsel and Erni, 2010), questions of concern arise. How much of the city's daily bread and daily water might best still come from afar on the upside of the city, to reach each of the "internal" miniature replicates progressively breaking away from the city's originally centralized wastewater infrastructure? How much might *safely* be the share of the internally re-generated nutrients and water (and rainwater) supplies, recovered from the downside residuals of the growing throng of internal replicates? The thrust of SiB, towards (in principle) ever tighter water and nutrient cycles, conveys the risk of compressing the coiled spring — to the point where it snaps back.

The risk, lesser or greater, surely depends on one's perspective. "Ever more local needs ever more automated control", it has been said (Olsson, 2006); or, to paraphrase, "Ever more local needs ever more of the generic style of D&C's school of engineering thought". Yet, as we have said, one may be no more secure with such use of ICT in this context (see Zimmerman, 2001) — of its doing the right thing unfailingly, automaton-like ("Too clever by half") — than with either ill-trained professional personnel, or untrained, "unpoliced", technically lay members of the public, who fail to do the right thing at the right time. To put this in a nutshell: is a single, large failure in the professionally supervised and policed municipal government's (remote, river-side) centralized treatment plant better or worse than a lot of small failures in lots of unprofessionally supervised (and unpoliced) households, including one's own, in the heart of the city?

S5: Earth Closet (EC)

Where neither the WC has been introduced, nor the entire water-based paradigm for removing human excreta from one's very personal space — 20CTP, in effect — some would say they should better *never* be introduced. Thus would we have an infrastructure of dry sanitation, gathered around the Earth Closet (EC), or composting toilet, or some other variation on this basic theme, hence the designation of EC for this style of engineering sustainability. Human waste would thus never be introduced so conspicuously and directly into the water cycle.[3]

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[2] Survey data on the introduction of urine-separating toilets indicate a clear preference for having such devices installed and maintained in *public*, institutional spaces (such as a library) as opposed to the *private* space of the household (Lienert and Larsen, 2009). Bearing responsibility *personally* — for maintenance of this form of "technological individualization" — is significant.

[3] Except *via* groundwater systems, as precipitation drains through the earth-compost deposited on the land (Drechsel and Erni, 2010). Or, if "dry" is sufficiently dusty to be whipped up by a wind, via the atmosphere, with subsequent deposition on the land (or the skin of citizens). Everything is related to everything else, in one way or another.

BOX 1

If, in the cities of the Global North, we were to take the belt-tightening of eco-efficiency to the possible absurdity of its logical end-point, the water metabolism of the city would be cut to an absolute minimum, with effectively zero-discharge of water on the downside of the city, hence the prime motivation for drawing the third structural arrangement of the urban metabolism according to Figure 1(d).

The essential dryness of EC, with its appeal to terrestrial ecosystems as opposed to the aquatic ecosystems of SOS, ought at least to be able to circumvent the risk-prone syndrome of the "pathogen-factory" of SOS's historical origins. It should thus be deemed low risk in that particular respect, except where (i) flooding is a serious prospect, hence mobilization of the pathogens and nutrients temporarily immobilized by EC, or (ii) pathogen inactivation chemicals (such as lime) may be carried aloft as dust, with insufficiently inactivated pathogen spores ready to take advantage of any skin irritation created by that chemical treatment.

S6: Separation at Source (S@S)

Like the preceding style of EC, this last school of thought is defined by its own basic structural configuration of the city's water and nutrient infrastructures. Figure 1(c) is its embodiment. This is how the essential challenge of Cities as Forces for Good was originally conceived (Chapter 2.4), although it would not then (*circa* 1998) have been considered what is here styled the Separation at Source (S@S) school of thought. S@S is distinguished by a path of technological transitions inducing structural change in the conventional configuration of the city's water infrastructure (Figure 1(a)). In its pursuit, the various fluxes of residuals from the city's notional households are not mixed (Figures 1(a) or 1(b)), but separated at source, hence the progressive transition from Figure 1(a) to 1(c), and even beyond to Figure 1(d) — attached, as it is, to EC above.

One might argue that S@S is not another school of thought, since it calls for the same kinds of Civil Engineering interventions as 20CTP. Yet 20CTP was driven by an utterly dedicated, single-minded "water-centric" goal of pollution control. Water-borne substances, including nutrients, were to be removed as environmental "bads", in order to generate a single product, namely, progressively less polluted water. *Removal* of nutrients from wastewater remains a most active domain of engineering invention and design; and it may well remain so for many years to come. Before there was the challenge of Cities as Forces for Good (Chapter 2.4), there was the more specific challenge of producing a "perfect fertilizer", through re-engineering of the city's wastewater infrastructure. The intent was therefore quite other than that of the water-centric 20CTP. Nutrient recovery and the production of a perfect fertilizer (as an environmental good) were to become the single-minded purpose of (re-) design, deliberately to turn the previous intent on its head, with crystal-clear water relegated to the status of mere by-product.

There are three segments to the S@S strategy, each distinguished in respect of space-scale: what happens locally in the household (L), i.e., source separation of feces from urine (and from water, as the means of residuals transport); what happens, if necessary, by way of transporting (T) the separated fluxes to somewhere else, possibly somewhere remote (R); and what happens at the possibly remote "somewhere else" (R), in terms of resource recovery (nutrients, energy, water), typically at the centralized wastewater treatment plant of 20CTP. It is hard to imagine the household urine-separating toilet (UST) — and like sanitation devices applicable at the very local and personal scale (L) — as *not* being key to an S@S style of engineering sustainability (Larsen *et al*, 2009; Larsen, 2011).

BOX 1

The intensely local segment (L) of S@S may inherit some of the risky features of the individually empowering style of SiB. Siting and operation of the machinery and facilities for resource recovery may create the potential for too much of the "wrong" materials — incompletely recovered nutrients; the chemical additives and microbial communities of recovery; and incompletely inactivated pathogens — to be in the "wrong" place in the event of failure. Transport of the wrong materials to the right place (*via* T) may also be risk-prone, in particular, if (T) must rely on the legacy infrastructure of 20CTP, i.e., through adaptations of the existing, combined city sewer network. Separation in time — of a sequence of pulses of water, yellow water (urine), black water, or whatever water, through the network — will be prone to the chance occurrence of precipitation triggering the combined sewer overflow.

Nothing is without risk, however, not S@S, EC, SiB, SOS, D&C, or 20CTP. Rectifying the always re-emerging Achilles heel of each is what drives innovation — in perpetuity.

Engineering and its Anthropology: Orthodoxy, Rebels, and Cranks

Writing on "*Uncertainty and Quality in Science for Policy*", Funtowicz and Ravetz (1990) introduced what they called a "research-pedigree matrix". As a field of enquiry matures, they argued, colleague consensus passes from "no opinion", to "embryonic field", "competing schools", to "all but rebels" and "all but cranks". The inference in this progression is that "competing schools" will — or should — eventually yield to the orthodoxy of a single school of thought. It could be, therefore, that "sustainability engineering" for IUWM within IWRM has presently progressed from an embryonic field to the several competing schools of thought set out in this Box.

This, of course, is not exactly our argument here. For we assert throughout this *Concepts Paper* that a state of competing schools of thought is (and should be) enduring. In the spirit of Cultural Theory, whose seminal text was also published in 1990 (Thompson *et al*, 1990), if there is an orthodoxy, then even the voices of the rebels and cranks should not be entirely ignored. After all, whence derives the anomaly and its irritant advocate that motivates the paradigm shift (Kuhn, 1962)? How is the flagship enterprise of SOS — the "Living Machines" of Todd *et al* (2003) — working its way within or without 20CTP? Cultural Theory inherently permits the notion of each school of thought asserting its orthodoxy, hence its hegemony over the other fervently held orthodoxies — all thus being rendered mutually contradictory "certainties". Hunt (2010) records the anthropology of the struggle of the "irritant" ecological engineering and eco-technologies to be acknowledged in the (over-bearing) presence of environmental engineering (the 20th Century Technocratic *Paradigm*, in effect).

Evidence of similar struggles is recorded elsewhere (McCann, 2005; Chapter 3.2 in the main body of the text; and Box 2). An "eco-san" toilet, for instance, seeks nutrient recovery as a priority, along the lines of SOS, or EC, or S@S. The professional (engineering) sub-group within the International Water Association (IWA) who are promoting thinking about this kind of device/technology used to call themselves the Ecological Sanitation (Eco-San) group. They now associate under the rubric of Resources Oriented Sanitation (ROSA) — a change chronicled between the 2006 and 2008 editions of the IWA Yearbook. The motivation for the change may have been to better convey the intended (transformative) message to an audience populated by adherents of other schools of engineering thought, most probably (in their view) that of 20CTP. Yet the re-branding may have been precipitated by some fairly aggressive criticism of the term "ecosan" in McCann's 2005 article in the magazine *Water21* (see also Box 2). The headline jibe was of "eco-insanity" (McCann, 2005). The essence of

BOX 1

the argument against the eco-san toilet, in this particular instance, was that those yet to attain access to basic, rudimentary sanitation for survival should not be asked to consider a more expensive alternative dedicated to the luxury of recovering resources.

As with the manner in which ROSA may have grown uncomfortably out of a reaction to strident criticism of ecosan, what is now CFG was born in part of a reaction to the vituperation heaped by the establishment of the 20CTP school of thought upon the notion of producing perfect fertilizer from the conventional wastewater infrastructure of cities of the Global North. In the spirit of Funtowicz and Ravetz (1990), such a turning on its head of the motivation of 20CTP must have appeared then (a decade ago) as the doings of a rebel or, worse still, a crank.

Things do indeed change. With the benefit of the long view (1870-2000), the analysis of Neset *et al* (2008) for the phosphorus metabolism of Linköping reveals how the symbiosis amongst agriculture, diet, the city, and its wastewater infrastructure has waned over the centuries and decades — but that there is a hint it might now be on the cusp of waxing. Our (human) nutrient residuals are once again to be seen as resources instead of pollutants. They are already, as we know from the city of Ouagadougou, the capital of Burkina Faso (Dagerskog *et al*, 2010).

successful), notably in the rural, irrigation sectors of developing countries.[14]

Like so many things that appear new, this urge towards greater and better "participation" has been growing for quite some time (Reed, 2008). And like IWRM and the TBL, a degree of jaundice may soon set in (Reed, 2008):

> [S]takeholder participation has been increasingly sought and embedded into national and international policy. Although many benefits have been claimed for participation, disillusionment has grown amongst practitioners and stakeholders who have felt let down when these claims are not realised.

Governance *is* complicated. Reaching up to the heights of Dahl's (1989) classic theory of pluralist democracy, good governance has been defined as founded on the following (Ney, 2009; Thompson, 2008a):

(i) The voice of each of the three (active) solidarities should be heard in the debate, over choices in setting off "tomorrow" (in Figure 2) towards the collective set of distant aspirations;

(ii) Each solidarity should be responsive to each of the two other voices, i.e., not attempt to ignore or shout them down.

Drawing upon the phrasing of legal theorist Schapiro (1988), Thompson (2002) calls for a "clumsy institution" as the enabling mechanism of such good governance. Clumsy institutions would grant some recognition to each conviction as to how the world is, each Myth of Nature in Figure 3. They would be "messy, noisy, and argumentative" institutions. This, Thompson contends, would be (Thompson, 2002):

> ... in contrast to those more elegant, and more familiar, arrangements (tidy, quiet and suavely consensual) in which just one conviction holds sway.

It would be governance decidedly extolling the virtues of committed engagement (participatory, that is), if not seeking consensus. It would seek rather to harness contestation. So deeply defining may this be, some might want to change the aphorism "*Cogito, ergo sum* (I think, therefore I am)" to "*Dissentio, ergo sum* (I disagree, therefore I am)" (Nowacki *et al*, 2010).

Overcoming the Gravitational Pull of Consensus?

> "Simple systems are manageable in the sense that, once we understand enough about them, we can define some desirable state of affairs (sustainable development is the current favorite) and then steer the totality towards it." (Thompson, 2002)

Given consensus about the singular "it"— *the* shared vision, that is — policy preferences for the necessary "steering" ought to be all the more readily revealed.

If only we could agree on *one* choice of distant aspiration (one of the green oval domains in Figure 2, say that of the distant target of Perfect Fertilizer), we would know whither we should be headed, as well as the attaching technological path towards that destination from the present Business-as-Usual.[15] If we could only agree on an operational definition of "sustainability", or "sustainable development", we would know how to make progress away from unsustainability in the water sector and towards sustainability. If we could only agree on how to measure sustainable development, policy options for attaining it could be clearly ranked and the "best" extracted for implementation — rather along the lines of solving our caricature of the mathematical program of sustainability in Chapter 2.5.

Examining the manner in which communities and societies arrive at consensus — a shared vision of the future, or an agreed index of sustainable development — is thus important. For it lies at the heart of one of the deliberately contrarian postures of this *Paper*.

[14] Under the continuing migration of rural inhabitants into the city, it is not inconceivable that the institutional "culture" of rural water users associations could flow with these people into the institutional setting of urban water governance. It has happened before. At the time of industrialization and the growth of urban communities in Europe "migrants from the countryside imported their customs and requested free water of good quality from public taps" (Barraqué *et al*, 2006).

[15] We shall, in fact, choose the Perfect Fertilizer target — with its strong attachment to the challenge of CFG (Cities as Forces for Good) — as *the* anchoring device for much of the remainder of this *Concepts Paper*. Such a singular focus is necessary in the interests of specificity and clarity of exposition. It should not, of course, be read as any abandonment of the pluralities of stakeholder aspirations and styles of engineering sustainability so essential to the overall argument of the *Paper*.

According to Boulanger (2008), only the UNDP's Human Development Index (HDI) has achieved any real measure of success as an index of social well-being, and certainly more so than the Index of Sustainable Economic Welfare (ISEW) of Daly and Cobb (1990). Yet the HDI has been vehemently attacked by Baneth (1998), on the grounds that (as quoted in Boulanger, 2008):

> It was a vain, pretentious and slightly ridiculous endeavour to try and sum up human development in all its complexity and multiple dimensions with a single figure.
>
> A pilot flies an aircraft using data supplied by a large number of instruments and that data cannot be summed up in a single indicator.

For Boulanger himself, however (Boulanger, 2008):

> The aircraft metaphor is irrelevant ...
>
> In a human society, things are very different. All its citizens do not have, a priori, the same destination and perhaps most of them do not even know where they are going. Before even thinking about steering the social aircraft, its pilots must try to get everyone to agree on where they are headed.
>
> This is exactly where indicators for sustainable development come into play.

Now the struggles over which model of democracy is "right", which would threaten so severely to undermine the capacity to incorporate quantitative accounts of {social legitimacy} into any formal scheme of optimization (the mathematical program of Chapter 2.5), begin to matter.

Boulanger (2008) calls upon two such models of democracy: "aggregative" and "deliberative". Under the former, he does not expect his promotion of indexes of social well-being to come properly to pass, in liberal democracies which (Boulanger, 2008)

> ... see the political process as a simple choice, by voting, between a priori preferences which were generated before the electoral process.

Going to the heart of the dispute over all such indexes, their means of integrating indicators into indexes — through *aggregation* — he asks (Boulanger, 2008):

> [o]n what basis and using what procedure should the decision be made, for example, to give the economic pillar a 45% weighting, 35% to the social pillar and 20% to the environmental one?
>
> [Rather] ... there is another model for democracies, the "deliberative" model, in which the political process exists precisely for creating a common vision of what is good or just.
>
> It is deliberation which makes it possible to transform "pre-reflective" preferences, established ex ante, into ex post reflective preferences, capable of transcending personal opinions and taking the common good into consideration.

In other words, this is public participation of an active, not passively reactive, kind, underpinned by political theorist Dewey's strong preferences for such, as expressed in his 1927 text *The Public and Its Problems* (Dewey, 1927; as cited in Boulanger, 2008). The process is one of deliberately transforming and adapting prior preferences into posterior preferences: getting "everyone to agree on where they are headed", as Boulanger (2008) would have it, still seemingly captivated by the gravitational pull of consensus.

Thompson, however, writing here (above) about "*Man and Nature as a Single but Complex System*", would actively resist entrapment in the allure of achieving consensus (Thompson, 2002). He opens his piece with the subtitle "A Road Without End" — and one indeed whose eventual direction will only unfold as we travel along it, sometimes driven predominantly by the policy style of one solidarity, later by another, and so on.

Except that, to insist literally on consensus may be to be pedantic. Instead, a decent number of Boulanger's "everyone" might agree on where they are headed, for a while, with the others going along grudgingly (in Thompson's terms), until the disagreements — never banished, nor suppressed, nor entirely resolved — reassert themselves, bringing about a change of direction (Gyawali, 2004).

Referring to the mature regulatory context of environmental law and policy in the United States, Coglianese (2001a) says this:

> We are living, as some might have it, at the dawn of an age of consensus.

> This craving for consensus was institutionalized in 1990 with the passage of the Negotiated Rulemaking Act ...

His path-breaking — and hotly debated (Coglianese, 2001b) — analysis of the empirical evidence leads him to conclude that seeking consensus does not save time, does not lead to improved policy, and does not lower the rate of legal challenges to policies (Coglianese, 2001a). Consensus-seeking risks shifting policy-making away from serving the public interest, substituting the process with merely the design of policies people can "live with", by "lumping it" (Coglianese, 2001a), perhaps "going along grudgingly" (in other words).

Elsewhere, puncturing the notion of participant "satisfaction" as a measure of successful public policy-making, Coglianese (2003) observes that this is incomplete because "it excludes those who do not participate". As Thompson would say, all the voices have not had access to the process. Like Boulanger, Coglianese is not impressed by the aggregative model of democracy, which he characterizes as follows (Coglianese, 2003):

> According to one common conception of democratic theory, public decisionmaking is all about the aggregation of — and ultimately the satisfaction of — public preferences.

Such refinement of environmental governance, with ready recourse to an effective legal discourse, does not obtain everywhere, however.

What happens, moreover, in the *public* space of community debate and disputation may be quite unlike the view arrived at, hence the strictly personal decisions made (the acting very locally) in the *private* space of the individual in his/her dwelling or household.

Basic Instincts: Human Aspirations

Amidst the chaos and deprivation that are the enduring state of some cities in some parts of the world, sustainability must seem a luxury, if not an irrelevance. In the midst of an earnest academic debate of world views on the Man-Environment relationship — amongst the three myths of Nature "benign", "tolerant but perverse", or "ephemeral" — can dawn the realization: that so very, very many people in the world subscribe to none of these. For these three active voices in the debate around the community-environment-policy-design space are beyond conception of what it takes simply to survive in life, beyond comprehension of the advantages of a deliberative model over an aggregative model of democracy.

Writing well before any inkling of the HDI, Maslow (1943) — in his theory of human motivation — gave birth to what has since been summarized as his pyramid, or hierarchy, of needs. Other similar sets of "satiable needs" for achieving happiness can be found in Max-Neef (1991), whose elements include subsistence, protection, freedom, identity, participation, creation, idleness, affection, and understanding (see also Azar *et al*, 1996). In the prodigious four-volume treatise on "*Human Choice and Climate Change*" (Rayner and Malone, 1998), an entire chapter is devoted to a discussion of human needs and wants (Douglas *et al*, 1998). It reminds us of our commonplace experience: the attempts we all make to argue for this, that, or the other as a "need" *not* a "want", hence to justify its becoming *the* priority for policy action. "We" want what we assert to be "the" priority need, not someone else's want, which we seek to render inferior — as a want (not a need) — through the power of our voice. Seeking sustainability may just as reasonably be pursued as a need by some, while being perceived as a want or a luxury by others (as will become quite apparent shortly). There are those, then, who dispute whether needs and wants are in fact hierarchical. Maslow's metaphorical pyramid is to be flattened, as it were (Douglas *et al*, 1998).

Others, assuming still the hierarchy, have attempted since to give a more contemporary interpretation to the pyramid. They argue that those needs at its apex (values, beliefs, and aesthetic preferences) should *not* be considered the concern of seeking sustainability, if this is to become a more meaningful concept (Marshall and Toffel, 2005). Skeptics of sustainability, however, viewing it as a luxury of the Global North, would say it is unlikely to flourish below level 3 in Maslow's hierarchy (labeled "Love/Belonging"), where the over-riding, urgent priorities are: "Safety" (level 2), as in security of body, of employment, of morality, and so on; and — at bottom — sheer "Physiological" survival (level 1), i.e., matters of breathing, food, water, sex, sleep, homeostasis, excretion.

How, then, can investments specifically in water infrastructures promote individual and community development beyond raw survival towards meeting

the aspiration of love/belonging — if at all they can? How can these engineering interventions be deployed expressly so that those at the bottom of the pyramid of dignified human development may be brought to such a state where they care to engage in any debate over the challenge and vision of Chapter 2.4 — of cities as forces for good in *their* environment — beyond their desperate needs of survival for just today and tomorrow?

IWA's *Sanitation 21* document asks a more rudimentary question: "Why Do 'Well-designed' Urban Sanitation Systems Fail?" (IWA, 2006). Its answer is failure through the mis-matching of types of sanitation services provided across the different scales of human agency — household, neighborhood, district, city, and "beyond" — to the types of demands for such services by each of these actors.

In its analysis, *Sanitation 21* reports that actors expressly aspire to "environmental protection" at larger scales (the city, and beyond-the-city). This aspiration disappears from people's agendas at progressively smaller scales of agency, falling behind the goals of social status and cleanliness, which are priorities for the neighborhood and household actors (IWA, 2006). When plotted in Figure 4, as sets of ranked aspirations versus scale/domain, one candidate answer to our own question might run as follows. That style of basic sanitation somehow enabling convergence and consistency of significant aspirations amongst the household, neighborhood, and ward/district scales of human agency would need to be in place as a prerequisite for debating sustainability in the water sector around the community-environment-policy-design space. In fact, all but the "Onsite Dry" technical option, of the eight or so set out in *Sanitation 21*, would seem to satisfy this requirement (IWA, 2006). The barrier to acquiring a stake in the "luxury" of sustainability appears thus hardly insurmountable.

It is *not* that the poor and disadvantaged in their desperate, unsanitary circumstances comprise solely the passive fatalist social solidarity of Figure 3. On the contrary, as Box 2 relates in small and encouraging ways, we might conclude that healthy community debate and entrepreneurship (not to mention hope) spring eternal, including around the technological design space of a form of sanitation potentially vital to attaining several of the distant, global visions of Figure 2 (those of Perfect Fertilizer, Mother Nature, and Dry as Dust). Thus report Dagerskog *et al* (2010):

> Since March 2009, there has been a "human fertiliser" market in Ouagadougou, the capital of Burkina Faso. Human urine and dried faeces are collected and taken to eco-stations, where they are sold to farmers after adequate storage. In this way they increase sanitation coverage, create jobs in the private sector and provide urban farmers with complete and efficient indigenous fertilisers.

Things are altogether more subtle and complex than the simplified Figure 4 might suggest. The purpose of Box 2 is to explore such subtlety and complexity in greater depth.

Long View: Engineering and Inter-generational Equity — Ever in a State of Change and Flux

There is a deeply rooted moral and ethical role for engineers in societies. In his book *The Existential Pleasures of Engineering*, Samuel Florman reminds us of the moral cause that engineers once attached to Engineering: to install works — our engineering interventions — that would lift the ordinary people out of the drudgery of their daily existence (Florman, 1987). So great was their commitment to this vision that engineer Gantt — he of the charts around which we gather today's project time-lines — founded an association called the "New Machine" in order to pursue his vision of what society should be. Unlike sustainability, that association passed rapidly into obscurity (Florman, 1987). But the wellspring of the vision — the moral and ethical commitment — endures, less perishable, more timeless. It finds its way into the outcome of Box 2, for instance.

Value systems and *Weltanschauungen* do indeed change. Most of us today, both within and without the engineering profession, would probably be aghast at Gantt's early 20th Century vision. In the 19th Century, medics, clerics, politicians — all technically lay persons from our contemporary perspective, as water professionals — opined pertinently on the subject of Victorian city infrastructure, and were heeded by the engineers of the day. For most of the 20th Century, following the rise of the profession of sanitary and then environmental engineering, we experts believed we alone knew what was best for the water sector (Beder, 1997). In just these last 10-20 years, such self-

confidence (if not arrogance) has been punctured. How today should members of the community of environmental engineering professionals learn from the *seeming* "amateurism" — when it comes to water — of the public and the politicians?

We have come to recognize that the water engineering of the second half of the 20th century was not "self-evidently doing good by the biosphere". And there will surely be changes yet to come.

In many countries eutrophication remains a significant problem. If, however, one is reasonably convinced of the likelihood of the nutrient-rich residuals of our daily bread coming to be seen as resources gainfully to be recovered, how should one view the headlong rush to remove these resources of tomorrow as pollutants of today — even spending significant amounts of energy to "burn" them up into the atmosphere (through microbial nitrification-denitrification)? Or there again, over the decades, precisely the opposite of eutrophication might become *the* problem — could we call it "oligotrophication"? — through some exotic species invasion, such as zebra mussels in the Great Lakes of North America (Schertzer and Lam, 2002). What was once considered a polluting action may become a restorative action.

Science evolves. Understanding how the Environment works, and how Man interacts with it through policy prescriptions and the technologies embedded therein, may change the very grounds on which such policies are founded. The basin-shaped potential surface underpinning the Myth of Nature Benign in Figure 3 may be evolving, rims turning downwards, to that of Nature Tolerant but Perverse, or something

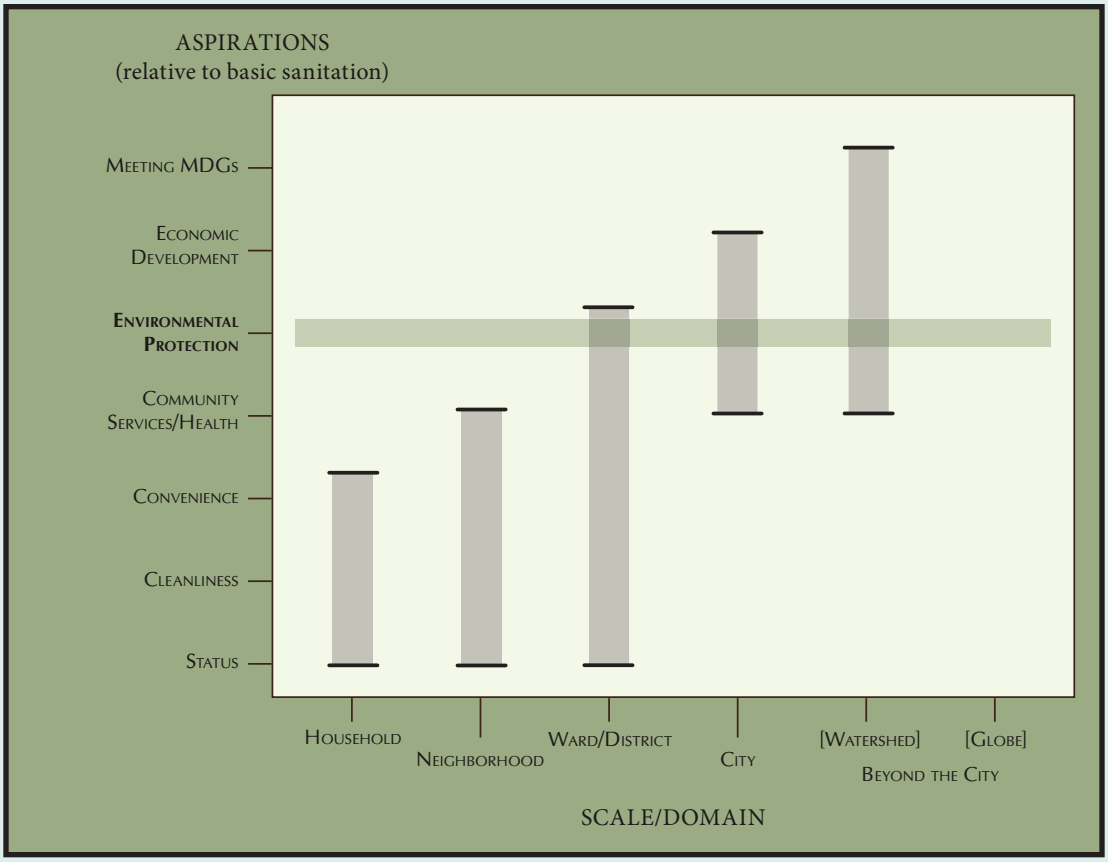


Figure 4:
Scale-dependent human aspirations relative to access to basic sanitation: a modest re-working and graphical portrayal of the hierarchy of preferences of *Sanitation 21* (IWA, 2006; Table 3 therein). In view of the discussion of the graphical (as opposed to tabulated) representation of this material in Box 2, the reader should note well this distinction. The intentions of *Sanitation 21* should not be confused with the present re-working herein of a small portion of its content.

else. The surface may in fact be co-evolving with the policy applied. At the moment of casting the policy action in stone, we simply cannot be aware of all that is happening — and may happen in the future — to the Environment (Beck, 2002; Dennis, 2002). Our "knowing" is not quite right, and will never be so. Policy originating from one style of management, involving technology from one school of engineering thought, may only come to pass in circumstances altogether alien to that conviction — that Myth of Nature; that school of thought — holding sway as the eventual policy was hammered out in the preceding disputatious debate.

Behavior, decisions, designs, and technologies that looked intrinsically "good" in their day can become "bad" in the eyes of a beholder generations later. Is then the young water professional of today, developing and applying software geared ever more efficiently to building an ever more successful, cost-effective infrastructure for nutrient removal, behaving inequitably by his/her children?

If we never asked such a question before, the fact of its being asked here and now is the consequence of seeking sustainability in the water sector.

No-one, of course, can presume to predict how our value systems (and fashions) might change over the generations, which is why it is so difficult to incorporate considerations of inter-generational equity into formal analyses of sustainability. Some core ethical attributes, such as the UN Convention on Human Rights (UNGA, 1948) are more "constant" or invariant than others. Even there, however, flux and change are in the air, in respect of the matter at the very heart of this paper, namely water: that access to it should become an inalienable human right; in response to a failing system of water supply in Jakarta (Bakker, 2006); through protest at the 2006 World Water Forum (Pahl-Wostl *et al*, 2007b); hence through the UN declaration of 28 July, 2010, to which nations are to sign up (BBC, 2010; www.bbc.co.uk/news; accessed 3 August, 2010).

A generation from now the concept of sustainability itself, with its triple bottom line and IUWM nested within IWRM, may leave our children and their children aghast; just as we are today looking back on Gantt's vision, or recoiling now at the caricature of a mathematical program in Chapter 2.5. Few technological systems are less capable of rapid adaptation and evolution than the water infrastructures of cities of the Global North (Collingridge,1981; and Box 1); to few others, therefore, can adoption of the inter-generational long view of sustainability be more fitting.

For the moment, however, aspiring to be less unsustainable is what still captures our imagination. Yet with the prospect now of our greatest hopes suffering the fate of Gantt's vision, with undertones of our vanity in contemplating the nature of our own legacy, are sustainable styles of IUWM nested within IWRM those designed for continual adaptation and evolution? Instinct would have us jump towards responding in the affirmative, perhaps. But was not much of Victorian engineering "built to last", in contrast — and largely, it has to be said, to our good fortune today, a century and more on?

BOX 2

A "Person-Centric" Perspective on the World of Water: Needs, Wants, Luxuries — and Motivations

Figure 4 conveys a simplified representation of how aspirations — needs, wants, luxuries — vary as a function of scale, from that of the individual household to that of the globe. It is based on tabulated material from IWA's *Sanitation 21* document (IWA 2006). Here, we reveal some of the subtleties and complexities masked by what is otherwise the benefit of Figure 4's graphical simplicity. Our argument will take us from the large (global) to the small (local), and back. En route, we shall be obliged to deal with a plurality of social perspectives, thus to bring some disorder (some deconstruction) to the neat, linear "correlation" of Figure 4.

Aspirations, Scale, and Agendas

Sanitation 21 was motivated by these questions:

> Just how important is the environment and how do decision makers value its protection when assessing a range of sanitation options? When, if ever, is it justified to expend energy created by the burning of fossil fuels on cleaning wastewater? Is it fair to charge very poor people the costs of wastewater treatment from which they experience no immediate private benefit? If this is not fair, how can utilities operate and who should pay them for the costs of running a system? How much can utilities be expected to promote environmentally optimum solutions if this results in no revenue for them?

Their collective point is this. In effect, ordinary urban dwellers — those unserved in respect of basic sanitation at the local household and neighborhood scale — are being asked to put in mind benefits and costs relevant to actors, agencies, and the environment at larger scales. But that is not how these individuals perceive their needs. Which immediate needs, if they are to be met for sanitation at the local scale, will not be driven by, or serve, any broader considerations of the environment. And that is the point of Figure 4. Citizens' preferences vary across scales (as observed elsewhere by Gatzweiler (2006)).

Sanitation 21 goes on to say:

> These questions are just a few of those which should be addressed by system planners when initiating or managing urban sanitation systems. Often they are not because the decision making process is dominated by one particular type of decision maker — perhaps an engineer with highly technical knowledge, or perhaps someone from a development agency with a strong social agenda or a strong home-industry export agenda, or again it may be the environment agency or a donor with a strong commitment to environmental protection. But in all these cases opportunities for exploring the whole range of potential solutions may be lost and the agenda may be 'hijacked' by one particular interest group.

These multiple decision-maker types we can now readily recognize in the archetypes of the social groupings and solidarities of Figure 3. They have their characteristic styles of management and they have their agendas: *their* solutions so well tailored to *their* specification of the problem. Whichever solidarity gets to rank and order the various aspirations up the vertical axis and within the bars of Figure 4, also gets to set the policy agenda and put "their" needs — as the policy priority — ahead of the thereby rendered (inferior) "wants" of others (whatever the others might argue!).

The voice of the ordinary people is not being heard; their needs are not being met. Another larger, louder voice holds sway in framing the problem, *ergo* its solution. "Why do 'well-designed' urban sanitation systems fail?" enquires the *Sanitation 21* report (IWA, 2006). Because what is 'well-designed' in the eyes

of one beholder is ill-designed in those of another.

The "Luxury" of a More Sustainable Toilet — the "Needs" of Basic Sanitation and Shelter

This too is asked in the *Sanitation 21* document (IWA, 2006):

> Can people who have no previous experience of recycling human wastes be persuaded to adopt such practices and who pays for the promotion of the approach?

The ecosan dry toilet is one such means of recycling. In particular, it is one already the subject of vigorous debate in professional circles, with accusations in the air of its epitomizing the expensive luxury of sustainability — for the multitudes of the poor and unserved, that is (Box 1; McCann, 2005; also Chapter 3.2). Kwame's recent field study (2007) of the social acceptability of ecosan dry toilets — amidst the tough realities of life on the ground in peri-urban Accra, Ghana — could hardly have been more timely (Kwame, 2007).

Adoption there of the new technology promised not just sanitation but the benefit of nutrient recovery (instead of environmental pollution) and the personal and community obligation to confront the actuality and proximity of our very human biological residuals. Those in the community with a strong individualist flare wanted to know whether a market for the sale of personal, composted residues could be created, not least to compensate them for the waste of their own personal time in achieving the composting. Hierarchical types, if they could not have the status symbol of a WC, preferred legislation — for punishing non-compliant members of the community — and trusted, certified experts, such as community health nurses and sanitary inspectors, as the bases of their scheme for managing the introduction and operation of the new ecosan technology. Egalitarian participants meanwhile, understood the benefits (without further expert endorsement), would allocate land to collective, community composting, even in favor of land for individual shelter, and stood ready to overcome the single obstacle to adoption. Their agenda was to change the perceptions of the individualists and hierarchists who had yet to be persuaded of the benefits of recycling human wastes through introduction of the ecosan toilet (Kwame, 2007).

The need of the community for basic sanitation had still to be met. Yet there were those within that self-same, unserved community, who argued for the seeming luxury — to others — of a more sustainable style of toilet. Indeed, this was a luxury needed by some over and above the want of others of a roof over their heads.

The simplicity of Figure 4 conveys part of the message, in particular, that of how aspirations vary with scale and domain. It implies however — as does the *Sanitation 21* document on which it is based (IWA, 2006) — that one nominal set of aspirations can be expressed (if not its elements ranked) at each scale, as though there is a single, homogeneous "actor" in that domain. Kwame's (2007) empirical evidence suggests quite otherwise. What is more, the tidily organized and coherent bars reaching up the vertical axis of Figure 4 might in practice be shot along the entire axis, fragmented and incoherent (but not necessarily at all vague).

BOX 2

The Small and the Big Things in Life

We are urged to eat less meat (by Lord Stern), entreated to generate a designer sewage (by Watts, 1993) and, better still, give house-space to an ecosan toilet.[1] Higher technology, in the form of the Information and Communication Technology (ICT) of the D&C style of engineering sustainability in Box 1, can be brought to bear on warning us of our imminent transgressions in excessive consumption of water (and energy) in the bathroom shower (Willis *et al*, 2010).[2] To these small and personal things of life can now be added the avoidance of divorce. For it is not environmentally sustainable, argue Yu and Liu (2007). It leads to more households, fewer people per household, less efficient use of the rooms in a house, and consistently so across 12 countries from both the Global North and South. As they report (Yu and Liu, 2007):

> 627 billion gallons of water could have been saved in the U.S. in 2005 if the efficiency per person in divorced households had been the same as that in married households.

Yet breaking down such lumped consequences and aggregated numbers into the very small and highly personal — and motivated by the empirical findings of what happens when cities *shrink* (for example, Leipzig in eastern Germany) — Skirbekk (2009) challenges the arguments of Yu and Liu (2007). Divorced individuals tend to live in more centralized settings, in apartments as opposed to free-standing houses, and their child-bearing patterns differ from those who remain married. These things also matter, as do the particular spatial arrangements of housing types *vis à vis* the specific spatial configuration of the attaching urban water supply network (not to mention its sewerage).

Lord Stern may have come upon the small and the personal from the bigness of global climate change and the high carbon-footprint of global fertilizer and food production. Would any of us chance upon the big and the global, departing from the intensely personal and intimate matter of choosing whether to divorce? What, then, far less stressful, but still close to home, might bring to mind the cumulative, outward propagating ramifications of such small and local actions in the bigger picture?

Motivation: Scale and a Person-centric Perspective

As water professionals, we have always asked ourselves: "What can environmental engineering do for public health in the city?". Driven by the big issues in the world (sustainability and climate change), we peer into the city from the outside, much as in Figure 1: "Thinking globally; acting locally"; posterior action flowing from prior debate.

We should ask this too, of the small (but vital) things in life: "What can my personal health and well-being do for (re)engineering of the water and nutrient infrastructures and metabolisms of the

---

[1] But this last would be a hard sell in some countries. For if even "water use is often overlooked" in building codes for sustainable homes in a water-centric world (the UK, in this instance; Gaze and McKeown, 2009), what chance is there for the sustainability of the nutrient metabolisms of those homes to be taken into account? However, one might find that in the round — in the big scheme of things — eating meat is not all that bad, if somehow downstream of the home it enables relatively easier recovery of nutrients in forms more readily and beneficially recyclable than those deriving from a vegetarian diet. The question should at least be raised.

[2] National building codes derived from the deliberations of large (national) institutions may stimulate the re-design of household water-consuming (hence energy-consuming) appliances for maximum eco-efficiency. But it is local, individual human behavior in respect of their deployment and operation that is crucial (Kenway, 2010).

city, as well as the global cycling of nutrients (and water) beyond?". Our concern could — perhaps should — be the fashioning of policy interventions with scope *primarily* for broadening people's perceptions. Our circumstances change. Individuals in the city find their circumstances shifting back and forth along the continuum: from survival; to having then a life with less health, and then more health; to a sense of well-being, including the well-being of a dawning awareness of the more distant, remote facets of the natural and global environment. If we, as professionals, are so convinced of the universal "good" of our all being less unsustainable, what devices, technologies, and styles of water-nutrient infrastructure should be invented and installed, deliberately to create a yearning within the community for a sense of the bigger picture, hence for disputing and debating that universal good itself?

What if, as engineers — yet motivated by the small and personal things in life (of our personal health and well-being) — we were to adopt the person-centric view of the world of Figure B2.1? If we understood how people reason outwards, from themselves, in their own strictly personal, local circumstances, to grasp the big issues; and if we could associate specific engineering and technological interventions with each element of such reasoning; could we then prioritize those interventions nudging the community faster — rather than more slowly — towards the desired apprehension of those big issues? Having thus divined some key "pressure points" in the logic of the beliefs of that person-centric perspective, what might we propose as promising and specific, professional engineering interventions intended deliberately to make the remote and the global palpable to the local and personal? Would this, in the present century, be a coming to pass of "environmental conservation ... as a core state interest", in succession to that of social welfare in the last century and economic success in the 19th Century (as hoped for by Dryzek *et al*, 2002; see also Chapter 3.2)?

"What makes people care?" asks the psychologist. "What evokes empathy within the individual?" These days, with the technological advances of Imaging Neuroscience (Schmitt *et al*, 1998), we can observe the minuscule of those neural networks in the brain that are activated when we, as individuals, are confronted with the experiences of others: their physical/cognitive circumstances; their psychological/social circumstances; their hunger, their poverty, their lack of sanitation. Our brains respond to such things, it appears (Immordino Yang *et al*, 2009), not through activation of any higher-level, culturally acquired neural networks, but through the profoundly existential, subliminal, visceral bits of brain function. These are primal drives of survival. With monumental significance, we know that "people will kill for ideas". And yet we also know that under evolution, from the beginnings of solely the "selfish gene" (of popular book titles; Dawkins, 1976), can emerge cooperation: beyond the gene, the cell, the organ, and the organism (as we climb up the scales), amongst human individuals, expressed and acted out within their society (at a yet larger scale).[3] In 1943, when Maslow published his seminal "Theory of Human Motivation", he could not have imagined how the minuscule of that motivation might today be empirically observed (Davidson, 2004; Davidson and Lutz, 2007).

What then might engender empathy for the big (remote) issues in Figure B2.1, in particular, of sustainability and climate change (Chiao and Mathur, 2010)? Might engineers have an ethical role in

[3] This synthesis is based on a presentation of Terrence Deacon at a workshop on "The Human Brain and the Social Bond" (Konrad Lorenz Institute and International Institute for Applied Systems Analysis, Altenberg-Laxenburg, Austria, September, 2010). The merest hint of how such grand synthesis might be assembled can be found in Deacon's published work on the evolution of language capacity (Deacon, 2010).

this? For this would be a case of:

"[Engineers] Acting Locally, [as deliberate stimulus to community yearning for] Thinking Globally"!

Now the goal would be to promote posterior debate through prior action. In turn, of course, further (posterior) action should emanate from what would by then have become that prior debate.

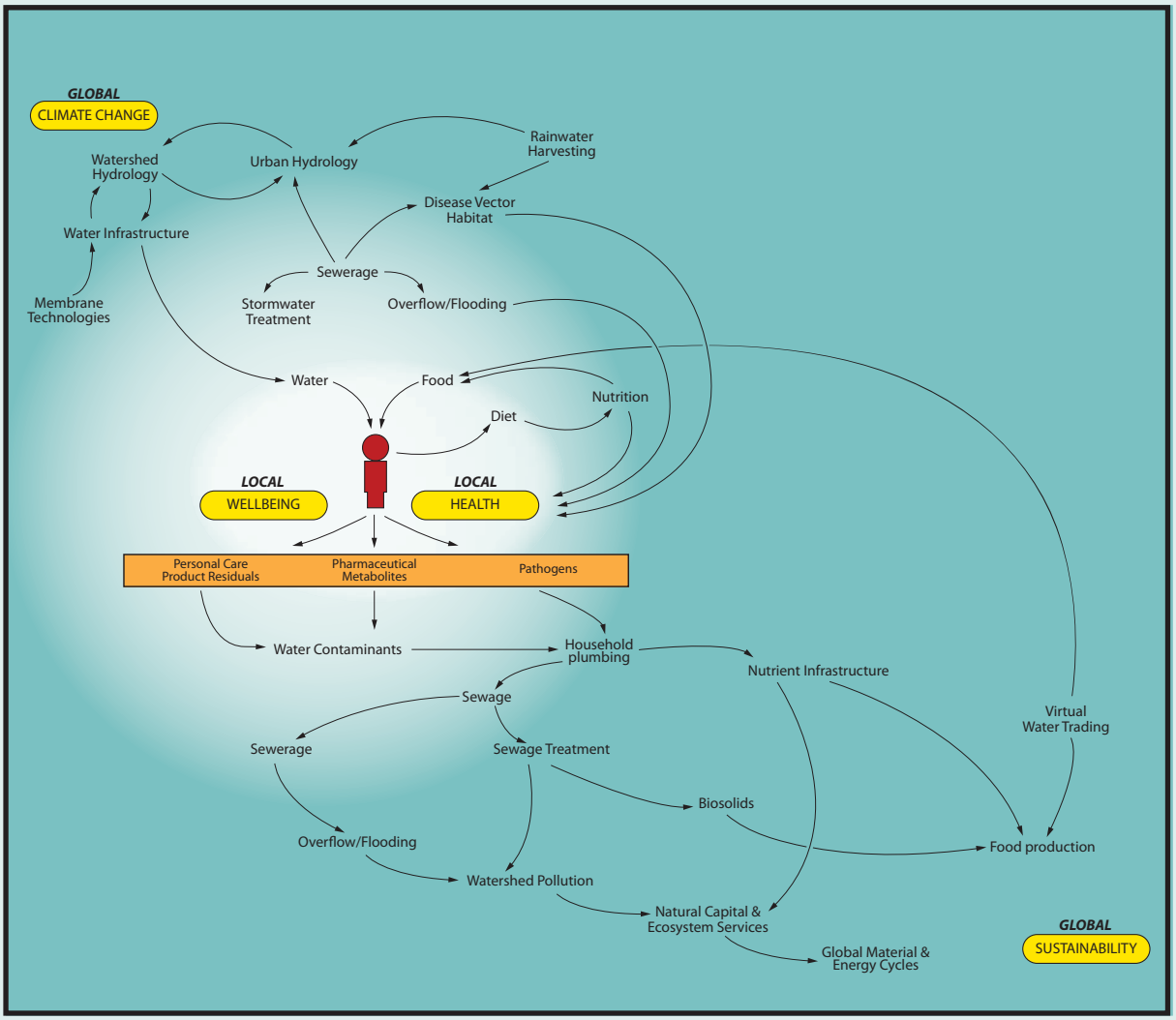


Figure B2.1:
A person-centric network of conceptual associations among entities in the ever-widening perception of the individual citizen (urban dweller). In other words, scale ranges from the local and most intimate of personal choices outwards to the global, whole perspective of Earth Systems Analysis, including thoughts of Sustainability and Global Change. "Think (ever more) globally, while continuing to act (very) locally".

3.2 Economic Feasibility

Our goal in this *Paper* is to strike a balance between a sense of "knowing broadly what to do" and our remaining unsettled in the knowledge that "that 'knowing' is itself not quite right". Our goal is also to facilitate an effective balance between the routine and the uncommonly innovative.

In the introduction of Chapter 1, a commitment was made to adopting a contrarian stance: not to heed the siren calls to convergence on some settled, crystalline, immutable, unquestioned, operational definition or procedure for sustainability (at least, not to heed these calls for the moment); and to insist on taking the long view. Writing from the disciplinary standpoint of Engineering, we could readily admit to the discomfort and difficulty of dealing with all the plurality of perspective that has now burst out of the foregoing discussion of {social legitimacy}. As engineers too, we can look back to the mathematical program caricatured in Chapter 2.5 and readily appreciate the impossibility of pouring the contents of Chapter 3.1 into some crisply shaped mold of quantitative, mathematical representation. As for the long view, we have turned this back onto our own discipline, almost as shock therapy, to emphasize the way in which the very foundations of our science, technologies, styles of management, and outlooks on the world are continually evolving in the longer term — of today looking back aghast at Gantt's aspirations.

Inasmuch as we may have horrified social scientists with the crudeness of our appreciation of what it may take to achieve {social legitimacy} in IUWM within IWRM, so we now risk offending economists.

In the Language of Business: Natural Capital, Ecosystem Services, and Service Providers

According to Hawken *et al* (1999; p 4), an economy needs four types of capital — its factors of production — to function properly:

> human capital, in the form of labor and intelligence, culture, and organization
>
> financial capital, consisting of cash, investments, and monetary instruments
>
> manufactured capital, including infrastructure, machines, tools, and factories
>
> natural capital, made up of resources, living systems, and ecosystem services

This last is the newcomer. Its significance for Hawken *et al* (1999) is not in doubt, for their book is entitled *Natural Capitalism: The Next Industrial Revolution*. At the beginning of the first industrial revolution, they relate, human capital was the scarce variety of capital and therefore the limiting factor in the economy. Natural capital, conceived of as "resources", as opposed to the more modern interpretation of resources *and* "ecosystem services", was abundant — indeed, so much so, it was not even granted the significance of being considered a form of capital. At the close of the first industrial revolution, human capital has become abundant, while natural capital is threatened with being driven towards scarcity.

It is clearly still a titanic, polemical struggle to gain recognition of this, as the title of another recent book makes clear — *Natural Capital and Human Economic Survival* (Prugh, 1999) wherein we can read (Prugh, 1999; p 19):

> The fundamental error of the dominant economic worldview is to treat land (the environment) as merely a factor of production (and one of declining importance, at that). In effect, this outlook locates the environment within, and subordinates it to, the human economy ...

We have inherited from neo-classical economics (Prugh would argue) the profoundly wrong-headed view that the environment is enfolded within human economy; human economy is not enfolded within the environment, as it should be.

In 1963, Barnett and Morse wrote a classic text on *Scarcity and Growth: The Economics of Natural Resource Availability* (Barnett and Morse, 1963). The subject was addressed again in 1979, in *Scarcity and Growth Reconsidered* (Smith, 1979); and then revisited in 2004, with the publication of *Scarcity and Growth Revisited: Natural Resources and the Environment in the New Millennium* (Simpson *et al*, 2004a). Over these four decades, scarcity has come to be reclassified as an "Old Scarcity", of fossil fuels, minerals, agricultural products (Pearce, 2004), and the "New Scarcity" (Simpson *et al*, 2004b), as in the

> sky, water, and land ... employed for waste disposal with [previously] little thought about

> the consequences

or (Pearce, 2004)

> [the Earth's] life support assets, such as biological diversity, the global atmosphere, ocean resources, tropical and boreal forests, coral reefs, and wetlands.

The difference between old and new is as that between how the environment was viewed in the *Limits to Growth* of the early 1970s (Meadows *et al*, 1972), as stocks of resources, and how in the contemporary *Natural Capitalism* (Hawken *et al*, 1999), as stocks and flows of services provided by those stocks.

While some elements of the legacy of neo-classical economics are clearly contentious, others are apparently not (Ayres (1998), as cited in Hawken *et al* (1999; p 165)):

> If there is any implication of neo-classical economics that seems to be beyond challenge it is that shifting the relative prices of factors of production (i.e. labor, capital resources) will eventually induce the economy to substitute the cheaper factor (labor) for the more expensive one (resources). For the same reason, I want to increase the tax burden on activities that damage the social or natural environment, so as to discourage such activities and reduce the resulting damage.

Environmental taxes, or pricing a polluter's use of the environment to receive his/her waste, and tradable permits to discharge a given quantity of pollutant, are both forms of market-based instruments of environmental policy (Pearce, 2004).

Given the four forms of capital, sustainability can be interpreted as a matter of passing on to future generations an undiminished aggregate of capital stock, summed across its four types. Thus, if substitution is possible — if forms of capital are entirely fungible (interchangeable) — sustainable behavior in the present could embrace replacing, say, some natural capital with at least as much equivalent manufactured capital (Figure 5(a)). Human economy could thereby continue untroubled on its path into the future.

Economists would call this meeting the conditions of "weak sustainability" (Pezzey and Toman, 2004). No-one would argue there would be no trouble should this notion of fungibility be pushed to the logical absurdity of all natural capital being replaced by manufactured capital. The trouble with the notion, however, is that natural capital, especially in the dimensions of ecosystem services and living systems (as opposed to non-renewable resources), is essentially not substitutable (as Dyllick and Hockerts (2002) reiterate). The survival of the human economy, as Prugh (1999) has put it, cannot be ensured without the passing on to future generations of some minimum stock of natural capital.

Still, if forms of capital are fungible — an assertion Norton and Toman (1997) ascribe primarily to Solow (1993) — inter-generational obligations reduce to a concern for a "fair investment policy". There are no particular things that we owe to the future. Hence, the present generation will pass an "unstructured bequest package" on to future generations (Norton and Toman, 1997; as recorded in Figure 5(a)).

If fungibility does not obtain, however, so that a minimum stock of natural capital must be passed on, then arrangements must be made for a "highly structured bequest package". This now is as represented in Figure 5(b), and qualified by the term "strong sustainability".

Ecosystem Services

Figure 6 (Aronson *et al*, 2006) encapsulates this same history — from first to subsequent industrial revolutions — although it chooses to focus on the correlation between declining natural capital and rising manufactured capital (as opposed to human capital). At the same time, it confirms the growing appreciation of the significant difference between natural capital and ecosystem goods and *services*, the historic fall in whose quality and diversity is matched — according to Aronson *et al* (2006) — by the increasing cost and difficulty of their restoration, if not its impossibility (Dyllick and Hockerts, 2002).

We do indeed work in an inter-disciplinary setting. Aronson *et al* (2006) would probably not baulk at being labeled ecological *restorationists*; their paper was composed expressly for the purpose of engaging in a cross-disciplinary dialog with ecological *economists* Farley and Daly (2006); and that dialog takes place in the journal of Ecological *Engineering*. Figure 6 (Aronson *et al*, 2006) is a carefully thought-through adaptation of an earlier diagram composed by Daly and Farley (2004). In opening the dialog, Aronson *et al*

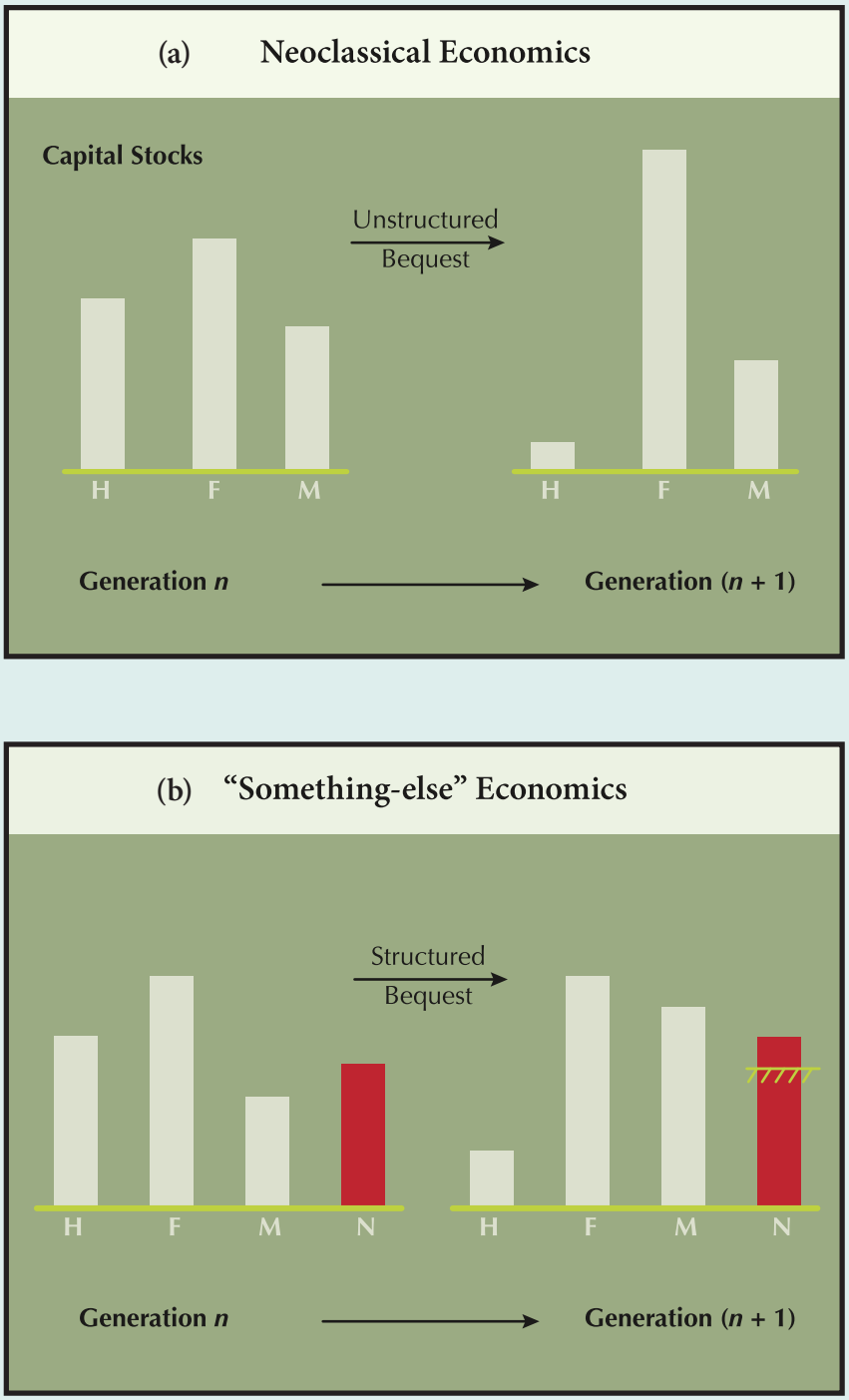


Figure 5:
An engineer's caricature of capital stocks and Solow's notion of bequests to the future: (a) an "unstructured bequest", nominally attached to neoclassical Economics; and (b) a "structured bequest", nominally attached to "something else" Economics. H is human capital; F is financial capital; M is manufactured capital; and N is natural capital.

(2006) quote a personal (prior) communication from Daly:

> More and more, the complementary factor in short supply (limiting factor) is remaining natural capital, not manmade capital as it used to be. For example, populations of fish, not fishing boats, limit fish catch worldwide. Economic logic says to invest in the limiting factor. That logic has not changed, but the identity of the limiting factor has.

In their response, Farley and Daly (2006) begin by pointing to what they see as inadequacy in the scope of ecosystem services portrayed by Aronson *et al* (2006), who overlook "one of the most important roles of natural capital", i.e., "the ability of natural systems to absorb and recycle waste", which "may prove more limiting than [natural capital's] role as a source of raw materials" (the "New Scarcity", in other words, of Simpson *et al*, 2004b). Farley and Daly proceed then to help us ground our thinking in neo-classical economics, as a subsequent point of intellectual departure (though doubtless this was not their original intention; Farley and Daly, 2006):

> The problem is that humans, like all other species, rely for their survival and economic welfare on intangible, non-marketed ecosystem services such as climate stabilization, water regulation, waste absorption and so on. Though increasingly scarce, the majority of these ecosystem services have no price, and therefore no feedback from markets signaling their scarcity and no market incentive to produce them.

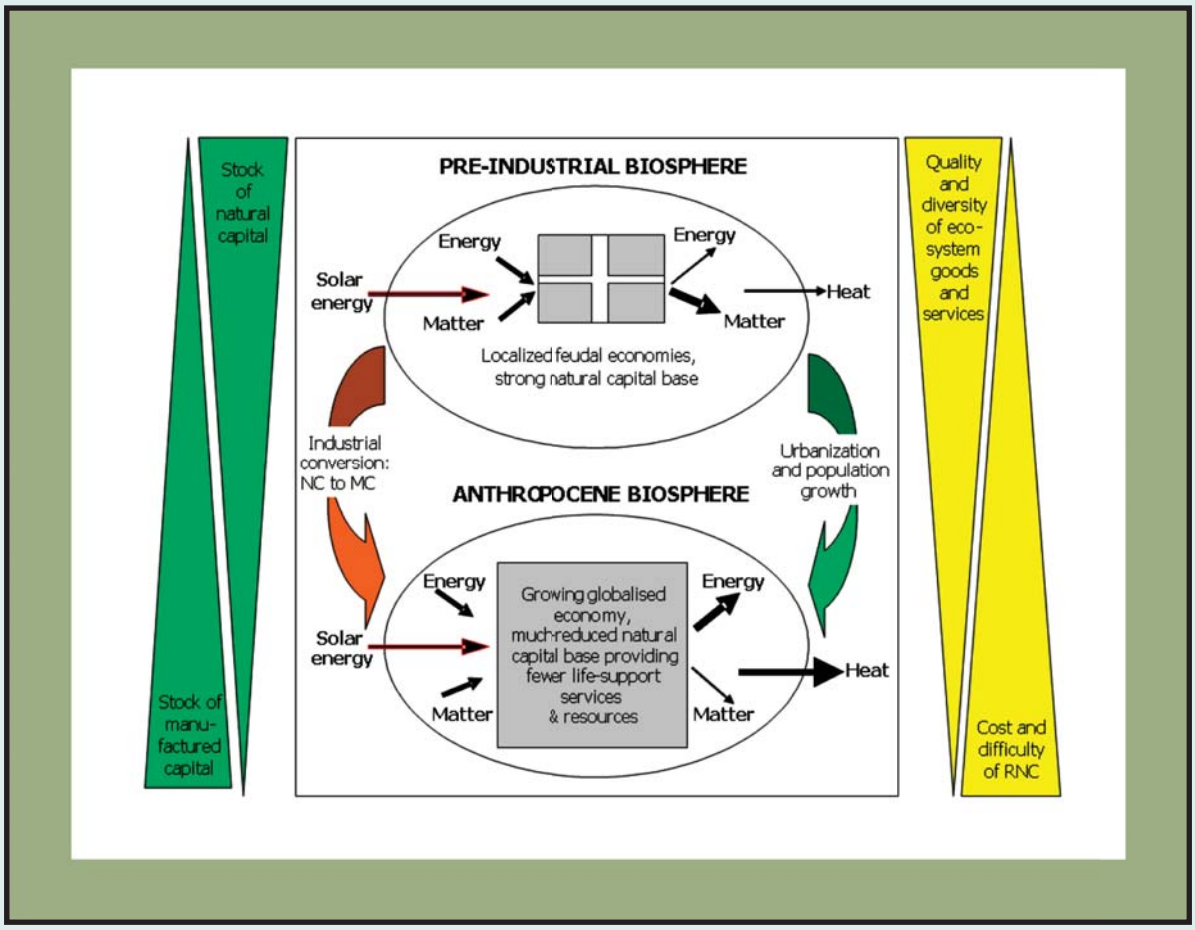


Figure 6:
Figure 2 from Aronson *et al* (2006), whose caption for this figure reads: "Pre-industrial and anthropocene biospheres diagram. Note that in the anthropocene biosphere a relatively lower proportion of energy is contained in matter on earth (e.g., forests) with the balance leaving earth as heat or accumulating in the atmosphere as carbon dioxide. RNC stands for Restoring Natural Capital." (Reproduced with permission).

Service Providers

Building upon the platform established through this dialog, with now, in particular, a more complete appreciation of the nature of ecosystem services, we can approach the concept of an "ecosystem service *provider*" (Kremen, 2005). We may talk easily of the supply and demand for such services. In respect of the threats to their continuing provision, however, even estimates of their economic values, Kremen suggests we understand but little of the role of biodiversity in providing these ecosystem services. She employs an oft-cited case study in water supply to make her point (Kremen, 2005; see also Heal, 2000):

> When New York City decided to protect the Catskill Watershed rather than build an expensive water filtration plant, ... it vindicated the economic potential of ecosystem services. It is remarkable, however, how little ecological information went into this decision. Planners reasoned that even if they underestimated the area required by half, it would still be far cheaper than building the water filtration plant. Numerous urban centres around the world depend on natural water purification mechanisms to provide safe drinking water for hundreds of millions of people, yet we have little ability to predict how much land must be protected and nearby land use must be restricted to provide water of sufficient quantity and quality.

In the service of "purification of water", vegetation, soil micro-organisms, aquatic micro-organisms, and aquatic invertebrates are identified as the ecosystem service providers (Kremen, 2005). Choices in engineering a more sustainable IUWM within IWRM, therefore, should be guided by the extent to which they direct investment towards the prosperity (or otherwise) of these entities — collectively, the natural capital — in order to ensure lasting streams of high quality ecosystem services therefrom (see also Tilman *et al*, 2002).

Yet how exactly might the classical technology of the activated sludge process of wastewater treatment be reworked so that the city could contribute to restoring natural capital and enhancing the watershed's ecosystem services? The question is neither fanciful nor rhetorical. It arises from Kremen (2005) herself, albeit in a mere footnote to her tabulation of (global) ecosystem services classified according to the Millennium Ecosystem Assessment, no less (Carpenter and Folke, 2006; www.MAweb.org). The question ranks thus as but the "smallness" of a footnote to a tabulation of the "largeness" of global ecosystem services. And in that sense, "thinking globally, acting locally" — an awareness of the "tele-connections" in things — is epitomized.

The activated sludge process exemplifies an engineered microbial ecosystem. Emerging from the quasi-rural, quasi-natural setting of the sewage farm of the 19th-Century, the activated sludge process has become the culmination of engineering intensification: enabling what Nature does for herself, but of necessity in the increasingly confined urban spaces of the 20th-Century wastewater treatment works.[16] At the heart of the 20th-Century Technocratic Paradigm (20CTP) of Box 1 resides thus much of the style of those who might most implacably oppose the paradigm; those who espouse the principles of engineering sustainability through the Self-Organizing Systems (SOS) of ecology — specifically here, a microbial ecosystem. Indeed, precisely because of its *engineering* over the decades into well-confined industrial, *ergo* quasi-laboratory settings, the activated sludge process provides a remarkably apt microcosm for the experimentation characteristic of the *science* of ecology. And in those settings, Graham and Smith (2004) seek to promote the idea of "designed ecosystem services".[17] Moreover, they look to the development and application of models (***M***) as the means to articulate and realize this idea (Saikaly and Oerther, 2004), rekindling the youthful exuberance, as it were, of systems ecology from the 1960s and 1970s (Curds, 1973a,b). In turn, this image of experimentation with the "heavy" concrete, steel, pumps, and blowers of the activated sludge process, giving rise eventually to its own re-invention in the

[16] Historical changes in phrasing over the decades and centuries — from sewage farm to sewage works, then wastewater treatment works, and water reclamation plant — tell us much about the motivation attaching to our various schools of engineering thought (in Box 1). The contemporary water-centric system, born of the WC and today labeled "water resources facility", is free of any connotations of the manures, nutrients, and fertilizers customarily associated with the long-since forgotten sewage *farm*.

[17] This may be different from, or fall short of, the notion of restoring the pre-city ecosystem services implied in Aronson *et al* (2006). But it is something resonant with our vision and challenge in Chapter 2.4, as much as with comments also expressed in Grimm *et al* (2008) in their work on "Global Change and the Ecology of Cities".

"lighter" form of much better understood ecosystem services, echoes the notion of a dematerializing economy (Kander, 2005).[18]

Here, then, we see the role of Engineering and engineers in re-working (re-engineering) the palette of alternative technological trajectories — the red rectangles in Figure 2 — for moving away from the present conditions towards the distant aspirations of society, in response to the challenge and vision set out in Chapter 2.4.

Plurality of Economic Valuations

The problems in all of this increasingly complete invasion of "business speak", of course, are profound and several. They are ones of how

> to put a number on that minimum stock of natural capital;
>
> to assign tangible prices to those ecosystem services;
>
> to assess the risks of business failures amongst the ecosystem service providers; and
>
> to devise a system of valuation so that, amongst the other factors of production in the economy, things are steered away from depleting that of which there is deemed to be too little and towards exploiting that of which there appears to be too much.

To provide perspective on what this might entail, let us paraphrase an illustration given by Prugh (1999; p 95) of three alternatives for assessing the value (V) of having "entities" such as oysters, as service providers in Chesapeake Bay (on the east coast of the USA):

(i) *Classical Economics:* V_C is the sum of the monetary values of all dock-side sales of oysters harvested and of the transactions of oyster-related commerce thereafter.

(ii) *Environmental Economics:* V_E is the foregoing (V_C), plus the value to the present human population of knowing the oysters are there in the Bay and knowing too that future generations will likewise appreciate this knowledge.

(iii) *Ecological Economics:* V_X is all of the above, i.e., V_E, plus the value of the services of the oysters in filtering, and thereby cleansing, the Bay's waters to the benefit of their (the oysters') ecosystem and the members of the human population that appreciate the benefits of a healthy, integral environment — with some of its clearest origins in Leopold's land ethic (Meine and Knight, 1999; Rosenblum, 2005).

Mindful of the stunning abundance of species, ecologies, and environments, it should not take much to imagine an equally vast and labor-intensive industry devoted to producing just the valuations themselves implied in V_E and V_X.

Key, however, are these two points. First, there is the unmistakable and unsurprising *plurality* of these three economic perspectives. This will manifest itself in working back through the commercial framework — from failing service providers, to service streams, hence to stocks of natural capital — to evaluations of the {economic feasibility} of re-engineering the elemental technology and policy components of IUWM within IWRM. Second, conspicuous by its absence is a sense of the long view in the classical economic valuation of V_C, perhaps by design for the purposes of the original argumentation (Prugh, 1999).

In Söderbaum's recent book, *Understanding Sustainability Economics: Towards Pluralism in Economics*, the pluralism for which he pleads would be that in which there is a viable and acknowledged school of economic thought *other* than that of neo-classical economics, which he labels "Business as Usual" (Söderbaum, 2008). What he then calls "Social and ecological modernization" (see also Hunt, 2010), we here would approximate as the school of environmental economics. That to which Söderbaum himself would be inclined to subscribe, he calls a "Radical interpretation of SD [Sustainable Development]". We surmise this would be closely aligned with what we refer to above as ecological economics.

Spun a slightly different way, economic "goods" come in more than just a single form. Pearce (2004) equates those of the Old Scarcity of *Scarcity and Growth*

[18] Not necessarily to be confused with a service economy (Stahel, 1997) or a performance economy (Stahel, 2006) or with the impacts of "digital technologies" on the dematerializing and/or re-materializing of economies (Berkhout and Hertin, 2004) or, more specifically, cities such as Singapore (Schulz, 2007).

(Barnett and Morse, 1963) with "private goods" and those of the New Scarcity as "public goods". The two imply their differing respective styles of valuation and management. Since "scarcity" has been inextricably conjoined with "growth" — for four decades — Pearce goes on to acknowledge that there are (and long have been) "[a]nti-growth protagonists". They argue for "no growth", because of the very "scarcity" itself, be it new or old (Pearce, 2004). This "vocal force" (Pearce's phrase), we observe, might well be arguing against resource depletion, hence to conserve "common-pool goods" for a more equitable caring and sharing by all. Thus should we have private, public, and common-pool economic goods (and their attaching styles of preferred policy).

Long View: Inter-generational Discounting

Looking out over the marine fisheries industry, Sumaila and Walters (2005) ask:

> [H]ow much in 'current generation discounted dollars' do we need to give up in order to ensure that future generations have the benefit of inheriting 'healthy' natural and environmental resources[?]

To answer their own question, they, as ecologists translating material from decades of economic thinking (Peña, 2009) — as we in our turn are now transcribing that material into terms familiar to water and environmental engineers — must cycle through almost all of the facets of seeking {social legitimacy} set out in the foregoing Chapter 3.1. They do so as follows.

They propose an equation for discounting to a net present value (NPV) future streams of (annual) net benefits to flow from ecosystem services and natural capital. In their words (Sumaila and Walters, 2005; p 138):

> For each simulated future year, we treat the benefits as accruing to the current generation (at standard discount rates) plus to each of the annual 1/(generation time) increments of new stakeholders who will have entered the stakeholder population by that future year. Each incremental group of new stakeholders is assumed to discount future benefits at the standard or normal rate after entering the stakeholder population.

"Generation time" here is taken as 20 years, for the sake of illustration, such that after 20 years those of our children born in the present year will have joined the body politic and will then (20 years on) have a basic democratic right: that government should reflect only the preferences of the individuals who are members of that enfranchised body and able, therefore, to participate (at the least) in Boulanger's (2008) aggregative model of democracy.

The Sumaila-Walters scheme straddles the values and preferences of *current* and *future* generations. It straddles the difference, therefore, between *standard* and *inter-generational* approaches to discounting. And in this dichotomy it reflects choices they label *empirical*, or indicative of *personal* tastes — we and you acting individually as consumers (largely in our "private spaces") — and choices they call *ethical*, or indicative of *social tastes* — you and we acting collectively as citizens (in the "public space" of community and society debate). To these alignments, can be added this, from Prager and Shertzer (2006), who commend the Sumaila-Walters scheme:

> [I]f one believes that a major goal of economics is to quantify *human preferences* (and the corresponding goal of resource economics is to quantify *societal preferences*) ... the use of conventional discounting is logically inconsistent ... [emphasis added]

In short, if the discounting equation of Sumaila and Walters (2005) is adopted, future streams of net benefits flowing from ecosystem services and natural capital will be valued more highly in the present than they would were a conventional rate of discounting applied.

In the face of the social and community diversity suffusing our discussion throughout this *Paper*, their approach assigns to all stakeholders (present and future) but a single, uniform outlook on the Man-Environment relationship, and one that is not only *invariant* over time but *singularly* egalitarian in spirit. Or as Gatzweiler (2006) has put it, in writing about governance for a public ecosystem service economy:

> [T]he choice of the discount rate strongly reflects a certain ethical standpoint, which is not necessarily the one held by people concerned about or affected by biodiversity conservation measures.

This invariance and singularity of perspective in the Sumaila-Walters scheme seems at odds with our discussion of ever-evolving "fashions", in respect of how considerations of inter-generational equity contribute to achieving {social legitimacy} (witness the changing perception of engineer Gantt's motivations in Chapter 3.1). In assessing now the {economic feasibility} of a given technology or policy, it is not all that difficult to imagine the following kind of logical inconsistency: an invariant, inter-generational discounting procedure conditioned upon the myth of "Nature benign"; which is applied under a valuation scheme (such as V_C, V_E, or V_X) originating in the myth of "Nature tolerant but perverse"; in the design of a policy now whose consequences will be inherited in the future by those eventually convinced quite otherwise by, say, the myth of "Nature ephemeral". Simply put, our utopian vision of today may come to be inherited as dystopia in the eyes of our children.

Even without reaching for such diversity, economists of apparently the same broad persuasion — those adhering to valuations V_C, it seems — may be pitted one against the other, as Godard (2008) notes in his review of the reviews of the "Stern Review" (Stern, 2006) on the economics of climate change:

> Paradoxically, the much-attacked choice of a low discount rate chosen to ensure an equal treatment of the utility of all generations is best grounded in the utilitarian philosophy that underpins the type of economics that both the Stern Review and most of its critics share.

Once was the time when Engineers might have been rather smug about such highly contested variations on but one basic economic theme amongst the thoroughly disputatious plurality of schools of economic thought. Not amongst our profession would such diversity hold — the accounts of Box 1 notwithstanding — nor our outlooks change with time. But many of us today *are* ruffled by what Gantt had in mind a century ago; while conversely just as many might be comforted by what seems to have moved the first three Presidents of the (UK) Institution of Civil Engineers a century or so before Gantt (Wynn, 2009). We are not all uniformly in the same boat — or aircraft, as Baneth (1998) and Boulanger (2008) would have this — heading in the same direction, without deviation, across the generations. Smugness about uniformity may come to be (constructively) substituted by the "disputatious plurality" formerly perceived as the weakness of Economics.

Economists, in return, are not above calling into question the style of Engineering. When Söderbaum (2008) suggests as further reading beyond his own book that of Nobel-laureate Sen — *On Ethics and Economics* (Sen, 1987) — he does so on the basis that Sen is critical of neo-classical economics for its

> almost exclusive reliance on an 'engineering tradition' where ethical aspects more or less disappear.

Sen, says Söderbaum,

> recommends a development path for economics where ethics is taken seriously.

Plurality of outlooks, variability therein over time (if not sea-changes), hence uncertainty in respect of the discount rate (if not mutual contradictions), can all exert an influence over the composition of the longer-term technological trajectories (the red rectangles of Figure 2) towards less unsustainable forms of IUWM within IWRM. Facets of this significance have just begun to surface in our own technology and policy sector, in studies of inter-generational stewardship of lakes prone to eutrophication (Ludwig *et al*, 2005). They are considerably more mature in the much more prominent policy sector of shaping strategic public- and private-sector investments in energy technologies for mitigating global climate change (Ringuest *et al*, 1999; Lempert, 2002; Lasry, 2008; Peña, 2009; Lemoine *et al*, 2010). Yet despite all the debate ensuing in the wake of publication of the Stern Review (Godard, 2008; Lasry and Fessler, 2008), including over the shape of the discount function — that it might better be hyperbolic instead of the customary exponential (Sumaila, 2008)[19] — the choice of a single, time-invariant value for the discount rate-constant seems somehow to be a matter of tinkering at the fringes of a deeply intractable problem of social debate and

[19] This is notably a discount function proposed by psychologist George Ainslie (Ainslie, 2001), and presciently so for us under the prospect of climate change. Ainslie's goal, hence his choice of the hyperbolic discount function, was to understand how addicts continue to make decisions in the here and now that they know full well to be harmful to their future well-being and survival.

democracy.[20] As with the fine line in the archetypal mathematical program of Chapter 2.5, there is only so far one can penetrate effectively with quantification and numerical analysis.

Bequests to the Future and Grand Social Programs

As reported by Boulanger (2008), Sen

> ... was the first recognized economist to propose a multidimensional vision of development, focused, not on economic growth or an increase in monetary income but rather on an extension of the real freedom of people to achieve their goals.

The body politic of the modern state, we are told, acquired such *economic growth* as a core state interest — one of its "imperatives" — in the 19th Century and *social legitimacy* in the 20th Century (Dryzek *et al*, 2002).[21] Simple extrapolation suggests *environmental benignity* will take this present century to become a third imperative of the state.

As in ascending the steps of the seeming hierarchy of economic valuations (V_C, V_E, or V_X), or Maslow's much disputed pyramidal form of human motivation, or the ranked aspirations of Figure 4 (which places economic growth above all else, except notably achievement of the Millennium Development Goals), one has a sense of scaling the heights of some lofty social program, just as Gantt had contemplated. What is the environmental engineer, busying him- or her-self with the nuts and bolts of urban water infrastructure, to make of such high-minded notions of {economic feasibility}? Their sweeping scope must seem a far cry from the engineering economics of Total Annual Economic Cost (TAEC): employed to discriminate amongst alternatives for upgrading infrastructure performance (Jiang *et al*, 2005); where the upgrading aspires to nothing grander than simply lowering the phosphorus content of an effluent; with horizons spreading little beyond the fence-line of the wastewater treatment plant; hence a style of valuation (V_0) subsumed under those of V_C and the others?

What then, in the light of contemporary pragmatism, might be our bequest to Brundtland's next generation? For things can be altogether undignified, rather desperately personal, and far from grand.

Ecological sanitation systems — the ecosan we now know from Boxes 1 and 2 — allow adopters of this technology to cut water use and provide a source of fertilizer. Claiming a degree of "eco-insanity" in all of this, however, Mara (2005) begins his polemic with these words (themselves already touched upon in Boxes 1 and 2):

> The basic philosophy of ecosan is beguilingly attractive: we each produce enough nutrients in our excreta to grow all the maize or wheat that each of us needs. We need to use, not waste, these nutrients; if we waste them by mixing our yellow [urine], brown [feces] and grey waters [wash waters] together (to form domestic wastewater), then we end up spending a lot of money removing them at wastewater treatment plants, or else they get into our rivers and lakes where they may cause eutrophication.

He continues, to issue the bluntest of market signals: "'If I'm a poor rural villager in India, why should I spend 4200 rupees on an ecosan toilet, rather than 1900 rupees for a single-pit pour-flush toilet?'". And there we have it in a nutshell: the tension between eloquent lofty vision, the "luxury" of earnest debate about collective, global sustainability, and hard — brutally hard, and very immediate — local, personal pragmatism.[22]

In her analysis of the companion matter of connecting the poor of Jakarta, Indonesia, to a formal, networked supply of potable water, Bakker (2006) concludes that abject failure was likewise a function of economic disincentives, and at every turn: as public sector gave way to public-private sector partnership, bringing forth in turn an audible civil-society voice; and with all this unfolding across the local, municipal, and national

[20] One current view is that the discount rate-constant should in any case better be time-variable (Obersteiner, 2010).

[21] Their work was confined to nation-states of the Global North, however: Germany, Norway, the USA, and the UK.

[22] With the rest of that particular debate being played out in McCann's (2005) article in *Water21*.

scales of governance in a specific, and specifically important, cultural context.[23]

Lofty Principle and the Little Things in Life

How now indeed should we contemplate the high-minded principle of our bequest to the next generation? How much of an investment in the longer-term future — into fungible, natural, or other forms of capital — would an ecosan toilet be, relative to a single-pit pour-flush toilet? How too then could we resolve Solow's moral dilemma (Solow, 1991), or respond to the challenge put to (now) Lord Stern by Landau (2008): that those of us who would care so much for the well-being of the next generation — by bequeathing to it, at the very least, no less natural capital than that in the world today — might thereby seem to care so little for the masses of today's poor? For they need something to be done right now about their water situation — and something Solow would assert is inevitably consumptive of current natural capital, quite the opposite of a constructive bequest to some distant future.

Scale, in its various manifestations, is yet again important here. On the one hand, there is a need to consider accounting for the time preferences exhibited in *individual* behavior with respect to the future, as those individuals aspire to local social status and cleanliness in their households (according to Figure 4 and IWA's *Sanitation 21* document; IWA, 2006). On the other, account must be taken of society's *collective* and changing preferences over inter-generational time, especially if, say, *large-scale* ecosystem services are in danger of degradation (Norton and Toman, 1997). Aspirations vary across these vastly different scales. And the ranking of policy-critical needs ahead of mere wants, let alone luxuries, may often be a function of s/he who can shout the loudest (as we have seen in Box 2). In this resides the hugely complex compound of {environmental benignity}, {economic feasibility}, and {social legitimacy}, making it so tortuous for us to engineer our way out of unsustainability in IUWM.

Besides basic physiological survival and security of body (ranked elsewhere at levels 1 and 2 in Maslow's hierarchy), and before aspiring to "Think globally, act locally", the individual contemplating investment in a single-pit pour-flush toilet might best be brought to a position where "Debating somewhere *districtly*, acting locally" has been facilitated, if Figure 4 holds true. To that end, the engineer might thus ponder how to design and install forms of household, neighborhood, and ward/district supplies of potable water and sanitation infrastructure, deliberately to initiate debate about sustainability, and as soon as possible. This is just such a change in perspective as that related in Box 2: from peering in on the problems of IUWM within IWRM, from a professionally detached distance (Figure 1; and Figure 2, as well); to looking outwards and upwards from the individual and the self (from Figure B2.1 embedded in the detail of Box 2). After all, we know that slum-dwellers in some of the cities of South America place dwellings in their neighborhoods in a rectilinear, grid pattern (Thompson, 1979); one that is all the more conducive to any subsequent introduction of basic water infrastructure by the powers that be, in anticipation of this community moving on to its next aspiration.

[23] A context suffused with corruption and mafia-style control of water-vending operations, as if there were not already enough impediments to network connections for the poor (Bakker, 2006).

3.3 Environmental Benignity

We began in Chapter 2.4 with a challenge and a vision, grounded, as sustainability is itself, in the perception of Man bumping up against the limits of the Environment. The charge to the engineer is to come up with technological (and policy) trajectories tending towards a contemporary vision of what should be good for the Environment, i.e., first and foremost, promote movement positively along the dimension of {environmental benignity}. That "goodness", nevertheless, will be subject to a plurality of fervently held interpretations, which interpretations will surely manifest themselves in what constitutes {economic feasibility}, in what grants {social legitimacy} of action and innovation, and — perhaps more contentiously — in a plurality of schools of thought on environmental and sustainability engineering (in Box 1).

Scale, both in space and time, is yet again important. In the preceding discussion of economic valuations the reader was being invited to expand his or her horizons successively outwards (from V_C, through V_E, and on to V_X): from me and you acting as consumers (literally of the oysters) to you and me thinking more as citizens. Not at all apparent there was the reverse, of thinking being pushed backwards and ever more inwards: through the urban water and wastewater infrastructure; to the intimacy of our personal dietary preferences and their consequences for sewage; hence to the choices in those private, inner circles that enable the oysters to survive and prosper in the estuary, in spite of the city. With "lofty principle and the little things in life" was how Chapter 3.2 was closed.

That was a matter of space: the tele-connections between the relative smallness of personal choice and engineering economics and the big picture of natural capital, ecosystem services, and service providers. It was a matter of thinking through the strings of reasoning flowing outwards to climate change and sustainability from the person-centric perspective of Figure B2.1 in Box 2.

What, then, might be the companion tele-connections along the dimension of time? For time, like space, has the same intuitively separated spans. They are manifest in the many commonplaces we have already encountered:

> in the great debate in economics over the choice of a discount rate that could run from now until the next generation (in Chapter 3.2);
>
> in our behaving as consumers for today, yet as citizens for the sake of our grandchildren (also in Chapter 3.2);
>
> in Solow's dilemma of the need to be consumptive now of natural capital, in the interests of attaining a greater stock of such capital in the more remote future (again in Chapter 3.2);
>
> in looking back, from what may inspire the engineers of tomorrow, to Gantt's motivation of a century ago, and that of the early Presidents of the (UK) Institution of Civil Engineers, a century or so before Gantt (in Chapters 3.1 and 3.2);
>
> and here last (but there first, in Chapter 2.3), in the life-cycle of any technological system of infrastructure.

We know — from Crandall Hollick's (2007) account of the city of Kanpur in India (at the very beginning of Chapter 2) — that it might just be so much more convenient (and surely much simpler) to ditch considerations of what may happen over one span of time in order to focus on another. We might (and surely do) overlook the seeming minutiae of what may happen over the short term of operations (minutes, hours, days, weeks) in favor of attending to the strategic "bigs" of planning, designing, and constructing a future wastewater treatment facility (over months, years, and into distant decades). Now we know the adverse consequences of *not* paying sufficient attention to cross-scale influences along the dimension of time: of being insufficiently mindful of the *interactions* amongst the "here and now" and the (possibly) "there and then". In particular, the "here and now" may come to *dominate* the system's behavior from time to time in some remote "there and then", when having to deal in real-time with a sudden crisis in the distant future.

Interactions Across Time: "The Long and the Short of it All"

We begin by recalling Figure 1. And for the moment, let us put aside considerations of the daily bread and nutrient metabolism of the city, to focus solely on its daily water and water metabolism.

As the city lands down on the ground over geological time (a long view indeed), it alters the spectrum of

hydrological fluctuations in the flows of water through the watershed, i.e., the watershed's hydrological regime. It does so in various ways, most obviously through:

(i) the diversion and accelerated transfer of precipitation-induced flows from the city's surfaces to the receiving streams, *via* the storm sewer network;

(ii) the creation of artificial storage, such as reservoirs — or the exploitation of other naturally highly-damped, slowly-changing systems, such as groundwater in aquifers — in order to lower the vulnerability of the city's supply of daily water to the vagaries of natural fluctuations in precipitation; and

(iii) the supply/removal of water flows to/from the city, to suit the city's economic and social metabolisms, with their emphatic diurnal and weekly oscillatory components.

Tuning the infrastructure of the city to those specific rhythms and routines that are so much to our liking, as we go about our urban economic and social lives, distorts the spectrum of fluctuations in the watershed's hydrological regime.

Construction and operation of a reservoir will tend to transfer some of the power in the higher-frequency components of the regime (fluctuating over minutes, hours, days, and weeks) to the lower-frequency components (with periods of years, decades, centuries, and millennia). Installing the city's sewer network has the opposite effect. Once the city has arrived, it is then as though all the variety of periodic fluctuations in the behavior of the environment are ever thereafter progressively subjugated to the predominant 24-hour and 7-day cycles of steadily intensifying city life. This historic process, moreover, increases the vulnerability of the city-watershed couple to very fast, aperiodic crises on the scale of hours, minutes, and even the seconds of abrupt failure. In sum, what happens at the frenetic pitch of minutes is by no means utterly independent of the lugubrious undulations and rumblings over the decades — and perhaps quite the opposite.

Thus it is that we write of "the *long* and the *short* of it *all*": hence the frustrating inevitability — for we always knew it — of the inseparability of the parts from the whole, as much in time as in space. Expressed somewhat lyrically (Holling, 1996):

> Not only do the large and the slow variables control small and fast ones, the latter occasionally "revolt" to affect the former.

The ecosystems we encounter in the streams and rivers of the city's watershed, and therefore what we today recognize as their services, evolved over geological time in sympathy with that pre-existing, pre-city hydrological regime (Odum *et al*, 1995; Grossman *et al*, 1990, 1998; Reice *et al*, 1990; Naiman *et al*, 2002; Poff *et al*, 1997, 2003, 2010).

For Holling, it is the semi-arid grasslands of east and south Africa that best reveal this role of the spectrum of perturbations in understanding the impact of man on the environment (Holling, 1996):

> Under natural conditions ... the grasslands were periodically pulsed by episodes of intense grazing by various species of large herbivores [not quite our bull in any kind of shop!]. Directly as a result, a dynamic balance was maintained between two groups of grasses.

But then such ecological resilience was lost with the advent of man and the modernity of arranging things — in time — to his liking (Holling, 1996):

> When such grasslands are converted to cattle ranching, ... the cattle have been typically stocked at a sustained [always present], moderate level, so that grazing shifts from the natural pattern of intense pulses separated by periods of recovery, to a more modest but persistent impact. Natural variability is replaced by constancy of production.

Taking our lead from Odum *et al* (1995), who write of Nature's pulsating paradigm in respect of aquatic environments, the pulse of the imposed city could be said to have quickened the pulse of its surrounding watershed (Beck, 1996). The notion of a system's frequency spectrum illuminates succinctly such cross-scale influences (Beck and Cummings, 1996; Beck, 1996, 2005; Beck *et al*, 2010a).[24] It is as pictured in

[24] The discussion of Grimm *et al* (2008) on "Global Change and the Ecology of Cities" hints at the same benefits of this particular means of describing the behavior of a system.

Figure 7 (Beck, 2005); its supporting narrative is as follows.

At the outset, there is the spectrum for the environment without the city. A first snapshot is then taken (in Figure 7(a)) of the spectrum for a mature city with an infrastructure for urban drainage and foul sewerage, but no treatment of any wastewater. Some of the "power" in the slower, lower-frequency components of the natural drainage of water over the pristine, pre-city land surface (over months, years, decades) has been shifted and concentrated into the faster, higher-frequency fluctuations in city behavior (the weekly and daily patterns of life). Impervious surfaces, pipes, and large engineered conduits simply focus volumes of water and speed them on their way from one place to another.

The spectrum for the second stage of infrastructure evolution is drawn for the subsequent installation of the kind of comprehensive wastewater treatment facilities presently the custom in cities of the Global North (Figure 1(a), in other words). We suppose it transforms the spectrum of Figure 7(a) yet again (Beck, 2005). Some of the power in the weekly and daily rhythms is attenuated, through the elimination of significant amounts of pollutants previously imposed on the city's environment (under the first stage of urban development). This success of the infrastructure of wastewater treatment, however, merely separates the city's undiminished and continuing potential for issuing polluting disturbances from a now visibly restored aquatic environment. Things can go dramatically wrong — they fail — in hours and minutes, hence the piling up of the second-stage frequency spectrum towards the yet higher-frequency components of Figure 7(a) (Beck, 1981, 2005; and Box 1). The more the effort invested in maintaining the barrier of the city's wastewater treatment, so grows the vulnerability of the city's progressively restored watershed.

While post-city ecosystems and services might be able to remain intact under an enhanced, even predominant diurnal component, they doubtless did not evolve in the presence of a prominent weekly (societal) cycle in the hydrological spectrum, nor the shock of the city suddenly breaking free of the restraining padding, as it were, of its comprehensive wastewater infrastructure.

We already know well enough what it may take to reverse some of the alterations in the post-city hydrological spectrum: programs such as those of constructed wetlands, restoration of canalized urban streams, low-impact residential development (Dietz, 2007), and sustainable urban drainage systems (cast in the framework of the triple bottom line by Jacobs (2008)). All of these strategies are capable of attenuating the exaggerated powers of the high-frequency components of urban water flow fluctuations (and the influence they exert over the spectra of Figure 7(a)). Almost certainly they were not presented hitherto as frequency-spectrum manipulations, or the means to lower the pulse-rate of the city-watershed. But that is what they are. Stream ecologists recognize them expressly as such: in their wrestling with how to compensate for the effects of dams and impoundments, within the broader context of IWRM (as opposed to IUWM). Their efforts have come to be known as providing for "environmental flows" (Arthington *et al*, 2006; Richter, 2010). Their goal, however, is reversal of the changes in the spectrum sketched in Figure 7(b), i.e., the complement of restoring the city-induced distortions of the spectra in Figure 7(a).[25]

The impact of the "large animal" of the city "grazing in its pasture" can be gauged not only by its footprint (Rees and Wackernagel, 1996) and metabolism (Wolman, 1968), but also its pulse-rate. Yet the foregoing illustrations of pulse-rate manipulations are essentially just restorative. Further, they are confined to mitigating the impact merely of the city, as opposed to the rest of man's interventions in the watershed (for the purposes of irrigating agriculture, for instance); and they are confined to the goal of adjusting the city's water metabolism alone, uncoupled somehow from its nutrient metabolism.

It is time to re-introduce considerations of the daily bread of the city, and build through the analogies of

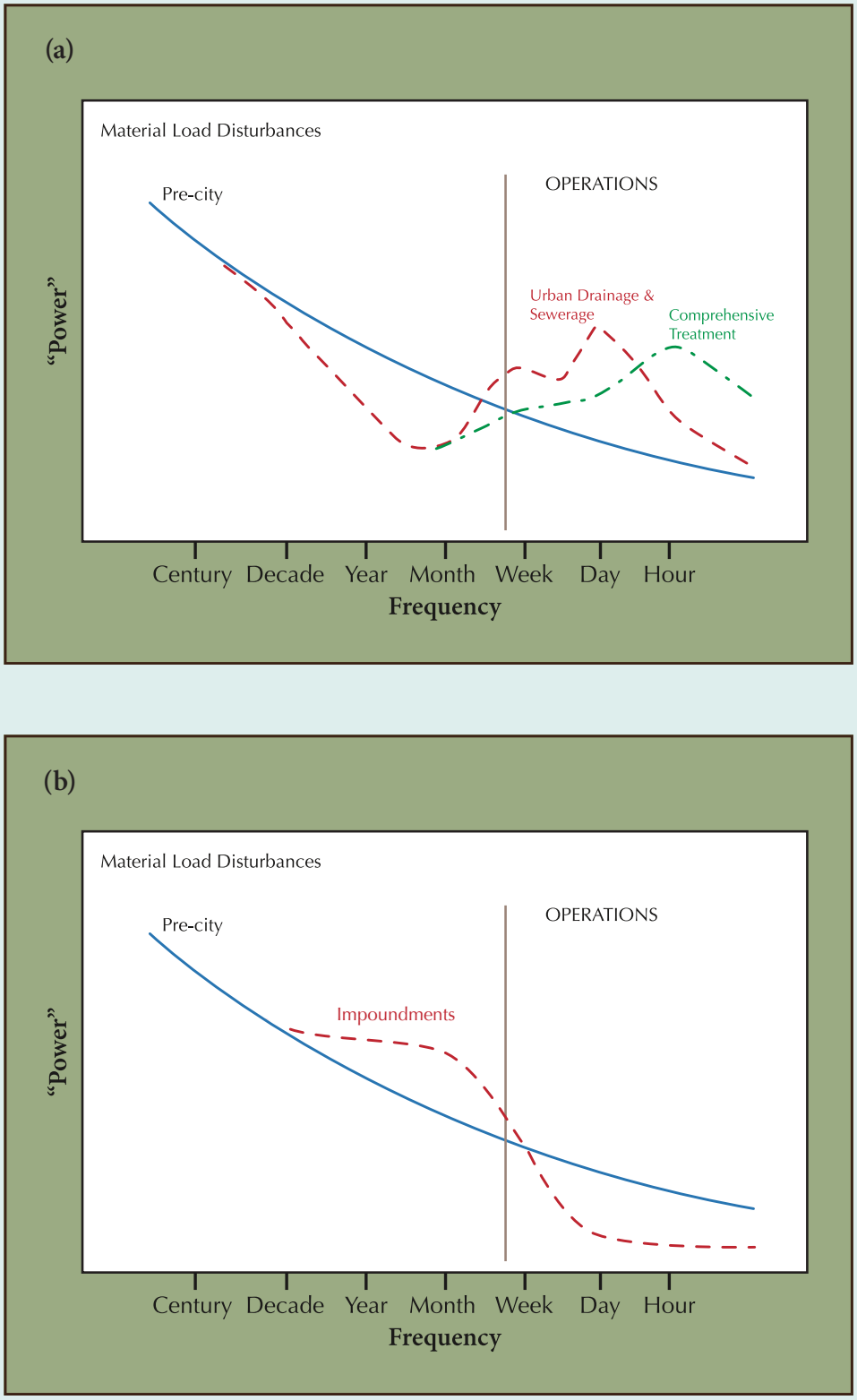
[25] Intuitively, one might think the respective changes wrought over time in the two (Figures 7(a) and 7(b)) should cancel each other out. The evidence of contemporary ecosystem impacts in watersheds so modified by man's interventions indicates quite otherwise. The "long and short of it all" are entangled in complicated, non-additive, nonlinear ways (see also Holling, 1996).

Figure 7:
Visualization of the notion of pulse-spectrum.

(a) City-watershed pulse, or spectra, summarizing perturbation regimes for three successive stages of city water and wastewater infrastructure. In other words, these are the spectra of material load disturbances to which the surface water environment of the city is subject: continuous line represents the pre-city condition; dashed line represents the situation with urban drainage and sewerage installed as infrastructure (but not wastewater treatment); and dashed-dotted line represents conditions under a comprehensive system of urban wastewater infrastructure.

The vertical line separating out the higher frequencies of primary concern to assessing and managing behavior under "Operations" is redolent of the fixation of Beck (1981) and the historic oversight of such great concern to Crandall Hollick (2007).

(b) Companion historical change in the pulse-spectrum of watershed hydrological behavior brought about by the installation of impounded reservoirs along the river (dashed line).



appetite, metabolism, and (now) pulse — as entailed in {environmental benignity} — towards possible responses to the challenge and vision of Chapter 2.4: of the city-infrastructure couple as a force for good (CFG) in the environment.

Appetite and Ecological Footprint

We know the extent of the Earth's surface, the area of land occupied by the city, the number of people in the city, and their economic and commercial activities. In the life of the city, resources for its metabolism are drawn in and the residuals and detritus of its activity evacuated (just as in Figure 1). If we could calculate the areas of land and sea required to generate the incoming resources of the city and assimilate its outgoing residuals, we would have an areal estimate of the city's footprint. Which we already have (Wackernagel and Rees, 1995; Jansson *et al*, 1999; Lenzen *et al*, 2003; Jenerette *et al*, 2006). The result, like so many other indices, reveals the scale of our misdeeds in terms we can all readily grasp, whether technical expert or technically lay person. Wikipedia, for example (accessed 14 January, 2010), reports humanity's total Ecological Footprint to have been some 1.3 times the (biologically productive) area of planet Earth in 2005 (see also Hoekstra, 2009).[26] Projections elsewhere suggest that by 2050, with a world population of nine billion people, our collective global appetite could consume planet Earth more than twice, if not several times over.

Like Integrated Water Resources Management, or the Triple Bottom Line, the Ecological Footprint (EF) has its critics. For what such analysis gains through its clarity and intuitively understandable quality, it loses in other ways through being perhaps too simple and unsubtle. Newman (2006) has gone further, beginning by saying this:

> Policy is largely about what cities need to do — not what they should try to stop doing.

The admonishing tone that comes with the EF is somewhat at odds with our sense of searching for expression of the "force for good" in CFG. Newman (2006) continues:

> The Ecological Footprint model is used largely as a symbolic parameter representing the problem of resource consumption.

The plain phrases of the footprint are indeed so easily understood. Bidden to "tighten our belts" through ever enhanced efficiency, the exhortation to reduce the city's footprint speaks simply, loudly, and clearly. It speaks to the debate, moreover, in the voice of the egalitarian solidarity: "Salute frugality, especially in the profligate Global North". That we are in danger otherwise of consuming the planet several times over is a quite unpalatable, apocalyptic vision.

But now we stand at odds with Newman (2006), when he concludes:

> Analysis from this perspective [of the EF] can help a city frame a variety of policies to begin reducing global ecological impact. However, it does little else.

Specific policies can be framed and acted upon, with a practical impact on the ground. There is a detailed calculus that works, below the arresting headline figures: to select alternative, candidate items of technology; to follow the principles of the EF to compute their respective consequences; hence to make choices to reduce the city's footprint. Technological alternatives for wastewater treatment facilities for the city of Petaluma, California, USA, were just so evaluated (already in 2000) — under the customary coupled and centralized paradigm of wastewater infrastructure of Figure 1(a) (Davis, 2008).

Availing ourselves of the calculus, we can embark on building a response to the challenge and vision of Chapter 2.4. Our work-space is composed as follows.

Case Study

In our social setting, we shall act as though quite convinced of the merits of "Perfect Fertilizer" (PeFe) as our target vision. This will be our favored, specific green oval domain of Figure 2. In addition, we shall pick out essentially the Separation at Source (S@S) style of engineering sustainability, from the portfolio of red rectangles of technological

[26] The ecological footprint has a younger sibling: the water footprint (Hoekstra, 2009). It was born of a reaction to the fixation of classical water resources management on "supply" and the "local". Matters of "consumption" and the "global" — Hoekstra tells us — are just as important (if not more so). Our global water footprint, however, is not yet quite as dramatically bad as our global ecological footprint (Hoekstra, 2009).

paths in Figure 2 (and Box 1). These choices, however, presume nothing about their superiority over any other convictions others may hold about either the green ovals or red rectangles of Figure 2. For that would be to go against everything said hitherto about the nature of {social legitimacy} and {economic feasibility} in the challenges we face.[27]

To be computationally and numerically specific, we shall further take the particular case of re-engineering the wastewater infrastructure of Atlanta, within the watershed of the Upper Chattahoochee (Figure 8), so that that city might become a force for good in this environment (our CFG, in short; Beck *et al*, 2010a, 2011a).[28] Sitting in the headwaters of the Chattahoochee watershed in the south-eastern US, even the literal areal significance of Atlanta is unmistakable (Figure 8(a)). Comparing Figures 8(a) and 8(b), Metro Atlanta is significantly more extensive than the portion of it lying strictly within the Upper Chattahoochee watershed. The population estimate for Metro Atlanta is 5.4M, of whom just 1.3M inhabitants reside in the Upper Chattahoochee watershed.

Our primary observing point in the affairs of this city-watershed couple will be that where the largest of Atlanta's wastewater treatment plants, the R M Clayton facility (Mines *et al*, 2004), discharges its treated effluent to the Chattahoochee River (the yellow dot in Figure 8(b)).

The inset of Figure 8(a) shows that the Chattahoochee watershed (as a whole) straddles three states, Georgia, Alabama, and Florida. Access to its water resources has been the subject of "water wars" amongst the three since the early 1990s. These remain as yet unresolved (in 2011). At one stage, in the early 2000s, a treaty seemed possible. It was not. It unraveled into failure because downstream Florida insisted on a spectrum of environmental flows being maintained in the river as it crossed the Georgia-Florida state line. Yet further downstream, the cumulative impact of all the various engineering interventions along the Chattahoochee is known to be affecting the well-being of shell-fish populations in Apalachicola Bay, in the Gulf of Mexico (Wilber, 1992; Figure 8(a)). This impact is encapsulated in the altered relative strengths of fluctuations in tidal salt- and fresh-water exchanges. And it was precisely at these coastal interfaces in Georgia, Florida, and the south-eastern US seaboard generally, where members of the Odum family found the inspiration for developing their ideas on Nature's pulsating paradigm (Odum *et al*, 1995).

Assembling our response will take a total of four steps forward, together with a step backwards into a salutary case history of the city of Paris and eventually a companion reflection into the future, beyond the discussion of this *Concepts Paper*. We begin thus.

Step (1)

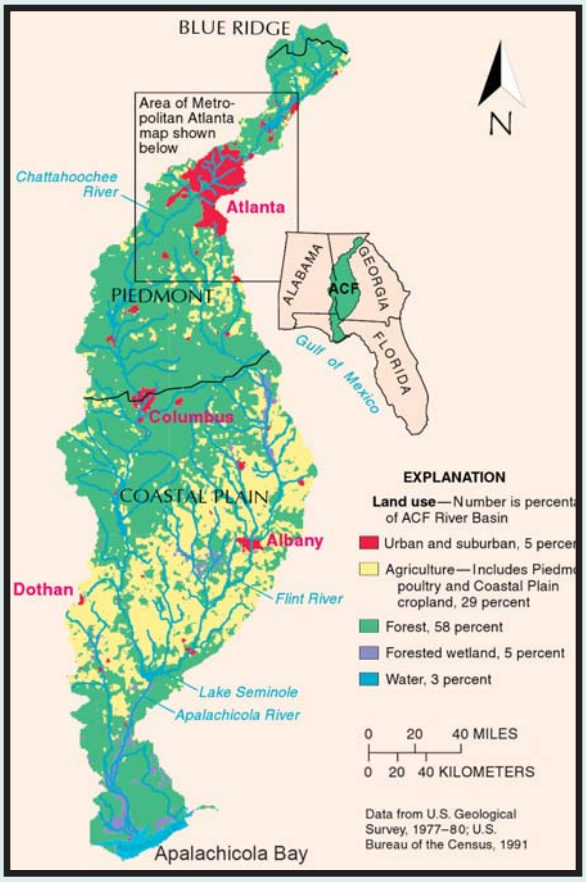
Customary sources of household wastewater can be distinguished crudely as yellow water (urine), black water (feces), and grey water (wash waters). In the conventional wastewater infrastructure of today's cities of the Global North, all are mixed and collectively removed in a single flux from the household (or office block, etc). From there they are conveyed by the added water of WC flushing through a centralized sewer network to a distant wastewater treatment plant. This is essentially the present arrangement in Atlanta. It is conceptually the structural configuration of Figures 1(a) and 1(b). It is the reference base-case all such assessments require. It is accordingly the (green oval) vision of "Business as Usual" in Figure 2, shaped by the 20th Century Technocratic Paradigm (20CTP) school of thought (Box 1) and its attaching portfolio of technological trajectories in Figure 2 (its red rectangle).

We assume that our preferred alternative style of engineering sustainability, Separation at Source (S@S; Box 1), can be implemented in two ways (Jiang, 2010). In the first, to which we shall refer as S@S(1), yellow water is separated at source through a urine-separating toilet (UST) (Hellström and Johansson, 1999; Lienert and Larsen, 2006, 2007, 2009; Larsen,

[27] In any case, things are always so much more combinatorially complex. PeFe itself might need to be produced in a variety of grades, contingent upon subsequent, downstream outlets and processing. By reflection, there is also greater variety than solely S@S, and several minor variations on that basic technological theme of source separation, in the means by which to migrate towards the target PeFe.

[28] This is one of the roles of Engineering, after all. For without the use of formal mathematical models (***M***), our attempts at grasping and debating the options for the distant future will remain vague and inconsistent.

(a)



(b)

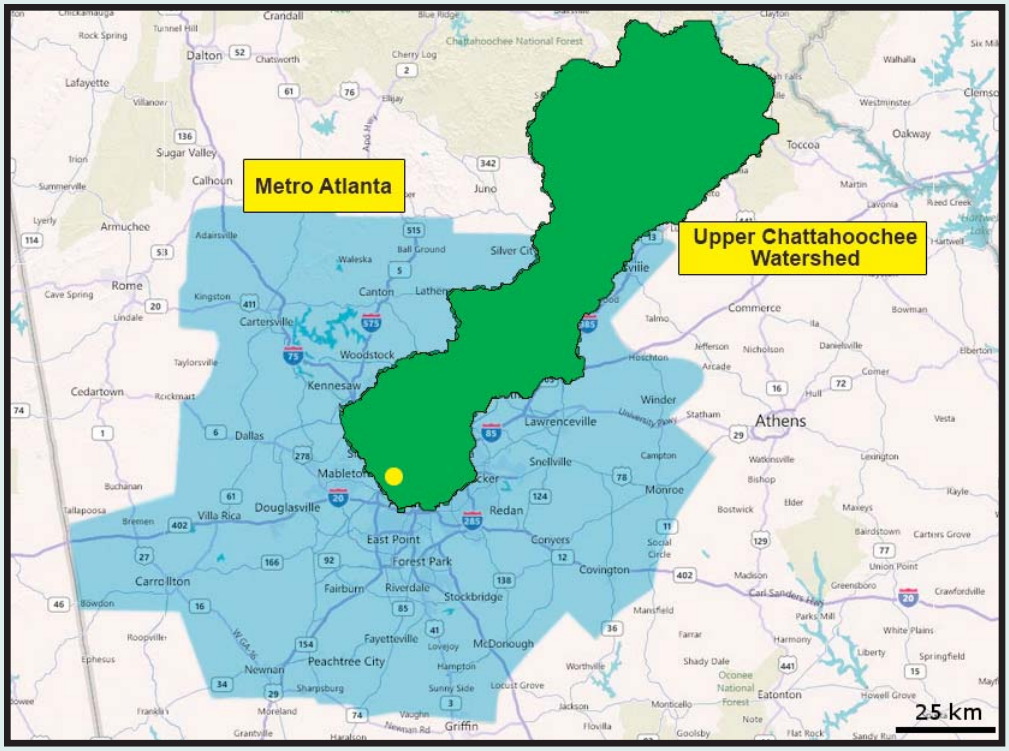


Figure 8
Geographical location of the case study of the city of Atlanta and the Chattahoochee watershed: (a) entire Chattahoochee watershed, showing the river eventually discharging into Apalachicola Bay (Gulf of Mexico); (b) Upper Chattahoochee watershed (green area), with location of the R M Clayton wastewater treatment plant (yellow dot) as the largest of Metro Atlanta's (blue area) treatment facilities

2011) and thereafter conveyed separately out of the household — by truck transport — to the R M Clayton wastewater treatment plant. There, as imagined at some point in the distant future, the yellow water is simulated as being processed strictly separately to produce fertilizer materials. Hence we have a specific realization of PeFe; the applicable unit processes of treatment can be found in Beck *et al* (2011a). In the second alternative (S@S(2)), the combination of yellow and black waters is separated from the grey water and then removed by a vacuum-pipe system to the treatment plant, where it receives strictly separate processing to generate fertilizer products (again, see Beck *et al*, 2011a). The presently existing sewer network is used (unchanged) to convey the combined grey water and black water to the treatment plant in S@S(1); it likewise conveys just the remaining grey water to the plant in S@S(2). Of the two variations on the basic theme of source separation, S@S(2) is the more complete realization of the structural arrangement for the city's water and nutrient metabolisms in Figure 1(c). It is a matter of fact that the majority of the nutrient material (nitrogen, phosphorus, potassium) resides in urine, whereas feces are richer in their carbon content.[29]

By implementing these separations at source, for a typical, large city of the Global North (such as Atlanta), the ecological footprint (EF) of the related infrastructure — household, conveyance (sewer, vacuum, truck), and treatment — could be reduced to roughly 75% (for S@S(1)) and 66% (for S@S(2)) of its value under present (unseparated) arrangements (Jiang, 2010). That is to say, these reductions follow from proceeding from the structural arrangement of Figure 1(a) to that of Figure 1(c). They are driven significantly by reductions in the equivalent areas of land required to assimilate the diminished nutrient residuals (of N and P) under the strategies of separation at source. Such reductions, however, can vary significantly as a function of the applied process operating strategies: down just to 87% and as much as down to nearly 50% (Jiang, 2010). The changes of infrastructure include the re-plumbing of households. Reductions in the footprint of S@S(2) might be yet greater still, absent vacuum conveyance and the innovation of some accompanying re-design of the toilet.

Thus would we have begun to unweave a good deal of what today is seen by some as the "bad" of coupling the city's metabolism of its daily bread with that of its daily water. Our footprint calculations provisionally confirm our prejudice (in favor of an S@S strategy), although the numerical differences are not that substantial.

Taking stock, we have the image of the city as an organism with an appetite, but the simplicity of its mere footprint is a rather lifeless form. It is as though just a snapshot of its metabolism has been taken, much as the photographic still of a speeding athlete, frozen in time, one foot impinging on the ground. It renders lifeless and static all the live forests, wetlands, agricultural lands, marine fisheries, and so forth, as sheer amounts of "stuff" — the stock of natural capital, that is — required to keep us going, like the bulk of the inanimate mineral resources of conventional economic production.

We have now an appreciation of the inputs to, and the outputs from, the city. Its footprint clearly calls for us to think of these within the dimension of space, as in area (and volume). But this assessment of the footprint yields no insight into how the one bundle (of inputs) is transcribed into the other (outputs). How then is all this stuff circulated through the body of the city and around the Earth? Portrayal of a sense of the processing and transformation of materials in variegated space (and time) is missing. Additional, complementary ways are needed for judging the {environmental benignity} of innovations, policies, and actions intended to achieve less unsustainability of IUWM, not least within the wider context of IWRM. We must also think in terms of the dimension of biogeochemistry.

Metabolism: Webs of Interaction and Material Cycles

Let us again adopt the perspective of the big picture.

Our species inhabits today the land surface (not the water environment). Before reaching us, our nutrients (C, N, P, K, and so on) arise from the earth and are not naturally passed through the aquatic environment in the cycle of their being returned to the earth. As in ecology, or as for planet Earth as a whole, natural behavior of the system — as it evolves over the millennia — can be understood in the terms

[29] About 80% of the nitrogen and 50% of the phosphorus in domestic sewage derives from urine (Larsen *et al*, 2009).

of conceptual models of global material (element) cycles (Schlesinger, 1991; Galloway and Cowling, 2002; Galloway, 2003; Galloway *et al*, 2003). It is these images of the "perfection" of the "balanced", "complete", "closed" material cycle that are celebrated in current visions of the future of engineering, industrial, and economic design (Hawken, 1993; Benyus, 1997; Hawken *et al*, 1999; McDonough and Braungart, 2002). The concept of the global material cycle and, in particular, its form prior to the industrial revolution, conveys the notion of Man living in a desirable harmony with the Environment. But the city, as it lands down on the ground in geological time, induces distortions rippling through the pre-existing cycles of water, C, N, P, and other materials (Beck *et al*, 1994; Beck and Cummings, 1996).

The hydrological cycle is most familiar to us; the global carbon cycle too. Nitrogen, however, is "the very stuff of life" according to Galloway and Cowling (2002). Invention of the Haber-Bosch process just before the First World War accelerated and expanded the production of ammonia (NH_3) from atmospheric N_2 (and not without a sizeable energy and carbon footprint, as we now appreciate). It changed the course of 20th-Century history — argue Erisman *et al* (2008) — and will bring about a global "nitrogen economy" in the present century. Thus, we observe, have Erisman *et al* (2008) done their bit to promote a "nitrogen-centric" perspective on the world (if not the metabolism of cities), while Elser and White (2010) have done theirs for "Peak Phosphorus". We, in our turn, have used the anthropogenic distortions in the global cycling of nitrogen to cast a sharp and critical light (in Chapter 2.3) on why the water-based paradigm of the city's *nutrient* (*ergo* nitrogen) infrastructure might reasonably be considered "broken" — at least in part.

Galloway and Cowling tell us further that in the late 20th Century anthropogenic (Haber-Bosch) N fixation from the atmosphere overtook natural terrestrial N fixation. Were the 9 billion people or so expected in the late 21st Century to have the same *per capita* rate of producing reactive N — the essence of its form in fertilizer — as currently in North America, there would be a six-fold increase over the 1995 estimate, which itself was 9 times larger than in 1890. Are we destined to pedal ever faster on this cycle? Or, as the challenge has been put in Chapter 2.4, should we rather strive to uncouple human development, not only from rising water and energy usage, but also from the growing industrial fixation of N?

Much of the reactive N produced in the world finds its way, through one route or another, into the aquatic environment, whither it would not previously have been naturally headed. Certainly, if we struggle mightily to increase the efficiency of its chain of transfer from fertilizer to the mouths of city-dwellers and to "optimize" their diets — as Erisman *et al* (2008) advocate[30] — the focus on managing its fate thereafter should be all the sharper. Better put, given the inevitability of reactive N species in wastewater, one might argue these should be endlessly recycled — indeed "upcycled" — into the system of food production, neither diverted into the aquatic environment nor converted back to unreactive nitrogen gas in the atmosphere. In recycling paper and textiles, the recovered material may spiral downwards (its quality being degraded at each turn) eventually to reach the landfill, albeit after more than just one rotation of the recycle. That would not be the objective. It would be so much better here, if the recycled reactive-N never entered the water environment, and better still, if its efficiency and retention within the "inner" fertilizer-mouth-urine cycle were elevated systematically towards 100% — upcycling, then, in the words of McDonough and Braungart (2002).[31]

[30] Their figures indicate that of all the reactive nitrogen produced industrially from the Haber-Bosch process in 2005, just 17% was consumed by humans in crop, dairy, and meat products, as their dietary N (Erisman *et al*, 2008).

[31] The complement of seeking to achieve upcycling of natural nutrients is the goal of cleaving into strictly separate cycles the circulation of natural nutrients and the circulation of technical nutrients, or quite unnatural substances, such as our legacy of industrial and xenobiotic materials, including the residuals of pharmaceutical metabolites and personal care products.

A Step Back: Case History of Paris[32]

Well before Haber filed his patent in 1908 on the "synthesis of ammonia from its elements" — and well before the British WC had been introduced to Parisian households half a century or so earlier — Bridet had acquired a patent in 1796 for making *poudrette* (a fertilizer) from human urine and excrement (Barles, 2007b). More were to follow. During the 1850s and 1860s, patents for manufacturing related chemicals on an industrial scale came "thick and fast". And until that time, those reactive species of N we would now have upcycled were largely *not* present in wastewater — because Paris had no wastewater as we know it today. 150 years ago, the city had already attained a decent measure of our contemporary vision of PeFe. Entrepreneurs were making good businesses out of urine and human excrement, as today might members of the individualist solidarity in a peri-urban community in Accra, Ghana, for example (Kwame, 2007; Box 2). This, then (the 1790s through the 1850s) was for Paris "the age of no waste" according to Barles. In 1817, she records, 20% of the dietary N of Paris's (human) population was returned to agriculture. "From today's daily bread unto tomorrow's", we might conclude.

These too were the times of predominantly dry sanitation in Paris. Its (nutrient) infrastructure, for dealing with the residuals of the city's metabolism of essentially just its daily bread, was that of Figure 1(d). The city's intake of daily water was employed primarily for street fountains and road cleansing. Attaining (and maintaining) such a good measure of PeFe was achieved over time in two waves: first, the rise to market penetration of the dry, *poudrette* form of fertilizer, across the first half of the 19th Century; and then the growth in liquid forms of fertilizer during the second half of the century. Hence came Barles' (2007b) second era, of the "1860s-1910s: liquid fertilization". The second wave somewhat undermined the commercial success of the first. The raw material was being weakened in strength at its source. The contents of cesspools were being diluted, not initially with the flushing of WCs, but through the grey waters of the growing water metabolism of households following in the wake of the increasing appeal of the household bath for cleansing oneself.

Demise of both the dry (*poudrette*) and liquid forms of fertilizer was to follow the First World War. Both the war and this demise owed something to Haber's patent (Erisman *et al*, 2008). The one would have been associated with the consequent expansion in industrial production of new explosives, the other with that of fertilizers. There was a growing sense of distaste and disgust amongst Parisians at the unpleasant, unhygienic nature of the infrastructure for collecting cesspool contents and their transport through the city's streets to the centralized sites of subsequent chemical transformation. Eventually, by the 1920s, Paris's "nightsoil" had become worthless. It was being generated at source in progressively wetter form, hence the increasing cost of its greater bulk (for transport) and likewise the increasing cost of recovering its valuable nutrients and other chemicals from its inevitably less concentrated character. Barles (2007b) has dubbed this era the "1920s-1970s: the birth of wastewaters".

To summarize, the symbiosis between Paris and its rural surrounds rose, from the return to agriculture of 20% of its (human) dietary N in 1817, to 24% in 1869, and 40% in 1913 — with population growing substantially all this time — only then to fall. The symbiosis was severed by the advent of today's conventional water-based paradigm of wastewater infrastructure, marked by a tripling of the re-direction of the city's dietary N into the Seine River by 1931, when it had reached 36%. From the basic configuration of Figure 1(d) in the 1850s, with dry latrines (and the manufacture of *poudrette*), Paris had thus passed through Figure 1(c) (from the 1860s until the 1910s), with a progressive "wetting" of the source-separation arrangement, to end up (from the 1920s onwards) with today's comprehensively mixed paradigm of Figure 1(a).

We now — in our case study (our work space) — want to reverse this historic progression, without in any way turning back the clock, and most emphatically not so in undermining maintenance of the high standards of public health we have come to enjoy in cities of the Global North. In order to fashion our second step towards CFG, the boundaries of what constitutes

[32] The following has drawn extensively on the work of Barles (2007a,b), especially Barles (2007b) (see also Billen *et al*, 2009). However, in the interests of not being repetitious — if nevertheless punctilious about giving due recognition to one's sources — the formalities of citation are kept to a minimum.

the "system" to be analyzed must be cast much more completely over the city-watershed couple of Figure 8(b).

As water professionals, we enquire into what can be done about the water metabolism of a city. And to find answers we usually define the system as that of the aquatic environment, the water infrastructure, and the aqueous effluent discharged back to a body of water. Classical systems analysis tells us that a richer set of answers — of options albeit for *water*-sector policies and technologies — should follow from adopting a wider purview: of accounting formally for the interactions amongst the water sector and some of the other sectors participating in the metabolism of the city-watershed couple. Our vision remains steadfastly fixed on PeFe. But it is informed now by the obvious symbiosis that once obtained in the Paris-Seine system, amongst the city, its waste-resource handling facilities, and the proximate (surrounding) agriculture.

Step (2)

A multi-sectoral, materials-flow model has been constructed to account for the interactions within the green (watershed) and blue (city) areas of Figure 8(b) and amongst the five sectors of water, food, energy, forestry and waste-(fertilizer)-resource management (Villarroel Walker, 2010; Villarroel Walker and Beck, 2011a,b). Five state variables — nitrogen, phosphorus, carbon, energy, and water — are tracked in the various flows through and around the web of multi-sectoral interactions. Given this bigger picture, we ask: how would the flows of materials constituting the metabolism of the city be changed by inserting this or that technology into the existing hull of Atlanta's infrastructure, inextricable, as it is, from the metabolism of the whole city-watershed couple (and, in truth, the rest of the world)? In particular, holding here to our chosen technological path of S@S, how much fertilizing material might be recovered on the downside of the city — and re-directed away from "polluting" the atmospheric and aquatic environments — were we to drop urine-separating technologies (USTs; Lienert and Larsen, 2006, 2007; Larsen *et al*, 2009) into all of Atlanta's households, office blocks, other work-places, public facilities, and so forth? What, moreover, might this achieve for the city's water metabolism?[33]

It turns out that replacing the kernel of why we have the water-based paradigm of today's Business-as-Usual — the household WC — with the UST (or like devices), and the associated changes to household plumbing, has the following illustrative consequences within the city and beyond. Water use, and therefore the water metabolism of the city, is attenuated by 5% (in terms of overall crude sewage flow). Beyond the water sector, 4,000 tonnes of N can be recovered annually, this being about 40% of the N content of fertilizer currently imported into the Atlanta-Chattahoochee system (Villarroel Walker, 2010). Its value as a fertilizer would be about $4.3M per annum.[34] Alternatively, if used as feedstock for the production of algae (possibly on-site at the R M Clayton facility) with subsequent conversion into a biofuel, roughly $3(10^6)$ litres of that fuel, with a value of $1.2M, could be generated on a yearly basis (Villarroel Walker, 2011). Concomitant with these illustrative rates of recovery of resources — from within the water sector, but to the benefit of the food and energy sectors — about 58% less N and 65% less P would be destined for disposal in landfills as municipal sewage sludge (within, therefore, the waste-handling sector; Villarroel Walker, 2010).[35] The prospect of uncoupling human development

[33] In order to eliminate nitrogen as a pollutant, wastewater treatment plants are by convention constructed with larger capacities than would otherwise be the case. Estimates show that some 60% diversion of urine away from the sewerage and (conventional) centralized wastewater treatment system, i.e., at 60% substitution of USTs in the city's household/office plumbing, the treatment plant could achieve complete removal of the remaining nitrogen without being "over-sized" and possibly with the bonus of net energy production (Wilsenach and van Loosdrecht, 2006; Larsen *et al*, 2009).

[34] Numerical estimates refer to that portion of the city of Atlanta within just the Upper Chattahoochee watershed, with a population of 1.3M. Much of metropolitan Atlanta and its population (currently 5.4M) resides in adjacent watersheds, as already noted. Recovered amounts of resources and their economic worth would be proportionately greater.

[35] This is equivalent to 7% less N and 20% less P disposed of to landfills as fractions of all the organic waste from all sectors in the entire Upper Chattahoochee watershed.

from industrial N fixation, if not the quarrying of P-containing ores, has appeared on the horizon.[36]

Put another way around, for comparison with the ecological footprint analyses of *Step (1),* the present assessment of Atlanta's metabolism indicates that comprehensive separation of material fluxes at source might enable these kinds of gains (Jiang and Beck, 2007): recovery of up to as much as 75% of the N as ammonium-N in the currently generated volumes of raw sewage (somewhat under 60% for P recovery). In addition, less than 3% of the N entering the re-engineered treatment plant of the (source-separated) future would be lost as a gaseous N-species emissions (Jiang and Beck, 2007), compared to a two-thirds loss under present arrangements in Finland (Sokka *et al*, 2004).

It took some 120 years — four or five generations — for Paris to realize a measure of PeFe, peaking at a "metabolic rate" of 40% of the dietary N of its citizens being returned to agriculture by 1913. Looking to the future, Neset *et al* (2008) estimate that about 25% of the P required in the average diet of a citizen of Linköping, Sweden, could be recovered from the sewage of that city. Phrased slightly differently, Mihelcic *et al* (2011) calculate that, if fully recovered, the P available in human urine and feces could amount to as much as 22% of total global P demand. The prospect is sufficiently "mainstream" to have become the stuff of headlines in the popular news services: "Where Sewage Meets 'Peak Phosphorus'" (Burkart, 2010). *Step (2)* suggests now that en route to a CFG over coming generations (two or three, very roughly, in Figure 2), just above 40% of the dietary N of Atlanta's citizens might become available as a conceptual PeFe fit for some further purpose, other than pollution (Villarroel Walker, 2010).

The "systems thinking" of *Step (2)* has drawn out and revealed our possibilities, well beyond the confines of the water sector. The complexities of the webs of intricate interactions in the city-watershed's metabolism have been brought home to us. They are echoed and illustrated in Moddemeyer (2010).

In contrast to *Step (1)*, the significance of not severing all the ties between the city and the watershed has become apparent (here in contemporary times, as previously for Paris). The metabolism of the body of the "bull" of a city is far more subtle than the crude footprint impressed upon the watershed. It is as if there has been an explosion of opportunities, with some ricocheting even into the transport sector. In a bygone era, nutrients were needed in fodder for horses as the means of transport; today they might serve as the basis of generating biofuels for the modern internal combustion engine. There are possibilities not only for policy, but also for entrepreneurship for innovation. This obviously once thrived in Paris. It may today seemingly spring from just about anywhere. Consider this cluster of now revealed logical and economic links. Renewable fuels are sought (for the energy and transport sectors), while recognizing Nature's provision of solar radiation and Man's deleterious contributions to atmospheric CO_2. In our pursuit of PeFe through a policy of separation at source enabled by urine-separating toilets, matching nutrients can be recovered (from the water and waste-handling sectors). Blooms of algae — to be avoided at all costs in the pollution of lake and coastal eutrophication (driven by the water-based paradigm of sewerage in the water sector) — are instead decisively to be welcomed. Climate change might conceivably drive the market for urine-separating toilets. That will be unsurprising to some.

A Step Ahead: Inter-mingling of the "Doings" of the City and the "Doings" of its Watershed

The grander sweep of the case history of Paris reminds us of how the modernity of the 20th Century, and the technocracy of its second half, have only relatively recently established habits of mind that in many ways blind us to what existed long before. Having forgotten the history of Paris, or never having known it, cities have come to be associated with the intensification of industrial production and the deliberate construction of infrastructure, both to sustain that production and contain the ills of its unwanted side-effects. We have come to think of the watershed and the rural surrounds of the city as the locus of agriculture.

[36] "The city of Ghent in Belgium will declare every Thursday a vegetarian day in an attempt to fight climate change" reported the *Daily Telegraph* of London on 14 May, 2009. Doubtless the global water and nitrogen metabolisms would benefit too. On 15 April, 2010, Wageningen University and Research Centre and the Dutch Ministry of Agriculture, Nature & Food Quality jointly announced a €1M program of research into "Sustainable production of insects as food" (www.fbr.wur.nl; accessed 19 March, 2011). The announcement noted that "Europe and North America are the only parts of the world that do not share [the] taste for insects". Any impacts on global water and nutrient metabolisms were not disclosed.

Yet poultry production in the Chattahoochee watershed surely qualifies as the intensified industrialization of Confined Animal Feeding Operations (CAFOs). Having a CAFO calls for a deliberate (ex-urban) infrastructure to "contain the ills of its unwanted side-effects". This very concentration of the CAFO, however, creates scope for entrepreneurial business and technological innovations. Pyrolysis of the chicken litter (the unwanted side-effect) can yield the goods of a gas fuel, a diesel-like fuel, and a pelletized fertilizer (Das *et al*, 2008). If this single piece of technology were to be incorporated wholesale into the CAFO (food) sector, hence the nutrient infrastructure of the Atlanta-Chattahoochee system, it could regenerate some 900 tonnes of N as fertilizer, 2100 tonnes of P as fertilizer, and 270 GWh of energy each year, i.e., an annual value stream of some $21M (in total) for the regional economy (Villarroel Walker, 2010).

Reminded of this exchange and intermingling of the "conventional" roles of the city and the watershed, an impertinent question has surfaced — and cannot be banished. What are cities, if they are not Confined Human Feeding Operations (CHFOs)? What then would spark the interest of the sustainability-minded CAFO entrepreneur, coming from outside the water sector, in any such business opportunities for fertilizer (PeFe) and energy recovery from the CHFOs of cities? Through what forms of social, sectoral, and institutional lock-in would that entrepreneur have to break, to gain access to the market, perhaps to create one? Is his/her voice not even gaining access to the debate — about IU*Water*M within I*Water*RM — let alone being acknowledged and responded to by the other "voices"? Where there is money to be made and a favorable regime of governance, one suspects, so there will be a way to break into the process.[37] And when it comes to making money (on the downside of the city), so much of this stems not from the residuals of the city's daily water, but its daily bread.

People use the phrases "urban forestry", "urban natural resources", and "urban agriculture", as if deliberately to break — by the pairing of words alone — the historic, but largely 20th Century, severance of city doings from watershed doings. There has always been urban agriculture of some form, although it may not always have been labeled as such. Today it is being promoted as an adaptive response to climate change (Dixon *et al*, 2009). Indeed, it is taking advantage of the modern shapes, forms, and abandoned industrial sites of the contemporary built environments of cities to open up creative niches for its implementation and success. Will Allen, for example, has been described as an urban farmer (Milwaukee Journal Sentinel, 29 April, 2010; www.jsonline.com; accessed 15 May, 2010). He received a 2008 MacArthur Foundation grant (a "genius award") for pioneering vertical farming in a five-storey Milwaukee building.

We are guilty now of having emphasized metabolism of the city's daily bread at the expense of taking care of its daily water. It is time to re-focus back in upon the water sector, to ponder whether all this systems thinking of *Step (2)* and the case history of Paris has expanded the portfolio of options for re-engineering the city's wastewater infrastructure.

Amidst the explosion of opportunities for change and innovation arising from taking *Step (2)* — in pursuit of the inter-generational vision of PeFe; in striving to justify the choice of Separation at Source (S@S); or in following the decentralizing zeal of Small is Beautiful (SiB; Box 1), to recombine it with the companion "miniaturizing" sentiment of local urban agriculture — certain things, grounded fundamentally in the water sector, are neither to be forgotten nor sacrificed. We know this. It was the *Water* Closet that cut the riskiest and shortest of all water-borne disease-vector paths, within the small and personal spaces of households, hence its supreme achievement in securing public health for urban dwellers.

When earlier we took *Step (1)*, we assumed there would be conveyance by road of the urine separated at its household point of origin. We could have made the same substitution — of truck for water (as the means of conveyance) — for the combined residuals of urine and feces (but instead we worked with the assumption of a vacuum system of conveyance). Truck transport of these household fluxes of nightsoil is known to have "dramatically contributed to improved sanitary conditions in Japan", especially in peri-urban areas (Matsui *et al*, 2006). A retreat from the water-based paradigm — from the structural arrangement of Figure

[37] Although economist Pearce seems somewhat pessimistic about the prospects for success in practice with market-based instruments of environmental policy (Pearce, 2004).

1(a) to that of Figure 1(c) — does *not* need therefore to be a turning of our back on all that has been achieved for public health in cities.

If we were to be so aggressively eco-efficient as to lower the water metabolism of the city yet further, to nigh on zero — the highest of egalitarian salutations to water frugality in the profligate Global North — what then would be the challenge? If we were to tighten our collective belts to the very limit of excising altogether the "Water" flux emanating from the downside of the city, to progress conceptually beyond Figure 1(c) to the driest of sanitation arrangements implied in Figure 1(d) (and the target vision of Dry-as-Dust in Figure 2), how then should *water* utilities, *water* associations, and *water* professionals gainfully employ themselves? Looking back to the Paris of the 19th Century, what, we might well ask, should any of us be doing, had the Reverend Moule — with his (dry) Earth Closet (EC) — beaten out Mr Crapper's WC in the technological sweep-stakes of Victorian Britain?[38]

In spite of the several further building blocks added now to the platform of our response to the challenge of re-engineering the city, so that it may act as a force for good (in the environment), this calculus of metabolism also has its limits. Our numerical results are restricted to statements essentially about the flows of substances and material transformation. They are silent in respect of the maintenance, if not enhancement, of ecosystem services. They are silent too on the question of gauging the *distortions* in the global cycling of materials wrought by the arrival of the city over geological time, and by the subsequent installation of its water and wastewater infrastructure. Taking the long view, across future generations, we might ask: what constitutes harmony, as opposed to "cacophony", in the way in which the city and its infrastructure are suspended in the global web of material cycles? How could one measure the topology of the network of flows in a distorted web relative to a restored web; and could the difference meaningfully inform policy, *ergo* direct specific actions towards urban infrastructure re-engineering?

Taking stock again, something is still not complete in our big picture. Appetite (footprint) conveys a sense of the sheer volume of stuff required to support the city — spatial thinking. These biogeochemical cycles give us a sense of flux, circulation, chemical transformation, and the connectivity of the city suspended in a web of interactions with the rest of the biosphere. The bulk of the bull is standing there in our mind's eye, its footprint static and obvious. Latent is the fact of the bull's metabolism quickening to a pace more akin to that of the shrew. Something, some sense of metaphorical movement, is missing yet. Some thought must be given to what happens in time, as opposed to space and biogeochemistry.[39]

Pulse: Speed, Variation, and Frequency Spectrum

The body belonging to the foot that makes the print, is quintessentially dynamic: mainly growing, sometimes declining, but bounding up and down, hither and thither, changing all the time.

As more infrastructure is put in place in the city — as successful wastewater treatment is more fully realized — this will have the effect of quickening the pulse of environmental disturbances yet further. We know this already from Figure 7(a). Construction and installation of the treatment system should restore an ever elevated average level of stream water quality, but arguably a condition ever more prone to fast, transient mishaps and failures in the installed web of city infrastructure (Beck, 1981, 1996, 2005; Beck and Cummings, 1996). Over (geological) time, the spectrum of material load disturbances has migrated through the three stills sketched in Figure 7(a) (Beck, 2005). Power in the spectrum has been shifted from the lower-frequency to the high-frequency components.

At the very least, there will be more pumps, more blowers, more gates, and more valves to be operated in the ever more comprehensively implemented wastewater infrastructure, all of which will be subject to abrupt failure, including the very system of control designed to pre-empt failure. All of the technological options — any of the red rectangles of Figure 2 or the styles of engineering sustainability of Box 1 — have an Achilles heel. Studies of the interdependence of

[38] For one thing, Moule's EC is celebrated as the title for one of the styles of engineering sustainability in Box 1. For another, reflecting on the word many believe (incorrectly, speaking etymologically) Mr Crapper has given to the English language, the ungracious might accuse me here of writing a "load of old Moule" in this *Concepts Paper*.

[39] The three — space, biochemistry, and time — define the logic of how we monitor the behavior of things, hence assess them too (Beck *et al*, 2009).

multiple infrastructure elements (transport, energy, water, and so on) emphasize repeatedly the likelihood of their increasing vulnerability to cascading failures from their growing reliance on information technology for effecting communication and operations (Zimmerman, 2001; Rinaldi *et al*, 2001; Little, 2002; Zimmerman and Restrepo, 2006). Vulnerability of the wastewater infrastructure may be further exacerbated, if climate change is likewise transferring power in the frequency spectrum of hydrological/precipitation regimes to the higher-frequency, possibly extreme (high-amplitude), components (Beck *et al*, 2010a).

To reiterate, we have the ecosystems we once saw because of the spectrum and variability of disturbances — including things of pulsating intensity and pounding strength — through which they survived, evolved, and prospered (Poff *et al*, 2003). In geological time, the city appeared in the landscape. The persistent, day-in-day-out, year-by-year, decade-on-decade, chronic stress of untreated sewage discharge eliminated fish from the river. The previous existence of the fish was lost from the living memory of the city dwellers. With comprehensive wastewater infrastructure the fish returned, even to prosper again. Citizens regained the pleasure of angling for them, by way of recreation. And then came the combined sewer overflow (CSO) — or some other acute fault — to wipe the fish away, in just a heartbeat. As the city of Atlanta well knows, so too does the city of London: suppressing transient pollution events from CSOs, with their predominantly high-frequency components in the spectra of Figure 7(a), can be expensive — very expensive in the case of London (estimated as $3.3 Billion in 2006; McCann, 2010).

As geological time passes, the pulse-rate of our athlete of a city has been quickening. It is as though the bass tones are progressively being removed from his voice, pushing him to an ever more dominant falsetto, frenetic pitch — another metaphor for conceiving of the changes recorded in Figure 7(a). He can be provided with the very best of trainers to cushion the jolting, jarring, pounding of his footprint on the ground; but this will not stop him from crashing to that ground, imprinting then his entire body therein.

In cities of the Global North, it is the wastewater infrastructure that prevents polluting activities becoming pollution actualities. These arise largely from the need to juggle with the inextricably intertwined tasks of *jointly* returning the residuals of the city's daily bread and daily water to the city's environment (Figure 1(a)). If successful for long enough, that water-based paradigm of infrastructure makes the city's environment all the more vulnerable to such events when they happen, as they do. The River Rhine, now rehabilitated, is reported to be less resilient in the face of accidental spillages of certain kinds of noxious chemicals, essentially because of removal of the persistent stress of inadequate urban and industrial wastewater treatment, which forearmed the river against such insults (Malle, 1994). Inadvertently, the inadequate infrastructure supported a set of ecosystem service providers we might still want today, albeit for somewhat different services.

It matters too against what background *level* of ambient "good health" of the river a transient pollution event occurs. Sustainability will be measured in ways other than that there is an appropriate balance amongst higher-frequency (event) changes and lower-frequency (ambient) fluctuations, most obviously in terms of the relative amplitudes attaching to the various frequencies of oscillation. The same high-frequency (transient) event will have different consequences according to whether stream dissolved oxygen (DO) concentration is on average high or low (Beck, 1981). Yet one more event imposed on a chronically degraded river of lowly health will cause no diminution in, or interruption of, ecosystem services, since these in all probability are no longer being provided by that river. After restoration of the pre-city natural capital, through installation of the high-performance barrier of the city's wastewater infrastructure, even a high-frequency event of modest amplitude may bring about a significant deterioration in services. Indeed, the restored aquatic ecosystem, but rarely tested by the high-frequency disturbance of barrier failure (such as a CSO), may have become mal-adapted to such minor (possibly major) events. The ecosystem may lack resilience. But as in a public health system, the aquatic ecology of the river might benefit from vaccination through controlled pollution incidents (mock barrier failures), capable of promoting better resistance in the face of eventual and actual barrier collapse (Beck, 1996). This, however, may strike some as not merely provocative, but offensive to their valuing of ecological health and integrity.

Uncoupling the city's water- and nutrient-return infrastructures (Figure 1(c)) ought, by reflection, to have obvious and welcomed benefits, because it is

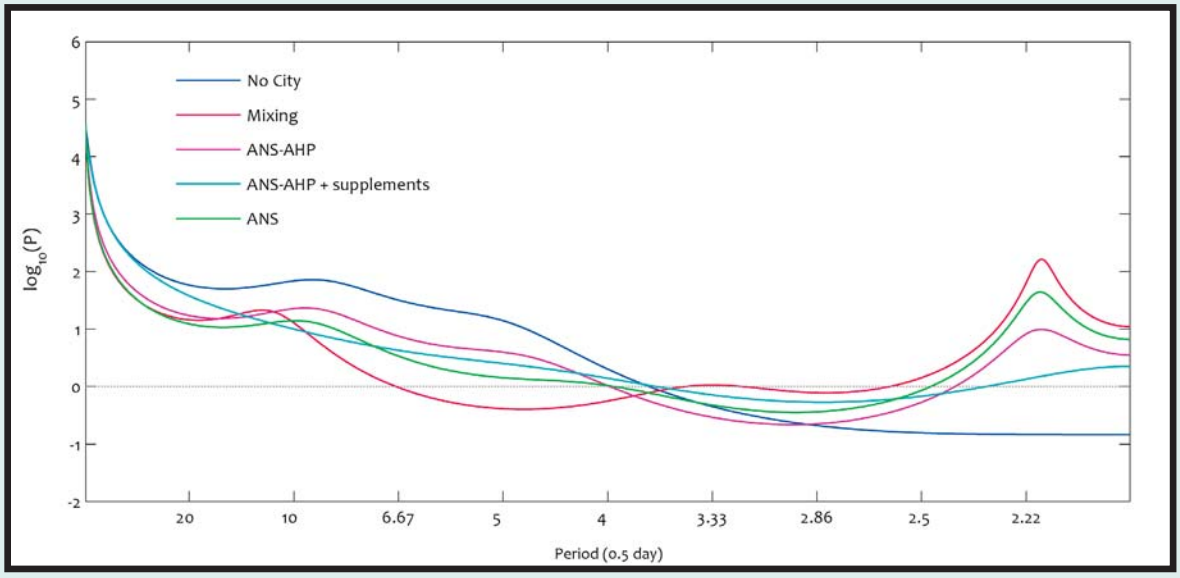


Figure 9
Specific computational realizations of the concept of spectrum sketched out in Figure 7. Frequency spectra (or city-watershed pulses) computed from time-series, such as those of Figure 10, generated from a simulation model (***M***) of the city of Atlanta within the Upper Chattahoochee watershed in the South Eastern USA. Hydrological conditions relate to the year 1986, in the Chattahoochee River immediately downstream of the discharge of the R M Clayton wastewater treatment plant of the city of Atlanta (yellow dot in Figure 8(b)). A variety of conditions are reflected: current conditions, i.e., with the conventional water-based paradigm of wastewater infrastructure ("Mixing"; the situation, in effect, of Figure 1(a)); source separation, for example, using a device similar to the urine-separating toilet, in which urine ("anthropogenic nutrient solution"; ANS) is separated from all other household fluxes of sewage ("ANS"; the situation, in effect, of Figure 1(c)); an alternative form of source separation, in which urine and feces ("anthropogenic humus precursor"; AHP) are separated from all other household fluxes of sewage ("ANS-AHP"); source separation with the issue of nutrient supplements to the river ("ANS-AHP + supplements"); and conditions without the city ("No city"; perhaps even the "city with dry sanitation").

essentially the coupling of the two that makes a bull of the city in the china shop of its restored watershed. To the case being assembled in response to the challenge of Chapter 2.4, therefore, can yet another building block be added.

Step (3)

Our favored technological path for uncoupling these water-nutrient infrastructures through source separation (S@S; Box 1) should make the river and watershed less vulnerable to accidents, faults, and failures. For it is not the water released in an uncontrolled manner from the city's currently coupled wastewater infrastructure (Figure 1(a)) that is the greater threat to the watershed, but the nutrients and contaminants borne in the sewage *and* the biomasses employed to remove them from the water flux, at the heart of the engine of biological wastewater treatment. The sudden, intense release of both, beyond a certain level, constitutes impairment of the receiving water body.[40]

Synoptic representations of the pulse of the city-watershed system, computed from simulation experiments (Figure 9; Beck *et al*, 20011a), substantiate earlier conjectures on how arrival of the city has "quickened" the pulse of the city-watershed system (Figure 7(a); Beck, 2005). These numerical results refer again to the city of Atlanta (Beck *et al*, 2010a, 2011a). Roughly speaking, the presence of the city transfers some of the power in the signal of the pre-city watershed from the lower-frequency (bass tones) to the higher-frequency (treble-falsetto) components of the spectrum, especially those at the weekly and diurnal frequencies. These appear (in Figure 9) as peaks in the spectrum of the in-

[40] And once that biomass engine is lost or compromised during an event, its fully-functioning state takes a significant amount of time to be restored after the event.

stream total P concentration variations, even under a current regime of fairly comprehensive biological wastewater treatment of the conventionally mixed flux of influent crude sewage to the plant.

When the various sewage fluxes are separated at source and the treatment plant re-arranged for the express recovery of perfect fertilizer (in the distant future), it is apparent how the pulse of the system — in terms of in-stream total P behavior — can be lowered, but only up to a point. Expressed technically, when the structural change by separation at source is effected from Figure 1(a) to Figure 1(c), some of the "power" (predominance) of the diurnal-frequency component is attenuated and some of the originally present, "primordial" (or "No City"), somewhat lower-frequency components (with periods of some 2 to 6 days) are recovered. The difference is as that between the red line indicated as "Mixing" in Figure 9 and either of the green and magenta lines in Figure 9, indicated respectively as ANS and ANS-AHP.[41]

Cast in symphonic terms, some of the over-abundant flutes and violins have been removed from the orchestra and replaced with clarinets and violas, if not cellos. Put otherwise, yet again, the entire picture of Figure 9 — whichever structural arrangement or re-arrangement is being thought of — has to do with keeping in mind the "long [wave] and short [wave] of it all [spectrum]".

This, however, is to be thinking of merely restoring the watershed to something approximating a former condition, by compensating for the ills of the city. The challenge of re-engineering the wastewater infrastructure of the city, so that the city-infrastructure couple can act *par excellence* as a force for good in the watershed, calls for yet something more — one further, culminating step.

[41] ANS stands for Anthropogenic Nutrient Solution, a sanitized term coined by Larsen and Gujer (1996) for urine; AHP stands for Anthropogenic Humus Precursor, a like term for feces. Separation of ANS from the other household fluxes is re-engineering strategy S@S(1) of *Step (1)*; separation of ANS-AHP from the other household fluxes is re-engineering strategy S@S(2) of *Step (1)*.

3.4 An Expansive Prospect: The City and Its Infrastructure as an Intelligent Bull Gifted with Deft Movement

Think on this. There was a pre-city hydrological regime, or frequency spectrum, a similar sediment spectrum, *and* a similar spectrum of nutrient perturbations, all collectively giving rise to the pre-city natural capital, ecosystem services, and service providers in the watershed. Man's structural interventions in the watershed to meet the demands of agricultural and energy production have in part distorted that frequency complex (Figure 7(b)), as have, in other ways, the interventions geared to the rise of the city (Figure 7(a)). If then the uncoupling of the city's water- and nutrient-return infrastructures were to be realized through the wholesale introduction of urine-separating toilets, with subsequent conveyance of the separated urine to a riverside treatment facility, for recovery and preparation there of a nutrient product, to what further purpose should this conceptual PeFe be put? Most obviously, it should be returned to the agricultural sector, subject to considerations of transport costs, which themselves might be diminishing where intensive agricultural production is itself pressing in upon the city (Ermolieva *et al*, 2009). Less obviously, after decades of removing nutrients as the causes of polluting eutrophication, this PeFe might instead be turned to the intensive cultivation of algae, hence the beneficial production (on-site) of a diesel-like fuel (Lardon *et al*, 2009).

Less obviously yet, we can imagine the following. From time to time, perhaps contingent upon the competing demands for directing this product into agricultural and/or energy services, it might instead be dosed to the river. The deliberate intention would be to go beyond merely restoring the distortions wrought in the nutrient spectrum by the city, to achieve — no less — the *good* of compensating for the distortions arising from the needs of agriculture elsewhere in the watershed. From computational assessment of this conjecture, we can set one last plank into place in our preliminary platform, on which to build a response to the challenge of Chapter 2.4.

Step (4)

It is indeed possible to simulate the occasional injection of nutrient supplements into the Upper Chattahoochee River from the re-arranged treatment facilities of the city of Atlanta, attuned at some point in the imagined future to a comprehensive uncoupling of that city's water- and nutrient-return infrastructures (Figure 10; Beck *et al*, 2011a). The spectrum of in-stream total P concentration variations can thereby be manipulated, deliberately to shift power out of the higher-frequency and back into the lower-frequency components (Figure 9). There is the capacity to wield power in this way, in principle. What is more, the simulated prescription for these nutrient supplements (Beck *et al*, 2011a) looks remarkably similar to those designed to deliver environmental flows for sustaining river ecosystems (Figure 11; Richter *et al*, 2006). The strategy is also (provisionally) robust in the presence of a relatively simply prescribed changing climate for the Atlanta-Chattahoochee system (Beck *et al*, 2010a).

Technically speaking, the nutrient supplements re-shape the spectrum by attenuating still further the prominence of the diurnal (24-hour) and weekly (7-day) frequencies. The turquoise spectrum of the ANS-AHP + Supplements in Figure 9 is markedly lower than its ANS-AHP counterpart (magenta line) at the 24h frequency. The progressively fading peak at the weekly frequency has disappeared altogether. This is especially apparent in Figure 9, if one tracks the changes in the spectral curves around this frequency across the sequence from red (current situation) to green to magenta and finally turquoise (separation with PeFe supplements). The S@S strategy with these supplements ameliorates the consequences for the aquatic environment of the way in which we have tuned the intensity of socio-economic life in the city to the focus of the 24-7 routine.

In the metaphor of the symphony, more of the previously still over-abundant flutes and violins have been taken out of the orchestra; some of the original complement of bassoons, cellos and double basses has been re-introduced.

What we have yet to discover is how to wield such power wisely, if at all, eventually in practice, and with {social legitimacy}.

Eco-efficiency and Eco-effectiveness

This culmination of a response to the challenge of re-engineering the city so that it can act as a force for

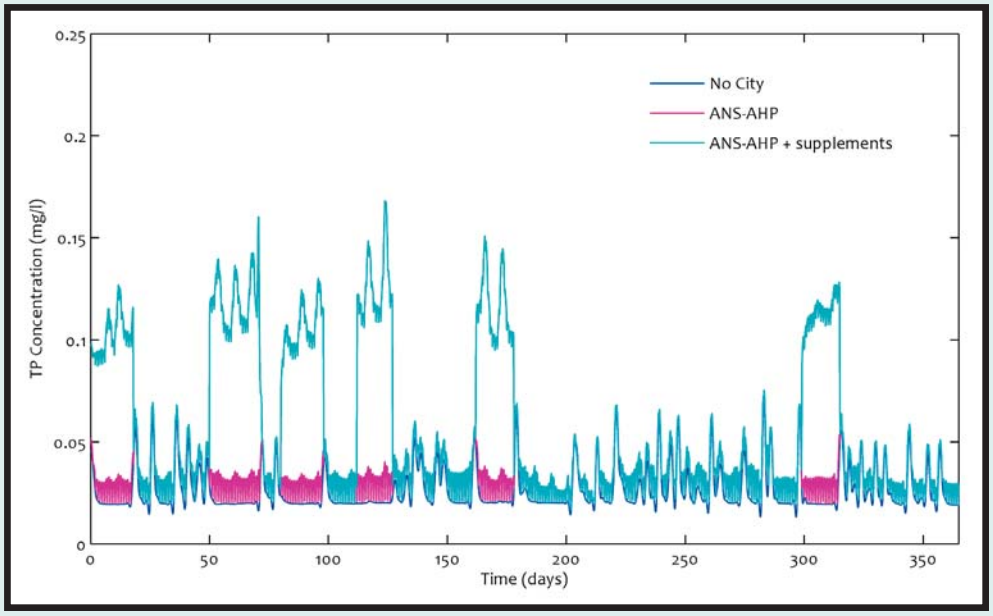


Figure 10
Model (***M***) simulated variations in total-phosphorus concentrations for 1986 in the Chattahoochee River immediately downstream of the discharge of the R M Clayton wastewater treatment plant of the city of Atlanta (yellow dot in Figure 8(b)), for conditions without the city ("No City"), for the ANS-AHP source-separation strategy, and for the ANS-AHP strategy with occasional nutrient supplements.

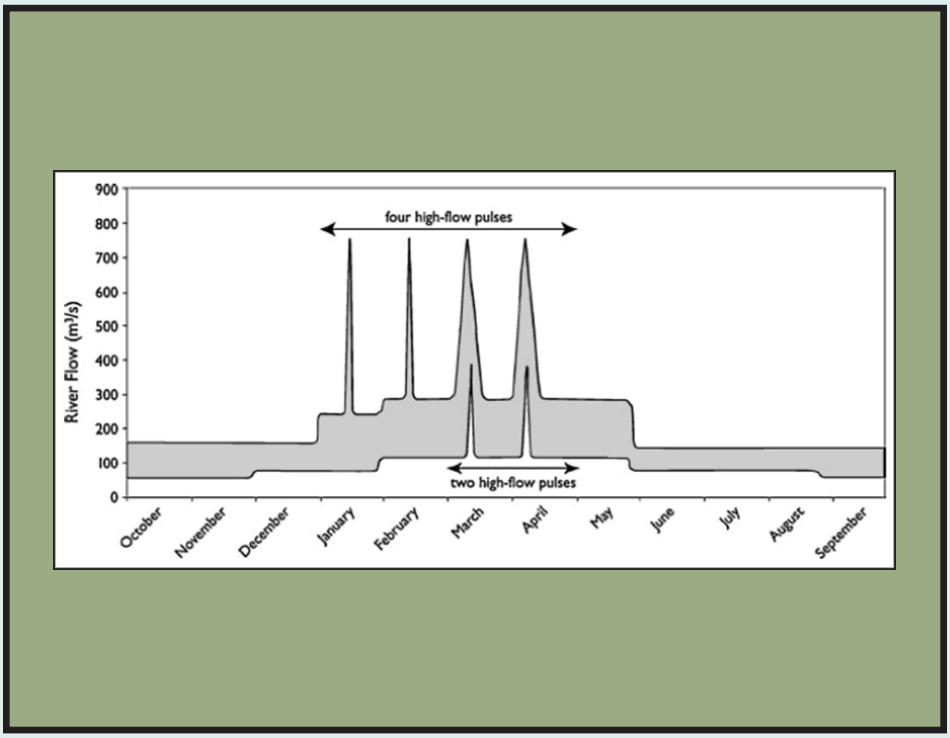


Figure 11
Specification, i.e., prescription, of the temporal pattern of environmental flows intended to restore and preserve the well-being of fish assemblages in the aquatic ecosystem of rivers, such as the Savannah River in Georgia and South Carolina, South Eastern USA (reproduced with permission from Richter *et al*, 2006).

good, however, has been expressed in terms of the subtle, if not obscure, image of the pulse (spectrum) of a system. That image may lack the intuitively understandable quality of the city's ecological footprint. Reducing the footprint of the city, as well as reducing its water and nutrient metabolisms (using yet another biological analog), conveys simply and succinctly the intent of a collective tightening of our belts — of our becoming "less bad". Yet being less bad, some have argued, is not the same as being "good". Associating frugality with the phrase eco-efficiency, they claim this will not in fact guarantee sustainability (Huesemann, 2004). The same has been expressed before (Dyllick and Hockerts, 2002) and since (Rees, 2009) — in more measured tones.

Terms such as eco-efficiency and, especially so, ecological footprint, can be aligned with the sentiment of "bounded by zero" and the invocation to head towards "zero" — as in cutting out altogether the "Water" efflux from the city in Figure 1(d). These terms too might be understood by some as redolent of an accompanying moral rule of "shouldn't do".

"Eco-effectiveness", on the other hand, has been introduced as cleaving to a principle whereby human systems are designed to nurture and feed natural, ecological systems, rather than depleting and contaminating them (McDonough and Braungart, 2002; Villarroel Walker, 2010). If "more good" is to eco-effectiveness what "less bad" is to eco-efficiency, then the understanding of eco-effectiveness that has guided our discussion towards its present culmination has more to do with the sentiment of things being "unbounded" (and a moral compass of "can do").

This is what the criterion of pulse, opaque and unfamiliar though it may be for the time being, has enabled us now finally to conceive of and explore. It evokes a sense of expansiveness of outlook, of being a liberating thought: the sheer *joie de vivre* of up-ending a "bad" and opening it out into an ever-expanding "good". If the expected outcomes, such as those adumbrated in the principle of nutrient supplements, could be cast in the much more familiar calculus of the Ecological Footprint, the city might almost be judged capable of "walking on air".

Taking Stock

In retrospect, we opened our computational-model ($\boldsymbol{M}$) course through the Atlanta-Chattahoochee case study with an assessment of the {environmental benignity} of policies of re-engineering according to the criterion of ecological footprint, rooted in the dimension of space (relative to that of the globe's surface). Self-evidently, this begins with the city, yet the numbers it generates are all about the input resources ($\boldsymbol{u}$) and output residuals-wastes ($\boldsymbol{y}$), with a loss of how the one is connected to the other. Symbolically, judgements are made on the basis of [$\boldsymbol{u} \parallel \boldsymbol{y}$], where || symbolizes indeed a gap — the absence of an account of how $\boldsymbol{u}$ is transcribed (→) by the city into $\boldsymbol{y}$.

That, of course, is precisely what is achieved through the assessment of the metabolism of the city, suspended (as it is) in the web of biogeochemical transformations taking place around the globe. With it, judgements can be made about [$\boldsymbol{u} \rightarrow \boldsymbol{y}$]. According to the way in which we have herein employed the notion of metabolism, moreover, the city is inextricably interwoven with the watershed, so that strictly speaking [$\boldsymbol{u} \rightarrow \boldsymbol{y}$] refers to the city-watershed couple. Notwithstanding the *water* in the *water*shed, furthermore, our account of [$\boldsymbol{u} \rightarrow \boldsymbol{y}$] has been multi-sectoral and — for the sake of argument — decidedly non-water-centric at times.

These assessments of the appetite (footprint) of the city and the metabolism of the city-watershed couple are both static. The notion of the pulse of the city-watershed system provides the element of "dynamics", of things varying throughout the dimension of time (t), encapsulated succinctly in the plots of spectrum. In particular, Figure 9 charts the changes wrought by different ways of configuring — *and* operating — the technological complex ($\boldsymbol{\alpha}$) of the infrastructure that mediates some of the ways in which $\boldsymbol{u}(t)$ is transcribed by the city into $\boldsymbol{y}$(t): [$\boldsymbol{u}(t) \rightarrow \{\boldsymbol{\alpha}(t)\} \rightarrow \boldsymbol{y}(t)$]. All — appetite, metabolism, pulse — contribute to a more rounded sense of what might constitute an environmentally benign policy intervention.

We have pushed our biological-ecological metaphor towards an engineering turn of mind: of the city and its water-nutrient infrastructures ($\boldsymbol{\alpha}$) as the bull invested now with enhanced intelligence enabling purposeful and deft (metaphorical) movement about the china shop of a restored yet vulnerable watershed. What the rural-agricultural parts of the watershed cannot do for themselves, lacking this technological intelligence and deftness of action, the city-infrastructure couple might do on their behalf, in the interests of contributing

to enhanced ecosystem services across the entire watershed.

Such smartness, intelligence, and deftness are, of course, the very essence of the vision of "Control Freak's Delight" in Figure 2. They are also core features of the Dynamics and Control (D&C) school of thought in Box 1, as one means of engineering our way out of the currently unsustainable "Business-as-Usual" (BaU), in concert with S@S (Separation at Source) or some alternative strategy, towards the favored vision of PeFe so convincing to our hypothetical community in the foregoing case study of Atlanta. It is through contemplating D&C in rather more detail, however, that we can gain a better sense of the true scope of how to infuse ecological resilience (Holling, 1996) into the behavior of the city's web of infrastructure. Given that, there is then Holling's ecological definition of sustainable development to be considered, and its relationship with biodiversity, not to mention the biomedical notions of self-healing and the auto-immune response of systems. But all that is the subject of Box 3 (see also Beck *et al*, 2009).

While Stepping Out in a Different Direction

Other conceptual and logical circuits could be circumnavigated around the city and its strands of infrastructure: always on the lookout (again) for the positive expansiveness of cities as forces for good, but this time in respect of restoring and enhancing terrestrial ecosystem services rather than their aquatic complements.

Following *Step (2)* in our case study of Atlanta (above in Chapter 3.3), we have seen how urban agriculture may benefit from occupying the urban land forms and space vacated by fallen industries. Urban biodiversity may likewise thrive. The titles of presentations from an October, 2010, conference on Urban Biodoversity signal how: "Brownfields: Oases of Urban Biodiversity" (Craig MacAdam); "Biodiversity on Bings [spoil heaps from past mining of coal]" (Barbra Harvie; see also Harvie, 2007). The conference was organized by the Glasgow Natural History Society (www.glasgownaturalhistory.org.uk; accessed 11 March, 2011). That conference would also have heard how prosperity of the urban flora and fauna should lead to well-being in the community of urban dwellers (from a presentation by Malcolm Muir).

In its turn, wildlife conservation tends to anticipate the forward process of urbanization, i.e., the conversion of natural habitat into urban forms with but fragments of the pre-existing landscapes, and "to the detriment of wildlife" (Marzluff and Ewing, 2001). Our interest would be in the reverse: in marshaling these fragments so that they may become a force for enhanced urban biodiversity, which might then reverberate outwards into enhanced terrestrial ecosystem services (in the surrounding watershed).

For his part, Lefèvre (2009) pleads for planning of the city to be based on a joined-up understanding of the way land-use and transport co-evolve. He asserts this has hitherto rarely been the case. He fears that cities of the Global South might otherwise grow rapidly in ways contrary to the needs of conserving energy under the threat of climate change. For those cities he sees a stark choice, between the extremes of Atlanta and Barcelona, Spain, as contrasting exemplars of cities of the Global North. The two have about the same population (somewhat above 5M), but Atlanta occupies over 25 times as much land as Barcelona and its associated system of transport emits over ten times more CO_2 (at about 7.5t/hectare/annum).

Amidst this complex of climate, energy, transport, urban form, land-use, and biodiversity, Grimm *et al* (2008) have observed that "[i]ntroduction of nonnative species combined with the UHI [urban heat island] may in some cities actually *enhance* ecosystem services, such as soil mineralization" (emphasis added).

Sparking the Transition

Altogether, given the ambition of PeFe, and S@S as a means of attaining it, we judge we have the promise of a policy that is variously:

climate robust (Beck *et al*, 2010a);

capable of uncoupling human and economic development from industrial N fixation (the Haber-Bosch process);

capable of being "calming" in respect of lowering the city's nutrient and water metabolisms;

a potential contributor to ecosystem services;

but not disposed towards jeopardizing the security of public health in the city.

Yet we risk all this being quite a bit too good to be true. For it mirrors exactly the challenging juxtaposition of "lofty principle" with the "little things in life", which we placed at the close of Chapter 3.2 on {economic feasibility}. Surveys show that attaining the heights of PeFe through S@S will be contingent upon just the right kind of intensely local, intimate, and strictly personal behavior (Lienert and Larsen, 2009).

The entirety of our reporting on the Atlanta-Chattahoochee case study has been a "quantum leap": from start (BaU) to any other kind of "finish", i.e., any one of the plural visions, drawn as the green ovals in the upper right corner of Figure 2.[42] Our numerical results relate to just two instants in time: present and distant-future annual performances. No account is taken of any transient increases in ecological footprint, or temporary increases in the water, energy, or nutrient metabolisms, or yet further emphasis on the 24-7 character of life in the city, in implementing the transformation over time — stepwise from the current initial conditions to the completed target "end point" generations hence. Things may have to get worse before they can get better. This was the dilemma put to us by Solow in respect of what constitutes {economic feasibility}. Indeed, choosing the technological trajectory of source separation (S@S) may itself have great appeal, both at its outset and in the sunlit uplands of its end point. Yet it may also require the city-watershed system to pass through an especially risk-prone intermediate phase (Beck *et al*, 2010a; Box 1). Beware of not "optimizing the part while pessimizing the whole", caution Hawken *et al* (1999). Optimizing for the "short-term" and for the "long term" might somehow add up to pessimizing for "all" of the technological path over time from BaU to PeFe (or whatever).

Thus has our discussion threaded its convoluted way through the triple bottom lines of the present chapter, in order to generate a set of technological alternatives (the red rectangles in Figure 2) enabling paths of progress towards but *one* of the several, alternative green ovals in Figure 2, of distant aspirations for greater sustainability in IUWM within IWRM. What, we must now ask, might spark the transition; and how might we gauge progress in such change?

Prevailing water policy seems an unlikely instrument of change (Beck and Villarroel Walker, 2011). In the years it has taken to produce this *Concepts Paper*, the City of Atlanta has been obliged under such policy to commit its wastewater treatment facilities (specifically the R M Clayton plant) to further aggressive and expensive extensions for eliminating "phosphorus the pollutant". According to our analyses (Jiang *et al*, 2005), ridding the system of a further 50 tonnes of phosphorus the pollutant (beyond typical current rates) might easily cost at least $2-4M for a large-scale plant (as a Total Annualized Economic Cost). Costs could be perhaps as much as three times more, if these 50 tonnes had to be eliminated from a collection of small-scale treatment plants, possibly amounting to $6-10M per annum. Recovering instead 50 tonnes of "phosphorus the resource" could return each year the benefit of $130k worth of fertilizer (Villarroel Walker and Beck, 2011b). Is this sufficiently visceral to spark the transition? Might not "small" — and incrementally "decentralized" — not only be "beautiful", but also "economically compelling", if not socially legitimate?[43]

Addressing these questions is the purpose of Chapter 4, and then Chapter 5.

[42] "Finish" or "end point" fully deserve their wrapping in quotation marks. Attainment of the attaching targets will not imply cessation of the search. Any "end points", labeled as such for convenience in our discussion, will merely punctuate the process of continual adaptation and evolution in the form and function of the city's infrastructure.

[43] The authors of the "Peak Phosphorus" scenario would probably tell us $130k will look cheap at the price before not too long (Elser and White, 2010). However, the benefit stream has been expressed *without* the costs of plant adaptations required to bring it into being, such as those, for example, of Britton *et al* (2007). Nevertheless, in principle, an incoming benefit stream still appears more attractive than none whatsoever.

BOX 3

Engineering Resilience into the System: At the Interfaces Amongst Ecology, Engineering, and Biology

There is a style of engineering sustainability, or school of thought, with vision extending but very little beyond birth and infancy in the life-cycle of an urban infrastructure. We know this from Crandall Hollick's sorry account of the wastewater system in the city of Kanpur, India (Crandall Hollick, 2007). There are many who will now rail against this kind of technocracy, myopic or otherwise, and not least against the engineering technocracy in that country (India). There are other schools of thought, or technocratic styles, which adopt the long view essential to sustainability. They look beyond planning, design, and construction, almost from before project conception; and they have been described herein as fixated, no less, on the adulthood of operations and beyond (Beck, 1981). We recognize this as the Dynamics and Control (D&C) school of thought in Box 1.

Thirty years on, after the passing of more than a generation, the inability of this school of thought to have gained any real purchase in the water sector, can still (regrettably) be argued with conviction (Beck, 2005). There are still institutions not ready to release any funds to study/enact operations in the life-cycle of water-sector infrastructure and governance, not even ready to release funds for planning, but prepared only — in effect — to allocate funds for planning to plan. Myopia, and the absence of a long view expressly peering into the details of the more mature stages of the infrastructure life-cycle, can still prosper, if not prevail.

Pulse, Spectrum, Dynamics and the Engineering of Control

All these phrases — pulse, frequency spectrum, dynamics — have quintessentially to do with the way things vary with time.

Sir Alan Harris, an eminent engineer who regretted the intellectual and professional separation of mechanical engineering from civil engineering, put it this way: if an object is meant to move, that is mechanical engineering; if it is meant to stay put, that is civil engineering. Control engineering, taught in the disciplines of mechanical engineering, electrical engineering, aerospace engineering, and chemical engineering, is about engineering the dynamics of change and variability in the behavior of an entity — "movement" in an object — *after* its conception, design and construction. Civil engineering, which embraces engineering hydrology and environmental engineering, has generally had little pressing need to devote attention to the operational stage in the life cycle of its products, even over the past three to four decades.

Control engineering concerns itself, then, with manipulating the system so that such changes are more to "our liking", as in achieving for us a smooth, as opposed to a bumpy, flight in an aircraft, for example. In this sense, control is primarily about manipulating the function (performance) of the system, not its structure. It is not about manipulating the manner in which the parts of the system have been put together, or come together naturally (through evolution).

In terms of our metaphor of the bull in the china shop, control amounts essentially to what we have described as the attributes of "smartness", "intelligence", and "deftness of movement" in the re-engineered city-infrastructure couple (in Chapter 3.4).

BOX 3

Engineering Resilience and Ecological Resilience

Holling, an eminent ecologist and author of the Myths of Nature caricatured in Figure 3, has argued persuasively that we have engineered most of our infrastructure, technologies, and industrial production systems so as to enslave their functioning to achievement of what he calls "engineering resilience" (Holling, 1996). To this has control engineering historically been dedicated. For as long as the system is not subject to significant disturbance, the exercise of control can maintain function at some desired level, usually constant or narrowly circumscribed, because that so often seems to be much more to our liking. This is life, in effect, on the potential surface in the lower-left quadrant of Figure 3. In the face of substantial disturbance, however, such achievement of engineering resilience can be revealed as brittle in quality (Holling would argue). The performance of the system may be knocked out of its comfortable equilibrium and descend into an altogether quite different pattern of function, not at all to our liking — a consequence of the vulnerability of contemporary wastewater infrastructure depicted in the frequency domain of Figure 7.

"Ecological resilience", on the contrary, would enable the maintenance of essential (and desired) functions under even such circumstances. In other words, dynamic behavior would be experienced according to the stability surface in the upper-right quadrant of Figure 3. Its manifestation in the "self-organized" behavior of a system, especially the Environment, is considered to be the result of natural evolution — anything but induced by the hand of Man. It undergirds Niemcynowicz's urging retreat upon us, from the modern technocracy of environmental engineering (20CTP), towards a renaissance of *manipulating* the more natural systems of ecology of earlier times (Niemcynowicz, 1993; as SOS in Box 1). Having the attribute of ecological resilience in the behavior of what we cherish would seem only but to add to what we should just as much understand as sustainability. It might also have a vital role to play in responding to the search for robustness in the face of climate change (Beck *et al*, 2010a).

Ought we not, then, to consider engineering ecological resilience deliberately into IUWM, if not IWRM? For as (dynamic) pulse is to (static) metabolism in Chapter 3.3, so these notions of resilience complement those of industrial ecology. If successful in such a re-engineering, would this not be an apt riposte from the (humbled) Engineer to the Ecological thrust ascendant in that great "sustainability debate" of the 1990s?

Changing Function and Changing Structure

As caricatured in Box 1, 20CTP and D&C stand respectively at the two boundaries — 100% and 0% — of a scale of reconstruction. At the one extreme (0%), not a metaphorical brick of the urban water infrastructure is removed, except for inserting the small boxes housing instrumentation and real-time control devices, the essence of intelligence and deftness of movement — a change of function, in other words. At the other (100%) everything is demolished, including the vast hull of the sunk historical investment in plumbing, pipe networks, channels, tanks, and so forth, as the prelude to building completely anew — a change of structure. Without thoughtful management, the "hard path" of a 100% reconstruction strategy (changing structure) should suffer from a large ecological/carbon footprint arising from the movement, if not the recycling, of so much material. In like terms, the 0% strategy (changing function, i.e., D&C on a grand scale), would in principle retain the hull of the city's sunk investment of past decades and centuries in its unreconstructed, centralized forms of sewerage and wastewater treatment (rather now, nutrient-resource recovery).

BOX 3

Pragmatically, in between the extremes, simulation results for a large wastewater treatment plant indicate that upgrading plant performance from an effluent total P requirement of 2 gm^{-3} to that of 1 gm^{-3} could be achieved at a cost of about $2M, as a Total Annualized Economic Cost (TAEC), assuming a facility life-span of 20 years under a (nearly) 0% reconstruction strategy, as opposed to $5M for a strategy more akin to substantial, if not 100%, (re)construction (Jiang *et al*, 2005; Jiang, 2008).[1]

Engaging in a wider, constructive disputation amongst the differing schools of thought of Box 1 (the portfolio of red rectangles of Figure 2) might be initiated by charging 20CTP and D&C with the task of coming up with strictly comparable triple-bottom-line accounts of their respective paths: of soft (→0% reconstruction) versus hard (→100% reconstruction). The alternative (technological) paths would be required to proceed from the initial conditions of today's hull of conventional centralized wastewater infrastructure (BaU) and to arrive generations hence at the target end-point of, say, the PeFe aspiration. For D&C, the additional challenge would be to engage in occupying the quite unknown territory of requiring the operational water-centric goal of BaU to be re-oriented to maximizing resource recovery (nutrients, energy), without abandoning the constraint of producing very clean water. This is no small challenge, given the historic operational straitjacket of BaU, at least on the downside of the city in Figure 1(a) or 1(b) (Beck, 1981, 2005).

Introducing More Cellular Function

In its pure form, the "0% school of thought" would seek to suffuse the system of infrastructure with ecological resilience by applying control "externally". Barely a brick would be moved. But as observed in Chapter 3.3, it might make the system increasingly vulnerable to cascading failures arising from a growing reliance on information technology for effecting communication and operations (Zimmerman, 2001; Rinaldi *et al*, 2001; Little, 2002; Zimmerman and Restrepo, 2006). Such vulnerability would be heightened in the face of high-frequency (fast-acting), high-amplitude threats. The pure strategy could thus yet run the risk of coming to epitomize (again) the brittleness of Holling's engineering resilience. This we can recognize quantitatively in our own simulation studies of the concept of pulse and frequency-spectrum of the city-infrastructure couple (Figures 9 and 10; see also Beck *et al*, 2011a).

Relaxing strict adherence to a pure strategy, there could be significant merit in designing ecological resilience into the system, as opposed to enacting it through operations from "without". Seeing how this might be achieved requires us to shift disciplinary gears, from ecology to the features of dynamic behavior found in cellular biology — a kind of "biologizing of control" that theorists have argued should be the next strategic step in the development of control engineering itself (Casti, 2002; Beck *et al*, 2009). This is to ask, in effect, whether technological parts of unit processes capable of mimicking the cellular, biological properties of subliminal immune response, damage limitation, self-repair, and self-replication could successively be incorporated into the body of the infrastructure as a whole (an intent already embodied, in fact, in the idea of a "self-healing energy infrastructure"; Amin, 2001).

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[1] These results derive from a study of cost estimation for pollutant trading schemes assuming only a conventional mixed crude sewage influent to the plant.

BOX 3

Ecological resilience in behavior over time is a function of the interplay amongst relatively slowly changing (low-frequency) and relatively swiftly changing (high-frequency) components of behavior, i.e., the cross-spectrum interactions introduced at the beginning of Chapter 3.3. These inescapable interactions — the fact that the proper study of high-frequency, transient pollution events could not be isolated from all the other frequencies of variation in the behavior of the system — were indeed the motivation for reaching out to the concept of spectrum-pulse in the first place (Beck, 1996).

Ecological resilience has companion interpretations in respect of cross-scale interactions (Peterson *et al*, 1998):

> [E]cological resilience is generated by diverse, but overlapping, function within a scale and by apparently redundant species that operate at different scales, thereby reinforcing function across scales.
>
> The combination of a diversity of ecological function at specific scales and the replication of function across a diversity of scales produces resilient ecological function.

What principles for re-designing the dynamic performance of a city's water infrastructure could we derive from these, through merely substituting the word "species" by "unit process technology" (and eliding thus the disciplinary and conceptual distinctions amongst Engineering, Ecology, and Cellular Biology)?

For Holling, sustainable development itself is founded upon such insights about redundancy and (in)efficiency of function, specifically in endotherms (warm-blooded animals), whose "average temperature is perilously close to lethal" (Holling, 1996):

> Five different mechanisms, from evaporative cooling to metabolic heat generation, control the temperature of endotherms. Each mechanism is not notably efficient by itself. Each operates over a somewhat different but overlapping range of conditions and with different efficiencies of response. It is this overlapping "soft" redundancy that seems to characterize biological regulation of all kinds. It is not notably efficient in the engineering sense.
>
> At least some aspects of ecologically resilient control are equally familiar to the control engineer, for operation at the edge of instability is characteristic of designs for high-performance aircraft. Oddly, the result is opportunity. Effective control of internal dynamics at the edge of instability generates external options. Operating at the edge of instability generates immediate signals of changing opportunity.
>
> That surely is at the heart of sustainable development — the release of human opportunity.

To summarize, four determinants of ecological resilience can be extracted from these various insights: (i) cross-scale interactions, in the senses of space and the levels of hierarchy; (ii) cross-spectrum interactions, in the senses of slowly- and quickly-varying phenomena; (iii) diversity of species (or of agents and agencies); and (iv) redundancy and (in)efficiency of function within a system. How, then (again), might a policy or technological intervention increase (or decrease) ecological resilience in the behavior of the city-watershed system? For Salingaros (2005), intervening to change the connectivity amongst a diversity of (socio-economic) agents across space in a city would be key. "Living cities have intrinsically fractal properties, in common with all living systems", he argues. For Lietaer *et al* (2009), it would be a matter of introducing "diverse complementary currencies": to circulate around networks, and sub-networks within networks, of national financial systems; hence

to mimic the spatial-hierarchical patterns of material and energy flows that imbue ecosystems with their evident coherence and capacity to endure shocks.

Pulse-Spectrum and the Volume/Quality of Ecosystem Services

The idea of pulse-spectrum has been drawn herein from the perspective of Engineering. We have projected it outwards therefrom, i.e., from the infrastructure of IUWM, into the domain of gauging the volume and quality of the services provided by the aquatic ecosystems of watersheds (within the setting, therefore, of IWRM). And we have explored the capacity of the city-infrastructure couple to work to the betterment of those services. What, we must ask now, are the theoretical and empirical justifications for asserting that the spectrum of variations to which ecosystems are subject is related to the volume and quality of ecosystem services?

On theoretical grounds, we find that (Arthington *et al*, 2006):

> ... [T]he literature does strongly support the generalization that different types of flow variability support different ecological communities and life history strategies ...
>
> There is now general agreement among scientists and many managers that to protect freshwater biodiversity and maintain the essential goods and services provided by rivers, we need to mimic components of natural flow variability, taking into consideration the magnitude, frequency, timing, duration, rate of change and predictability of flow events (e.g., floods and droughts), and the sequencing of such conditions.

The "mimicking" advocated by stream ecologists would be strongly akin to the abiding motivation of control engineering, no matter how shocking such might be to them.

On empirical grounds — if we are permitted to equate these with practical prescriptions for maintaining environmental flows and to accept as fact that "environmental flows" are intimately related to "vibrant ecosystem services" — we find in Richter *et al* (2006) a sampled approximation of spectrum (variability) comprising the following elements: (i) "floods", or higher-amplitude, high-frequency[2] events; (ii) "high flow pulses", or lower-amplitude, high-frequency events; (iii) "low (base) flows — normal", or low-amplitude, low-frequency events; and (iv) "low (base) flows — drought", lower-amplitude, lower-frequency events.

Elsewhere, in a quite different setting, there is further empirical evidence touching upon the same generic principle. Studying the scope for discharging toxicants in a manner less unsympathetic to the recipient (marine) environment — the obverse of nutrient supplements, yet not quite the notion of environmental vaccination — Johnston and Keough (2005) assert that:

> Managers will benefit from experimental work that identifies ways of reducing environmental impacts by varying the frequency and intensity of toxicant releases.

We may conclude that vibrant ecosystem services are sensitive to disturbance spectra, in general, and derive specifically from a given spectrum of stream flow variations, but — as yet — not necessarily that they derive from a given spectrum of nutrient concentrations (or fluxes).

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[2] "Frequency" refers again here strictly to the components of variability with time, not to the statistical property of how often a flood, or a pulse, or a drought occurs.

Chapter 4: Adaptive Community Learning

To our surprise, perhaps (after Chapter 3.4), the centralized wastewater treatment facility of the much denigrated, old, end-of-pipe, water-based paradigm of cities of the Global North, might now rather be looked upon as enabling, if not the *sine qua non* of beneficial nutrient supplements for enhancing watershed ecosystem services. For being "centralized" very often stands for the treatment plant being "riverside-proximate": at the end of the pipe, no less; and a location with therefore considerable appeal from the perspective of effective control over the issuing of those supplements.

It has been our purpose in this *Paper* to provoke just such thoughts, in particular, from the perspective of being deliberately contrarian: here, of turning to potential advantage attributes of a paradigm increasingly perceived over the past two decades as but an unmitigated disadvantage, with no redeeming features. Looking back at Box 1, then, dare we ask: is this 20th Century Technocratic Paradigm (20CTP) truly "broke"? Looking back further, to Chapter 2 and to the deeply challenging debate in the approach to the new millennium, have Chapter 3 and Box 3 now culminated in any case for rehabilitating (in the eyes of their critics) those engineering professionals who may have become intellectually downtrodden over the past two decades?[44]

Every bit as deliberately contrarian has been to argue, in effect, that alongside the titles of popular books and articles such as *When The Rivers Run Dry* (Pearce, 2006), *The Big Thirst* (Fishman, 2011), and *The Last Drop* (Specter, 2006) there is a companion story to be told: of *When the Soils (Do Not) Starve*. It would be the narrative, in large part, of the progression through Figures 1(a) and (b), to Figure 1(c), even Figure 1(d). The struggle is to write some alternative, attention-grabbing headlines.

And so our discussion may have spread divergence, disquiet, disorder, where we could instead have expected convergence and clarity in what it might mean to be less unsustainable. It is time to redress this tendency.

In keeping with the essence of sustainability, our thought experiments and their computational corroboration in Chapters 3.3 and 3.4 have been locked into the long view of the future, perhaps breathtakingly so in their tacit demands on the suspension of disbelief. This imbalance must also now be addressed. For when it comes down to it — for all the plurality of distant aspirations 25-75 years hence and for all the possible twists and turns of what is thought good and what bad over the generations (for the Environment as much as for Man) — one singular routine step forward must be taken "tomorrow", no matter the vagueness of working out how exactly to place that step.

Engineering, Engineers, Their Technologies, and Their Computer Models

Consider once again Figure 2.

As stakeholders in a community we are all free to have aspirations for the fate of our cherished environments in the long-term future. These are the green ovals of Figure 2: what we call sustainable IUWM within IWRM in our professional, technical phrasing. Some of us, binding together in a social solidarity, will broadly share a particular distant vision. Yet there is a plurality of such solidarities, each with its own vision, each defined in opposition to the others. We take such plurality not only as a given in a healthy democracy, but also as the point of departure in conceiving of how to move forward.

Motivated by the perception of Man bumping up against the boundaries of the Environment, the contents of these green ovals in Figure 2 should be authentic, lay expressions, of what constitutes primarily {environmental benignity}. Yet in being authentic aspirations, springing from the idiosyncratic life experiences of those shaping the views of the various solidarities, hence not tidily categorized, these contents cannot be disentangled from the ethical underpinnings of the various world views on economics and {economic feasibility} seen in Chapter 3.2. Nor will they be strictly separable from awareness,

[44] Even the mere asking of the question "Is There a Link Between Engineering and Autism?" seems a sign of the times (Baron-Cohen *et al*, 1997).

no matter how casual, of those technological alternatives of Box 1 that enable paths towards these distant societal aspirations, hence also their fashioning. The {social legitimacy} of these stakeholder aspirations, furthermore, will be gauged according to the collectively appreciated quality of the processes of social deliberation, debate, and negotiation from which they emerge. We know well enough now how sustainability is that immensely complex compound of {environmental benignity}, {economic feasibility}, and {social legitimacy}.

Writing from the perspective of Engineering and the engineer, it is unsurprising that we wish to make clear and specific points about their roles in the overall process of generating that singular routine, practical step "tomorrow", at the origin of Figure 2.

First, beyond the engineer as ordinary member of the community (with values, hopes, and fears, just like everyone else), s/he is *uniquely* well qualified to contribute, in respect of the possible contents of the red rectangles representing the alternative technological trajectories in Figure 2. That there are several of them is merely a reflection of the possibility of more than one school of thought on engineering for sustainable development (Box 1).

Second, it is in the destiny of Engineering to be heading towards simulation as Virtual Reality (NSF, 2006; Beck *et al*, 2009), whether we welcome this, trust the results, or view models simply as the latest incarnation of the ancients' oracles (Schaffer, 1993; Pilkey and Pilkey-Jarvis, 2007; Beck, 2007). Cynics jibe that engineering for sustainable development, succeeding half a century of expert technocracy, amounts to nothing more than engineers rediscovering a Society "out there". Such computational facility as we have today, however, presents a profoundly significant departure from the terms, conditions and dialogs of the Victorian era, when members of the lay public (medics, clerics, and so on) opined on matters of urban water engineering — and were heeded by the engineers of that former time.[45]

[45] As any viewer, technical expert or otherwise, will readily appreciate of portrayals of our possible, distant futures (or pasts) on the *National Geographic* (or *History*) television channels, not to mention the emergence of "decision theaters" for stakeholders (Hall and O'Connell, 2007; Gober, 2009; White *et al*, 2010).

4.1 Within the Frame of Figure 2: The "Engineering Mechanics" of Arriving at One Routine Step

We argue now expressly from a computational standpoint, as a mathematical "microcosm" in which to expose the mechanics of the process with the greatest possible clarity and specificity, including — perhaps paradoxically — all the uncertainty therein.

Consider the "system" here to be the city, its water-nutrient infrastructures, and the watershed. A model $\boldsymbol{M}$ of that system relates policy actions and incoming disturbances (such as a changing climate) — all collectively enfolded under the label $\boldsymbol{u}$ — to outcomes $\boldsymbol{y}$, the green ovals in the upper right-hand corner of Figure 2. The ovals are either to be reached (as hopes) or avoided (as fears), depending upon one's outlook on the Man-Environment relationship. Policy elements of $\boldsymbol{u}$ — caricatured as comprising that immediately pragmatic "one routine step tomorrow", $\boldsymbol{u}_{now}$ we shall say — are conceptually anchored at the lower-left origin of Figure 2.

Embedded within $\boldsymbol{M}$ are elements referred to as parameters (or coefficients) $\boldsymbol{\alpha}$. They characterize mathematical relationships for the mechanisms assumed to be involved in transcribing the consequences for $\boldsymbol{y}$ arising from the choices and assumptions about $\boldsymbol{u}$. These $\boldsymbol{\alpha}$ can be expressed so as to reflect the performances of all the alternative candidate technologies and unit processes that might participate in enabling us to proceed from the one routine step tomorrow ($\boldsymbol{u}_{now}$) to some set of distant future outcomes $\boldsymbol{y}$. Center-span in Figure 2 — and at the core of the model $\boldsymbol{M}$'s structure — the red rectangles of the alternative technological paths (conceptually, the $\boldsymbol{\alpha}$) bridge the gap between the $\boldsymbol{u}_{now}$ and the $\boldsymbol{y}$.

Simply put, we have a computational triplet, [$\boldsymbol{u}$, $\boldsymbol{M}$, $\boldsymbol{y}$], or [$\boldsymbol{u}$, $\boldsymbol{M}\{\boldsymbol{\alpha}\}$, $\boldsymbol{y}$], in slightly more refined terms. And like the mathematical textbook, we can have three basic ways of solving for one unknown given the other two components as knowns: (i) given $\boldsymbol{M}$, for the city-watershed system, and assuming a decision $\boldsymbol{u}$, find the outcome $\boldsymbol{y}$; (ii) given $\boldsymbol{M}$ and some expression of a desired (feared) outcome $\boldsymbol{y}$, find $\boldsymbol{u}$, such that $\boldsymbol{y}$ is attained (avoided); and (iii), given observed $\boldsymbol{u}$ and $\boldsymbol{y}$, find the model $\boldsymbol{M}$. This last will not be of direct concern *per se* herein, which is not to imply it presents no great challenges — quite the opposite. For these challenges

have significant consequences for how the other two textbook problems are to be solved, in particular, in respect of coping with the inevitable uncertainty of $\boldsymbol{M}$ never being the "real thing" (Beck *et al*, 2009).

To reiterate, what is important here is explanation of the mechanics of the process of going forward under (a) plurality, (b) uncertainty, and (c) the absence of myopia, not the particulars of any model that might be mobilized for such a purpose, nor whether a model might even be called for in the first place. Central are matters of technology exploration and assessment, for engineering and re-engineering the infrastructure of IUWM within IWRM. Doing something about our becoming less unsustainable, however, is hardly a textbook mathematical problem. This *Concepts Paper* is not about to assert that it is. Yet the elementary triplet $[\boldsymbol{u}, \boldsymbol{M}\{\boldsymbol{\alpha}\}, \boldsymbol{y}]$ can reveal much about the nature of this "becoming less unsustainable", with but little further elaboration.

Plurality and Disagreement

Our point of departure, once more, is the upper right-hand corner of Figure 2, with the cluster of green ovals of community aspirations for the environment. Chapter 3.1, and Figure 3 in particular, have made it abundantly clear: in a healthy democracy, $\boldsymbol{y}$ is not singular, but plural. Under the archetypal "world views" of the individualist (I), hierarchist (H), and egalitarian (E) solidarities (Figure 3), we should expect there to be outcomes (aspirations, hopes, fears) that may be distinctly different. That is to say, we should expect to have to deal with the multiple and disparate aspirations $\boldsymbol{y}(I)$, $\boldsymbol{y}(H)$, and $\boldsymbol{y}(E)$. *Dissentio ergo sum*![46]

To the left and below these community aspirations in Figure 2 is the technology portfolio of red rectangles. Box 1, from Chapter 3.1, has argued that there is also a plurality of styles of engineering sustainability, or schools of engineering thought. They have been labeled there as 20CTP, D&C, SOS, and so on. The candidate technologies, with their material, environmental, and economic performances parameterized as $\boldsymbol{\alpha}$ in our triplet, might equally so be subject to preferences for the future conditioned upon these several differing styles. We know that ecologists can hold to the disparaging view of engineers as purveyors of "quick fixes" (Poff *et al*, 2003). Thus could the ecologist be implacably opposed to the kind of engineering and technology to which the control engineer might incline ($\boldsymbol{\alpha}(D\&C)$). Much preferred in the ecologist's view would be technical innovations along the lines of $\boldsymbol{\alpha}(SOS)$. We must contend then with the plurality of $\boldsymbol{\alpha}(D\&C)$, $\boldsymbol{\alpha}(SOS)$, and so on. Worse still for we engineers (perhaps), it is conceivable that the control engineer would write his/her model $\boldsymbol{M}_{Control}$ altogether differently from the ecological engineer ($\boldsymbol{M}_{Ecology}$). Each would appeal to differing knowledge-science bases. The former might then intend the web of technology in the city's infrastructure to function as $\boldsymbol{M}_{Control}\{\boldsymbol{\alpha}(20CTP); \boldsymbol{\alpha}(D\&C)\}$, the latter as $\boldsymbol{M}_{Ecology}\{\boldsymbol{\alpha}(SOS); \boldsymbol{\alpha}(SiB;EC)\}$. Given the same $\boldsymbol{u}$, different $\boldsymbol{y}$'s are implied, and *vice versa*.

Such diversity — if not a plurality of fundamental principles for building a water purification plant (as we challenged ourselves in opening this *Paper*) — may seem alien to us working in the domain of IUWM nested within IWRM. It is not to those in other fields, however, such as in the model-based assessments of policies for coping with global climate change undertaken by van Asselt and Rotmans (1996). Solidarities I, E, and H, they assert, will build different elements of the science base into their respective $\boldsymbol{M}_I$, $\boldsymbol{M}_E$, $\boldsymbol{M}_H$ of the behavior of the global atmosphere.

Yet of no surprise to the engineer would be the way in which economists have vigorously contested the nature and form of what is to be done about the inter-generational discounting rate: whether it should be $\boldsymbol{\alpha}(I)$, $\boldsymbol{\alpha}(E)$, or $\boldsymbol{\alpha}(H)$ (as in Chapter 3.2 and Godard (2008)). Opponents of Cultural Theory might well dispute this threefold plurality, observing that the mainstream debate persists as that between the duopoly of just markets ($\boldsymbol{\alpha}(I)$) and governments with their regulations ($\boldsymbol{\alpha}(H)$). Cultural theorists, in their turn, would charge the mainstream debate with being impoverished and wholly inadequate as a result (Thompson, 2008b; Ingram and Thompson, 2010). It

[46] Our point (again) is not that social groupings and their world views *have* to be arranged according to the typology of Cultural Theory. It is rather that in a healthy, democratic community of stakeholders, groupings adhering to certain beliefs and archly opposed convictions will be manifest. This is in the nature of things, and in more ways than we might previously have cared to suppose. It should be acknowledged as such. It makes things more complicated, but it should not be wished way. Indeed, perhaps it ought to be celebrated. Several quite different ways of looking out on the world and the Man-Environment relationship imply plural wisdoms from which to benefit. As already observed in Chapter 3.1, some cultural theorists have put it this way: "I disagree; therefore, I am" (Nowacki *et al*, 2010).

takes little further reflection to recognize the sensitivity of the promise of any one of the red-rectangular technological trajectories of Figure 2 to such possibly vehement disagreement, not least when backed up by all the numerical results of the (plural) scientific and technical models.

Decisions, the $\boldsymbol{u}_{now}$ at the left-hand origin of Figure 2 and the focus of this Chapter 4, are always made under uncertainty. Their formal analysis as such has stimulated the development and accumulation of a vast body of mathematical and computational methods, generally referred to as Decision Making Under Uncertainty (DMUU) (for example, von Winterfeld and Edwards, 1986). Yet there are qualitatively distinct classes of uncertainty, for some of which the toolkit of DMUU is far from being well stocked (Beck *et al*, 2009). Unfortunately, our going forward "under plurality, uncertainty, and the absence of myopia" is especially prone to the most severe of these degrees of increasing uncertainty. Disagreement is again at the heart of the matter.

Consider that the greatest hopes for the future of the individualist grouping ($\boldsymbol{y}(I)$) might entail some of the gravest nightmares of, say, the egalitarians ($\boldsymbol{y}(E)$). The domains of aspirations $\boldsymbol{y}(I)$, $\boldsymbol{y}(H)$, and $\boldsymbol{y}(E)$ may enfold mutual contradictions. Counter-intuitively, the greatest uncertainty may surround coming to a $\boldsymbol{u}_{now}$ when decisions have to be made under the "contradictory certainties" (CC) passionately espoused by those promoting *their* $\boldsymbol{y}(I)$, or *their* $\boldsymbol{y}(H)$, or *their* $\boldsymbol{y}(E)$, i.e., DMUCC (Thompson, 1985). Things that truly matter to people evoke passion. Convinced of the validity of their beliefs — including *their* science and *their* technology — the intensity of the public debate can force parties into ridding *their* position of all uncertainty (while piling it up onto those of the others). Not only may the respective outcomes to which they aspire ($\boldsymbol{y}$) harden towards "certainties", but also the assembly and manipulation of the respective models of the system's behavior ($\boldsymbol{M}$). The plurality and diversity of view tolerated in civil, if disputatious, debate may harden towards the apparent impasse of sharply contradictory certainties, hence the severe forms of uncertainty arising from impassioned disagreements amongst the parties to the debate.[47]

Somehow, the singularity of an "actionable" $\boldsymbol{u}_{now}$ (at the bottom left-hand corner of Figure 2) must be wrung from the confusion of this welter of disagreement.

Uncertainty Under Consensus

Let us imagine agreement breaks out. Absent then the deeply entrenched disagreement amongst the foregoing *Weltanschauungen*, specifically the plurality of core beliefs about the basic nature of the Man-Environment relationship, other forms of uncertainty remain to be addressed. They are largely the customary forms. Given but one agreed model $\boldsymbol{M}$ of the way the world works, a host of constituent hypotheses and assumptions must nevertheless be assembled into it. These concern:

(U1) The contemporary science undergirding the way the current, future, and distant-future candidate technologies are believed to work (hence incorporated into the city's water and nutrient infrastructures); likewise, the contemporary science and approximations of the manner in which the fluxes of materials through and around the city-watershed system are modulated as a function of the watershed's ecosystem.

(U2) The expected economic performance of the technologies; likewise, identification and valuation of the services rendered by the watershed's ecosystem.

(U1) is the technical-statistical uncertainty — as opposed to that of disagreement amongst experts — about the science, (U2) that of the economics. Much greater uncertainty should intuitively be assigned to those scientific and economic parameters ($\boldsymbol{\alpha}$) of the model associated with nascent innovations in prospect over the next 5-20 years, than those attaching to the tried and tested technologies of the past several decades. Much of the discussion of Box 1 is about the risks associated with these (and other) uncertainties.

[47] In the setting of the assessments of the Intergovernmental Panel on Climate Change (IPCC), Patt (2007) has argued that the uncertainties arising from disagreements amongst the technical (professional) experts is rarely properly accounted for and probably greater in significance than the "technical" (statistical kinds of) uncertainties arising from the conventional, quantitative assessment of models ($\boldsymbol{M}$) and their forecasts.

Then there is the uncertainty arising from the differing psychologies of our public and private personas, with their influence over:

(U3) The effectiveness of policy, hammered out in the public space of debate amongst the collective, openly expressed voices of the solidarities (*I, E, H*), when contingent on the strictly personal, undisclosed choices of individuals, made in the isolation and quietude of their private space — choices about, for instance, the adoption of alternative household plumbing appliances and, subsequently, assiduous attention to their appropriate operation.

(U3) is the uncertainty regarding what policy $\boldsymbol{u}$ — including $\boldsymbol{u}_{now}$ — can actually deliver in respect of its commitments, no matter how sustainable and socially legitimate has been its genesis. Solidarities might have agreed in public to opt for innovations that are small, beautiful, and individually empowering (SiB). Yet the same individual who went with the crowd in public, may blithely ignore the smart device in the shower that warns of imminent excessive consumption of water and energy (Willis *et al*, 2010).

Absence of Myopia in the Face of Constant Change

The further any analysis is projected away from the myopia of just the here and now, both forward into the future and backward into the past, the greater will be the uncertainties clouding the making of a decision. From the framework of Figure 2 we wish somehow to extract from the daunting morass of even our mathematical microcosm just the one routine step for tomorrow. Our *singular* $\boldsymbol{u}_{now}$ at the bottom left-hand corner (of Figure 2) must be snatched from the jaws of all the plurality, vagueness, contentiousness, and uncertainty of the social aspirations $\boldsymbol{y}(I)$, $\boldsymbol{y}(H)$, and $\boldsymbol{y}(E)$; from the economic valuations V_0, V_C, V_E, or V_X ; from the schools of engineering thought, such as $\boldsymbol{M}_{Control}\{\boldsymbol{\alpha}(20CTP);\boldsymbol{\alpha}(D\&C)\}$ and $\boldsymbol{M}_{Ecology}\{\boldsymbol{\alpha}(SOS);\boldsymbol{\alpha}(SiB;EC)\}$; and with all of these being subject to flux and strategic change under the long view over future time (t_{future}).

We may attempt to do so calculating forwards with our notional model ($\boldsymbol{M}$), i.e., given a candidate policy/choice/decision $\boldsymbol{u}_{now}$, and given $\boldsymbol{M}$, determine the future outcome $\boldsymbol{y}$. We did just this across Chapters 3.3 and 3.4, developing a case there for re-engineering the city of Atlanta so that it might become a force for good in the Chattahoochee watershed.[48] Sustainability was gauged according to the nutrient spectra of the outcomes, under the PeFe aspiration ($\boldsymbol{y}$), and experimenting with a policy $\boldsymbol{u}_{now}$ gathered around the possible implementation of urine-separating toilets, truck transport, digesters, stripping towers, absorption towers, and so on. The logic of the exercise was wound forwards (many times) across the framework of Figure 2, essentially left to right. We asked, in effect, "what if" we were to take such and such a $\boldsymbol{u}_{now}$ to attain some (very) distant desired, sustainable, green-oval, environmental future, $\boldsymbol{y}(t_{future})$. In fact, those disillusioned, jaundiced, or cynical about sustainable development might scoff: $\boldsymbol{y}(t_{future})$ is $\boldsymbol{y}(t_\infty)$, as time t goes to infinity (t_∞)!

Inverse Approach

How might things turn out, were we instead to wind the logic backwards, as in the second of our mathematical textbook problems (determine $\boldsymbol{u}$ given $\boldsymbol{y}$ and $\boldsymbol{M}$), to run across Figure 2 from the expansiveness of the cluster of green ovals at its upper right-hand corner to the singularity of the one routine step at its lower left-hand corner, at the origin of Figure 2? This is not rhetoric. For we can ask this kind of question:

> To what extent, under gross uncertainty, can a candidate policy for taking "one routine step tomorrow" ($\boldsymbol{u}_{now}$) offer the prospect of: (a) not foreclosing on attaining (avoiding) the plural, not necessarily shared, positive (negative) visions of the future (the set of [$\boldsymbol{y}(I;t_{future})$, $\boldsymbol{y}(H;t_{future})$, $\boldsymbol{y}(E;t_{future})$]); (b) contingent upon which handful of key technologies $\boldsymbol{\alpha}_{key}$; and (c) amidst all the scientific, system-wide unknowns about how a local, context-specific technical innovation relates to a global environmental good?

[48] The metaphorical turning of each cog within the model $\boldsymbol{M}$ can be metered for the resources mobilized and the services provided, be they the materials, energy, and chemicals consumed in each local, unit process of the infrastructure, or the prosperity of each ecosystem service provider in the watershed. Numbers pertaining to determinations of those uncommon facets of {economic feasibility}, let us say V_E or V_X, can be generated, just as in using engineering simulation to generate conventional, marginal cost (V_0) data in the more pragmatic context of watershed nutrient trading (Jiang *et al*, 2005).

We already have the proven prospect of deriving pertinent answers, as in the Adaptive Community Learning (ACL) of Beck *et al* (2002) and the computational "inverse" approach of Osidele and Beck (2003) (see also Chen and Beck (1997), Beck (2002), and Villarroel Walker (2010)).

Conceptually, the mechanics of the process of going forward under plurality, uncertainty, and the absence of myopia, are a matter of going backwards across the framework of Figure 2: entry at the cluster of several green oval domains (plural $\boldsymbol{y}$); exit at the origin of one routine step "tomorrow" ($\boldsymbol{u}_{now}$). Formally and practically, it would be a sheer delight to find some way of digging a trench ($\boldsymbol{u}_{now}$), as the epitome of that one hum-drum, routine step for tomorrow, which may not be to the liking of all the stakeholders (I, H, E), but which does not undermine their capacity to hold fast to their respective distant, cherished aspirations, of $\boldsymbol{y}(I;t_{future})$ or $\boldsymbol{y}(H;t_{future})$ or $\boldsymbol{y}(E;t_{future})$ — at least for a while (Δt) — as $\boldsymbol{u}_{now}$ is put into practice, from $\boldsymbol{t}_{now}$ to $\boldsymbol{t}_{now} + \Delta t$.

Given all the varied perspectives, the trench might need to be seen as pointing metaphorically every which way down the street. Far from narrowing the hopes of our distant visions, moreover, this immediately pragmatic decision ($\boldsymbol{u}_{now}$) should instead expand our horizons. How should we dig such a trench, under the prevailing thinking of 20CTP (from Box 1), so that in 5, or 10, or 15 years' time the equipment and pipework laid down today would need minimal adaptation in order for a neighborhood to migrate towards either of the structural rearrangements of Figure 1(c) (in pursuit of S@S) and 1(d) (to promote EC)? How could this trench pave the way for incorporating ever more of the styles of D&C or SOS into the three basic configurations of that Figure 1? Inspired by an SiB style of engineering sustainability, how might the trench honor systematic decentralization of any one of the three strategic configurations? The possibilities for the form of any such marvelously "sustainable trench" are combinatorially complex (Figure 12).

The metaphor of the model ($\boldsymbol{M}$) has served its purpose, of enabling as much clarity as possible regarding the mechanics of fashioning the one routine step tomorrow from the plurality of the community's innate aspirations for the distant future. The naked, rattling bones of the yet intricate anatomy of the challenge of Chapter 2.4 have been laid bare. We know that whatever candidate policy steps are to emerge from Figure 2, courtesy of the mechanics of the foregoing process, none will be successfully implemented — as *sustainable* actions — if the scheme of their generation lacks {social legitimacy} in the eyes of the community of stakeholders.

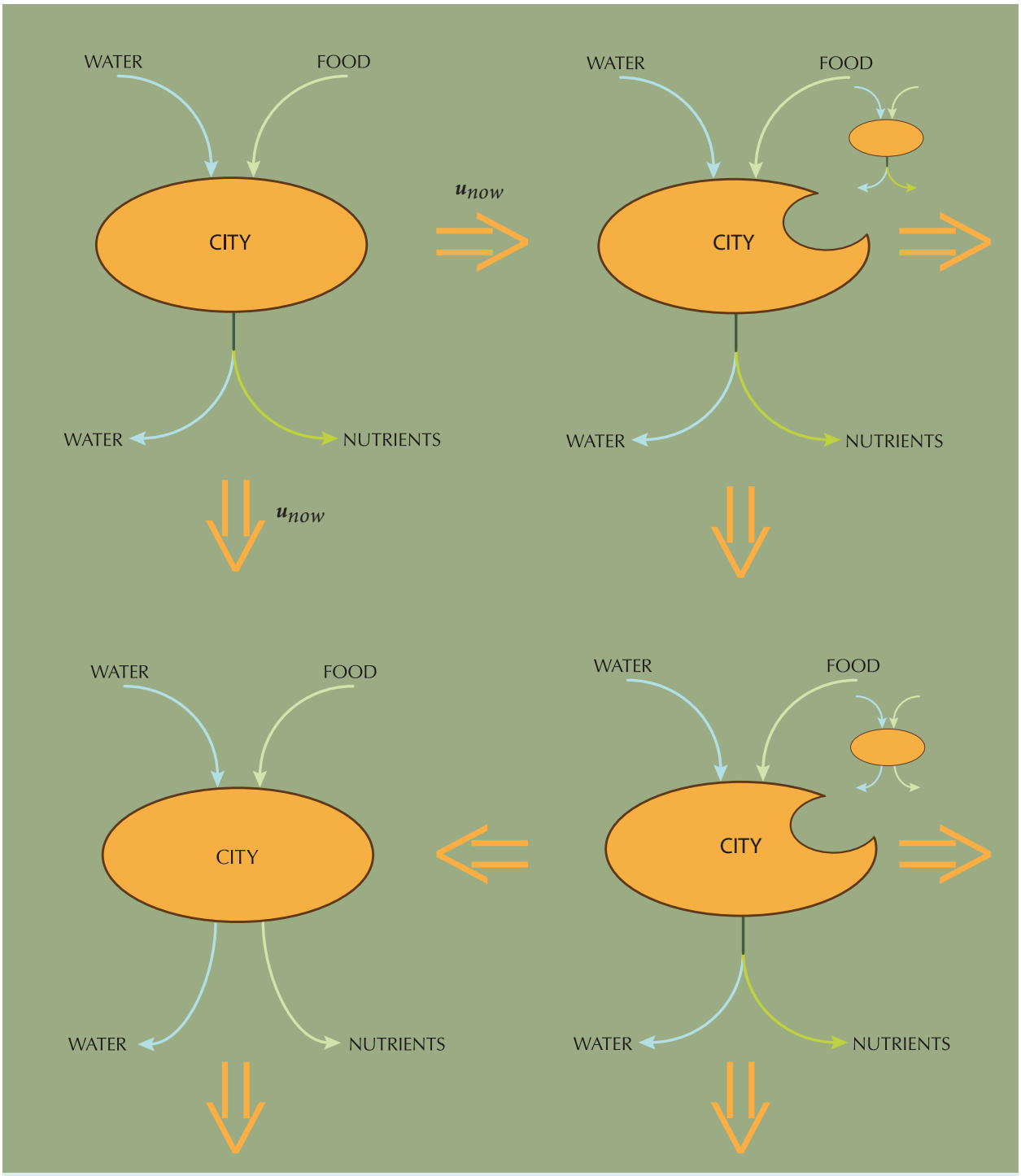

Figure 12
One routine step "tomorrow" ($\boldsymbol{u}_{now}$): the combinatorially complex challenge of inventing the "sustainable trench". This figure has been assembled from the iconic caricatures of the structural arrangements of the city and its water-nutrient infrastructures of Figure 1, namely Figures 1(a), (c), and (d). Starting from current arrangements (top left icon), and signaling incremental decentralization according to the top right icon, just a few of the many structural re-configurations are imagined (as structural transitions, =>). The challenge is to conceive of what kind of trench, pipework, and other fittings might be integral to facilitating the maximum number of transitions (=>) over time into the distant future, while being environmentally benign, economically feasible, and socially legitimate in an inter-generational sense. The alternative of dry sanitation (the icon of Figure 1(d)) has been omitted in the interests of bounding the potential visual complexity.

4.2 Around and About the Frame of Figure 2: Legitimacy of the Social Process of Arriving at One Routine Step

Our argument has reached out for the elegance and tightness of mathematical metaphor to expose the *inner* workings (in concept) of Figure 2. Since governance can be either enabling or disabling of those mechanics, we now appeal to some elevated principles of democracy for conducting the public debate *surrounding* the entire space of Figure 2.

Succinctly put, and to reiterate (from Chapter 3.1), each solidarity within the given community should have a voice; that voice should not be rendered inaudible by any other voice sufficiently raising its volume; each voice should instead be acknowledged by those of the other solidarities and be credited with a reasoned response from them. Ney (2009) has proposed the simplicity of a matrix for assessing exactly where any particular governance structure lies in terms of *access* — being granted a voice in the debate — and *responsiveness* (these being Dahl's (1989) two crucial dimensions of pluralist democracy). The strong implication is that the greater the access and responsiveness of a scheme of governance, the greater will be the probability of {social legitimacy} being accorded not only to that scheme but also its outcomes.

The Specialist Group on Sustainability in the Water Sector of the International Water Association (IWA) has begun experimenting with its own microcosm of such a pluralist democracy, namely the (2006 and 2008) biennial Sustainability *Agora* (Beck and Jeffrey, 2007). In the spirit of good-humored theater, the *Agora* stages the scene of a market place wherein problem framers pitch their stalls and vie with each other for the attention and purchasing power of IWA shoppers — as professional engineers — seeking to sell them genuine articles of sustainability problem-solving.

As Box 4 relates, there is a growing appreciation of how to construct the stalls and identify the stall-holders — to get into the processes of Figure 2 — but not of the shopping experience, i.e., the manner of "buying into" that one routine step tomorrow, hence exiting subsequently from the deliberations of Figure 2. The uncertainties surrounding the process, moreover, may technically render no one routine step tomorrow unambiguously worth buying into by a majority.

This uncertainty, of course, is the whole problem, yet we may know which key uncertainties are the prime targets for our collective attention in order to reduce them, by whatever manner of research or policy action.

These Sustainability *Agora* have been experiments: two trials; two volumes of errors. How might we now translate insights from a concocted, simplified, laboratory-theater microcosm into better designs for structures of governance in the complex, practical, messiness of the "real world"? Is there a particular structure, or scale, of governance lending itself to experimentation, learning, and adaptation? Or, at the least, how should we re-design the next *Agora* as a device for catalyzing improvements in the quality of governance in a real-world community? In closing the discussion of Box 4, we draw upon practical experience from South Asia — on water, sanitation, and human settlements — to illustrate the conceptual distinction between a form of governance enabling "constructive engagement" amongst the vying parties and that disabling such, hence destructive impasse (Gyawali, 2004). The business of the *Agora* is clearly unfinished. Its purpose has hitherto been solely that of learning about constructive engagement, not the occurrence of destructive impasse. A sound appreciation of both is important. There is plenty of scope for further experimentation.

Experimentation, Learning, and Adaptation

In just two steps this discussion has now vaulted over the mathematical abstraction of a model (***M***), as metaphor for exposing the mechanics of our working within Figure 2, up to the highest ideals of pluralist democracy, for navigating around that picture, hence bestowing {social legitimacy} on its enfolded processes of seeking {environmental benignity} of action. Command of such mental gymnastics, we might say, is what sustainability is all about. It is every bit as necessary in making the most of these tensions: between the sharply juxtaposed "one routine step tomorrow" and the "inspired visions generations hence"; and between achieving ever greater efficiency and reduction in the city's metabolism of its daily water, for example, and manipulating the metabolism of the city's daily bread as a force for good in the watershed.

Making decisions is not a static thing, wherein participation of the community occurs once and for

all during a process itself restricted to a finite period of time (Shepherd, 1998; Steinemann, 2001; Borsuk *et al*, 2008). Making credible commitments to, or buying into, one routine step at time t_1 (t_{now}), towards the origin of Figure 2, should take the state of affairs — of community-environment interaction — to that at time t_2 ($t_{now} + \Delta t$) in Figure 13. That is to say, we should be quite deliberate about the fact that the community's aspirations for the distant future (green ovals), as well as the candidate technological trajectories (red rectangles), will have evolved, or been rearranged with the passage of time. Beyond the framing of Figure 2 and working within and around it, now subsumed as merely the first of endless such iterations in Figure 13, we must consider by what means a community should move itself from one state of affairs (at t_1) to the next (at t_2), prudently experimenting with its style of governance, as it proceeds.

This begs various questions. What exactly is to be learned from a preceding iteration (at t_1), by the solidarities within the community as a whole, and by the engineers, in particular? How is that learning to be put to good use in proceeding to the subsequent iteration? How does the action or policy emerging from the "origin" at t_1 create the possibilities evident at t_2, while yet "solving" the central problems on the minds of community members as they were at t_1? In sum, the challenge is to assess how community views (on sustaining and stewarding a given piece of the environment) may change over time as a function of iterative interaction with engineers as generators of technological options (and with the science base, in general), within the overall framework of Adaptive Community Learning (ACL; Beck *et al*, 2002).

We know what adaptive management is (Holling, 1978; Figure 14(a)). In essence, policy therein fulfils two functions: to probe the behavior of the environmental system in a manner designed to reduce uncertainty about that behavior, i.e., to enhance learning about the nature of the *physical* system; and to bring about some form of desired behavior in that system (an adaptation itself recommended as the next step in IWRM; Pahl-Wostl *et al*, 2007a). ACL ought both to subsume the principles of adaptive management (so defined) and

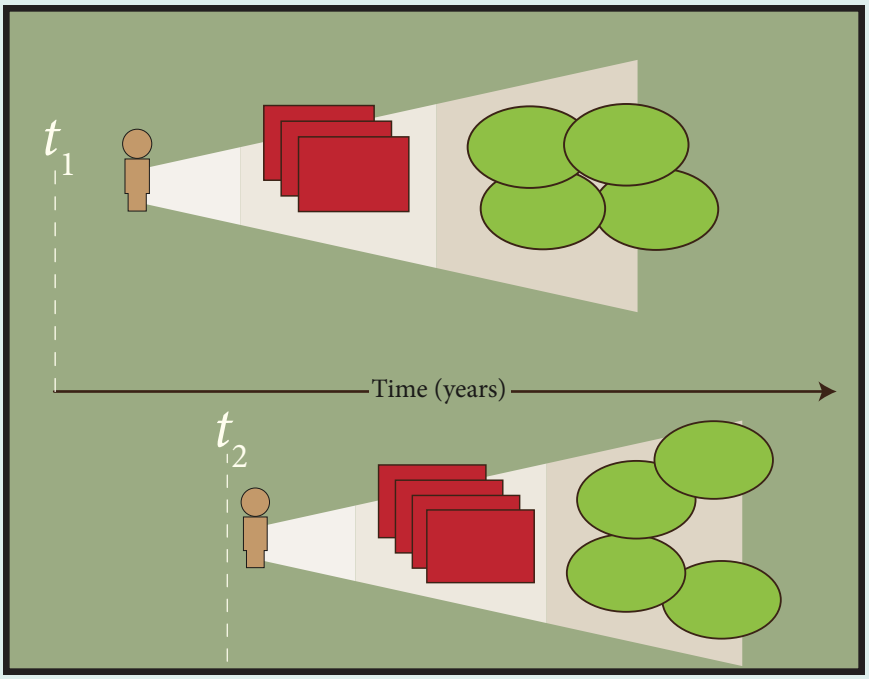

Figure 13
Two frames in the evolution of the "big picture" of Figure 2 frozen in time at t_1 and t_2, with different numbers of distant, inter-generational futures (green ovals) and alternative technological paths (red rectangles), all with their contents changing over time.

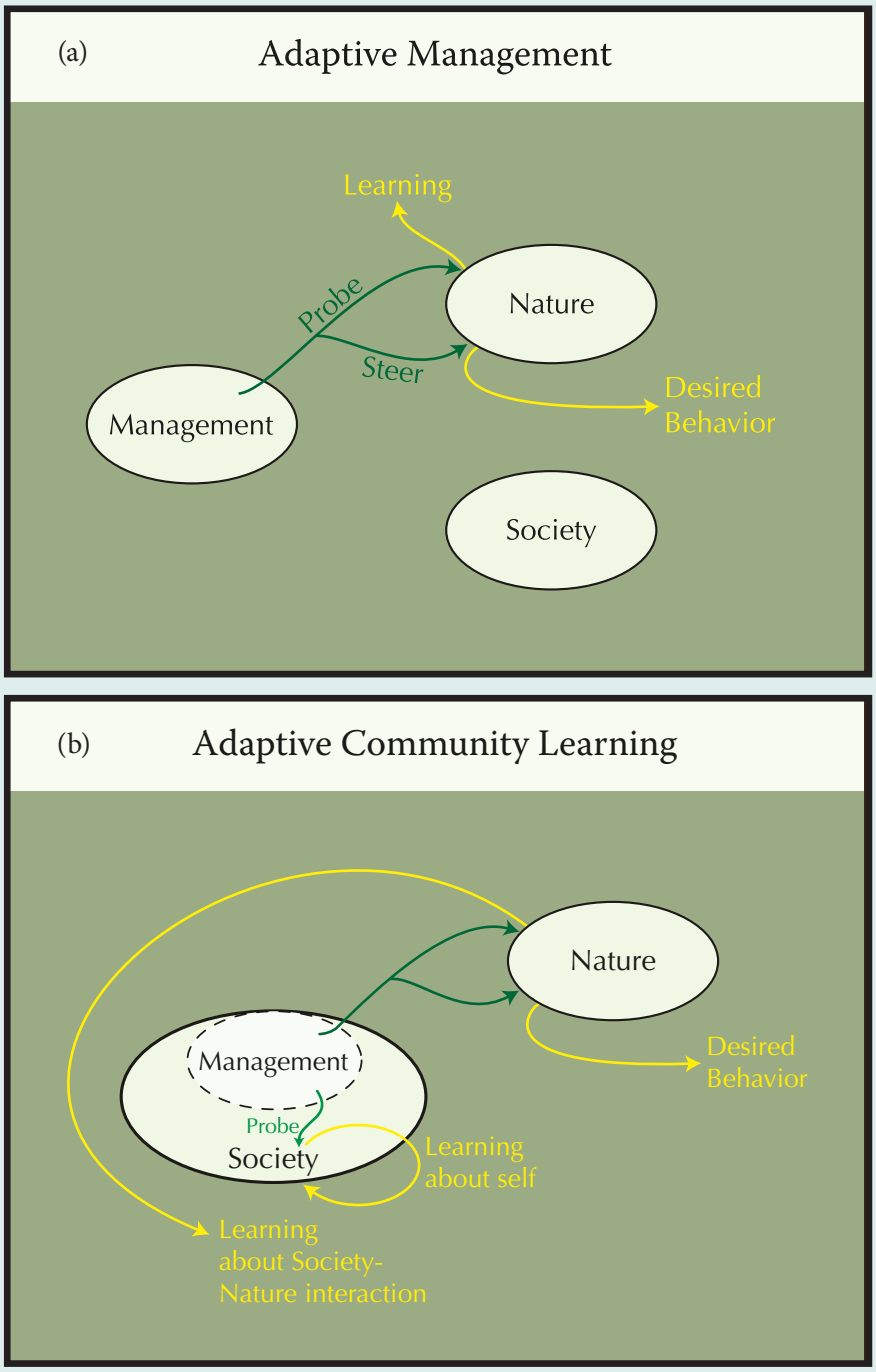

Figure 14
Figurative renderings of the ideas of "learning" and "management": (a) adaptive management, in which the dual purpose of policy, emanating from "management", is to steer the behavior of Nature (or the Environment) in some desired direction while probing the nature of that behavior (at one and the same time); and (b) adaptive community learning, wherein "management" is seen not as somehow separate from Society, but embedded within it, and the purposes of policy are not only those of adaptive management but also that of probing the nature of Man's interaction with Environment and Man's interaction with Man.

include actions, or a process of decision-making, whereby the community of stakeholders experiences learning about *itself*, its forms of governance, its relationship with the valued piece of the environment, i.e., the community-environment relationship, and the functioning of the physical environment (Figure 14(b)).

When ACL was first conceived (Figure 15(a)), "Analysts" were considered to be standing quite apart from "Society" (Box 4). Just two "green ovals" of future aspirations were supposed. They had been generated from a professionally facilitated "Foresight Workshop", as a matter of the *collective* imagination (aspirations) of all the workshop participants, i.e., independently of

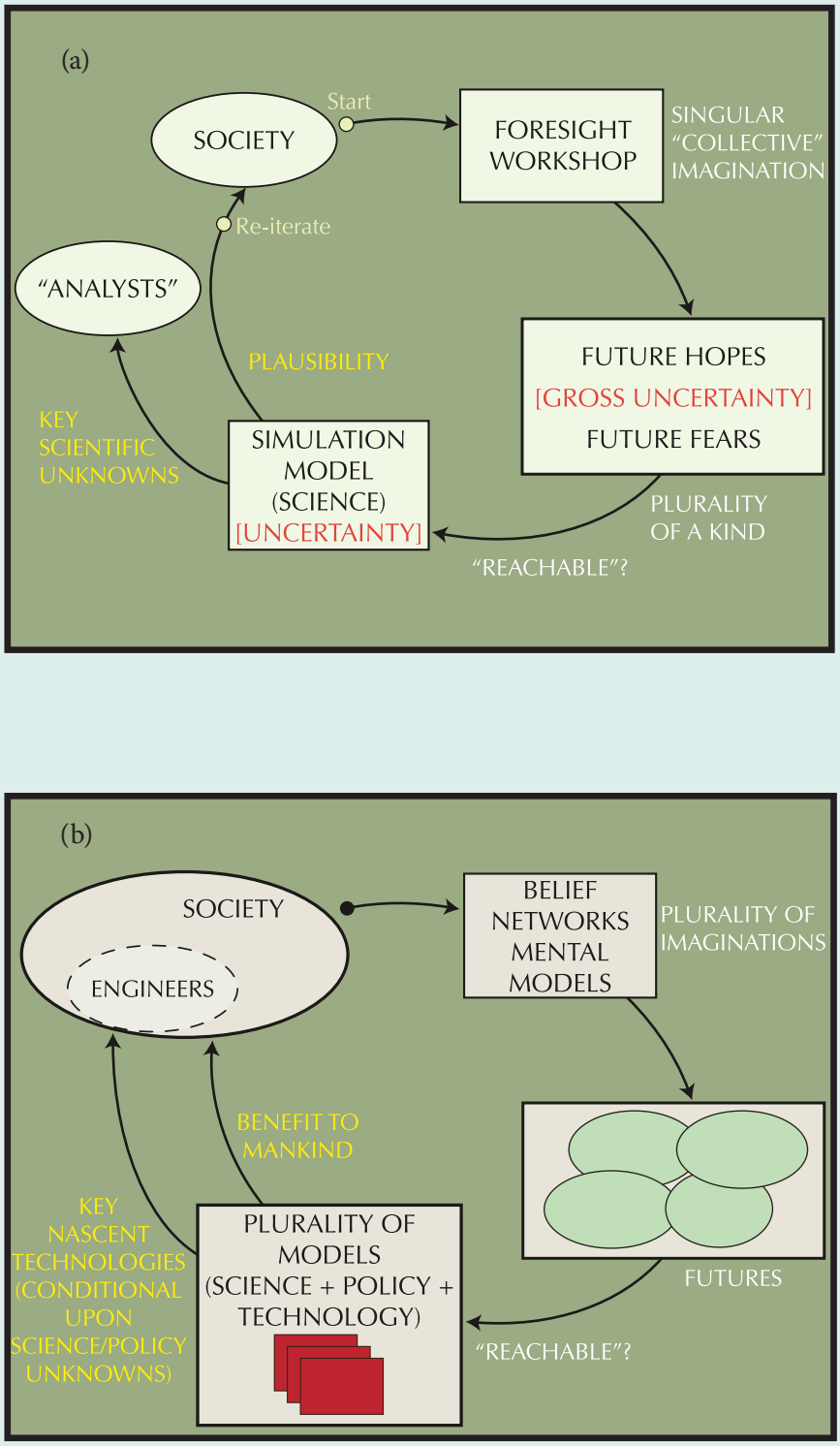

Figure 15
The endless iterations of "going forward in spite of vagueness": (a) as originally envisaged in an earlier prototypical study of adaptive community learning in the context of assuring the ecological health of Lake Lanier (in the Upper Chattahoochee watershed, Georgia; Beck *et al*, 2002); and (b) as adapted in the presently wider purview of seeking strategies for re-engineering the city as a force for good and sustainability in the water sector. The authentic green oval aspirations of the plurality of solidarities within the given community (in (b)) have replaced the single set of future hopes and single set of future fears derived from a professionally facilitated workshop (in (a)). Likewise, a plurality of plausible models (***M***), formally embracing respectively differing sets of red rectangles for the alternative technologies appealing to each solidarity, has in (b) replaced just the single notional model of (a), which covered but the bits of the science base (and their respective uncertainties). Furthermore, the "Analysts" previously conceived of in (a) as strictly and clinically separate from "Society" are in (b) viewed as integral members of "Society".

any solidarities. They were that whole group's greatest "Hopes" and worst "Fears". In other words, they were not the set of disparate aspirations $\boldsymbol{y}(I)$, $\boldsymbol{y}(H)$, and $\boldsymbol{y}(E)$ introduced earlier (and which are of concern in Box 4). "Society" was to learn something of the "Plausibility" (or "Reachability") of these "Hopes" and "Fears", conditional upon the current "Science" base, all its uncertainties notwithstanding. The "Analysts", for their part, were to acquire a sense of what might be the small handful of "Key Scientific Unknowns" crucial to the reachability of society's hopes and fears (Beck *et al*, 2002; Osidele and Beck, 2003; Fath and Beck, 2005; Hare *et al*, 2006).

In proceeding thus from t_1 to t_2 in Figure 13, what members of the various solidarities within the community acquire is several-fold:

(B1) an appreciation of the plausibility, or otherwise, of their distant visions (at t_1) (Figure 15(a); or its future realization as Figure 15(b));

(B2) reassurance — perhaps — of no foreclosing on the promise of attaining their distant hopes, if not the express pursuit of these hopes, for the time being (over Δt); and

(B3) a sense of how those visions might be re-shaped, when the time (t_2) comes, according to their personal exposure to the technology and science as they too stood at t_1.

For their part, the professional engineers acquire:

(B4) an appreciation of those key technologies ($\boldsymbol{\alpha}_{key}$) likely both to better serve the community's longer-term aspirations, as imagined at t_1, and to promote burgeoning possibilities for both those aspirations and the technological options the next time around, at t_2.

For Boulanger (2008), the deliberative style of democracy should succeed over any mere aggregative style, as the means for the community to be collectively engaged in taking prior societal preferences (at t_1) and fashioning posterior preferences by t_2. Thompson (2002), envisioning future times t_3, t_4, t_5, ... (beyond t_2), would call this a "Road Without End". Mutual learning amongst his various solidarities would ensue at each t_k, as they proceed along that way — with now these refinements and embellishments of (B2):

($B2_1$) some getting more of what they want, others — having realized the possible threat of getting absolutely nothing attractive (Gyawali, 2004) — getting less of what they do not want (which is what the others would want), or (as related in Thompson (2011)), no one group having things all its own way, no one getting much more than the others, each getting much more than nothing, and each getting more of what it wants than it would have got, had it "gone it alone" and succeeded in imposing its needs on all the others;

($B2_2$) all, perhaps essentially, being allowed still to cherish what they hope for (and harbor what they fear) in the ever distant long term (multiple Δt's ahead, in t_{future}), i.e., to hold fast to their differing views of the Man-Environment relationship; and

($B2_3$) all collectively moving forward to t_{k+1} — albeit some grudgingly and for just a while (Δt) — when plans and experiences (some surprising) may all change once more ("always learning, never getting it right").

Looking to a future realization of Adaptive Community Learning, we imagine Figure 15(b) as a procedural and conceptual advance upon Figure 15(a). "Engineers", we note further, have there been gathered back into "Society"— in fact, welcomed, we trust(!) (Figure 15(b)).

These high-minded ideals are not floating entirely free of their counterparts in the mechanics of the models ($\boldsymbol{M}$) and computation. The fruits of their application must be channeled back — given all the outcomes ($\boldsymbol{y}$) and models $\boldsymbol{M}$ — into the singularity of a $\boldsymbol{u}_{now}$ and the intensely practical action, for example, of digging the sustainable trench (according to Figure 12). Working thus on the prospects for broad-scale adoption of the urine-separating toilet (part of a red rectangle in Figure 2), in a framework ($\boldsymbol{M}$) of Multi-Criteria Decision Analysis (MCDA), Borsuk *et al* (2008) envisage a sequence of incremental transitions, away from today's Business-as-Usual towards *inter alia* the distant-future target vision of Perfect Fertilizer (green oval).

The computational studies of Janssen and Carpenter (1999) on the decades-long resilience of farmer-landscape systems, with agents (simulated farmers) imbued with the differing perspectives of Cultural

Theory (Thompson *et al*, 1990), could be imported into the urban setting. There, the model (***M***) could be used to play out the endless negotiations amongst citizens and other agents (public- and private-sector) over this, that, or the other technology and policy prescription for moving away from unsustainability in IUWM, as the years pass by. Might there be a "social tipping point" — of mass buy-in to the ideas of the sustainable lifestyle — somewhere in the person-centric beliefs of the kind set out in Figure B2.1 of Box 2? Would it be ethical for engineers to ponder fashioning a $\boldsymbol{u}_{now}$ as an intervention intended to push the affairs of the community towards any such tipping point? These types of agent based models (ABM; ***M***) are the focus of Lempert's (2002) analysis of the adoption and diffusion of alternative technologies in the energy sector, under the prospect of climate change.[49] They might even be put to investigating schemes of inter-generational discounting, such as those of Sumaila and Walters (2005) from Chapter 3.2, with new agents entering the fray as they come of age, acquiring the right to vote — better, as Boulanger (2008) would assert, to deliberate (and, as we shall assert in Chapter 5, to deliberate with improving quality).

Just as adaptive management celebrates a prudent measure of experimentation, so should ACL (Norton and Steinemann, 2001). And so we ask:

> Can there be a routine, policy action designed to probe uncertainties in the performance of the current structure of governance?
>
> Can it be one designed to inspire improvement in the deliberative quality of the scheme for attaining {social legitimacy} of that and future actions?
>
> Could it be designed to increase creativity in inventing, re-arranging, and re-shaping all the icons in Figure 13 (both the greens and the reds)?

Experimental and Adaptive Governance on an Urban Scale

Our focus is on integrated *urban* water management (within IWRM). Yet for all the global recognition of the current water crisis as a crisis of water governance (GWP, 2000b, 2002; WWAP, 2006), hardly anyone has pointed specifically to the institutions of *urban* governance as bearing any promise of a means of resolving the perceived crisis. The work of Gatzweiler (2006) is therefore of special interest. For he has recently proposed "borrowing from the organization of public economies in *metropolitan* areas" (emphasis added) in order to suggest design principles for polycentric, multilevel governance in a coffee forest conservation project in Ethiopia.[50] This he labels a "public ecosystem service economy for sustaining biodiversity".

If Gatzweiler can borrow thus from the focus of our discussion herein (in this *Paper*) to explore a form of governance *enabling* the maintenance, if not expansion, of ecosystem services, this surely has to be of some interest to us. Little imagination should therefore be required to appreciate the benefits for I*Urban*WM of its being lodged already within metropolitan governance and those further benefits that might then flow outwards therefrom to IWRM in respect of watershed ecosystem services.

Gatzweiler (2006) opens with this:

> Scholars have suggested that the governance of complex systems should be dispersed across multiple centers of authority and that any regulative system needs as much variety in the actions that it can take as exists in the system it is regulating.

He then executes a swift, comprehensive sweep across the foregoing elements of solidarities, voices, and pluralist democracy, which together amount to {social legitimacy}. This he does apparently independently of the contributions from Dahl, Thompson, and Ney, to the betterment therefore of our own present arguments.

[49] For the energy sector, however, simulated agents might not require priming with the same diversity of cultural inclinations as they would for assessing human-engineering interactions in the water sector. Energy as fire can have some significance for some cultures, but this will not be the case — we suspect — for energy in the form of an electricity grid system.

[50] Echoes of which polycentric governance can be found in proposals for future structures of governance operating at the somewhat wider scale of IWRM (Pahl-Wostl *et al*, 2007a). Crossing scales in the opposite direction, as it were, Bai (2007b) suggests there is a persuasive body of evidence in favor of issues of *global* environmental change being addressed effectively at the scale of *city* governance.

Because of market failure, he reports, there are those who argue we need public intervention, adding (Gatzweiler, 2006):

> Preferences of citizens also vary sharply across regions within a state, and if one takes such heterogeneity into account, the optimal level of authority may be lower than economies of scale dictate.

However, yet others assert that (again according to Gatzweiler):

> Because so many individuals and businesses are involved in the production of environmental public goods, the government cannot manage their output and therefore the market has to be involved ...

whereupon he concludes (Gatzweiler, 2006):

> The better truth is probably that neither markets nor states, nor other governance types alone are panacea for the governance of a public ecosystem service economy.

And in this we can find resonance with the three actor-voices of "markets", "states", and "other" introduced into the discussion of {social legitimacy} in Chapter 3.1. Amongst the last of these voices (the "other") might be heard that of civil society.

We are reminded too (by Gatzweiler) of Solow's (1991) moral dilemma, embedded in the earlier discussion of {economic feasibility} in Chapter 3.2: that those of us who would care so much for the well-being of the next generation might thereby seem to care so little for the masses of today's poor. This Gatzweiler (2006) articulates in these terms:

> If not immediately required for the production or harvest of private goods, the maintenance of ecological regulation functions is reduced to a minimum, eventually resulting in resource degradation. Poverty (usually defined by the rules of the market economy itself) enforces this process because escaping from poverty requires individual farmers to adopt short-term survival strategies and disables long-term investment strategies.

Gatzweiler intends, therefore, to borrow from the better of the schemes of metropolitan governance to begin illuminating (for us) a path through Solow's dilemma (Gatzweiler, 2006):

> In sum, we know how to arrange for the private delivery of private goods and services by the means of the market and we also know how to organize the public delivery of public goods and services by bureaucracy. What we need to learn is how to better involve the private in the delivery of public services (e.g., co-production) and how to better involve the public [civil-society actors (?)] in the delivery of public ecosystem goods and services which are now exclusively organized privately.

All of this, nevertheless, remains merely something with promise in concept. For it is *scholars*, we note, who have pointed to the potential experimental benefits of polycentric governance, just as much as the same have engaged in further conjecture (Gatzweiler, 2006):

> Other hypothesized benefits of multi-level governance are that it provides more complete information of constituents' preferences, is more adaptive in response to changing preferences, is more open to experimentation and innovation, and that it facilitates credible commitments.

We might very well want this form of metropolitan governance to surround the mechanics of entry into and exit from the processes of Figure 2.

4.3 Cities as Forces for Social Good

In this *Concepts Paper*, we have arrived where we are now through an argument driven by the prospect of cities as forces for good (CFG) in respect of {environmental benignity}. Economist and activist Paul Romer, however, has for quite some time been thinking of CFG in respect of {social legitimacy} and good governance — "charter cities", in his vocabulary (Romer, 2010). "How to free people from bad rules?", he asks (Romer, 2010) and proclaims: "Forget aid — people in the poorest countries need new cities with different rules. And developed countries should be the ones that build them" (Romer, 2010). People, the argument runs, should be encouraged to move to places with better rules (better governance), specifically and importantly at the scale of the city. "The choice is not whether the developing world will urbanise or not — merely where and under what rules"; and for Romer that "where" should be some "piece of uninhabited land". This would be a rural-to-urban migration deliberately motivated by the desire to escape poor governance, as opposed to that of the rural-to-urban migrants of 19th-century Europe, who simply happened to take with them their culturally acquired styles of water governance (Barraqué *et al*, 2006; Chapter 3.2).

Could a "charter city" succeed for urban-to-urban migration, however, for impoverished individuals seeking to escape from the corruption and mafia-style water operations observed in modern times by Bakker (2006)? For they, acting alone or within their community, would essentially have to "decide for themselves", under the "right" incentives[51] — and surely not as a matter of any "bad" rule of governance, such as coercion. Much more clear is the fact that Romer's charter cities would require nation-to-nation agreements. And between these two scales — the local-individual and the national — that of the city is pivotal, precisely as it is for Gatzweiler (2006) and, indeed, for this entire *Concepts Paper*.

[51] Hong Kong during the 1950s and 1960s and post-independence Mauritius (from 1968 onwards) are suggested as models for charter cities.

BOX 4

Atlanta-Chattahoochee, the IWA Sustainability *Agora*, and Some South Asian Experience: Governance in the Microcosm and Macrocosm

Salutary Experience

Around the turn of the millennium, the concept of Adaptive Community Learning (ACL) was being developed and its prototypical procedure assembled in a "participatory study" of shaping policy for community-led stewardship of the long-term (inter-generational) ecological integrity of Lake Lanier (Beck *et al*, 2002; Osidele and Beck, 2003; see also Beck *et al*, 2011b). It is whence the "inverse approach" of Chapter 4.1 derives.

Constructed in 1958 through impoundment of the Chattahoochee River, Lanier lies to the north of Atlanta in the north-east corner of the framed "Area of Metropolitan Atlanta" in Figure 8(a) (from Chapter 3.3). The lake is the city's principal source of potable water. The way in which impounded water is released from Lanier to flow downstream, and the legal basis for Atlanta's appropriation of the impounded water, lie at the heart of the two decades of as yet unresolved "water wars" amongst the states of Georgia, Alabama, and Florida. It was known then (in 1998/9) that this research on ACL would be entering a highly charged political situation (as already noted in Chapter 3.3).

The experience was salutary and to this day has shaped the writing of this *Concepts Paper*. Much was learned, as recounted briefly in Hare *et al* (2006). What was funded as research intended to puncture the impulse towards litigation, over rules and policies emanating from the US Environmental Protection Agency (EPA), in due course provoked the issue of a formal threat of litigation to the project's Principal Investigator.[1] In retrospect, one may conjecture that a small solidarity within the governing committee of a stakeholder association — a solidarity, let us say, holding one of the positions in the Cultural Theory (CT) diagram of Figure 3 — came to fear that the research team's survey instrument would reveal sizeable numbers of the rank and file members of the association with quite other positions on the Man-Environment relationship of Figure 3. Indeed, there is some statistical evidence of this (Fath and Beck, 2005). Any such lack of a singular solidarity across the entire association, i.e., the position held by the governing committee, may have been perceived by the committee as undermining its stance (of implacable opposition) towards some of the other actors and agencies in the scene. Looking back, all this appears ordinary and unsurprising.[2]

IWA Sustainability Agora

In the much less politically charged setting of technical sessions of the World Water Congresses of the International Water Association (IWA), the Association's Specialist Group on Sustainability in the Water Sector has begun experimenting with its own microcosm of the kind of refurbished pluralist democracy already introduced in Chapter 3.1 (and the subject not only of the present Chapter 4.2, but also, more expansively, Chapter 5). This has been called the IWA Sustainability *Agora*, now twice hosted in 2006 and 2008 (Beck and Jeffrey, 2007).

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[1] This was myself. Thus I learned that engineers and computational analysts can, in practice, become a part of the problem, not its solution (Hare *et al*, 2006; Figures 15(a) and (b)).

[2] Doubtless too, there was an under-current: that we academics (not merely myself) may have conveyed the impression of being more interested in the outlooks and mind-sets of the stakeholders than in addressing the practical resolution of *their* issues.

BOX 4

With the benefit of learning from the experience of the prototypical 2006 Sustainability *Agora*, the 2008 edition was altogether more carefully plotted and better stage-managed, without in any way constraining the eventual flow of the market-place "banter" amongst its sellers and buyers (of styles of sustainability problem-solving). An earlier notion of plural "champions" of certain postures was adapted into three "actors", each primed to speak the archetypal "voice" of a particular (active) CT solidarity: George Crawford of CH2MHill (consulting engineers) as the individualist (*I*); Margaret Pageler (sometime president, City Council, Seattle, USA) as the hierarchist (*H*); and Ger Bergkamp, at the time transferring from the International Union for the Conservation of Nature (IUCN) to become Director General of the World Water Council, as the egalitarian (*E*). The remit of the *Agora* — in effect, the challenge of CFG from Chapter 2.4 — was specified for the actors beforehand as:

> What kind of technological innovations, and which paths towards alternative future metropolitan water infrastructures, might lower the global nutrient and (virtual) water metabolisms, i.e., uncouple human and economic development from industrial N fixation, for example, while yet securing essential public health for citizens — and all under the prospect of global climate change?

Armed this second time with a greater appreciation of quality in governance — of access to the democratic debate and responsiveness within it — and with Michael Thompson present to assist Dipak Gyawali as master of ceremonies, the *Agora* was arranged such that each voice was obliged formally to respond to each pitch of the second and third proponents of his/her style of tackling the challenge. Participants, i.e., the entire audience, could join the debate, to endorse, applaud, or criticize the various goods on offer. After the primary debate amongst the three protagonists, participants in the *Agora* were exposed to the theory behind it, demonstrated at work in practice in examples from South Asia.

South Asian Experience

Just as IWA's *Sanitation 21* document feared (in Chapter 3.1 and Box 2; IWA, 2006), the agenda of water and sanitation in South Asia has often been hijacked by one particular party. For example, argues Gyawali (2004), in the case of flood embankment defenses in the Indian state of Bihar (on Nepal's southern border), only a hierarchical government problem was framed — and one so very well attuned to the conventional solution of such a bureaucracy. As a result (Gyawali, 2004):

> Alternative solutions to achieving security from flooding would have been cheaper and environmentally more beneficial, but were never pursued in the single solidarity policy terrain of hierarchs [*H*]. Among these are many traditional practices such as building houses on stilts, raising the plinth level of village housing, crop insurance, etc., which market [*I*] and activist [*E*] now advocate. The very sciences of different solidarities, their framing of problems, the questions they ask and the areas they look into for answers are different.

Since India's independence in 1948, the embankments have caused more land to be removed from production as a result of water-logging than the land newly and productively irrigated by the associated infrastructure (Gyawali, 2004). The "closed hegemony" of entertaining only the single position

BOX 4

of one (powerful) party in the (non-)debate would not be described as an enabling form of governance — any more than some would say of the IPCC in respect of climate change (Pielke, 2010).[3]

It becomes pertinent to ask (and answer) this (Gyawali, 2004):

> Since the definitions of a problem vary from a social solidarity to the other, can we even ever hope to find the 'right' solution? ... [W]e should not be looking for 'a' solution at all. Because there are at least three different solutions (one from each of the three active social solidarities), the trick is to see:
>
> a) if there are overlaps in the solutions proposed which could serve as a point of consensus among the differing definitions;
>
> b) if the social solidarities are constructively rather than destructively engaged with each other; and
>
> c) if the proposed solutions are inflexible (and hence vulnerable to nasty surprises) instead of being open to adaptive improvements by people themselves at the local level without depleting their 'risk resilience'.
>
> If the three [voices of *H, I, E*] are constructively engaged, they could discover an area of consensual stability ..., which is less than what each would have individually liked to have, but is more than nothing they will have if there is a destructive impasse.

In respect of item (a), just such "overlaps in the solutions" of constructive engagement might reside amongst the $\boldsymbol{\alpha}_{key}$ technologies sought from the analysis of "reachable (*I, H, E*) futures" through the inverse approach embedded within the Adaptive Community Learning of Chapter 4.2. The technical attribute of being "key" (in $\boldsymbol{\alpha}_{key}$) could be cast in the sense of "not necessarily foreclosing on the attainability of each and every one of the disparate aspirations of $\boldsymbol{y}(I)$, $\boldsymbol{y}(H)$, and $\boldsymbol{y}(E)$ for the future".

Given Gyawali's vantage point, as a professional engineer and former Minister of Water Resources for Nepal, he can claim some requisite experience of politics and governance in the real world. Its essence was infused into orchestration of the microcosms of the two IWA Sustainability *Agora*. His constructive engagement (our enabling governance), he conjectures (Gyawali, 2004), should flow from a failing state undergoing the following changes: policy reform of national bureaucracies (*H* actors); a distorted market becoming populated with socially sustainable, far-sighted businesses (*I*); and disruptive civil-society actors (or auditors, as Gyawali calls them) evolving into non-violent, creative entities (*E*). His destructive impasse (our disabling governance) would see these instead coming to pass: the state becoming a fortress world of privileged cronies; the market becoming populated by Enron-style "hyper-globalisers"; and the social auditors turning into violent "rejectionists" in "communard" enclaves — altogether quite disabling (from our perspective herein).

All this, moreover, is taught to Nepali engineering undergraduates as "*Basic Water Science*" (Dixit, 2002).

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[3] In a different setting, economist Pearce provides a most insightful analysis of why Market-based Instruments (MBIs) are found so rarely in the practice of environmental stewardship (Pearce, 2004). Amongst various reasons, one is referred to as "regulatory capture". In this, scientists and engineers within a government agency fear (are threatened by) the fact that implementing economic instruments would undercut much of their role as experts. It might even make them redundant. Pearce's "regulatory capture" would seem to have much in common with what is here referred to as "closed hegemony".

BOX 4

From Good-humored Theater to the Gladiatorial Arena of Life in the Real World

To summarize these experiences of the two *Agora*, its staging has been proved and the profile of the human dimension within an association of professional engineers (the IWA) has been raised thereby. There is a growing appreciation of how to construct the stalls and identify the stall-holders, but not of the shopping experience. Neither *Agora* was designed to reveal the manner of (mass) "buying into" what must be, in all situations of policy making, decision-making, and choice, that singular "one routine step tomorrow" — setting off on some specific technological path towards realizing a CFG on the horizon (as in Figure 2).

Yet one might well wonder what, if anything, can individuals and communities learn from experience of the good-humored theater of an *Agora* (constructive engagement), when their "real world" is something of a gladiatorial arena (destructive impasse) — highly politically charged and a heart-beat away from litigation. We dare to push thinking somewhat beyond the experience of the two Sustainability *Agora* in Chapter 6.

Chapter 5: Present and Future TBL: Change — The Only Constant in Life

Things change over the generations: as much in respect of our substantially changing views on engineer Gantt's sincerest of intentions for the good of Society, as in flipping the fundamentals of what amounts to {environmental benignity} from a good to a bad and *vice versa*. Were the virtue of upcycling reactive N-species to be taken to its logical conclusion, for example, this could turn eutrophy from a bad to a good (and oligotrophy conversely so), especially in the face of other disturbances, such as climate change and the invasion of exotic species (Schertzer and Lam, 2002). The possibly quite unattractive notion of releasing muted pollution events to rivers, as pre-emptive vaccination against future insults and injury, might instead be re-cast as the good of beneficial nutrient supplements: for the purpose of spectrum reconstruction and thereby restoration, even enhancement, of ecosystem services.

If the long view is long enough — as it must be in respect of sustainability — such flux and strategic change will have a continual bearing upon on how we decide (now) to move forward. "Change" will indeed be "the only constant in life".

We stand amidst these things, then:

> A bewildering plethora of indicators for what constitutes sustainability.
>
> An ever-expanding volume of knowing about the behavior of the ever larger in natural systems, as in the "thinking globally" of Earth Systems Analysis (Figure 1), and the behavior of the ever smaller in human systems — as in neuroscience, brain function, hence human motivation — ergo "acting locally" (Figure B2.1).
>
> A growing awareness — because increasingly we are taking the long view — of the impermanence of what was once thought constant (the statistical properties of meteorology, for instance), even surprise at the preposterous suggestion (for some) that what was deemed bad for the environment less than two generations ago (eutrophication) might well today be seen (by others) as not so bad after all.

Let us therefore acknowledge that the outcome to be achieved by the close of our *Sustainability Concepts Paper* will inevitably be hopelessly incomplete.

And yet, in spite of our predicament — the ever shifting foundations of knowledge, the ever expanding purview — can we erect any signposts to chart progress through the tangled complexity of the real world, framed within the terms of the Triple Bottom Line (TBL)? In essence, can we map all of the foregoing discussion of *concepts* as succinctly as possible onto some kind of template within the *N*-dimensional space of sustainability assessments as presently conducted in practice? Can we even say something of how the criteria of these assessments might change over time?

We have three purposes, therefore:

(i) To summarize the most frequently cited components of today's applications of TBL thinking (the TBL_{now}, say) for achieving, in particular, sustainability of IUWM within IWRM. These are, or are becoming, the custom and convention in assessing sustainability.

(ii) To introduce some strong, if not bold, conjectures about how to organize the guiding threads of thinking underpinning these components of the TBL_{now}; to reduce these threads in turn to their most elementary parts, collectively the "axes" of the *N*-dimensional assessment space; thus to extract a skeletal template of what might become such thinking on sustainability assessments generations hence, which we shall consider as the scaffolding for a TBL_{future}. In short, we seek to construct a logic for the manner in which the ensemble of line items in the TBL_{now} might evolve over the longer term to embrace those of a TBL_{future}.

(iii) To identify progress at the frontiers of contemporary practice, i.e., to capture a snapshot of the $TBL_{frontier}$, illustrating how our communities and professionals are stepping out from the TBL_{now} en route to features dimly discernible within TBL_{future}, which further practice (and research) should seek to

> clarify, adapt, and — as need be — change. To this will an entire chapter be devoted (Chapter 6).

Each of the TBL_{now}, TBL_{future}, and $TBL_{frontier}$ will in due course be associated with its own tabulated material.

Both Constant Revolution and Consistent Routine

We recognize a strong counter-current to the setting out of this spread of threads: the urge, that is, to boil all of the "tangled complexity of the real world" down to an invariant TBL_{∞}; a TBL_{∞}, moreover, that is quantified and scalar, just a single number (Krajnc and Glavič, 2005).

There are indeed persuasive, practical reasons for wanting invariance (over time) in the accountancy of the TBL. People wish to discriminate in what projects and enterprises they will invest their time, energy, and funds (or not); and projects and enterprises will seek to attract such "buy-in". Evidence and promises of delivering "more" and "more swiftly" in respect of moving away from unsustainability must, we acknowledge, be judged on a strictly consistent basis.

But why should we expect the criteria of the TBL to be invariant, especially over the longer term, which — need it be said (again) — is defining for sustainability? If all else around us is changing, why should we expect convergence upon an immutable set of line items for the TBL, i.e., a TBL_{∞}?

Writing of the single bottom line of profit and loss — the one we all knew of before he was credited with coining the phrase "triple bottom line" — Elkington (2001) observed:

> Despite 500 years — some people, counting early clay tablets, would say at least 5000 years — of evolution in mainstream accounting, there remain huge controversies over how companies account for acquisitions and disposals, record extraordinary and exceptional items, value contingent liabilities, capitalize costs and depreciate their assets.

The instinctive urge towards consolidation and convergence, to crystallize out that much sought-after, succinct operational definition of sustainability, can nevertheless obscure the apprehension, comprehension, and exploitation of change. Both change and constancy are, of course, worthy. The tension between them — between the flux and discomfort of constant revolution and the invariance and comfort of consistent routine — should be creative. We need the comfort of "knowing" *and* the discomfort of "knowing that that 'knowing' is never quite right".

5.1 From TBL_{now} to TBL_{future}

Tables 1 and 2 set out respectively those components of the TBL apparent and applicable in practice today (TBL_{now}) and companion components we can presently imagine as becoming candidates for application in the (longer-term) future (TBL_{future}). They are measures of how far we have come (Table 1) and how far there is still to go (Table 2). The TBL_{future} is not meant to replace or do away with the TBL_{now}, but evolve from it and, in particular, enrich it. Where there is mystifying difference between corresponding cryptic entries in Tables 1 and 2, seemingly without logic, it is the purpose of what follows to establish the thread of understanding that unites them.

Table 1, then, is based largely on the work of Balkema *et al* (2002), Jeppsson and Hellström (2002), and Hellström *et al* (2000). Supplementary material is drawn from Sahely *et al* (2005), Ashley *et al* (2008), Starkl *et al* (2009), and Sharma *et al* (2009), who consolidate much of what preceded their own contributions.[52] All, however, have been tailored to the needs of what we are calling IUWM herein. Between Tables 1 and 2, therefore, is an expansion in scope from IUWM to IWRM. This, in itself, is a significant part of the difference between the TBL_{now} and TBL_{future}.

Striking should be the fact that the tabulated line items (or threads) can neither neatly nor crisply be categorized as belonging to {social legitimacy}, {economic feasibility}, or {environmental benignity}. The strong temptation to separate them into three identifiable blocks of row components has been resisted, precedent and the structure of Chapter 3 notwithstanding. The sequence of these line items has a quite deliberate logic, nonetheless. It proceeds from top to bottom: from matters of the very local, personal, and human-centered, to matters economic, then environmental, and eventually to matters of a more global character. Considerations unfold thus in much the same manner as they do in the person-centric perspective of Figure B2.1 in Box 2.

Plotting Enrichment and Change

The fourteen rows are present in the structure of each table, for consistency in thinking from the present to the future and for comparing theory with practice. Around them, i.e., the tabulated line items of (T1) through (T14) below, we have re-organized the consensus of others (in Table 1). They are the warp and weft of our fabric of the TBL herein: less rigid than any companion, quantitative metrics; just as incomplete as any distant TBL_{∞} on which we might be converging, albeit asymptotically; yet something, nevertheless, with which to tame the rambling and tangled complexity of thinking about sustainability. They tie Table 1 (TBL_{now}) to Table 2 (TBL_{future}), and both to Table 3, with its path-breaking elements of the TBL at the frontiers of practice ($TBL_{frontier}$; in Chapter 6).

Fourteen threads for guidance seems enough. Yet even these do not suffice as a foundational matrix of "orthogonal axes" — adequately strengthened by that very quality of non-duplicate, unconfused, non-conflated orthogonality — with which to dare to extrapolate from a TBL_{now} to a TBL_{future}. We have to contend with two essential difficulties: (i) the ever-expanding purview of what constitutes sustainability; and (ii) the ever-evolving intricacy, subtlety, sophistication, complexity, and richness of what might be included in that purview. Figure 16 establishes how we propose to do so, across all the line items of our TBL.

First, according to Figure 16(a) there are provinces for the "wealth" of the analysis or assessment, bounded at its left by what we might usually label an origin, but which here we shall generally refer to as the pole or corner of "poorness" or "poverty" of coverage or thought (boundary (U), for "unrefined"). Along the axis are graduations marking successively wealthier (more extensive, more subtle) assessments as one moves rightwards to the boundary marked "rich". And this *is* a boundary, i.e., (R) for "refined" in Figure 16(a). It is one that decidedly does not indicate some hypothetical, infinitely rich coverage of analysis.

To assist in grasping our usage of the bounds of this span of wealth of assessment in Figure 16(a), "poor" can be equated roughly with "crude", "thinness of thought", "impoverished", "simple", "singularity", or "coarse net/

[52] Starkl *et al* (2009) and Sharma *et al* (2009), we note, were the other two recipients of the 2008 IWA Prizes for theoretical progress in Sustainability in the Water Sector (alongside Ashley *et al*, 2008). Stepping back into the record of published works on sustainability, and stepping outside the water sector, it should also be noted how perspicacious was the study of Azar *et al* (1996). Amongst other insights, they sought to form early-warning, social indicators for maintaining a healthy balance in the metabolism of what they called the technosphere, between the lithosphere and the ecosphere.

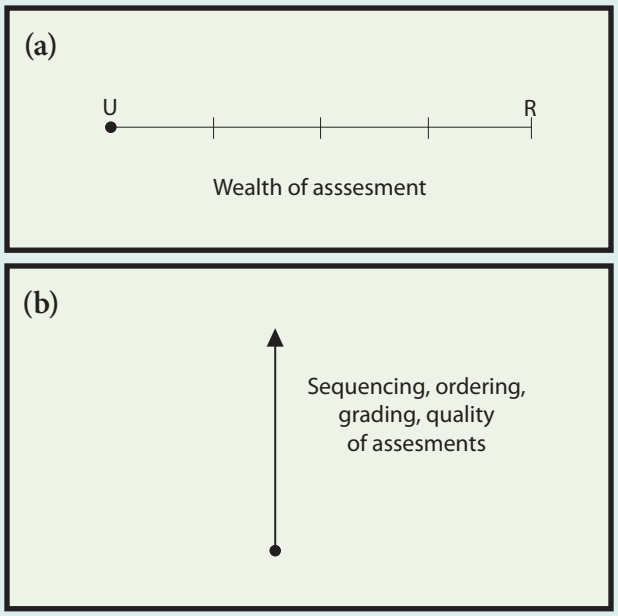

Figure 16
Axes for plotting enrichment of assessment and change (from TBL_{now} to TBL_{future}): (a) graduated provinces covering wealth of assessment between the bounds of poor, rudimentary, or unrefined (U), and rich, subtle, or refined (R); (b) familiar directional axis for gauging quality in some manner. A specific instance employing the two types of axis follows in Figure 17.

mesh". "Rich" can likewise be understood alternatively and respectively by the counterpart words of "subtle", "depth of thought", "complex", "plurality", or "fine net/mesh". The primary purpose in introducing and using these terms is that of aiding the reader's appreciation of how some TBL_{future} might enrich what is currently practiced through the TBL_{now}. To cast thereby some slur on this latter is not the intent. Simplicity is very often a virtue; while attempting to go beyond the rightward boundary of complexity clearly has its disadvantages. These are neatly summed up in the old saw about the "mental paralysis of the systems analyst", who is unable to think through something because s/he perceives everything to be related to everything else, which it is, of course. Paralyzed thereby, this systems analyst is unable to draw a line around what is to be included in the analysis and what excluded from it, in order actually to start the analysis.[53]

Figure 16(b) shows a directional axis, with an arrowhead. It will be the more familiar of the two axes and is probably what one would expect of a *Concepts Paper* about "moving away from unsustainability and towards sustainability". We sequence, order, and grade things all the time: Maslow's pyramid in (T1) below (Maslow (1943)); Arnstein's ladder in (T2) (Arnstein (1969)); something to be attained now, something else later; something better, and something yet better still; and so on.

Counter-intuitively, perhaps, the majority of the axes to be introduced in the following — to assist appreciation of the threads of logical connections amongst the cryptic entries in Tables 1, 2, and 3 — will be ones of the style of Figure 16(a), not Figure 16(b). Maslow's (putative) pyramid and Arnstein's ladder are rather the exception, accompanied equally exceptionally by a directional axis of "deliberative quality" in governance (T4). On the other hand, there can be a sense of desirable direction, rightward along the wealth axis of Figure 16(a). We shall encounter such in respect of ethics and equity under (T5), in that we should care about more things in the world than the self alone — a richness as opposed to a poverty of thought (and spirit), in other words. For that is the essential exhortation in our attempting to become less unsustainable.

Our journey through the fourteen threads of the TBL will begin with the most local, intimate, and personal of considerations. The device of the axes of Figure 16 will be wielded frequently as the discussion addresses matters primarily of {social legitimacy} and {economic feasibility} — just as might be supposed for an engineer as author of this discussion. That of (T4), on quality in governance, epitomizes the use of both directional and wealth axes. That on ethics and equity (T5) supremely makes the case for the value of axes having to do with the wealth of thought. By the time we arrive at thread (T10) on "space", the need to introduce any further, unfamiliar axes will have passed.

Yet we shall here no more miraculously extract simplicity from the jaws of irreducible complexity than was any singularity ever plucked from the jaws of plurality in Chapter 4.

(T1) Personal Aspirations

Looking inwards to the self, as the iconic stick figure in Figure B2.1, to what might you or I aspire: a need; a want; a luxury? Do these aspirations line up in a

[53] The skeptical reader presently lost in the thicket of this discussion may well think that *I* can neither see nor appreciate the simplest, fastest, and most pragmatic route from A to B. And I might have some sympathy with that reader.

(T1) Personal Aspirations	Health and hygiene
(T2) Citizen Participation	Individuals empowered to acquire and employ expertise and "know-how"; development of community skill base; taking responsibility
(T3) Social Bonds	"Cultural acceptance" — not bonding to group — as in adoption of a style of device or technology
(T4) Quality in Governance	Presence of an institutional-regulatory framework *per se*, irrespective of its deliberative quality
(T5) Ethics and Equity	
(T6) Valuation	Engineering economics (Total Annualized Economic Cost; TAEC); user/service fees/ revenues; derivative attributes
(T7) Environment Within the Language of Business	Biodiversity
(T8) Supply-Value Chains	None beyond "factory (treatment plant) fence-line"
(T9) Commercial Sectors	Water ... alone
(T10) Space	IUWM or IWRM; rarely, if ever, both (and not including citizen agency)
(T11) Life Cycle and Time	Expenditures and revenue streams over time, with "set-asides" for technical R&D (innovation) and reserve funds
(T12) Function	Adaptability; durability; robustness-vulnerability; reliability
(T13) Gauging Environmental Benignity	Environmental degradation: pollution syndromes (issue domains) of LCA; impaired quality of outputs/emissions; eco-efficiency
(T14) Cycling of Materials	Man's appropriation/consumption of resources (water, nutrients, energy, and land area); soil fertility

Table 1
Contemporary expression of the line items of Triple Bottom Line (TBL) accounting, as found in water-sector literature (TBL_{now}).

(T0) ORGANIZATIONAL LEARNING	"Always Learning, Never Getting It Right"; in pursuit of the self-transforming mind, which "leads to learn"; entertaining self-contradiction, including abandoning a TBL line item, even "sustainability" itself
(T1) Personal Aspirations	Towards a well-being sufficient for self-reflexive apprehension (grasp, appreciation) of the "big picture"; Engineers "Acting Most Locally" to engender a community eager to engage in "Thinking Globally"
(T2) Citizen Participation	Deliberative democracy
(T3) Social Bonds	Benefitting from multiple (four) wisdoms on how to live with one another and nature
(T4) Quality in Governance	Refurbished pluralist democracy of Dahl; clumsiness; adaptive community learning
(T5) Ethics and Equity	Variety of standpoints on the consequences of inappropriate behavior in man-to-man, man-to-nature, individual-to-group, present-to-future generation, seller-to-buyer, and other relationships
(T6) Valuation	Plurality of what counts, in which ways, to whom or what; bequests to the future ("final environmental wills and testaments")
(T7) Environment Within the Language of Business	Natural capital, ecosystem services, and service providers, *ergo* loss of biodiversity as failure of ecosystem service providers; "New Scarcity" of resource economics
(T8) Supply-Value Chains	Exercise of power ever further along ever more extended and intricately interwoven chains of commercial relationships
(T9) Commercial Sectors	Water sector ... and nutrient and energy sectors ... and more ...
(T10) Space	From Earth Systems Analysis to individual agency (e.g., dietary preferences)
(T11) Life Cycle and Time	From cradle to cradle analysis
(T12) Function	Ecological resilience and (biomedical) self-repair
(T13) Gauging Environmental Benignity	Biomimicry: appetite; metabolism; pulse
(T14) Cycling of Materials	Natural nutrient cycles and technical nutrient cycles; eco-effectiveness; dematerialization

Table 2
Companion elements (of Table 1) in Triple Bottom Line (TBL) accounting that we can presently imagine as becoming candidates for application in the longer-term future (TBL_{future}).

sequence, to be picked off one after another? Are they arranged in a hierarchy, as so often are the (purported) "needs" of Maslow's (1943) theory of human motivation in Wikipedia (accessed 18 April, 2010) and elsewhere?[54]

Acknowledging the evident dominance of today's hierarchical portrayal of Maslow's ideas, this thread of personal aspirations works upwards from a tranche of deficiency needs — from basic physiological needs; up to safety needs; then love/belonging and social needs; thus to esteem needs — and on to a tranche of growth needs, comprising cognitive needs, aesthetic needs, self-actualization, and self-transcendence. Security of body, of "health and hygiene" (as in the TBL_{now} of Table 1), and of employment, are associated with safety needs, standing just above the profoundly basic physiological needs. Creativity, spontaneity, and problem-solving attach to self-transcendence, where this can be associated with notions of ascending towards becoming all that we are capable of becoming, at the apex of the hierarchy.

The discussion of Box 2, as well as that of Douglas *et al* (1998) in *Human Choice and Climate Change* (Rayner and Malone, 1998), suggests something otherwise, however: that ranking and labeling of aspirations, as "needs", "wants", or "luxuries", change from time to time, from solidarity to solidarity, and place by place, as community debate ebbs and flows. The pyramid should be flattened, in effect. The supposedly self-evident axis of Maslow's staged sequence of needs, with progress along it from the base to the apex of the (presumed) pyramid, would be pushed aside. Might thus there be similar flux in our individual, personal aspirations, which are the essence of the present guiding thread (T1)? On this account, the contents of both the TBL_{now} and TBL_{future} for this thread of personal aspirations might essentially be stochastic, continually undergoing a strategically unpredictable random walk across a level plain of aspirations and needs, up and down along the directional axis of Figure 16(b), as it were — the very opposite of what we might have expected to plot as an orderly sequence.

Yet some fundamental elements of existence seem stable and sequenced, along the following axis:

- unless (i) we avoid death, we cannot (ii) survive to suffer ill-health or enjoy good health, without which latter (iii) a sense of burgeoning well-being appears less likely.

There are traces of both direction and enrichment about such an axis. For it is generally better for people to be in the state of (iii), with direction in moving up the axis of Figure 16(b). A policy addressing issues of survival, treating ill-health, and exploiting good health (all three of (i), (ii), and (iii)) should strike one as richer in its scope — rightward along the axis of Figure 16(a) — than one addressing merely (ii) and (i), or another addressing, say, solely and exclusively (iii), towards the leftward pole (U) of Figure 16(a). A "wealth of analysis" may be graded as follows: acknowledging none of the elements of this existential thread (T1) — none of (i), (ii), or (iii) — will be labeled a 0-fold typology; any one of the three, as a 1-fold typology; any two a 2-fold; and all three as a 3-fold typology. Wealth of analysis grows as one moves from the 0-fold to the 3-fold typology, traversing successively the sequence of graduations left-to-right in Figure 16(a).

What is recognized of such things in the formation of policy?

Pragmatically, as engineers, we want something to happen in respect of sustainability. Our concern is to identify that policy or technological intervention of IUWM within IWRM that will pull the human condition away from unsustainability and on (we trust) towards sustainability, along the axis of this particular guiding "existential" thread. Where the state of affairs lies on the axes of Figure 16 clearly matters a very great deal. We might be especially interested in attaining that sense of personal well-being — the corresponding element of the TBL_{future} in Table 2 — which brings with it appreciation of the "big picture" (thinking globally) and the inclination to debate the good (or ill) of sustainability. And we might grade the attaching intervention as all the more sustainable for provoking such a self-reflexive — even self-contradictory — kind of disputation. This would be engineers "acting most locally" to engender "thinking globally" amongst a community (as already imagined in Box 2 of Chapter 3.1).

[54] The hierarchical interpretation could be said to be rampant. Any number of pyramid-like images of Maslow's needs can be found by a Google search (accessed 18 April, 2010). Indeed, the Official Nebraska Government Website says "[a] person cannot move to a higher level until each preceding level is satisfied" (www.das.state.ne.us; accessed 18 April, 2010).

(T2) Citizen Participation

Looking outwards from the self, to what extent are you or I permitted or encouraged to engage with society, or barred or discouraged therefrom?

Shirley Arnstein's landmark paper on "A Ladder of Citizen Participation" was published in 1969 (Arnstein, 1969). Ascent of the ladder begins with manipulation and therapy, i.e., non-participation, through three degrees of tokenism — informing, consultation, placation — and up to partnership, delegated power, and eventually citizen control, with this second triplet of steps called degrees of citizen power. Her ladder seems an obvious candidate for a pair of axes in the space of our *N*-dimensional assessment of sustainability:

- participation of citizens in governance, graded according to the degree to which they do so

and

- the locus of power, whether balanced, or see-sawing and sliding back and forth (over the generations) between the pole (or province) of the citizen and that of the government.

In contemporary IUWM, citizen participation as such is manifest in a number of more or less similar ways in the corresponding line item of the TBL_{now} in Table 1. Stationed roughly midway at the level of partnership or delegated power on Arnstein's ladder, is where we might expect to place the acquisition of expertise and citizen "know-how" (as in Table 1): the end-user of a technology, such as a member of the public (a citizen, in fact), is presumed to know how to operate and maintain that device. The "development of a community skill base" (also in Table 1) could be perched on the same rung, as well as what Balkema *et al* (2002) call "sustainable behavior". In our interpretation, assuming a license to adjust the original use of these phrases, an employee or community is aware of technological and environmental endeavors. They participate in these endeavors; and they assume, therefore, the attaching responsibilities. They take responsibility, for example, for personal and community actions and for success or failure in the operation of devices owned and operated by that individual or community. They vote with the group in the public space of community debate, for a technological strategy of decentralization, say, of Small is Beautiful (SiB) in Box 1. In their private space, they would accordingly turn off the bathroom shower before having any alarm alert them to the imminent profligacy of their consumption of water and energy (Willis *et al*, 2010).

Once the image of a ladder has been introduced (every bit as much as a pyramid), the natural impulse might be to applaud a policy or technology that seeks ultimately to bring citizen participation to the top of that ladder. For Arnstein this would be "citizen control". Yet from there one can barely banish the further image of a toppling off the ladder into some kind of anarchy. In contrast, towards the bottom-most rungs on the ladder, the tokenism of informing, consulting, and placating smacks of government planning authorities checking boxes in some prescriptive procedure intended yet to keep *their* authority dominant in the community power structure. From Boulanger's (2008) perspective, inviting citizens to endorse a decision already made (the readily recognized lowest form of tokenism) would be a manifestation of the workings of a democracy inferior even to his aggregative model thereof. In sharp contrast, we should enter his (and Dahl's) "deliberative democracy" into the TBL_{future} of Table 2.

Viewed from another angle, the line of Arnstein's ladder might bring to mind the vertical axis of Figure 3, running between the egalitarian spirit of symmetrical transactions and the asymmetrical transactions of the hierarchy. Arnstein was concerned with the relationship between government and the individual. The continuum of participation along this (T2), and the attaching notion of power in this government-citizen relationship, is not the same as the symmetry-asymmetry of transactions of Cultural Theory in Figure 3 (and eventually (T3) below). Hierarchies, in the upper right quadrant of Figure 3, institute status differences, with their asymmetrical transactions. Of society in Boston, USA, it has famously been said that "Lowells speak only to Cabots, and Cabots speak only to God". That, then, is the kind of asymmetrical social transaction that egalitarians, with their passion for "symmetry", would abhor.

Being engaged with society, and the extent to which citizen participation is achieved, in the sense of Arnstein's ladder, is thus different from an individual belonging to a like-minded group (or solidarity). The like-mindedness is about signing up to the tenets that

make the solidarity what it is: egalitarian, hierarchist, and so on. The two pairs of axes — participation and power (here, (T2)); transaction and competition in the ways solidarities form (there, in Figure 3) — are out of alignment.

(T3) Social Bonds

Still looking outwards from the self, how monolithic or endlessly variegated and differentiated is our perception of Society "out there"? Are there any groupings? In how many ways do these groupings organize and bind themselves into solidarities? And to which such grouping might I choose to belong, because there lies the greatest empathy between my perception of the world — in particular, on the Man-Environment relationship — and the solidarity's collective perception?[55]

Along this thread, considerations may be as rudimentary as grading the (technological, environmental) performance of an entity as though society does indeed exist — somewhere vaguely "out there" — and is somehow pertinent (our cynical engineer's jibe at engineering for sustainable development). It is acknowledged merely that technical, economic, and environmental performance may not be the only, or the primary, grounds for adopting a technology or policy, but little more. Society is relevant to the assessment, but largely by default, as it were: an impoverished 0th-order, or 0-fold typology — or non-recognition, in other words — of the various ways people organize and bind themselves into groups and then act within that society. If the axis of Figure 16(a) were to stand for depth and subtlety in the appreciation of "social bonds", then under such superficial treatment we should be grounded at its leftward pole, i.e., (U).

Moving towards the other end of Figure 16(a), assessment may distinguish between "markets" and "hierarchies", which in their turn constitute just two of the yet further differentiated four solidarities of Cultural Theory. Given the axes in Figure 3, of

- transactions, gauged between the poles of symmetrical and asymmetrical

and

- competition, ranging between unfettered and fettered

subtlety and complexity (wealth of thought/assessment) can be judged to be increasing as one passes the successive graduations (in Figure 16(a)) of 0-, 1-, 2-, ... *n*-fold (and so on) ways individuals may organize themselves into groups and differentiate themselves from each other. By adding in such subtlety and complexity of the *n*-fold typology, we should have traversed the axis and provinces of Figure 16(a) to occupy the refinement of boundary (R).

Detached in the present discussion from any specific solidarity, these axes of transaction and competition should not be understood as "directional" (according to Figure 16(b)). To hold a (directional) preference for fettered over unfettered competition is to be committed already to a hierarchist (*H*) or egalitarian (*E*) solidarity, as opposed to the individualist (*I*) or fatalist (*F*) camps. Similar kinds of attachments are implied in preferring asymmetrical over symmetrical transactions. Wealth of analysis here (according to Figure 16(a)) is about how many solidarities (actors, voices) are recognized, not any preferences — *ergo* a sense of "direction" — of being committed to any one of them. This wealth grows as one recognizes and accounts for, say: first solely *I* (as in markets); then *I* and *H* (markets and hierarchies); then *I*, *H*, and *E*; and finally *I*, *H*, *E* and *F*. The graduations in turn mark four intervals (domains) along the generic wealth axis of Figure 16(a).[56]

Armed with this understanding of a 4-fold set of social solidarities and their interactions, an assessment of the sustainability of a policy, decision, or technology will be less or more fully attuned to the rich heterogeneity of implications and consequences of each of the plural solidarities' aspirations for the future. And better more so than less so, we submit, in respect of {social legitimacy}, with thus now indeed a hint of some (arrowed) direction of quality in policy formation. The mesh of the social assessment would be finer with all four solidarities acknowledged, than with the coarse

[55] In fact, how do I relate to you (as another individual)? Fiske and Haslam (2005) maintain there are but four ways: a four-fold typology, but not one (and this we should welcome) necessarily mapping over that of Cultural Theory and Figure 3.

[56] The four quadrants of Figure 3 were constructed according to the axes of "transactions" and "competition". In that respect these two axes provide a basic and unchanging way of thinking about the nature of social bonds. Here, however, wealth of analysis is plotted according to how many of the so-constructed and thus revealed solidarities are taken into account in the given policy assessment.

mesh of not recognizing the way any groups organize and express themselves in a society.

We have written frequently of *Cultural* Theory. Table 1 has an entry for *cultural* acceptance. But the adjective (cultural) is not being used identically in the two phrases. Each household in a community may adopt a quite different stance on whether it will give house space to a new piece of plumbing, such as the urine-separating toilet, hence the phrase "cultural acceptance" in Table 1 in association with the TBL_{now}. In Europe, acceptance may be high (Lienert and Larsen, 2009), while elsewhere, in Inner Mongolia, it is known that the installation of similar devices has suffered from a lack of cultural acceptance (Yu, 2010). More dramatically — as the 2010 Haiti earthquake (and others before it) has revealed — even in the most dire of circumstances, individuals will not seek to protect themselves from the elements in the "house space" of technically well-performing emergency shelters, if their designs are not *culturally attuned*. No matter how basic and desperate might be the need of shelter from the storm (viewed from our perspective), some other want, or need, or personal aspiration (within (T1)), over-rides it.

Less dramatically, yet important nonetheless, there is something essentially different and unique about the cultural dimension of water, relative to that of energy, including in respect of re-engineering city infrastructure. Except possibly and rarely in its manifestation as fire, energy does not seem to play such a fundamental role as water in our massively diverse spiritual cultures. As Davis (2008) puts it:

> No substance in the world is endowed with more cultural and religious significance than water.
>
> No substance in the world has deeper emotional resonance or aesthetic appeal than water.

No-one would argue this might not be profoundly significant for re-engineering the infrastructure of a city and re-balancing the city's interaction with its aquatic environment. This meaning of the word (culture) is hugely important for engineers with their proposed and preferred devices and technologies. People care about how they interact with their water infrastructure and environment in ways absent from their interaction with an energy or transport infrastructure, for example.

"*Culture*" in these senses — and in that of the entry for "cultural acceptance" in Table 1 — assumes a meaning somewhat different from the "ways people bind themselves into groups" (as in Figure 3).

The labyrinthine complexity of society may seem overwhelming to the water professional in its supposedly endless variegation and differentiation. Cultural Theory and Figure 3, however, tell us that there are four, and only four, ways of organizing (and disorganizing) — omitting, that is, the autonomous existence of the archetypal hermit (at the origin of Figure 3; Thompson, 2008a). Things are neither as simple as the customary dichotomy of merely "markets" (the individualist style of organizing) or "government regulation" (the hierarchist style of organizing), or Arnstein's focus on "citizens" and "government". Nor are they as complex as being infinitely variegated and differentiated, with each individual having *his* or *her* personal construction of the way the world is (and its attaching science). The corresponding axis of wealth and enrichment of Figure 16(a) is bounded at *both* ends, at (U) *and* (R).

While surely *no* theory can explain everything, Cultural Theory appears less flawed (for the time being) than any other framework acknowledging fewer than its four ways of associating within society. Besides, to take advantage of just one or two sets of experience and wisdom on how to live with one another and with Nature is to risk being impoverished and coming up with less unsustainable policies, designs, products and technologies. For this reason, the corresponding entry for (T3) of the TBL_{future} in Table 2 seeks recognition of a fourfold set of wisdoms.

Yet the indeterminacy brought about by there not being simply a dichotomy, entails the life-like, complex dynamics of interactions amongst the four solidarities, which may lead things in sometimes destructive and sometimes constructive directions (Thompson,

2008b; also Gyawali (2004) and Box 4).[57] This, while it may be frustratingly unpredictable, is not utterly incomprehensible. There are rules that seem to work. What is more, they can be rooted in the physics of stability-instability in the dynamics of nonlinear systems.[58]

(T4) Quality in Governance

In his book *Resolving Messy Policy Problems: Handling Conflict in Environmental, Transport, Ageing and Health Policy*, Ney (2009) has argued thus:

> Over the past three or four decades, the institutional settings of policy-making have changed as rapidly and profoundly as have our society. In the not too distant past, policy was something produced and owned by 'government'. Working within recognizable institutions, governments steered societies by making and enforcing rules. Today we use the far more amorphous term 'governance' to describe a confusing myriad of criss-crossing activities, institutions and processes that all seem, in some way or other to contribute to similarly opaque things called 'policies'.
>
> Widening and deepening the remit of policy-making has meant that governance involves more, and a rather different mix of, people than did government.
>
> By widening the scope of policy actors and weakening the hierarchical control of central governments, the differentiated polity creates the potential for intractable policy controversy.
>
> German political commentators have called this Reformstau — a backlog or congestion of urgent reforms necessary to revitalize our societies.

Our interest here is not in "Reformstau", even if it were the destructive kind of impasse of concern to Gyawali (2004) (and to our discussion of Box 4). It is rather in the refurbishment of Dahl's pluralist democracy, which Ney (2009) has proposed as a means of unblocking the policy logjam. Above all, Ney's scheme provides us with yet another elementary, irreducible guiding thread: of *deliberative quality* in governance, i.e., (T4). In turn, thread (T4) is conditioned on the ways of organizing recognized in the preceding thread (T3) of social groupings. Yet this deliberative quality is not the thread of participation of (T2).

Here now is where the generic forms of both axes of Figure 16 assume specific and substantial import. Access and responsiveness are the two guiding axes, above which the surface of deliberative quality rises. We define three axes, therefore, the first pair having to do with wealth of assessment (as in Figure 16(a)):

- access to the debate, ranging from one to several given voices-actors (which in its turn is still *not* the same as Arnstein's "participation")
- responsiveness, by none, or one, or two, or several of the other voices, to the say-so of the given voice-actor (which was the organizational goal in staging the IWA Sustainability *Agora* of Box 4)

and the third being associated with direction (Figure 16(b)), i.e.,

- quality of deliberation itself.

A surface can be plotted in this specific three-dimensional space in Figure 17. It has two axes on the horizontal plane of wealth of assessment, with arrowheads for neither, and the third rising vertically, with an arrowhead.

Dahl's classic theory gives us an over-simple and dualistic scheme: *closed hegemony*, when there is neither access nor responsiveness; or *pluralist democracy*, when both obtain. This is pictured in the inset of Figure 17. No third axis is needed on this two-dimensional plane. Under this coarse mesh of thought, betterment is associated simply with moving out of the box of closed hegemony and into that of pluralist democracy.

[57] If surprising failure (such as a global economic crisis) brings about the need to organize and manage affairs differently, the twofold typology is entirely predictable: unfettered markets will be abandoned in favor of strict regulation — individualist style (*I*) is shed for that of the hierarchist (*H*) — and *vice versa* (*H* for *I*). With four ways of organizing and disorganizing, it is not likewise determined how an *I* style of managing might in the event be obliged to reorganize as hierarchist, egalitarian, or fatalist instead, and so on (and on).

[58] This, I readily confess as an engineer, has been the supreme achievement of Cultural Theory for me personally. I have tried to resist its appeal on many occasions, but to little or no avail. As a result, Table 2 is replete with entries for the TBL_{future} that reflect an underlying and pervasive plurality of perspective in addressing matters of stewarding the Man-Environment relationship.

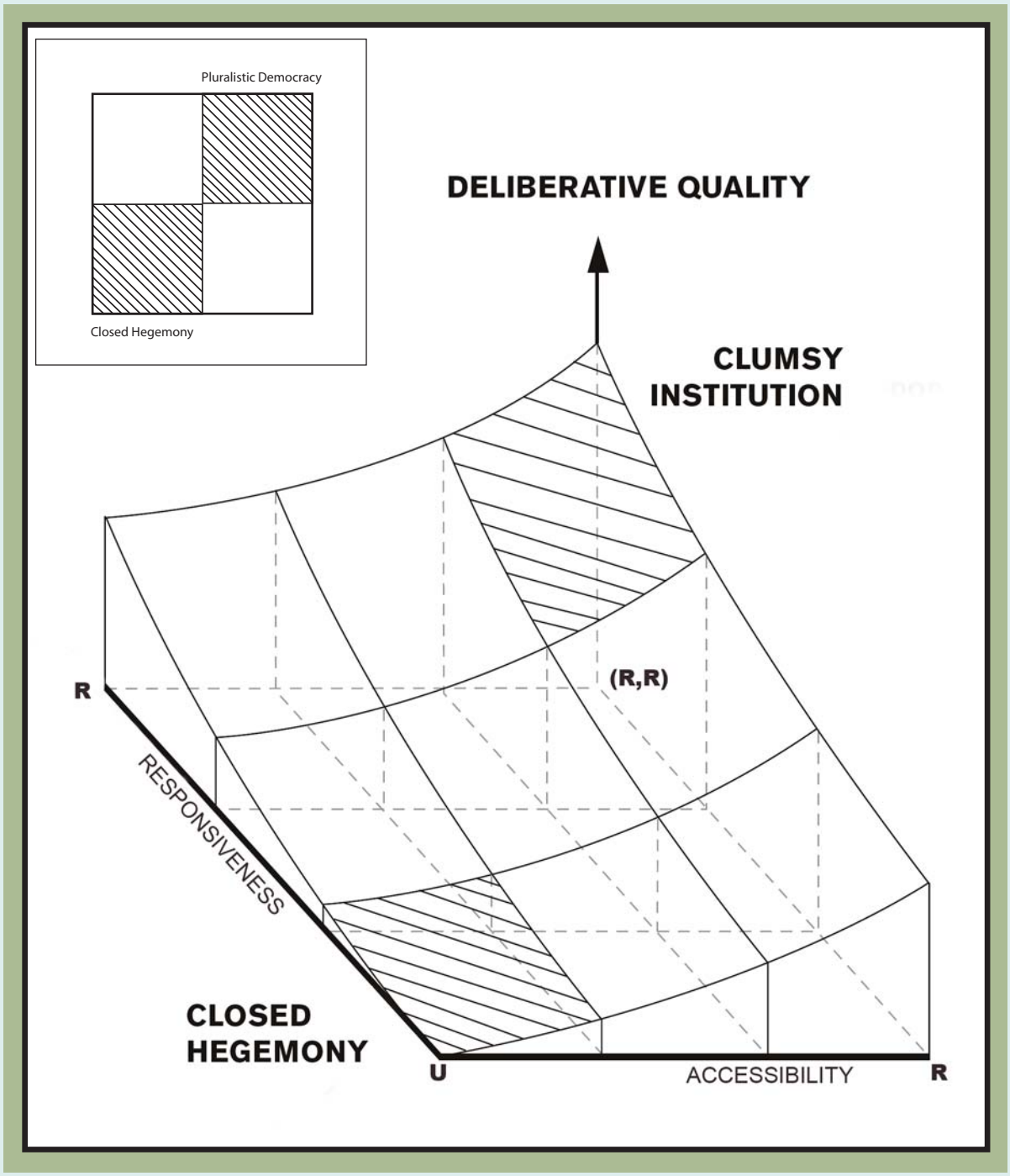

Figure 17
3-D space of assessment for (T4) "Quality in Governance". Axes of accessibility and responsiveness bear no arrowhead and gauge accordingly wealth of assessment. The axis of deliberative quality, in contrast, is directional. The domains (provinces) of "closed hegemony" and "clumsy institution" are shown cross-hatched. Inset: the 2-D matrix of Dahl, showing the companion "closed hegemony" and "pluralist democracy". In effect, the inset is a (past) "bare-bones" assessment of governance, whereas the complete (contemporary) 3-D space has "fleshed out" — refurbished — that earlier conception of what amounts to good governance, as gauged by deliberative quality therein (adapted from Thompson, 2008a).

Refurbished by way of the typology of Cultural Theory — *enriched*, that is — we are able with a finer mesh of thought to map an extensive "excluded middle" (Ney, 2009). Each graduation along the two axes of accessibility and responsiveness in Figure 17 marks thus the addition of another voice to the debate, be this hierarchist, individualist, or egalitarian, in any order. In the generic sense of Figure 16(a), affairs are progressively becoming more subtle, richer, and more complex, as one moves away from the origin (U) along either axis. As the eye travels along the axis of responsiveness (in Figure 17), more voices are seen to be responding to the debate, although some may have no access to it. Plotted thus on Figure 17, closed hegemony grants access-responsiveness to just a single voice, while the inelegant but exemplary clumsy institution is the refurbished form of Dahl's original pluralist democracy. The former has a vanishingly small deliberative quality — on the third, directional axis of Figure 17 — while the clumsy institution has scope for attaining the highest of such quality. It grants access-responsiveness to all three of the active solidarities; thus it lies at point (R,R) above the two-dimensional plane of access and responsiveness. Most policy sub-systems fall somewhere between the two.

In the worst place of closed hegemony, the one actor granted access (agency; institution; solidarity) will choose to frame the problem such that it may be solved by that actor's favored style of problem-solving and governance. Under this lowliest quality of governance, just as the International Water Association's *Sanitation 21* document complains (IWA, 2006; see also Box 2),

> [O]pportunities for exploring the whole range of potential solutions may be lost and the agenda may be 'hijacked' by one particular interest group ...
>
> ... perhaps an engineer with highly technical knowledge, or perhaps someone from a development agency with a strong social agenda or a strong home-industry export agenda, or again it may be the environment agency or a donor with a strong commitment to environmental protection.

In other forums, such as the IPCC (according to Pielke, 2010), the hierarchical voice alone has framed the debate, while the voice of the so-called voodoo-science solidarity has been denied access and merits no reasoned response from within the (closed) debate, hence the dismissive jibe. A form of power — to recall this axis from the relationship between citizen and government of (T2) — is here being exercised through the matrix of access-responsiveness. This too would have been the situation in respect of the South Asian experience of flood management, as related in Box 4 of Chapter 4.2 (Gyawali, 2004). All are redolent of the tokenism of *government* behavior, towards the bottom-most rungs on Arnstein's ladder, with the government agency being the only voice granted access to the closed hegemony of Figure 17, hence its lowest quality of *governance*. Thus can we appreciate better the changes in phrasing between Arnstein's and Ney's times — between "government" (Arnstein, 1969) and government as a player within a system of "governance" (Ney, 2009; see also Termeer, 2009).

The clumsy institution, so the normative argument runs, is where we should strive to be. We should incorporate it into the scaffolding for a TBL_{future} of Table 2. The relative richness of the nine "provinces" on the surface of Figure 17 should allow us to discern where our given, problem-tailored, policy subsystem presently lies, thus to identify the various pathways by which we can move closer to where we want to be (Ney, 2009) — progressing step by step along and up the axis of deliberative quality. The foregoing advocacy in Chapter 4 of an experimental and adaptive structure of governance might be just such an enabling device, in particular, on an urban scale. Cultural Theory does not guarantee the benefits of a clumsy solution. Nevertheless, if institutional arrangements are as in this uppermost province (in Figure 17), and there exists the possibility of a clumsy solution, then it ought to be discoverable with greater probability than would have been the case, had those institutional arrangements remained "suavely elegant" (with thus lesser deliberative quality). In particular, we might ask, what engineering intervention or technological innovation of CFG, IUWM, or IWRM, might project the quality of governance upwards?

The TBL_{now} of Table 1 acknowledges the significance of the "institutional-regulatory framework", but is otherwise silent on the quality of the deliberations it may deliver.

In its own small way, Figure 17, with its three axes, is essentially a 3-dimensional sub-space (or microcosm) of the *N*-dimensional framework by which we are seeking here to extrapolate from the TBL_{now} (from

Table 1) and within which we wish to erect the scaffolding for constructing some form of TBL_{future} (within Table 2). Beyond the abstractions of Figure 16, it is the specific, graphical epitome of our central purpose in this chapter on change. Figure 17 may not be quantitative, but its intent is clear. The key to insight and progress is not merely the definition of the axes, but also the separate graduations along them, hence revelation of the middle provinces interpolated between the bare bones of Dahl's original dualism. A step has been taken, from a sparse, original dualism, to something markedly *enriched*. We have moved along the axes of our logic from an ignorance, or non-recognition of something of import in assessing what sustainability amounts to (at worst, a 0-fold typology, for example), to the richness — and greater difficulty of grappling with (and judging according to) — a higher, *n*-fold typology.

(T5) Ethics and Equity

What do I owe to myself, or to any other entity, or that entity to me? What does any social grouping owe to any other entity? How should affairs be conducted, in respect of these relationships between the self and the self, the self and another individual, the self and the group, and any other entity? For such conduct may be good or bad, fair or unfair, noble or ignoble, right or wrong, just, dishonorable, virtuous, and so on. In fact, with how many other fundamentally different types of entity can the self/group have a relationship? For there can be superiors, peers, and subordinates ("inferiors"); competitors, collaborators, and neutral referees (or disinterested bystanders with whom there is little or no relationship); suppliers along a supply chain; all manner of associations and institutions in a policy-subsystem of governance; there can be mankind and a multitude of other species of organisms; and there can be past, present and future generations of man and beast alike.

What mesh of axes, orthogonal or not, might now chart the differing sub-domains and provinces across such considerations of ethics and equity? What space might be constructed to do for them what Figure 17 has done for the quality of democratic deliberation?

We cut a candidate path of logic amongst all the entities sprayed about like blunder-bus shot in the preceding paragraph, to suggest at least these four axes:

- the number of individuals, essentially distinguishing between the one (*ergo* the individual) and the more-than-one, i.e., the group
- financial status, i.e., the categories of non-monetary or monetary, which latter will include the distinction between buyer (customer) and seller (service provider)
- species, cleaved crudely into the pair of human and non-human, but recognizing a continuum of species spanning in theory from the blue whale across to the chemical species of minerals and inanimate rocks
- generations (time), as in the trichotomy of past, present, and future — and the different graduations according to whether one, two, or three of these generations are being entered into the assessment of sustainability

All of our threads ((T1) through (T14)) are cardinal with regard to sustainability. This on ethics (T5), however, must be granted special status. It is privileged. Its role is born of that most basic instinct: the dawning in the mind that one owes something — and something about the well-being of the Environment — to the future; and that, in particular, one owes this something to one's offspring. This last of the above four axes cuts through the heart of sustainability as it looks ahead to future generations. And the behavior of the present generation relative to that of past generations reveals much of the significance of the glorious diversity of culture in thinking about sustainability (along thread (T3)).

At one corner of what would need to be at least a 4-dimensional sub-space corresponding to Figure 17, might therefore reside the self, as if nothing else in the world mattered. At this pole of the intersection of the leftward boundaries of the four wealth axes (from Figure 16(a)), rather like the province of closed hegemony in Figure 17, the frame of ethical assessment could be said simply to be unrefined, empty, vacant, or undeclared (U) — the very coarsest of unrefined meshes of thought.

Proceeding away from this most rudimentary basis, provinces of ever greater richness, subtlety, and complexity of considerations can progressively be stacked up (just as they are as one moves away from closed hegemony in Figure 17): by the introduction of

another individual to whom one relates; to which can be added the refinement of distinguishing between the monetary and non-monetary status of that relationship; and then that of a group, as opposed to an individual (and groups to groups); then human and non-human; future human generation(s); future non-human generation(s); and past generations; and perhaps on and on and on, as far from corner (U) as the mind can conceive of. What is more, such extrapolation has not even begun to acknowledge a fifth axis of:

- ethical schemes, distinguished as motivational, behavioral, consequential, and more (Harremoës, 2002) and colored and shaded by the outlook adopted on caring (or not) for the consequences of action (Thompson, 2011)[59].

Remote now from the ignorance and coarseness of (U), we find subtlety, complexity, richness, and refinement (R) in gridding the frame of ethical assessment of any policy for CFG, or for IUWM within IWRM.

You or I might have voted with the group in the public space of community debate for the frugality and eco-efficiency of a decentralized, Small-is-Beautiful (SiB) policy. Yet in our individual private spaces of the bathroom shower, the alarm is blithely ignored as it flashes transgression into profligacy. There is a not-unfamiliar whiff of double (ethical) standards about this. The policy might be deemed wholly unsustainable — without ethics — on any and all accounts under (U), quite otherwise under (R). Or, according to (U), it might have seemed ethical and sustainable in principle in the public space, merely unrealizable and practically ineffective in the private space. Whatever the judgment, the policy is the same. It is just that the framing of the assessment has changed: blank and vacant for (U); finely and richly gridded and replete with axes and provinces for (R). It is as the difference between just the two provinces of Dahl's original notion of plural democracy in Figure 17 and the nine of Ney's refurbishment of the theory.

With considerations in Table 1 largely confined to those of entities such as engineered facilities for wastewater treatment in IUWM, an entry corresponding to this thread (T5) is conspicuous by its absence from the TBL_{now}. This does not mean that those, after whose contributions the contemporary consensus of Table 1 has been fashioned, thought nothing of ethics and equity. Rather, these matters would have been so obviously the motivation for sustainability in the first place, that they may well have been taken for granted — presumed, without any further debate (as we shall shortly see).

In contrast, the entry for this line item in the TBL_{future} of Table 2 anticipates the immense richness of thought caught in the highly refined mesh-like gridding of (R) (relative to the emptiness of (U)). Assessment would become dauntingly explicit in thinking about the multiplicity of ethical frames applicable to a host of all manner of relationships as though ethics and equity obey some inner, fractal, self-similarity with sustainability in *toto*. We *ought* to value many more of the entities in the world than merely the self. Increasing the collective wealth of awareness, along all of the axes (of Figure 16(a)) introduced for the current thread (T5) (of ethics and equity), has here a sense of a desired direction (up the axis of Figure 16(b)).

What is entered for (T5) into Table 2 is spurred no less by what we shall eventually see of (T5) in the $TBL_{frontier}$ of Table 3 (in Chapter 6).

(T6) Valuation

Traveling along one axis of (T5) in particular brings a certain clarity and immediacy of purpose to the foregoing discussion of ethics. It is that of the financial status of things. The instrument of the market places a price on entities, hence the axis of

- competition, as already drawn in Figure 3 (and therefore (T3)).

Its continuum ranges from one extreme — the utterly unfettered market (the way of organizing of the individualist solidarity) — over the commonplace of less or more fettering through government subsidies, taxes, and "cap and trade" policies, to the other extreme of an entirely regulated market (the way of organizing of the hierarchist solidarity). Figure 3 simply acknowledges just the two broad sub-divisions of this axis, into the provinces of fettered and unfettered.

To this axis of competition can be added that of

[59] Significantly for this *Concepts Paper*, Thompson's article is entitled "Material Flows and Moral Positions". It deals with two case studies, one of which has to do with community decision-making in the matter of renewing (or demolishing) housing stock in London.

- species, as for (T5).

Now, however, when it comes to monetary matters, it is the cut between humans and all else that is so profoundly important. Attempting thereafter to value the "all else" has provoked the emergence of environmental, ecological, and other schools of economic thought, together with so very much debate.

Thinking in a third direction, of discounting costs and benefits over time, and the no less disputed choice of its rate in the Stern Report (Stern, 2006; Godard, 2008; Lasry and Fessler, 2008), the axis of

- generations

comes back to mind, with the same scope for graduations, categories, and provinces as previously in (T5).

Towards the most rudimentary corner of this 3-dimensional space (symbolically, point (U)) lies the engineering economics (V_0) of Chapter 3.2: calculation of the construction and operating costs of a wastewater treatment plant for choosing amongst several alternative designs or upgrades (Jiang *et al*, 2005); fettered to the extent of needing to meet a regulation for environmental protection; metering within the facility fence-line the costs of electricity, process chemicals, labor, and so on — but leaving ecosystem services un-metered and therefore not evaluated; and discounting the sunk construction costs over the life-span of the facility (not the spans of human or non-human generations). Such things comprise the corresponding entry for the current thread (T6) of the TBL_{now} in Table 1. There, the "derivative attributes" (Table 1) of these expenditures of engineering economics would be expressed (according to Balkema *et al*, 2002) as cost-effectiveness, labor, and affordability. Thus are considerations of ethics and equity channeled indirectly into Table 1, through the lens of the affordability of a utility's services to its customers.[60]

According to our caricatured account in Chapter 3.2 of the economics of valuing the presence of oysters in Chesapeake Bay, V_E adds in the "value to the present human population of knowing the oysters are there in the Bay and knowing too that future generations will likewise appreciate this knowledge" (from the perspective of environmental economics). This is over and above what is valued in the purviews of V_0 and V_C, i.e., the "conventional" economic valuations. V_E would seem accordingly to lie somewhat further away from the most rudimentary province of the generations axis of (here) our 3-dimensional sub-space for valuation. It addresses more directly not one, but two segments of human generations (present, future). Moreover, since it expressly recognizes the value of the oysters in the environment, as opposed to their consumption in a dockside restaurant, it notches up something additional along the species axis (in comparison with V_C).

Relative to V_E, valuation V_X from the perspective of ecological economics should appear as more distanced yet from the leftward boundary of this same axis of species (its coarsest mesh of assessment). For it takes further into account "the value of the services of the oysters in filtering, and thereby cleansing, the Bay's waters to the benefit of *their* (the oysters') ecosystem" (Chapter 3.2).

It is *not* that distance from corner (U) in this space for Valuation (T6) gauges the attribute of "more/less ethical" from (T5), but that considerations of policy sustainability become ever more enriched, as one successively recognizes the legitimacy of, say, first solely V_X, then the pair of V_X and V_0, then the trio of V_X, V_0, and V_E, and so on — going from a single-fold to an n-fold typology, including the n ethical schemas behind the various kinds of valuation. Sustainability *is* about valuing a greater number of entities in the world. This thread (T6) of valuation relates back, therefore, to that of ethics (T5) and looks forward to the language of business in the next thread (T7).

No-one has ever said things would get simpler. We may crave this. The notion of some succinct operational definition of sustainability might extend the tempting illusion of such simplicity. But it is an illusion, nonetheless.

(T7) Environment Within the Language of Business

(T7) is manifest along a continuum of increasing subtlety and depth in the penetration of business thinking: from natural capital, through ecosystem services and service providers, and on to considerations of biodiversity. Indeed, on inspection of the entries in Tables 1 and 2 for this thread, we may be tempted to

[60] Affordability is a prominent consideration in the principal messages emerging from the 2009 UN World Water Development Report (WWAP, 2009a,b).

conclude that here we have a certain maturity: TBL_{now} approximately equals TBL_{future}.

Gauging "environment within the language of business" entails its own unique logic, with increasing depth and subtlety. First, there are "stocks" of capital. Second, we may choose to assess them in one or more forms, such as, for example, human, financial, manufactured, and natural. Third, natural capital may be differentiated into a number of environments: atmosphere, lithosphere, hydrosphere, and biosphere; and then into species — of the strictly *non*-human category; which species, fourth, are responsible for flows of services of benefit to mankind; integral to which, fifth, is biodiversity; and, sixth, the risk therefore of the extinction of species (over time), perceived as a threat to business — or "business-as-usual", that is.

Of interest furthermore are matters of exchanges and transfers amongst the forms of capital — fungibility (in the language of economics) — and between human generations, as in Solow's concept of bequests to the future, suffused with its moral and ethical dimensions, which returns our argument (again) to the thread of ethics and equity in (T5).

The key to the role of (T7) is not that it calls for any new axis, but that it is right for our times (for a few years, at least). It transforms into the contemporary idiom what was expressed in the less enriched language of four decades ago when Meadows *et al* (1972) wrote of the *Limits to Growth*. Theirs was the language of "resource depletion" and "pollution control". Thread (T7) extends the notion of {economic feasibility} away from the engineering economics of V_0 and embraces valuation of many more of the entities classified and addressed as matters of ethics and equity in (T5). It gives us, furthermore, a positive spin on what previously had a negative spin to them: it speaks of "things we should do", as opposed to "things we should *not* do". The obligation of Brundtland's definition of sustainability is to build (positively) all forms of capital, but especially natural capital. It is not as confining as was once the urging: not to deplete resources and not to pollute.

(T8) Supply-Value Chains

Business entities, such as water utilities (private or public), sit within an arc of flowing goods and services. They have suppliers and customers. They can apply their ethical systems of sustainability backwards to other business entities along the supply chain/ trajectory, and ever further so. Thus do such entities acknowledge risks to the violation of human rights, as in risks to those rights along the supply chain and amongst the most vulnerable customers, as embodied in the UN Global Compact (UN Global Compact, 2008; www.unglobalcompact.org; accessed 24 November, 2010). Where there is a buyer and a seller, i.e., a financial transaction, so there can power be exercised in that relationship (for good or ill) — purchasing power, or consumer power.

Where there is political power, or patronage, as in the mayor who champions (or not) pursuit of the sustainable city, so may the shots be called over the construction company hired to excavate trenches in the street. In the light of such power, the form of the trench and the mode of its excavation and filling may (or may not) be more or less sustainable. Context and place matter. The construction company (the seller) may be deemed sustainable in city S, led by its enlightened mayor (the buyer), and yet unsustainable in its behavior in city Y, which lacks a mayor with such enlightenment and for whom any old trench might suffice (sustainable or otherwise). Should a sustainability-driven asset manager judge that construction company to be therefore sustainable and worthy of its investment, or not? For like the curate's egg, it is good in some places, poor in others. A manufacturer purveying the latest technologies for desalination might be deemed sustainable in today's terms, for facilitating the access of more poverty-stricken people to wholesome, life-sustaining, potable water, but unsustainable in respect of exposing many more of the next generation to flooding from sea-level rise and increasing hurricane activity (as conjectured in Chapter 2.2). Place *and* the long view matter too.

Power is exercised across the levels in a hierarchical institution, of course. The supply chain is itself a form of hierarchy. Yet this is neither the same as, nor all that defines, the hierarchist outlook on the Man-Environment relationship, where predictability of outcome and the redemption of mankind from its erring ways are sought (under thread (T3)). The Cabots of Boston are not the buyers of anything the Lowells might have to sell; there is no monetary transaction defining their relationship one to another in the hierarchist solidarity of Cultural Theory. Just as it should, therefore, this current thread (T8) encapsulates something of relevance to assessing sustainability that

neither (T3) on social groupings does, nor (T2) on citizen participation.

Two axes chart the extent by which (T8) is gauged:

- the length of the arc of the supply-value chain, or the number of enterprises within it

and

- the manifestation of power along each link of the chain, segmented into provinces, for example, of apolitical/political, legal/illegal, monetary/non-monetary

A minimalist stance, towards the coarse-mesh corner (U) of the two-dimensional chart (like the inset in Figure 17), would acknowledge no chain. There would be but a single entity enclosed within the "fence-line" of the industry, or wastewater treatment plant, free of any acknowledged obligation to any other service provider or consumer. In the absence of any relationship, power seems irrelevant.

Moving away from (U), entity after entity can be added to the chain. Power can be categorized progressively as single-fold, if it is recognized as present; then two-fold, distinguishing most obviously between monetary and non-monetary (as previously in (T2)); and so on, separating out further the forms of "non-monetary" power — segment after segment, along the generic axis of Figure 16(a), or within the specific, figurative context of Figure 17.

Far from the leftward boundary (U) of the axis for length-of-the-arc, the province of a supply-value *circle* can be imagined (at (R)) — and just as much the deliberate breaking of that circle. The individual employee of the tail-of-chain business, or perhaps that entire business, may elect not to purchase any product or service from the head-of-chain entity. S/he (it) would be exercising consumer power, along the companion (orthoganol) axis.

The outlook of the corresponding entry for the TBL_{now} in Table 1 extends no further than the factory (treatment plant) fence-line. That of the TBL_{future} in Table 2 spirals ever outwards, from IUWM to IWRM and beyond.

(T9) Commercial Sectors

The logical thread of supply-value chains in (T8) is dominated by its axis gauging the length of the arc of enterprises and business entities, now qualified (notably) as within the chain of *solely* the water sector. It is applicable here also, with no further modification or embellishment.

A glance back at Figure 1 — and all the ensuing dogged argument in favor of projecting the image of an urban *nutrient* infrastructure into a conventionally *water*-centric outlook — brings to mind a second axis for the present (T9):

- the number of economic-commercial sectors.

From our entirely appropriate origin in the water sector — the lone entry in the TBL_{now} of Table 1 — sub-divisions and provinces fan out along this second axis, as further sectors are successively brought into considerations of what constitutes sustainability in the water sector, or what it might take to realize the notion of a city as a force for good. Like the graduations on the axes of Figure 17 or Figure 16(a), the different domains might best be defined by the number of sectors addressed *jointly*: first, and most rudimentarily, just the one (water); then two (water and waste-handling, say);[61] then three (water, waste-handling, and food); and so on, towards some remote province of a very high-order multi-sectoral analysis.

The analysis of Villarroel Walker (2010) for assessing eco-efficiency and eco-effectiveness in our Atlanta-Chattahoochee case study is a five-fold affair; it accounts for the interactions amongst the water, waste-handling, food, energy, and forestry sectors. Villarroel Walker's original analysis, however, is anything but one of the flows of money along the supply-value chains within (and amongst) these sectors.

Surveying the shape and extent of this ninth logical thread (T9) in the fabric of a candidate TBL_{future} calls for a third axis, of

[61] It is telling how words fail us: there is no "nutrients" sector as such; the best that could be done hitherto has been to use the phrase "waste-handling" (Villarroel Walker, 2010).

- "materials", such as carbon, nitrogen, phosphorus, water, energy — *and* money.[62]

Some of the greatest opportunities for progress towards sustainability and the CFG doubtless lie at the interfaces amongst the customary delineations of single strands of infrastructure (Beck *et al*, 2010b; Villarroel Walker and Beck, 2011a). The promise of a single, potentially innovative technology — originating, for example, in membrane science or biotechnology — cannot be properly assessed, if abstracted and considered in isolation (as it usually is) from the complex web of technologies of which the whole of the city's infrastructure is composed. An innovation in the food sector, say, may have significant consequences for innovations in the water and energy sectors. An innovation timed correctly (incorrectly), in a sequence of re-engineering steps, may substantially enhance (hinder) overall cross-sectoral progress towards more sustainable city-watershed systems. We should add a fourth axis here to the 3-dimensional sub-space of (T9) to reveal such latent synergies (or their antagonisms), as matters integral to gauging sustainabilility:

- interactions, with co-dependence[63] between the provinces of antagonism and synergy.

Taking a look back to the start of all these threads, to that of our "existence" along (T1), and then further back to the person-centric outlook of Figure B2.1, the health and well-being of you or I are key. Inasmuch as we have asked there under (T1) "What elements of re-engineering urban wastewater infrastructure for CFG might bring the aspirations of individuals to a self-reflexive grasp of the 'big picture'?" (the corresponding entry for (T1) of the TBL_{future} in Table 2), so might there be a case for introducing (here) the pharmaceuticals and health-care sector into (now) the multi-sectoral analyses of (T9) (ICSU, 2011; Warner Babcock Institute for Green Chemistry (www.warnerbabcock.com; accessed 10 March, 2011)).[64]

(T10) Space

We are bidden to "think globally, act locally". Thinking is to be propelled forwards and outwards from the confines of the wastewater treatment plant, across the province of the TBL_{now} for IUWM (to which the entries of Table 1 are largely attuned), and on to that of the watershed and IWRM, if not then the world (and the TBL_{future} of Table 2). Far out along this spatial axis reside the abstractions of IUWM and IWRM. But for the reminder to "act locally", we might easily forget the highly personalized "you or I" of the stick-figure icon of Figure B2.1, and the thread of intimately personal and most local of aspirations with which we began under (T1), at the origin (in space).

(T11) Life Cycle and Time

A life cycle is taken to run from the cradle to the cradle: from conception and planning, to design, construction, operation, disassembly and upcycling, and reincarnation. It is subsumed under one *generation*, one province of an axis employed already. To generations of man and animal in (T6) and (T5) can now be added generations of manufactured capital. The very concept of life-cycle was itself born of drawing the analogy between engineering projects and biological organisms. To introduce another axis — so obviously the number of life stages *and* their cross-stage interactions — might amount to little more than merely subdividing an existing province along an existing axis into ever smaller parts, and three, in particular (as here). If we single out the stage of operations and label it (O), all that precede

[62] As in Kytzia *et al* (2004) and Lang *et al* (2005), who attach flows of money to those of materials, to assess respectively alternative systems of food production and alternative recycling schemes for municipal biowaste (see also Malmqvist *et al*, 2010). The subsequent study of Villarroel Walker and Beck (2011a) examines the economic benefits that might attach to re-balancing the nitrogen cycle of the Atlanta-Chattahoochee system.

[63] In a randomized search of candidate technologies to occupy various niches in the stages of wastewater treatment it can transpire that the "fittest" is only such in the presence of another item somewhere else in the complex web of interacting, individual technologies (Chen and Beck, 1997).

[64] Warner's work has been cited specifically in respect of reducing waste from the manufacture of a drug for Parkinson's disease (see "EPA Scientist Advocates 'Green Chemistry'"; http://marketplace.publicradio.org/display, posted 23 March, 2011).

will have been the pre-operational stages of the life cycle (the (Pre-O)). All that follow add up to the (Post-O).[65]

What matters here — and what matters to the entirety of this *Concepts Paper* — is bringing the spread of such ordered thinking to the table of a policy assessment for sustainability. Our purpose has been to recognize, straighten, and tie together the logical threads of such assessments, strictly according to contemporary practice. It has been neither to introduce bundles of axes for their own sakes nor to impress upon the reader that things must thereby be quantified in some customary mode of engineering analysis (such as the mathematical program of Chapter 2.5). To reiterate, Figure 17 is not numerical, but categorical. We have, however, now left behind the realms of the social and economic sciences, to find ourselves on the more familiar grounds of engineering analysis, where axes — time here (T11); space above (T10) — barely merit much further explanation or the bulleted formatting of the twenty or so axes already introduced.

The logical thread drawing TBL_{now} out towards TBL_{future} is cast in terms of the extent (lesser-greater) to which formal, more or less detailed, consideration is devoted at any given stage in the life cycle to that which might happen, be needed, or prevail at any subsequent stage. Such *fore*thought is the essence of the "cross-stage interactions" cited above as a possible province along the generations axis. It is also the stuff of "the long and short of it all" at the beginning of Chapter 3.3: of not separating out one or more constituent life-stages for consideration in isolation. It has been the way in which (Pre-O) has historically received so much attention at the expense of (O) and doubtless — before we conceived of Life Cycle Analysis (LCA) — the way in which even less attention would have been given to (Post-O) during all the years of living with (O).

Life cycle and time work in somewhat different ways. The numerical assessments in Chapters 3.3 and 3.4 compared the {environmental benignity} of the current Business-as-Usual (BaU) configuration of wastewater infrastructure for the city of Atlanta with that of a future Perfect Fertilizer (PeFe) arrangement. They did so on the basis of operational (O) performance alone. The sustainability of PeFe{O(t_{75})} was compared with BaU{O(t_0)}, taking the span of three generations to be 75 years (for the sake of illustration). Assuming that the policy/technology intervention of re-engineering for source separation was a single event, occurring hypothetically in future year t_i (again for simplicity of illustration), no account was taken of:

BaU{Pre-O(t^-)}, i.e., the sustainability of the sunk investment in the infrastructure of BaU prior to the present (for all (t^-) before t_0); or

BaU{Post-O(t_i)} when dismantling BaU; or

PeFe{Pre-O(t_i)} when putting in place the new PeFe arrangements.

The companion algebraic caricature of LCA would be this: that it compares, say, l = 1, 2, 3 distinctly different options for the PeFe configuration, i.e., the respective sustainability of the three PeFe$_l${Pre-O(t_i); O(t_i); Post-O(t_i)}.

Within the grand, strategic sweep of affairs in the city, as it moves away from unsustainability (BaU{O(t_0)}) towards something less so (PeFe{O(t_{75})}), innovations are born. They rise, fall, and are returned to whence they came: the life-cycle of PeFe$_l${Pre-O(t_i); O(t_i); Post-O(t_i)}. Their place is taken by other innovations, which too have their finite time and place. Life cycle and evolution over time are different, yet complementary "angles of insight" into what it might take to attain a CFG.

To the degree that (O) is a lengthy stage in an entity's life cycle, so will inter-generational considerations be drawn into the frame of analysis, albeit here now in terms of assets and capital, as opposed to generations of humans. The corresponding entry for the TBL_{now} in Table 1 acknowledges this in the intention to set aside funds from (current) revenue streams not only for "reserves" (for asset management, future maintenance and renewal) but also for Research and Development (R&D) on future technological innovations and adaptations (Sahely *et al*, 2005).

[65] No-one will be surprised by this. It is humbling too to reflect on the fact that my fixation on the operational stage in the life-cycle occupied significantly more than a quarter of a century of my own professional life cycle (Beck, 1981, 2005). Such fixation has here been the wellspring of Box 1 on "Schools of Thought: Styles of Engineering Sustainability" and yet again of Box 3 on "Engineering Resilience into the System". There is some comfort, however, in seeing that the operational stages in each of three alternative systems for supplying water to the city of Phoenix, Arizona, USA, dominate the environmental impacts occurring over the life cycle of each (Lyons *et al*, 2009).

(T12) Function

Things have been conceived of, planned, designed, and constructed or manufactured. They are *in situ* and working. Large or small — from entire eco-systems, to infrastructures, unit processes, individual technologies, to single devices — all must fulfil various functions in various modes of operation. There are sub-divisions of function and performance to be staked out within the sole sub-province of operations (O) along the life cycle of (T11), in turn itself but a province of the axis of generations (from (T6) or (T5)).

These are also sub-divisions of qualitatively different styles of behavior over time, such as those dotted about the quadrants of potential surfaces of dynamical stability-instability in Figure 3, some with, some without their inherently nonlinear "tipping points" (in contemporary parlance). At bottom, knowledge, including *fore*knowledge (again), is required in three categories: the unsteady-state, i.e., dynamic, behavior of the system; the desired goals for services delivered and functions performed by that system (outputs $\boldsymbol{y}$); and the bundle of present and future disturbances inclined to upset, interrupt, or undermine such service provision (inputs $\boldsymbol{u}$). In all three categories the status of knowledge may range across the continuum of complete-incomplete, including more or less complete knowledge about the nature of the uncertainty in an incomplete knowledge base (Beck *et al*, 2009).

Sustainability of function (T12) can be assessed according to at least three levels of progressively greater depth, subtlety, and intricacy, i.e., assessment for:

(i) The provision of a single function (y, as scalar not vector), from a completely understood device or system (model $\boldsymbol{M}$, which relates all $\boldsymbol{u}$ to single y, is perfect), such as a clockwork mechanism for marking the passage of time, under normal disturbances ($\boldsymbol{u}_{normal}$) — the quintessence of engineering resilience (Box 3).

(ii) The provision of all of the multiple functions ($\boldsymbol{y}$), from an incompletely understood device or system (imperfect $\boldsymbol{M}$), such as the microbial ecosystem of activated sludge in wastewater treatment, under both normal *and* abnormal disturbances ($\boldsymbol{u}_{abnormal}$), i.e., the maintenance of function with ecological resilience (also Box 3).

(iii) The adaptation of function — *not* form or structure — to the provision of entirely novel services (different $\boldsymbol{y}$, same $\boldsymbol{M}$ and $\boldsymbol{u}$). These will be services *not* in mind for the device or system in its preceding stage of construction/manufacture (Pre-O). Their conception will originate in the self-awareness of accumulating operational knowledge of the system, its disturbances, and its scope for novel functions, i.e., from (O). This self-awareness, furthermore, will be accompanied by the function of learning, which in turn may span the gamut from passive to active.

Parts of this last would be referred to in Box 3 as a strategy tending towards "0% reconstruction".

We might further suppose the performance of the device or technology would culminate in some supreme capacity for mimicking the auto-immune system of the human body, the biological model of sustainability. Such immense richness of function would be almost infinitely remote from the origin, along any axis of quality of function. Failure by whatever means — through incomplete knowledge (imperfect $\boldsymbol{M}$), abnormal disturbance ($\boldsymbol{u}_{abnormal}$), or passing of a tipping point in behavior — would return quality-of-function to its minimalist province, at the leftward pole of the utter poverty of (non)function.

The corresponding entry for the TBL_{now} in Table 1 acknowledges some facets of the above virtues:

durability, i.e., a longer operating life-span as a consequence of no intrinsic tipping point being passed in the structural integrity of the system — in other words, maintenance of function in the presence of the very slow, seemingly invariant, dynamics of the material properties of a device (such as corrosion, which slowly but surely will lead to failure);[66]

robustness-vulnerability, i.e., the capacity to absorb shocks or otherwise (from ($\boldsymbol{u}_{abnormal}$)), while maintaining function (delivering $\boldsymbol{y}$); and

reliability, i.e., the capacity to avoid failure.

[66] A case of Holling's lyrical slow variables (dynamics of corrosion) determining what eventually happens very swiftly indeed (fast variables describing sudden rupture and failure) (Holling, 1996).

(T13) Gauging Environmental Benignity

Rooted within IUWM, the TBL_{now} of Table 1 categorizes output emissions from the city's wastewater treatment plant along the lines of the pollution syndromes found in LCA (Pennington *et al*, 2004), such as eutrophication, acidification, and global warming, for example. These rejects from the city are gaseous, aqueous, or solid and destined respectively for the atmosphere, hydrosphere, or lithosphere. The economic input output (EIO) LCA of Britton *et al* (2007) well illustrates this. They show that struvite (fertilizer) recovery from a wastewater treatment plant can reduce by typically 70-80% the emissions of gaseous pollutants (SO_2, CO, NO_2), greenhouse gases, and solid contaminants (Cd, Cr, As), relative to corresponding emissions from conventional fertilizer production.

In the life cycle of a product, process, technology, or configuration of wastewater infrastructure, "stuff" is entrained as input (***u***) and shed as output (***y***). Resources are depleted and pollutants emitted in tandem with the fluxes of the [***u***,***y***] couple. All manner of "china" in the environment is being broken by the "bull" of a city as it charges destructively about.

From the negative of this nature, so readily conveyed in the drama of its ecological footprint, an assessment of the sustainability of the city would be seeking actions of re-engineering for restoring the conduct of affairs to a balance of zero: a condition of fragile, valuable entities preserved unbroken for ever. The sentiment is that of "righting a wrong", of being "less bad", *ergo* of "maximizing eco-efficiency", with a hint of thinking about the environment in the language of business (T7).

Looking above and beyond to fashion outputs from the city that enhance the performance of its environmental surrounds — inching them beyond the origin into a positive province of this axis of environmental benignity — has been the struggle of this entire *Concepts Paper*, and Chapter 3.4, in particular. It has the positive spin of building natural capital and enhancing ecosystem services. It has much of the sentiment of eco-effectiveness about it, of being "more good" as opposed to "less bad", as McDonough and Braungart (2002) would argue.

(T14) Cycling of Materials

Eco-effectiveness embodies the slogan of "waste = food" (McDonough and Braungart, 2002), along the lines of industrial ecology. Thread (T13) evokes an image of materials propagating from one end to the other of disconnected segments of arcs. These can be joined up ("waste becoming food"), to complete the cycling of those materials.

With this accomplished, one cycle, extracted from all others, may be considered on its own: the hydrological cycle, because it is so inevitably dominant in IUWM, IWRM, and the commercial *water* sector as a whole. Apprehension of the prospect of climate change has achieved widespread, popular appreciation of the carbon (C) cycle, to which the water cycle can be coupled — and so on, inter-coupling the water and C cycles with those of other nutrients (N, P, Si, etc.). As in Figure 17 (and Figure 16(a) before it), provinces along an axis of materials — already used in (T8) — may be sectioned off. Starting from the crudeness of recognizing no such "closed loop" of cycling, would constitute a rudimentary, unrefined analysis at the leftward boundary of the axis (U). Rightward movement of increasing refinement of assessment would pass over provinces successively acknowledging one, two, three, and eventually *n* jointly assessed cycles. To these might be added further embellishment in order to accommodate sub-divisions between natural nutrient cycles and *technical* nutrient cycles for xenobiotic substances (Azar *et al*, 1996; McDonough and Braungart, 2002). There (at (R)), assessments of sustainability would be far from the opposite pole (U) of disconnected fluxes in arcs that are not parts of loops that are closed.

A single point of diversion from these cycles, or appropriation of them, or fragment of arc along one of them, is recognized in the corresponding TBL_{now} of Table 1: consumption of resources, water, nutrients, energy, possibly "soil fertility", as they are drawn into the construction and operation of the system (typically, a wastewater treatment facility) or "consumed" by virtue of their occupation (land area).[67]

[67] Global warming and carbon footprint, deriving from the intimate nexus of the urban water-energy sectors, are nevertheless prominent in the indicators and criteria (TBL_{now}, in effect) of Sahely *et al* (2005).

Our Bottom Line

Contemporary practice in Triple Bottom Line accounting for IUWM within IWRM has been consolidated according to the TBL_{now} of Table 1. The dense structure of this tabulated material — and the preceding paraphernalia of logical threads, axes, and provinces — have been crafted to enable an extrapolation: of how the TBL_{now} might evolve into a TBL_{future} of Table 2. Should this lead to a better appreciation of what constitutes sustainability, it will have served its purpose. All the paraphernalia might be set aside, like the preserved exhibit of the rock-boring machinery that had once enabled the UK and France to be connected *via* the Channel tunnel.[68] For now, however, the beast of complexity has not been tamed. Indeed, to our dismay, all the entries in Table 2 for the TBL_{future} should strike us as altogether more subtle, more complex, and more multi-faceted than their counterparts in the TBL_{now} of Table 1.

But Table 2 is markedly different in structure from Table 1. It has a *fifteenth* and — quite deliberately — *topmost* line. The phrase "Organizational Learning" has been added, as a notional (T0), and the phrase "Always Learning, Never Getting It Right" inserted alongside it.[69]

5.2 Truly a First Among Equals?

In their 2009 book "*Immunity to Change: How to Overcome It and Unlock Potential in Yourself and Your Organization*", psychologists Kegan and Lahey present an "updated view of age and mental complexity" (Kegan and Lahey, 2009). Where previously just two levels of mental complexity had conventionally been recognized — in the socialized mind and the self-authoring mind — now, they argue, there is neurological evidence of a third and higher state of mental complexity. This they call the self-transforming mind. In their view, the evidence from brain science of the brain's "phenomenal capacity ... to keep adapting throughout life" has caught up with what they had long supposed to be the case, since they first started reporting the results of their psychological assessments of individuals in the 1980s. Some of the evidence from brain science — albeit perhaps at the extremes — is reported in the work of Davidson and colleagues (Davidson, 2004; Davidson and Lutz, 2007). They have shown that "over the course of meditating for tens of thousands of hours, the long-term practitioners [of meditation] had actually altered the structure and function of their brains" (Davidson and Lutz, 2007).

By way of introducing their case for the uppermost level of mental complexity, Kegan and Lahey (2009) opine:

> When we experience the world as "too complex" we are not just experiencing the complexity of the world. We are experiencing a mismatch between the world's complexity and our own at this moment.

The observer of Tables 1 and 2, the reader of the foregoing Chapter 5.1, indeed any reader who has struggled through the entirety of this *Sustainability Concepts Paper*, will know the feeling. Kegan and Lahey go on to state the obvious:

> There are only two logical ways to mend this mismatch — reduce the world's complexity or increase our own. The first isn't going to happen. The second has long seemed an impossibility in adulthood.

The self-transforming mind, of course, is the actuality that breaks through the supposed barrier of the "impossibility". S/he who somehow cultivates a self-transforming mind becomes not just a leader, but a

[68] Rail passengers could witness the retired machinery just before entering the tunnel from the UK side.

[69] "Always Learning, Never Getting It Right" was the original title of what became "*Organising and Disorganising: A Dynamic and Non-linear Theory of Institutional Emergence and Its Implications*" (Thompson, 2008a).

"meta-leader", who "leads to learn" (amongst other talents). Hence we have the entry of such into Table 2, to accompany that of "Always Learning, Never Getting It Right".

We here might grant mental complexity the status of that of an axis for (T0), if it is to be an organizing thread of a sustainability assessment. It has three provinces, just as plotted, as three plateaus, along the axis of mental complexity in the Kegan-Lahey book:

- mental complexity, with provinces in ascending order of the socialized mind, the self-authoring mind, and the self-transforming mind

The self-transforming mind (Kegan and Lahey, 2009)

> is *wary* about any one stance, analysis, or agenda
>
> is mindful that, *powerful* though a given design might be, this design almost inevitably leaves something out
>
> is aware that it lives in time and that the world is in motion, and what might have made sense today may not make as much sense tomorrow.

Placing the "self-transforming mind" at the very top of Table 2 for the TBL_{future} signals approval of it as a desirable attribute. After all, once thus revealed to us, who would want to settle for the quiet life of the socialized mind (being a "faithful follower"), or even that of the self-authoring mind (basking in the contentment of having "learned to lead")?[70]

Situated appropriately adjacent to the thread of personal aspirations (thread (T1)) in Table 2, the self-transforming mind might approximate what Maslow (1943) had long ago intended for human motivation in his uppermost need of "self-transcendence". When therefore Kegan and Lahey (2009) write of the self-transforming mind as something that "holds contradictions", might this be what was to be sought under (T1), as here one of our greatest ambitions: a policy of re-engineering for CFG (IUWM, or IWRM) that brings with it appreciation of the "big picture" (thinking globally) and the inclination to debate the good or ill of sustainability? That is to say, given the Kegan-Lahey wariness of any one stance, analysis, or agenda, should we not be most wary of sustainability itself, as some "grand design" for everything? Thus derives the entry of "entertaining self-contradiction, including abandoning a line item, even 'sustainability' itself" into the topmost line (T0) of the TBL_{future} in Table 2.

We began our enquiry into the customs and conventions for assessing sustainability by looking to those line items of Tables 1 and 2 that come from the social sciences. We acknowledged their pre-eminence in legitimating what would otherwise have been the raw (brutish, for some) interventions of engineering and technology in moving circumstances away from unsustainability in the water sector and towards cities as forces for good in the environment. Now, towards the end of this chapter, we wish to reverse this precedence, to ask: how should the interventions of engineering and technology be fashioned in order to elevate our standing in respect of the existential thread of personal aspirations, of citizen participation, of social bonds, and of quality in governance? Such policies of re-engineering would be interventions beyond those of the internet and information and communication technologies (ICT), which so self-evidently are profoundly influencing social discourse and interaction. Innovations in ICT have a crucial role in arguably the most critical of all individual, personal aspirations, i.e., a grasping of the "big picture", with which indeed to debate the good or ill of sustainability itself. Achieving that would be no less, in some ways, than what motivated engineer Gantt in a bygone era (as reported in Florman, 1987). Yet fashioning those interventions we seek today should itself be shaped and guided by the concepts and practice of sustainability, as we see it today — perhaps better, if we are blessed with a self-transforming mind, as we might begin to imagine it for "tomorrow".

There is something troubling about all this, however. We have wrestled our way through the dense and expansive tangle of complexity about sustainability, to express Tables 1 and 2, as templates to be *followed*

[70] I have long thought the same about Cultural Theory (CT): that once revealed to all, could anyone then persist in being radically individualist about one thing, or rabidly egalitarian about another? Yes, I suspect, is the answer. In fact, all has now been acknowledged as revealed in Ingram and Thompson (2010). What Kegan and Lahey (2009) say of being "wary about any one stance, analysis, or agenda" has not escaped my notice either, in respect of the dominance of CT in this *Concepts Paper*. Elsewhere, Termeer (2009) seeks water experts who may become public leaders — leaders of movements who "want to make a difference". One imagines these individuals might need the self-transforming mind.

in moving matters away from unsustainability: as if a *routine* so perfectly made for the "socialized mind" — which we then rank as bottom-most in any personal aspirations an individual might have to better herself or himself. Is there a lack of humility about the supposed inspiration and creativity of the self-transforming mind? Or does it contain self-redemption within it, at its core, in its capacity to strike down the edifice it may so painstakingly have built up?

> Every so often, thou shalt abandon any one of the threads (T1) through (T14) and replace it with something other!

Should (T0) come with just such an invocation?

Chapter 6: Frontiers of Practice: Engine of Conceptual Change

In what has been essentially a *concepts* paper, how now should we best gauge the prospects for progress in the harsh, untidy world of *practice*? How should we bring down to earth all those exalted concepts and principles, such that they may be informed and *re-shaped* by practice?[71] How especially can such be achieved when the whole — of becoming less unsustainable about IUWM within IWRM — is arguably one of the most comprehensively multi-disciplinary matters of our times?

There is a danger here of being sucked into the vortex of attempting to write a manual of practice for the "whole of life". One can sense the same exasperation, if not exhaustion, in what Ashley *et al* (2008) say in their award-winning paper on sustainability in the water sector:

> Problems when devising sustainability criteria include the fact that they must encompass all aspects of human and natural systems if they are to truly relate to sustainability, and that they have disparate and incommensurate units of measurements.

The end is nigh, however. Just one more cycle in the argument of this *Concepts Paper* is to be executed.

We present our findings from a cursory search for evidence of who — which entities in the water sector — are in the vanguard, pushing at the forward-most, practical, operational boundaries of the ever-expanding purview of the (now) fifteen threads, (T0) through (T14). This, then, will be a brief narrative of the cryptic entries for the $TBL_{frontier}$ of practice in Table 3; and that should be the point of departure for re-shaping any next edition of a *Concepts Paper* such as this.

[71] Those who write from an academic background are usually persuaded by those who work in practice that theory and concept will be brought down when they meet the "real world". In a similar spirit, the feasibility of doing something about sustainability is often justified on the basis of this *not* requiring any uplifting "rocket science". Decisively to the contrary, sustainability should be a rocket science! For how otherwise are we to attract the very brightest and the very best to this field?

Meeting our charge will (again) hardly be any less daunting than what Ashley *et al* (2008) must have feared lay before them.

(T0) Our Topmost Line

We are mesmerized by the quest for change. "*Immunity to Change: How to Overcome It ...*" begins the title of the Kegan-Lahey book. In trumpeting the prize of attaining their self-transforming mind (which leads to learn), the self-authoring mind — which may have drawn you or me along in our having learned to lead — has become over-shadowed (and the socialized mind perhaps even more so). What Kegan-Lahey seek for the individual, hence unlocking the potential in "*... Your Organization*", is shared with the Society for Organizational Learning (SoL). "Leading and Learning for Sustainability" was the purpose of its November 2010 Workshop (www.solonline.org; accessed 13 November, 2010); "*The Necessary Revolution*" was the title of the book that was to support the Workshop (Senge *et al*, 2008).

The Australian Research Institute in Education for Sustainability (ARIES) at Macquarie University has published a case study on "Learning and Change for Sustainability at Yarra Valley Water" (Crittenden *et al*, 2010). The quest for change, in the view of the company's Executive Team, was to be delivered through "Organisational learning". Today, Yarra Valley Water has a Learning and Development Manager; Robert Wilson's skills encompass organizational learning, about which he writes professionally (http://search.informit.com.au; accessed 13 November, 2010).

(T1) Personal Aspirations

Few enterprises these days would declare themselves disinterested in the health of their employees, or their hygiene, security of employment, well-being, educational growth needs, and so on. The Sulabh Sanitation and Social Reform Movement of New Delhi, India (www.sulabhinternational.org), gives an extraordinary meaning to Maslow's notions of human motivation. Its achievements, and those of its founder, social entrepreneur and 2009 Stockholm Water

(T0) ORGANIZATIONAL LEARNING	Yarra Valley Water has a Learning and Development Manager; the company seeks change through organizational learning
(T1) Personal Aspirations	Sulabh Sanitation & Social Reform Movement (New Delhi, India) elevates women scavengers through the Nai Disha Rehabilitation Initiative to promenading the fashion catwalk at UN Headquarters
(T2) Citizen Participation	San Francisco Public Utilities Commission (SFPUC) holds itself accountable in respect of (a) engagement of stakeholders from conceptual stage of major planning programs and (b) feedback on this stakeholder input
(T3) Social Bonds	Severn Trent plc recognizes a number of community segments; Veolia frames multiple styles of management according to different ways or organizing; mutually benefitting synergy amongst Clean Water Services, Ostara, and the Clean Water Institute is the result of organizational adaptation and evolution
(T4) Quality in Governance	Nepal Water Conservation Foundation is pursuing a clumsy institutional structure for managing the Kathmandu-Bagmati system
(T5) Ethics and Equity	Sydney Water uses "inter-generational equity" as a matter of routine in assessing its projects; Cheryl Davis (employee of SFPUC) comprehensively addresses ethical dilemmas of water recycling
(T6) Valuation	Over 300 installations of its Water Health Centers signal the success of Water Health International's business model for bringing affordable, safe drinking water to small, scattered communities
(T7) Environment Within the Language of Business	
(T8) Supply-Value Chains	Some 50 cities committed to the UN Global Compact (with its protocols for protecting human rights); CH2MHill, Halcrow, GDF-SUEZ, and Athens (Greece) Water & Sewerage Company are signatories of the Global Compact's CEO Water Mandate

Table 3
Empirical evidence of who — which entities in the water sector — are in the vanguard, pushing at the forward-most, practical, operational boundaries of the ever-expanding purview of the Triple Bottom Line (TBL) accounting ($TBL_{frontier}$).

(T9) Commercial Sectors	Veolia Environnement offers itself as a sole provider of multiple services, such as management of water, waste, transport, and energy utilities; Veolia Water UK describes itself as a "Multi-utility Services Company" (or MUSCO)
(T10) Space	DHV Engineering Group (Consulting Engineers) "blurs the line between sewage treatment and river habitat" (between IUWM and IWRM) in re-engineering Soerendonk Sewage Treatment Plant; The Natural Step provided training for DHV employees
(T11) Life Cycle and Time	The Natural Step works with Yarra Valley Water on concepts and techniques of Life Cycle Analysis (LCA)
(T12) Function	Within IBM's Smarter Planet and Smarter City portfolio are various Smarter Water Management applications, including the SmartBay project of Galway, Ireland (www.ibm.com/smarterplanet; accessed 24 January, 2011)
(T13) Gauging Environmental Benignity	DHV Engineering Group's re-engineering of Soerendonk Sewage Treatment Plant generates rhythmic flow variations to enhance watershed ecosystem services. Ostara Nutrient Recovery Technologies, Clean Water Services (Durham, Oregon), and the British Columbia Conservation Foundation are partnering to issue recovered nutrient supplements to restore declining salmon populations. PUB, Singapore's National Water Agency, funds research into biomimetic membranes that seek to emulate behavior of micro-organism cell membranes (www.pub.gov.sg/ewi; accessed 24 November, 2010)
(T14) Cycling of Materials	Severn Trent plc bemoans the lack of policy joining up considerations of the carbon cycle with those of the water cycle; Resources Centres on Urban Agriculture & Food Security (RUAF) promote Sustainable Urban Nutrient Management coupling aqueous and nutritious human residuals

Table 3 (continued)

Laureate Dr Bindeshwar Pathak, seem to soar above the plain of aspirations many now take for granted.

His Laureate's presentation tells us this (www.siwi.org; accessed 17 November, 2010). The technologies of the Sulabh "twin-pit, pour-flush, compost toilet" and "public toilet complexes with biogas plants" were designed with the express intention of ending the "sub-human practice" of women scavengers obliged to clean bucket toilets and carry away their contents. Whatever the hegemony of better governance over any engineering interventions for enabling IUWM within IWRM, these were technological solutions (decisions $\boldsymbol{u}_{now}$) designed to eliminate a social problem. The women scavengers were lifted out of their almost unspeakable drudgery, taken through the Nai Disha Rehabilitation Initiative, and crowned (metaphorically and festively) by the President of India. Together with the celebrities of New York fashion models, they promenaded along the catwalk at UN Headquarters, in front of a backdrop of "Mission Sanitation". Their social status has been marvelously transformed and — one would like to presume — their personal aspirations too.

Pathak's innovation of the public toilet complex is "equipped with the provision of drinking water, telephones, laundry, health centres, lockers, cyber cafe, first-aid box, etc". One can only but conjecture whether individuals in such a "Happy Home" — his sobriquet, and the outcome of his tangible Acting Locally — were brought to a yearning for appreciation of the bigger picture (a Thinking Globally), hence to dispute the good (or ill) of sustainability and the relevance (or otherwise) of climate change, just as suggested by the iconic sketch of Figure B2.1 of Box 2.

(T2) Citizen Participation

Before the San Francisco Public Utilities Commission (SFPUC) consolidated expression of its 2008 "Sustainability Plan and Program" (SFPUC, 2008), gathered around the Triple Bottom Line, it had published an interim "Sustainability Plan" (SFPUC, 2006).[72] Community Issue CY6 therein shows empirical evidence of how affairs might be brought to climb the rungs of Arnstein's ladder of citizen participation.

Along this axis of CY6 — measuring the "extent and effectiveness of community consultation" — Indicator 2 was directed at "Timeliness", i.e., the "% of projects or major planning efforts where community input is sought ... at *early* or conceptual stages" [emphasis added] (SFPUC, 2006). Indicator 4 had to do with "Effectiveness": the "% of projects or major planning efforts where community input is received and *feedback* provided by SFPUC on how input has been taken into consideration" [emphasis added].

Adaptive Community Learning (Beck *et al*, 2002) starts by asking the community "What are your greatest hopes and worst fears for the future of your environment?", hence the sculpting of the green ovals in the "Futures" block of Figure 15(b) (and those in the upper right corner of the earlier Figure 2). This mirrors CY6 Indicator 2 of SFPUC (2006). Should SFPUC judge that it is doing well by its CY6 Indicator 4, however, that would be to have gone in practice beyond any of the theory of Adaptive Community Learning. One cycle from "Society" to "Society" would have been traversed in Figure 15(b). And perhaps from this one cycle alone, all — SFPUC and its entire community of stakeholders — would have exited from Figure 2 at its lower left corner with a socially more legitimate $\boldsymbol{u}_{now}$. Steps up Arnstein's ladder would have been taken.

In their case study of the Yarra Valley Water (YVW) company, Crittenden *et al* (2010) begin by observing that:

> Since 2003 YVW have developed and integrated a number of sustainability tools and approaches, including The Natural Step [www.naturalstep.org], Life Cycle Analysis and stakeholder consultation, to support more effective decision-making at all levels of the organisation.

What the "systems thinking" of The Natural Step (TNS) Framework offered the company was crucial, but then once grasped, frustrating (Crittenden *et al*, 2010):

> MD Tony Kelly, expressed this as:
>
> *Where we struggled with TNS is that it really didn't help us work out what we had to do on Monday. They gave us the beacon on the hill which was the thing to aim for* [the green ovals of aspirations at the upper right corner of Figure 2], *which was great and the principles are very sound I think, but after 18 months an*

[72] With its broad, *un*consolidated kaleidoscope of assessment dimensions, SFPUC (2008) can be read as the qualitative counter-point to the quantitative, all-encompassing, distillate of a single, scalar index (TBL_{∞}) derived in Krajnc and Glavič (2005).

unanswered question for us was "What are we going to do tomorrow?" [how do we exit from the lower right corner of Figure 2?].

(T3) Social Bonds

Severn Trent was an early leader amongst comparable water utilities in respect of sustainability performance and assessment. In 2005 it was ranked first in this category for a fifth year in a row according to the Dow Jones Sustainability Index (Severn Trent, 2006). Like its peer water businesses, Severn Trent well appreciates the significance of "community", segmented for them into the groupings of suppliers, customers, employees, government regulator, socially responsible investment asset managers, and so on.

In Veolia's 2008 "Annual and Sustainability Report", the company talks of a "partnership model that fosters sustainable development" (Veolia, 2008).[73] It goes on to draw a two-dimensional plot, delineated by axes of competition (all-none) and public-private, upon which it then locates four styles of management model: "public management"; "municipal companies"; "public-private partnerships" (Veolia's preferred style), and "privatization". The sketch smacks of Figure 3, at the core of the way social bonds are to be construed and counted in assessing sustainability. Veolia might here be said to be taking empirically observed styles of management, as they have evolved naturally in practice, and plotting them on a conceptual 2-D grid, thus to understand and succinctly define them — for its community of stakeholders, in its turn, better then to comprehend them. The public-private axis of Veolia's 2-D grid, however, provides no scope for plotting the emergence into practice of so-called Public-Social-Private Alliances (PSPs). There is no conceptual place for the "Social" segment thereof. Had this third way of organizing and acting been acknowledged, the resulting 3-fold categorization should have yielded up other, additional styles of management.[74]

These entities of organized individuals are not static. They may evolve into, give birth to, and merge or partner in changing ways with other entities. In 1970, ten cities and sixteen sanitary districts in Oregon, USA, formed what was then called the Unified Sewerage Agency; the Agency was subsequently renamed Clean Water Services (CWS) in 2001 (wikipedia, Clean Water Services; accessed 26 November, 2010; www.cleanwaterservices.org). CWS is a public-sector utility for handling stormwater and wastewater. In 2007, reconstruction began at Clean Water Services's Durham wastewater treatment facility. A nutrient recovery facility, invented and marketed by Ostara Nutrient Recovery Technologies (www.ostara.com; see also Britton *et al*, 2007), was being introduced. Ostara, as a private-sector business, was established in 2005; it sells the Crystal Green® slow-release fertilizer that is thereby recovered from its technologies. Clean Water Services has since developed the related WASSTRIP process, which is to be partnered both technically and commercially with the Ostara reactor — a public-private partnership in some sense, therefore. The Clean Water Institute™ (CWI) (www.cleanwaterinstitute.org) came into being in late 2009, when it was incorporated. It is a not-for-profit organization, with a vision that "looks 50 years down the road"(www.cleanwaterinstitute.org; accessed 24 November, 2010). Its purpose *inter alia* is to generate and hold the intellectual property that benefits from the Institute's access to the everyday practice of its public-sector counterpart (Clean Water Services).

From this interaction between theory (CWI) and practice (CWS), as it were, flow the financial incomes from their partnership with the private-sector entity (Ostara). And these incomes in turn support the existence of the not-for-profit Clean Water Institute™, notably in employing those who invent the intellectual property, provide the education, and so on (and on). To some, this cluster of CWS-Ostara-CWI would doubtless evoke the label of a virtuous circle amongst the "triumvirate" of public, private, and not-for-profit

[73] Phrasing is significant. Here, the very merger of the two (Annual Report; Sustainability Report) was strategically important for Veolia that year. Previously, 2006 marked the year when Severn Trent replaced its "Stewardship" report, which it had published annually since 1999, with the first of its "Corporate Responsibility Reports".

[74] These PSPs were cited in a session on social entrepreneurship in "Accelerating Innovation in the Water Sector", a Workshop held at the (September) 2010 IWA World Water Congress (Montreal, Canada). They were cited, moreover, in association with the work of Dr Bindeshwar Pathak (above).

partners. It seems an exemplary case study in how a way of organizing — and a structure of governance — can enable innovation in the re-engineering of city infrastructure. This Clean Water cluster has created for itself a way of partnering (a synergy) mutually benefitting each of the three separate entities within the cluster.

In these three illustrations of the $TBL_{frontier}$ for the current thread of (T3), i.e., Severn Trent, Veolia, and the Clean Water cluster, we find a variety of ways of organizing. One, notably that of Veolia, hints at the typology of Cultural Theory (so prominent in the TBL_{future}), but is surely not congruent with it. Another (Severn Trent) points to a quite different mapping and segmentation of groups within society.

The boundaries being drawn (by Severn Trent) around the social groups of asset managers, suppliers, customers, employees, etc, differentiate them according to the nature of their *functional* relationship with the given company, in particular, their financial relationship. The company is aware of how then it must attend to the different dimensions of well-being respective of each. From these follow considerations of the desired codes of ethics and equity that the business may choose to apply to each such relationship (as (T5)), in particular, in respect of suppliers along the supply-value chain (witness the Global Reporting Initiative and Global Compact of (T8) below). These are not, therefore, lines drawn across and within Society to mark out how groups of individuals bind themselves to one another in solidarities according to their differing world-views, including those on the Man-Environment relationship. You or I may belong to any one of these groups. But we do not necessarily choose to be a "supplier" on the basis of this group of like entities being egalitarian in outlook, say, because you or I may be likewise egalitarian in stance on the relevant issues at stake. We might, of course, choose to be a company's supplier for such reasons, just as we might choose (or decline) to join the ranks of that company's customers (or employees) according to a resonance between "our" and the "company's" attitudes towards the Man-Environment relationship (in Figure 3).

In practice, there is a multitude of ways of associating, and of entering into relationships with other entities — so much so, that we have been obliged to use the rather abstract phrase of "entity" in order to embrace them all. Groups will have *their* own say in any debate over *their* respective hopes, fears, and aspirations for the future. They do not present themselves at the table of debate as the *I* (individualist), *H* (hierarchist), or *E* (egalitarian) voice we now know so well; they do not see themselves as necessarily entering into a debate in the first place. They do not have an *I* or an *H* or an *E* emblazened on their foreheads, as they rise to have their say.

(T4) Quality in Governance

The city of Kathmandu, Nepal, is situated on the Bagmati River. In the two decades between 1981 and 2001 the population of the Kathmandu Valley more than doubled from 0.76 million people; and given the high in-migration since (of Nepalis fleeing the Maoist insurgency), the population is currently (2011) estimated to be close to 3 million. As a result,

> You don't have to be a trained ecologist to know that the river is polluted.

says a study of the Nepal Water Conservation Foundation (NWCF, 2009). The Bagmati river itself flows through the three districts of Kathmandu, Lalitpur, and Bhaktapur. There, the unique Bagmati civilization has flourished; and to this civilization, the rivers and tributaries of the Bagmati watershed are sacred. The same NWCF (2009) report goes on to state:

> [W]ater quality near the shrines of Pashupati, Sankhamul and Teku, places where people offer prayers and carry out rituals like funerals and bathing, has degraded.

It provides photographic material indicating the restrained under-statement here of the word "degraded".

In November, 2008, the Foundation hosted a stakeholder meeting. Representatives from the watershed's five municipalities were present, as were members of civil society, graduate students, media persons, water resource experts, environmentalists, community leaders, and non-governmental organizations (NGOs) — all as segments of society arising entirely naturally in practice. Now they were indeed entering into a debate.

The report maps their "plural perceptions" onto an unlabeled 2-D grid immensely suggestive of Figure 3. This plotting assigns the groups of media persons and graduate students to a quadrant with a very strong hint of the individualist (*I*) about it; elsewhere, as another

illustration, the collective perceptions of four other groups of stakeholders are lumped together as though those suggestive of an egalitarian (*E*) solidarity.

If the Foundation were to recognize where on Figure 17 might reside the deliberative quality of the governance it might hope to bring to bear on the Kathmandu-Bagmati system, things could be on the brink of some forward, if clumsy, momentum (for a while). A policy prescription ($\boldsymbol{u}_{now}$) — once more an exit from Figure 2 at its lower left corner (the one routine step tomorrow) — could then be accorded a degree of {social legitimacy} for its having emerged from something at least better than closed hegemony (Box 4). Multiple actor-voices were granted access to the stakeholder meeting, although we cannot tell whether each responded to any or all of the others.[75]

From an account provided subsequently by Gyawali (2010), here interpolated on the basis of the empirical 2-D mapping of NWCF (2009) (and reported in passing in Beck *et al* (2011b)), the outcomes would appear to have been these:

(G1) the water experts, environmentalists, NGOs, and civil society — collectively the *E* solidarity — got much of what they wanted;

(G2) the municipalities and ministries (jointly the *H* solidarity), did not get a great deal, but neither did they have to cede what they really would have wished for — they could still hold fast to an incremental nearing of their (ultimate) hope for a major inter-basin water transfer;

(G3) the media persons and graduate students (*I* solidarity) essentially got nothing of what they wanted, although they may putatively have gathered up some crumbs of comfort from around the table of the debate — on this account, they ought to be the most disgruntled group and, therefore, most likely to force changes upon the debate in a while (Δt); and

(G4) the apparently fatalist-like (*F*) community leaders and general public were left, as the theory would tell us, stuck in their "apathetic doldrums" (the rubric of their quarter in the 2-D grid of NWCF (2009)), with neither audible approval from them of the $\boldsymbol{u}_{now}$, nor complaints of which anyone else would take heed.

This is conjecture. Yet it is nevertheless the closest approximation of $TBL_{frontier}$ (Table 3) to TBL_{future} (Table 2) in the playing out of this particular thread (T4).

(T5) Ethics and Equity

The cell for our entry on this line item of the TBL_{now} in Table 1 is vacant. In contrast, its counterpart in Table 3 is brim full of entries. Some candidates for entry have even been deferred instead to thread (T8) below (on supply-value chains). Water utilities and businesses consider they owe a good deal in practice to those with whom they have a relationship. In return, they can expect — and do expect — certain things in the conduct of their suppliers (under (T8)). Conversely, these considerations of the ethics and equity in looking outwards beyond the "factory fence-line" have their uncommon reflections when turned inwards, onto the conduct of we engineers and water professionals (within a utility).

To begin, technology is today such that water can be so comprehensively purified as to become devoid of its taste and smell, in ways sufficient to affect the aesthetics of consuming wholesome and healthful potable water and the ethics of its being supplied. Indeed, so successful can the technology be that there are businesses with an interest in producing and marketing minerals for re-introduction into the thus purified water, to re-balance its taste, its wholesomeness, and its healthfulness, with an express view to preserving equity in supplying water to customers and consumers.[76] No member of a community should be discriminated against on the basis of the (varying) taste of drinking water (or its wholesomeness and healthfulness), not least when provided by one utility obliged yet to access a variety of

[75] Coincidentally, it appears that the portfolio of prospective technologies in this Kathmandu-Bagmati system (the red rectangles in Figure 2) might even have been inspired by much of what has been expressed here of CFG, in particular, through the case study of the Atlanta-Chattahoochee system in Chapters 3.3 and 3.4 (Beck *et al,* 2011a; NWCF, 2009).

[76] This was conveyed to me as a personal communication from Dr Martine Poffet, Switzerland (at the September 2010 IWA World Water Congress in Montreal, Canada).

raw water sources and applying a variety of purification procedures to those heterogenous sources.

Elsewhere, Sydney Water has for some time had an "Ecologically Sustainable Development (ESD) Policy", duly aligned with various Australian federal and state government policies (www.sydneywater.com.au; accessed 19 November, 2010). "Inter-generational and intra-generational equity" is one of the Policy's four Principles. It is applied as a matter of routine, for example, to evaluation of the sustainability of the Hoxton Park recycled water scheme (Sydney Water, 2007). There, 16,000 dwellings were to be served with recycled water for toilet flushing, outdoor use, and washing machines.

Writing of her first-hand, in-service experiences of the "Ethical Dilemmas in Water Recycling", Cheryl Davis (an employee of SFPUC) observes (Davis, 2008):

> As professionals in the water industry, we often perceive ourselves as upright people seeking to serve the common good, producing high-quality water to support commerce and protect public health. Although not generally a flamboyant or self-dramatizing group, sometimes those of us who support increased use of recycled water may even detect a quiet heroism in our battle against public ignorance, government inefficiency (or even corruption), and/or corporate greed. We may be more inclined to congratulate than doubt ourselves when rallying behind a cause which seems to offer so many benefits for both humanity and the environment. Recycling advocates, whose competence and motivations are often questioned by others, can end up feeling defensive or even self-righteous; this does not contribute to a spirit of open inquiry about possible ethical dilemmas.
>
> But in a complex world rife with competing values, only a zealot could avoid noticing that the right path sometimes becomes unclear — not because one wishes to do wrong, but because there are so many competing goods. The technical, legal, political, economic, regulatory and environmental challenges of water recycling are such that there is a tendency to ignore or over-simplify ethical issues. We are tempted to pretend (both to ourselves and the public) that there is a scientific, legal, or economic answer to every question. We are often more comfortable speaking in technical terms (where we are the experts) than in terms of values, which put us on a more level playing field with the public and other stakeholders. As a result, the values imbedded in our recommendations may not be clearly articulated or openly discussed.

For we engineers and water professionals this is telling — in fact, salutary.[77] The message is hammered home (Davis, 2008):

> Jack Ward Thomas has commented on the aversion of resource professionals to acknowledge their own values in policy discussions with the public. He believes there is no way to avoid emotions in important resource management decisions, and that "avoidance of expressing values — other than to indicate unmitigated reliance [on] dispassionate science" results in "persistent miscommunication between professionals and the public." He observes that "We speak calmly in science. The public speaks passionately in values." He believes that when professionals express their own values, they use a language that is more widely understood, resulting in communication that is not only more effective but more ethical: "Personal and professional integrity are more fully aligned when passions are expressed alongside science."

Our interactions with water, its supply, its infrastructure, and its source in the environment, are personal, wistful, lyrical, spiritual, and intimate matters. They are quite unlike the ways we interact with energy or transport systems, for example. Here, in respect of ethics and equity (T5) — as well as along other threads of the $TBL_{frontier}$ falling within Davis's experience at the "sharp end" of practice (Davis, 2008) — there is hard-won empirical wisdom to be put to work in shaping and re-shaping the conceptual threads of the TBL_{future}.

(T6) Valuation

Throughout the ages, people have settled where once there must have been a sustainable source of water to drink. Today, that water may still be available, but of unsafe quality. The intent of the business model of

[77] I have a sound appreciation of this. And with some irony, as Box 4 (from Chapter 4.2) has already revealed (see also Beck *et al*, 2011b; Hare *et al*, 2006).

Water Health International (WHI; www.waterhealth.com) is to (Bhatnagar, 2010):

> Bring Affordable Safe Drinking Water to populations through a low cost decentralized model using state of the art operations and technologies.

It takes technology to render water safe for consumption, as we now readily appreciate, be it high, low, appropriate, or whatever fervently promoted style of technology. WHI declares itself to be resolutely pragmatic and "Technology Agnostic". Its installations, called Water Health Centers (WHCs), are decentralized because settlements themselves are scattered and of all shapes and sizes. Users of WHCs are customers, not aid-recipients; they are not obliged to purchase their water from a WHC; its water might not meet customer preferences for taste; and WHC management can be held to account, since dissatisfied customers will not return. Cost per head of population for installing a WHC is (Bhatnagar, 2010):

> very low, a fraction of what was calculated by the World Bank in connection with the Millennium Development Goals.

WHI's business model bears all the hallmarks of a successful, straightforward valuation V_C of classical economics. It is customer-focused and it happens to be a hi-tech solution: of dual-media and activated carbon filters; and of remote sensing and automation, with smart-card technology — a merger of the styles of SiB and D&C (from Box 1). But it values just what lies in the short arc from water source to tap in IUWM. The business model works. Currently, there are some 325 WHCs across India, the Philippines, and Ghana.

Thinking outwards in wider circles, Environmental Management Pty Ltd of New South Wales, Australia (www.environmentalmanagement.com.au; accessed 21 November, 2010) "provides services in ecological economics and water studies", specifically in respect of "total watercycle management" for "various urban projects". In our terms, this would be valuation according to V_X.

(T7) Environment Within the Language of Business

A Google search on the combination of words {"biodiversity" "business risk" "water utility"} yields sites celebrating the language of business: www.ecosystemcapital.com and www.ecosystemmarketplace.com (both accessed 20 November, 2010). The former provides feeds to "environmental markets and finance news". The latter, a charitable organization, has published a Primer on "*Payments for Ecosystem Services: Market Profiles*" (Forest Trends and the Ecosystem Marketplace, 2008): "market description" identifies "Water Quality Trading markets"; the "Market Size" was projected to be "over $500 million" in 2010; and the "Market Players" comprise "buyers" such as the owners of urban wastewater treatment plants and principally farmers as the "sellers".

If our interpretation of the Google search is accurate[78], the forestry sector seems presently to be better attuned to evaluating ecosystem services than the water sector. In February, 2011, the Governor of the State of Georgia was handed a large check for $37B in recognition of the contributions to the State's economy of non-timber ecosystem services from private-sector forests, i.e., water filtration, carbon sequestration, and habitat preservation (Moore *et al*, 2011; see also http://www.youtube.com/watch?v=h80feaYX2mk). Amongst these various services, those for "water regulation and supply" could be quite the most valuable — possibly in excess of $8000 per acre, depending on forest characteristics (Moore *et al*, 2011).

(T8) Supply-Value Chains

The Global Reporting Initiative (www.globalreporting.org; accessed 23 November, 2010) has sought to bring consistency of routine to assessments, through what it asserts is "the world's most widely used sustainability reporting framework". One of its six blocks of sustainability indicators addresses Human Rights (HR), in particular, their protection in the Investment and Procurement Practices of any entity involved in

[78] It would seem so. Only in April, 2011, did the World Business Council on Sustainable Development publish its *Guide to Corporate Ecosystem Valuation* (WBCSD, 2011). The *Guide* is a "guide" because "[t]he concept of ecosystem valuation is new to many businesses". Two out of 15 of the so-called "Road Tester" businesses of the *Guide* are in the water sector.

procurement. Performance indicator HR2 gauges this, through the:

> Percentage of significant suppliers and contractors that have undergone screening on human rights and actions taken.

Commitment, as opposed to consistency, is sought from the UN Global Compact (UN Global Compact, 2008; www.unglobalcompact.org; accessed 24 November, 2010):

> Launched in July 2000, the UN Global Compact is both a policy platform and a practical framework for companies that are committed to sustainability and responsible business practices. As a leadership initiative endorsed by chief executives, it seeks to align business operations and strategies everywhere with ten universally accepted principles in the areas of human rights, labour, environment and anti-corruption.

The two, the UN Global Compact and the Global Reporting Initiative, are pledged to collaborate more closely (www.globalreporting.org; press release of 28 May, 2010):

> In addition to creating a reporting framework that will be implemented universally, the new collaboration is also intended to provide a benchmark for financial analysts and other stakeholders to better analyze and identify risks and opportunities as they relate to environmental, social and governance (ESG) issues.

Cities may commit themselves to the Global Compact. When accessed on 23 November, 2010, just under 50 were listed as having done so. Thus may mayors "call the shots" over those who dig the trenches for laying and re-laying the city's sewer pipes, not only in respect of the protection of human rights, but also in the city becoming less unsustainable more generally.

Likewise may purchasing power be exercised back along the supply-value chain by those chief executive officers (CEOs) who have committed their companies to the Global Compact's "CEO Water Mandate". Amongst some 70 signatories (on 23 November, 2010), CH2MHill (consulting water-related engineers), Halcrow (consulting water-related engineers), GDF-SUEZ (water, energy, transport utility), and the Athens Water and Sewerage Company (of Greece) are the most obviously focused on the water sector. As signatories to the Global Compact, all are bound to submit an annual Communication on Progress.

In sum, "Responsible Excellence Pays!", claims Claude Fussler in the title of a 2004 article (Fussler, 2004). For having asked (Fussler, 2004)

> How would a fund, solely based on Global Compact signatories, reward its investors compared to a fund of no-signatories?

he finds that:

> ... this group of 76 [Global Compact Signatories] outperformed the mainstream MCSI by 3.7% over the three-year period between June 2001 and June 2004.

Again, from our (principal) sectoral standpoint of water, Veolia Environnement numbers in the "group of 76". Fussler (2004), then, has been raising the volume of his voice in our "language of business". His analysis has been re-affirmed. A more recent review of the approach of Sustainable Asset Management (SAM) to Sustainability Investing, in which accounting for a firm's intangible assets is integral and key (see also Dyllick and Hockerts, 2002), finds a "positive relationship between sustainability and financial performance, as measured by stock returns" (de Groot and Churet, 2009).

Power and influence over more than money flows back along the supply-value chain. At the Copenhagen Climate Summit of December, 2009, Paul Polman (CEO of Unilever) and Muhtar Kent (CEO of Coca Cola) were prominent in the publicity and discussion given to carbon emissions and consumer goods supply chains. An article from *BusinessWeek* at the time (17 December, 2009) calculated that

> ... consumer goods companies' full supply chain represents as much as 5 billion tons of CO2 emissions globally [which could] mean in excess of over $100 billion of value ...

Amidst these large, high-profile numbers — tied to the cutting edge of carbon-trading and global climate change — water can get submerged. Thus was "Exploring the Forgotten Water Footprint" the topic of a February, 2010, business meeting (www.greenbiz.com; accessed 24 November, 2010). Speaking there of the (2007) "Global Water Tool" of the World Business

Council for Sustainable Development (WBCSD), Jan Dell of CH2MHill was driven to wonder:

> [Because] the world has been so focused on counting carbon emissions, we're concerned that in our race to low carbon energy, have we forgotten about water along the way?

(T9) Commercial Sectors

Municipalities everywhere have multi-sectoral public utilities departments. The San Francisco Public Utilities Commission (SFPUC) is one such, catering for water, waste, and energy. At the leftward (public) boundary of the axis for public-private management models in the 2-D grid of Veolia (2008), lies public management. Moving to the right, this is succeeded in turn by municipal companies, public-private partnerships (PPP), and then privatization at the rightward boundary. With its preferred PPP model (Veolia, 2008):

> Veolia Environnement draws on its experience of public-sector management to offer tailor-made solutions to companies in the industrial and tertiary sectors. These markets generated revenue of about €10 billion in 2008. Thanks to our ability to generate synergies between our four divisions [water, waste, energy, transport], we offer a wide range of integrated management solutions. These "multiservice contracts" offer a combination of services provided by several divisions, enabling us to cater for the needs of clients who want to outsource a wide range of tasks to a single service provider. This market is growing by over 10% a year, bolstered mostly by the trend for outsourcing.

From its historical roots in the water sector, it is entirely conceivable how a water-sector enterprise — echoing the "I" for Integrated in IUWM within IWRM — will make a commercial success of a running a multi-sectoral enterprise, quite possibly well beyond the water, energy, food, forestry, and waste-handling sectors of Villarroel Walker's Multi-sectoral Systems Analysis (MSA; Villarroel Walker, 2010; Villarroel Walker and Beck, 2011a).

The ambition for this thread of the $TBL_{frontier}$ (in Table 3) looks well ahead of whatever might have been theorized about (T9) in the corresponding line item for the TBL_{future} (in Table 2). Specifically, Veolia Water UK sees itself today as a "Multi-Utility Service Company (or MUSCO)" (www.veoliawater.co.uk; accessed 16 May, 2010).

(T10) Space

Developed and promulgated by The Natural Step (www.naturalstep.org), The Natural Step Framework, "is a comprehensive model for planning in complex systems." The Framework (www.naturalstep.org; accessed 7 August, 2010):

> ... has helped many hundreds of different organisations around the world integrate sustainable development into their strategic planning and create long lasting transformative change.

The following headline for one of its reports (29 June, 2010) is transforming indeed:

> DHV engineering blurs the line between sewage treatment and river habitat

Taken at face value, these words embody a vision of the spatial interpretation of IUWM within IWRM. They also intend that, in text and by acronym, the whole might evolve to become not just IUWM-IWRM, but yet IUWWRM. Thus The Natural Step's news bulletin enquires (www.naturalstep.org; accessed 7 August, 2010)

> [C]an a sewage facility actually help to enhance the health of natural systems?

and then responds and records these changes:

> These new possibilities are now on display at the sewage treatment plant at Soerendonk today. The facility now includes a 9 hectare, €1.2 million (22 acre, US$1.4 million) addition that consists of ponds, marshes and canals filled with aquatic vegetation that blends into the existing river ecosystem. The final pond along the riverbank is designed to be inundated during floods, and during dry seasons, a fish ladder provides a way for fish to spawn in the sewage facility's final pond. In this way, the line between the "treatment plant" and the "natural ecosystem" is intentionally blurred, providing a benefit to both systems.

(T11) Life Cycle and Time

"In My End is My Beginning" writes Oppenheim (2010), by way of an update on the *practice* of eco-effectiveness (as inspired by McDonough and Braungart (2002)). In the cradle of the life cycle, new ways of engineering city infrastructure with new technologies are nurtured (see www.designlondon.net, for example, for a water sector example — the LooWatt (www.loowatt.com) — cited by Oppenheim).

At the September 2010 (Montreal) IWA World Water Congress, a group of water industry professionals organized a Workshop entitled "Accelerating Innovation in the Water Sector". Speaking of "One Utility's Journey", Jonathan Clement, Director of Strategic Business Development, PWN Technologies, the Netherlands, observed that PWN is a rare entity — others were heard to say "very rare indeed". Numbers substantiate this observation (Daebel, 2010; here paraphrased):

> Venture capitalists normally invest their funds in as many as one out of 100 proposals that pass across their desks; we at Emerald Technology Ventures might invest in at most one out of every 200 water-sector proposals we see.

In the life cycle of companies, the birth-rate of new technology enterprises in the water sector is strikingly low.

Beyond organizational learning (T0) and the obvious influence of The Natural Step Framework (in respect here of (T2) above), the experience of Yarra Valley Water (YVW) has one further contribution to make to the $TBL_{frontier}$, specifically in respect of the life cycle (Crittenden *et al*, 2010):

> The selection of the pressure sewer system rather than more traditional technologies in the Gembrook project came about as a result of the use of LCA [Life Cycle Analysis] and was associated with significant environmental, social and financial benefits over its life cycle. The Gembrook project provides a tangible example of how cultural change combined with the appropriate sustainability tools can create significantly improved business and sustainability outcomes.
>
> In the old YVW culture, where new ideas were considered risky and actively discouraged, technical assumptions such as these[79] would be less likely to be scrutinised. Indeed, behaviour that challenges assumptions and the status quo would typically be actively discouraged.

Entirely deservedly — but technically incorrectly — Crittenden *et al* (2010) record the fact that in 2008 Yarra Valley Water was awarded the:

> Sustainability Specialist Group Prize for Research Excellence (runner up) by the International Water Association.

The award was *not* for "Research Excellence", but for pioneering achievement in *practice*. Its "runner-up" status was shared with a fellow Australian project; and both were runners-up to the success of yet another Australian project.

(T12) Function

We know that civil engineering projects have historically allocated much effort and thought to planning, design, and construction, while abandoning all subsequent stages to a much less fully thought-through fate. The way things can be operated is liberated or constrained by what has gone before in the life-cycle. The bull of the city in the china shop of the restored watershed should be endowed with intelligence and the deftness of metaphorical movement for yet expanding the shop's operations (Chapter 3.4) — the epitome of "smartness", then, about the city.

There is considerable contemporary interest in this notion (of smartness). Writing of the "Anatomy of a smart city", however, Heather Clancy cites nothing of the water sector in what she has culled from the source document from Forrester Research (www.smartplanet.com; article posted by Clancy on 30 November, 2010; accessed 4 December, 2010).[80] In a 7-page IBM Software Solution Brief of September, 2010, on "Smarter cities and smarter buildings for a

[79] These were the "historical technical assumptions that bigger is better and a centralised system is easier and cheaper to maintain" (Crittenden *et al*, 2010).

[80] "Getting Clever About Smart Cities: New Opportunities Require New Business Models", Belissent, J (with Mines, C, Radcliffe, E, and Darashkevich, Y), Forrester Research (www.forrester.com; article posted 2 November, 2010).

smarter world", the word "water" appears some 15 times, that of "wastewater" just twice. A bit like the pantomime donkey — stumbling and lurching about the theater stage, animated by one person at the front and another at the back — our bull risks acquiring smartness and deftness only in its fore-quarters, on the upside of the city in respect of its intake of daily water. Yet Figure 1 shows that all the strategic, structural re-arrangements needed for the city to become a force for good in the environment should occur in its downside infrastructure: smartness about its hind-quarters, if anything.

The gulf between this practice here of the $TBL_{frontier}$ and its companion projection of the TBL_{future} for thread (T12), into some higher realm of possibly effete, conceptual subtlety and complexity (witness the discussion of it in Chapter 5), seems as great as it ever was three decades ago (Beck, 1981).[81]

(T13) Gauging Environmental Benignity

Just as The Natural Step (TNS) was brought into Yarra Valley Water to effect change, so was its goal in entering engineering firm DHV (www.dhv.nl). Fifteen employees of DHV participated in a TNS certification course focused on the cradle-to-cradle concepts of McDonough and Braungart (2002). Taking up again the news bulletin on the Soerendonk wastewater treatment plant in the Netherlands, this is how TNS reported their impact on DHV (www.naturalstep.org; accessed 7 August, 2010):

> The change has been a deep one, as Hans van Sluis, senior advisor on vitalization of water at DHV notes. "The effect of this change in our way of thinking about sewage treatment has been fundamental. We now look at sewage treatment not as a necessity to reduce pollution and safeguard health but as a chance to enhance ecosystems and the related service provision."

On its own website (www.dhv.nl), DHV's briefing note on "Revitalizing effluent for STP Soerendonk" reveals the kernel of something more:

> A three-stage ecological filter [daphnia ponds, reed marshes, fish pond] — based on the *water harmonica* principle — removes the last remaining bacteria and pathogens and inoculates the treated effluent with appropriate surface water flora and fauna species.

Upstream of the first of these stages

> A flowformcascade is placed between the 'concrete' sand filters and the Daphnia ponds of the 'green' section [of the STP]. Flowforms ... evoke a rhythmical flow, which mimics a meandering river. ... [A] stimulating effect on the downstream ecosystems development is expected.

The alignment between this element of the $TBL_{frontier}$ for (T13) and that of the TBL_{future} is remarkable, and quite unexpected. What Soerendonk realizes in practice and in space, encapsulated in the words rhythm, meandering, and *harmonica*, so Chapter 3.4 imagines in concept and in time — spectrum and intermittent supplements — in the culmination of the computations for the R M Clayton facility in the Atlanta-Chattahoochee system. The one seeks to enhance ecosystem services in practice through inoculations of biological species from the treatment plant (Soerendonk; practice; $TBL_{frontier}$); the other imagines doing so through nutrient supplements (Atlanta; theory; TBL_{future}).

Yet more remarkable and just as unexpected, the notion of "nutrient supplements" is no figment of the imagination. It is an empirical fact; and has been for quite some time. "Fertilizers Boost Declining B.C. Fish Populations" runs the headline of an article by Randy Shore from the *Vancouver Sun* (British Columbia, Canada) of 14 February, 2011 (Shore, 2011; posted at http://www.ostara.com; accessed 9 January, 2012):

> Young steelhead and salmon grew dramatically in streams seeded with sacks of slow-release fertilizer, a method that shows real promise to help rebuild collapsed spawning populations, according to B.C. biologists.

[81] Still we can read the following, as one of the main "*Messages for Financiers*" from the UN's World Water Development Report 3 (WWAP, 2009b): "There is an imbalance between funding for capital investment — which is more attractive to external financiers — and funding for operation and maintenance (O&M), which tends to be deficient. To fund O&M, tariff revenues need to be enhanced and budgetary transfers provided on a more solid and predictable basis".

> The method has proven effective at improving steelhead growth and survival in Vancouver Island streams in programs dating back to 1989.
>
> Fisheries biologists are using fertilizers to replace the nutrients that would be added to the stream naturally by the rotting carcasses of fish that die after spawning ...

The "slow-release fertilizer" is the Crystal Green® product of Ostara Nutrient Recovery Technologies from the CWS-Ostara-CWI triumvirate of public, private, and not-for-profit partners of (T3) above. "The Ultimate Recycling" was the accolade accorded to this by Force (2011) in the magazine *Treatment Plant Operator*, followed by the qualification:

> An Oregon plant uses a proprietary process to extract nutrients from wastewater and uses them for salmon restoration and a high-quality fertilizer.

Irony, if not disbelief, is in the air. Here again is Force (2011), quoting Rob Baur, senior operations analyst of CWS at the Durham, Oregon facility:

> For 35 years, I've been removing phosphorus and ammonia from wastewater. It's hard to believe that now I'm putting them back into a river.

Timing, with a due hint of spectrum, is all. The supplements are not intended to be issued for ever, but for the decades it may take to restore historical, naturally evolved fluctuations in year-to-year salmon spawning. They are issued in phase with the seasons, coincident with "the descending limb of the spring hydrograph" at the turn of spring/summer (Pellett, 2010). The slow-release feature is crucial, since experience shows that the artificially elevated stream P concentrations should persist for some 90 days; and since the rate of release of P from the Crystal Green® product is relatively fast (in comparison with some of the alternatives), fresh supplements are placed twice in the stream, 45 days apart (Pellett, 2010).

Here we have the quintessence of mutually re-invigorating progress from the intertwining of concept and practice. It feels uplifting, as any rocket science should be. The City as a Force for Good (CFG) in the environment is not as far-fetched as one might have supposed.

(T14) Cycling of Materials

In 2005 Severn Trent published the results of an assessment conducted by the (UK) Carbon Trust of this water/waste utility's carbon-cycle footprint (Severn Trent, 2005; available from www.severntrent.co.uk). In a "closing reflection", we find a significant lack of "joined-up" thinking about the carbon and water (hydrological) cycles (Severn Trent, 2005):

> Each sector of UK society needs to bear an appropriate level of responsibility for reducing greenhouse gas emissions. Whilst Severn Trent Water and Biffa are prepared to contribute to reducing the UK's total emissions, it is clear that current water and waste policy is driving our emissions profile in the wrong direction.

It is not as Jan Dell of CH2MHill has put it — that the strength of the global focus on the carbon cycle has merely blinded us to the urgency of matters of the water "cycle" (including blinding us to the possible synergy of joint water-carbon policy interventions) — but that there is the danger of policy antagonisms. This is not the kind of enabling governance to be sought for re-engineering the multiple infrastructures of the city in a less unsustainable manner.

At a very different scale, Issue 23 (April, 2010) of the *Urban Agriculture Magazine* of the Resources Centres on Urban Agriculture & Food Security (RUAF), bears the title (www.ruaf.org; accessed 22 January, 2011)

> The Role of Urban Agriculture in Sustainable Urban Nutrient Management

while that of one of its articles (Drechsel and Erni, 2010) is about

> Analysing the Nexus of Sanitation and Agriculture at Municipal Scale

The Issue is replete with supremely practical case studies of the benefits of recycling the aqueous and nutritious residuals of the Confined Human Feeding Operations (CHFOs) that are our cities: from West Africa, to Vietnam, Brazil, Colombia, China, Mexico, and other countries. The article by Dagerskog *et al* (2010) on the city of Ouagadougou, the capital of Burkina Faso, is especially encouraging (as already noted in Chapter 3.1). The title of the Issue, then, is

the embodiment of the slogan of eco-effectiveness: "waste = food". The struggle to write a headline for Integrated Urban *Nutrient* Management (IUNM), within Integrated *Nutrient* Resources Management (INRM), has been taken off our hands. What has been written already implies the seamless coherence of IUWM&IUNM, if not yet its being nested within IWRM&INRM.

Where Practice Pulls Theory Along — and Vice Versa

From the perspective of sustainability, we enquired in Box 2 (Figure B2.1) into the nature of what kind of engineering or policy intervention would cause the individual — that most local of you or I — to apprehend and debate the why's and wherefore's of the big, global picture. At the close of the thread of human aspirations in the TBL_{future} ((T1) in Chapter 5), we said this would be a matter of engineers "acting most locally" to engender "thinking globally" amongst a community. It would be a form of technology push, for the individual/household does not appear universally to be clamoring for it.[82] It was arguably a case of an element of the TBL_{future} (Table 2) forging well ahead of its companion in the $TBL_{frontier}$ (Table 3).

But then in December, 2010, American Public Media reported from the Cancun (Mexico) Climate Conference on what motivated John Perry Barlow to establish his startup business, Algae Systems (www.algaesystems.com). Reporter Scott Tong summed up the company thus (7 December, 2010):

> It aspires to take sewage, combine it with sunlight and make fuel. And, along the way, take carbon dioxide out of the atmosphere.

From this we can infer that the nutrients in the sewage (PeFe) would be needed for algal growth. Then, extrapolating from sewage back through the sewer network, to the source of those nutrients in our households, office blocks and so on, the imaginary headline was obvious: "Climate Change Drives Market for Urine-separating Toilets". Here was the demand pull of innovation: drawn on by the global perspective of climate change. It has the synergy of some joined-up thinking amongst the carbon, nutrient, and water cycles, hence an entry for (T14) of the $TBL_{frontier}$ in Table 3 capable of outstripping what was imagined (at the time of writing) for its counterpart in the TBL_{future} of Table 2 (and Chapter 5). Doing something about the "very big" of climate change would be enacted at the "very small" and local scale of the household.

In places, comparing Tables 3 and 2, the $TBL_{frontier}$ of practice seems to be in the vanguard, ahead of its counterpart TBL_{future}. Elsewhere, true to form, concept (TBL_{future}) may be outstripping practice ($TBL_{frontier}$). Perhaps nowhere is this more so the case than in respect of matters at the heart of how we have discussed {economic feasibility} in Chapter 3.2, i.e., in the line items of (T6) (Valuation) and, especially, (T7). Insofar as this *Concepts Paper* has sought to gather hard, empirical evidence of water-sector entities pushing at the boundaries of thinking/practice on sustainability, the grand notions of valuing ecosystem services, biodiversity, and our bequests of these to the next generation are conspicuous by their absence from the $TBL_{frontier}$.

[82] Although where people have experience of the once-unfamiliar urine-separating toilet, for example, surveys show acceptance is high (Lienert and Larsen, 2009).

Chapter 7: Pause — For Thought and For Action

We set out in this *Sustainability Concepts Paper* to be deliberately contrarian: *not* to contribute to any further "operational", "quantifiable" definition of sustainability. We wanted to suggest that meaningful forward momentum could still be achieved in the absence of such, in the presence of vagueness. Yet in the so very many pages it has taken for this, doubtless I have been self-contradictory — effortlessly, of course, without trying. In the end, much of this hefty volume of text can be distilled down to an essence — Table 4 — printable on a single page. And that essence looks suspiciously like (yet) another set of criteria or indicators; it is guilty, arguably, of being just another product from the "indicators industry" derided in our opening statements. But is it? Figure 18, from Boulanger's (2008) discussion of sustainable development indicators, would suggest that this *Paper* has been all about "conceptual analysis", with Table 4 edging up towards "identification and selection of variables", but falling well short of the heartland of the indicators industry.

Given the space too, sufficient statements have no doubt been included for every reader to disagree with something, perhaps very strongly so. That is the point, however: to harness contestation — including disputing the fact of our having elaborated a multiplicity of competing schools of engineering thought.

There has been an undeclared theme to this *Concepts Paper*: that of the fluctuating image (if not fortunes) of Engineering for sustainable development, beginning with its descent (as opposed to the image of Ecology, say) in the great sustainability debate of the 1990s. Recounted across Chapter 2, this descent came with an awakening: that environmental engineers working with the water-based paradigm of wastewater infrastructure in cities of the Global North might *not* self-evidently be doing good by the Environment. Yet in the course of Chapters 3.3 and 3.4, in building a response to the challenge and vision of Chapter 2.4 — of cities as forces for good in the environment — we find ourselves at the beginning of Chapter 4 ready to question whether what some perceive as comprehensively a "broken" paradigm, is truly all that "broken".

From this has come the re-ascent of environmental engineering, rehabilitation of its image, and restoration of self-confidence in those who practise it. If they are not self-evidently doing good by the environment, they are at least doing "less bad". Things could be yet better, in fact. For Chapters 3.3 and 3.4 have broadened our horizons, away from the sole motivation of eco-efficiency symbolized in reducing the ecological footprint of the city (and doing ever "less bad" thereby), towards the joint motivations of eco-efficiency *and* eco-effectiveness: doing "good" as well, as in acting as a force for good.

This strategic cycle of descent, re-ascent, and so on, is echoed on a smaller scale, in the inner spaces of some of our discussion. For example, in matters of {economic feasibility} in the Triple Bottom Line (in Chapter 3.2) the reader is deliberately projected up to the heights of grand social programs and equally grand concept — economist Solow's "bequests to future generations" — only to be thrust immediately back down to the blunt depths of pragmatism — engineer Mara's notional, poverty-stricken Indian villager, who is confronted with choosing today between an ecosan toilet and a single-pit pour-flush toilet. These are the intellectual gymnastics of Systems Thinking, as we now well appreciate. They enable the switching, connecting, and creativity in the tension of the close juxtaposition of the expanse of the "global" and the intense intimacy of the "local" and very personal.

We began with a metaphor from Ecology: the large animal (of the city) grazing in its pasture (of the watershed), as announced already in the Introduction (of Chapter 1). The metaphor itself assumed more specific forms, becoming an unappealing "bull" in a "china shop" (Chapter 2.4), slipping into a speeding athlete (across Chapter 3.3), but re-emerging in Chapter 3.4 (and Box 3) as an intelligent bull gifted with deft movement — to epitomize a climax in the unfolding and burgeoning prospects for re-engineering the city's water- and nutrient-return infrastructures. Engineering has much to learn from Ecology, and the Biomedical Sciences as well. How now shall the most basic and deep concepts of sustainability be enlightened by the perspective of Engineering? Box 3 is one engineer's upward riposte to the ecological and

LINE ITEM	TBL_{now}	STEPPING OUT IN PRACTICE ($TBL_{frontier}$)	TBL_{future}
(T0) ORGANIZATIONAL LEARNING		Yarra Valley Water seeks change through organizational learning	"Always Learning, Never Getting It Right"; in pursuit of the self-transforming mind, which "leads to learn"; entertaining self-contradiction, including abandoning a line item, even "sustainability" itself
(T1) Personal Aspirations	Health and hygiene	Sulabh Sanitation & Social Reform Movement elevates women scavengers to the fashion catwalk at UN Headquarters	Towards a well-being sufficient for self-reflexive apprehension of the "big picture"
(T2) Citizen Participation	Individuals empowered to acquire and employ expertise and "know-how"	San Francisco Public Utilities Commission (SFPUC) is accountable to stakeholders from "cradle-to-cradle" in its planning processes	Deliberative democracy
(T3) Social Bonds	"Cultural acceptance", as in adoption of a given style of device or technology	Clean Water Services, Ostara, and the Clean Water Institute have evolved a tripartite, institutional synergy amongst public-, private-, not-for-profit sectors	Benefitting from multiple (four) wisdoms on how to live with one another and nature
(T4) Quality in Governance	Presence of institutional-regulatory framework *per se*	Nepal Water Conservation Foundation is pursuing a clumsy institutional process for restoring the Kathmandu-Bagmati system	Refurbished pluralist democracy of Dahl; adaptive community learning
(T5) Ethics and Equity		Sydney Water employs inter-generational equity as a matter of routine in screening projects	Variety of standpoints on the consequences of inappropriate behavior in man-to-man, man-to-nature, individual-to-group, present-to-future generation, seller-to-buyer, and other relationships
(T6) Valuation	Engineering economics; user/service fees/revenues	Over 300 Water Health Centers signal private-sector business-model success for Water Health International	Plurality of what counts economically; bequests to the future ("final environmental wills and testaments")
(T7) Environment Within the Language of Business	Biodiversity		Natural capital, ecosystem services, and service providers; risks to "business as usual" through loss of biodiversity
(T8) Supply-Value Chains	None beyond "factory (treatment plant) fence-line"	50 cities committed to UN Global Compact; CH2MHill, Halcrow and other water businesses are signatories of Global Compact's CEO Water Mandate	Exercise of power ever further along ever more extended and intricately interwoven chains of commercial relationships
(T9) Commercial Sectors	Water ... alone	Veolia Water UK as "Multi-utility Services Company" (MUSCO)	Water sector ... and nutrient and energy sectors ... and more
(T10) Space	IUWM or IWRM; rarely both	DHV Group (Consulting Engineers) re-engineers Soerendonk Sewage Treatment Plant to blur distinction between sewage treatment and river habitat	From Earth Systems Analysis to individual agency (e.g., dietary preferences)
(T11) Life Cycle and Time	Expenditures and revenue streams over time	The Natural Step has worked with Yarra Valley Water on Life Cycle Analyses	From cradle to cradle analyses
(T12) Function	Adaptability; durability; robustness-vulnerability; reliability	Within IBM's Smarter Planet and Smarter City portfolio, Galway, Ireland is acquiring a SmartBay	Ecological resilience and biomedical self-repair
(T13) Gauging Environmental Benignity	Environmental degradation: pollution syndromes; eco-efficiency	Ostara, Clean Water Services and British Columbia Conservation Foundation partner to issue nutrient supplements to restore declining salmon stocks	Biomimicry: appetite; metabolism; pulse
(T14) Cycling of Materials	Man's appropriation/ consumption of resources (water, nutrients, energy, and land area)	Severn Trent plc acknowledges water-cycle and carbon-cycle policy antagonisms; Resources Centres on Urban Agriculture & Food Security (RUAF) promote Sustainable Urban Nutrient Management	Natural nutrient cycles and technical nutrient cycles; dematerialization; eco-effectiveness

Table 4 Tables 1, 2, and 3 assembled as a whole.

political thrusts of the great sustainability debate of the 1990s.

Arise then the self-confident Engineer — or the water professional as "public leader" (Termeer, 2009)! If the "global water crisis" is a crisis of governance, we envision Engineering interventions as those tailored to resolving the crisis. But let us not be over-bearing. Thus has this intention been expressed in Box 2, as just a mere "aside" to the principal business of Chapter 3.1 on {social legitimacy}.

In the presence of the defining quantitative, codified turn of mind of Engineering, not to mention that of the accountancy of the Triple Bottom Line, the descent of Engineering into more subtly troubled waters was epitomized by the caricature of a mathematical program (***M***) for generating sustainable decisions in Chapter 2.5. There is a fine line separating that which should be included in ***M*** and that which should be left out, for due process of public debate and democracy. The resurgence of Engineering, perhaps paradoxically, was capped off in Chapter 4 by deliberate use of the mathematical, engineering metaphor — a model ***M*** and some basic notions of control engineering — to provide the tightest of specificity and clarity in how we might engineer our way out of a technological and socio-cultural lock-in, in the face of *vagueness*. Is this self-contradictory?

As for the *long view* — in general, too frequently conspicuous by it absence — this is surely present in the challenge and vision of Chapter 2.4, and again in our response to them, constructed across Chapters 3.3 and 3.4. Under this long view it seems inappropriate to entitle as "Conclusions" this closing chapter. We have chosen not to do so. The unrelenting pursuit of the long view, throughout this entire *Concepts Paper,* may nevertheless have blinded us to the nearness of tomorrow's first, practical step. We all have blind spots. For as long as *water* professionals, many from *water* utilities, meet to discuss *water* issues, under the *aegis* of *water* associations, issues of the nutrient metabolism of cities — the daily bread inextricably coupled with the

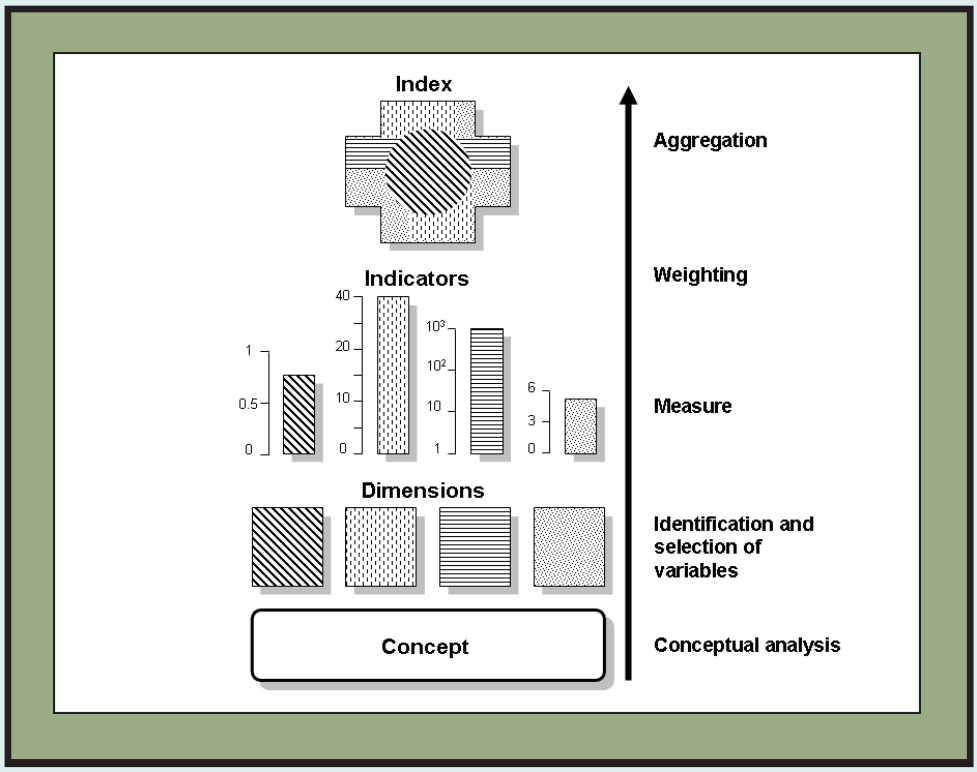

Figure 18
Boulanger's pictorial representation of Lazarsfeld's progression "from concept to indices" (reproduced with permission from Boulanger, 2008).

daily water of our very existence — will struggle to be adequately addressed. There is no IU*Nutrient*M within I*Nutrient*RM to accompany IUWM within IWRM. There are no City Nutrient Departments, as far as we know, nor any Soilshed Agency. To establish them, however, might be to head in the wrong direction of ever more compartmentalization.

If our *Paper* has succeeded in being thus contrarian, self-contradictory, and/or disagreeable, may it provoke actions and thoughts on how to make something better of it, to suit the very local circumstances of you, the reader.

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