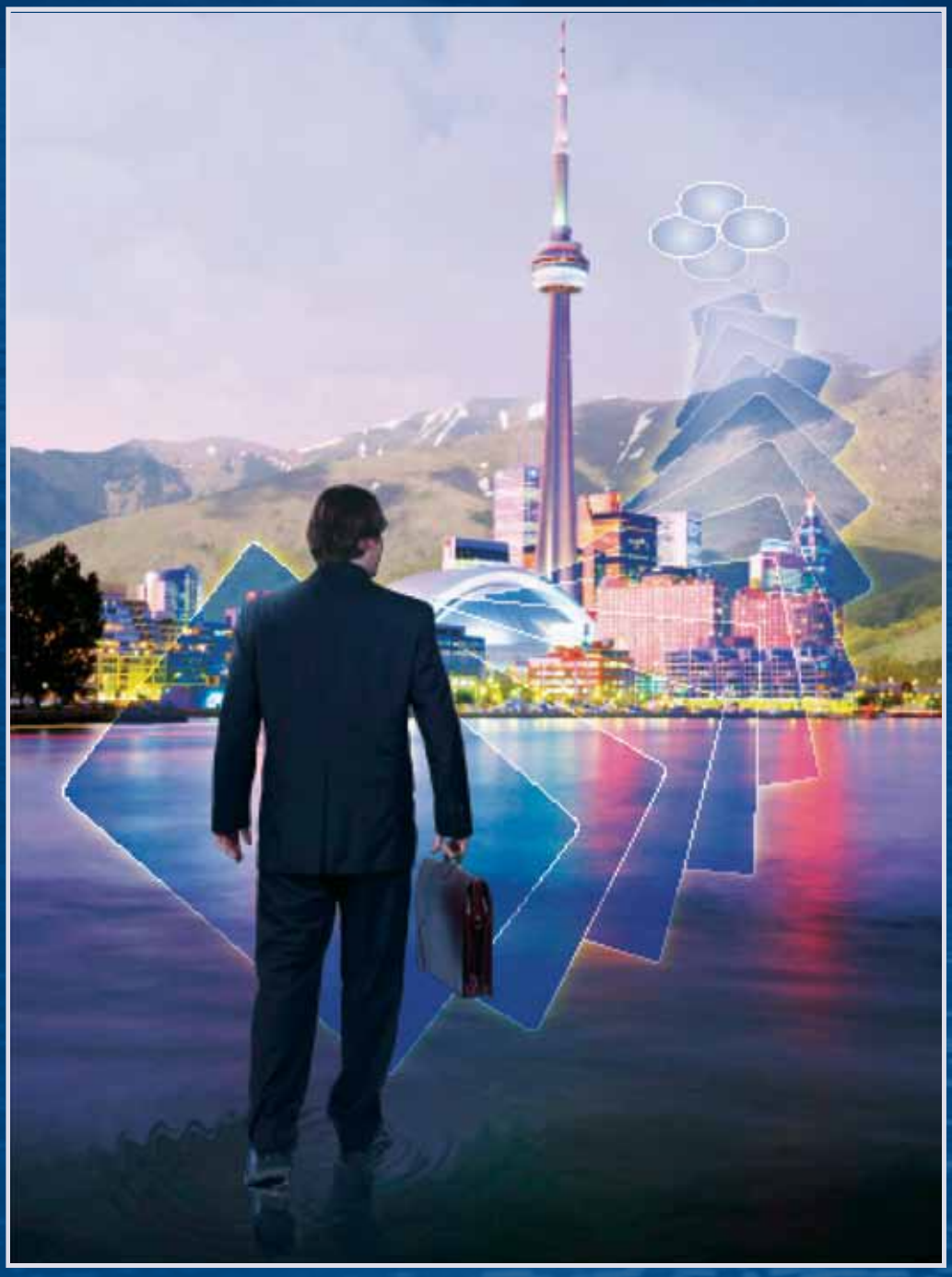
Cities as Forces for Good
in the Environment
Sustainability *in the Water Sector*



Sustainability Concepts Paper

M Bruce Beck

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

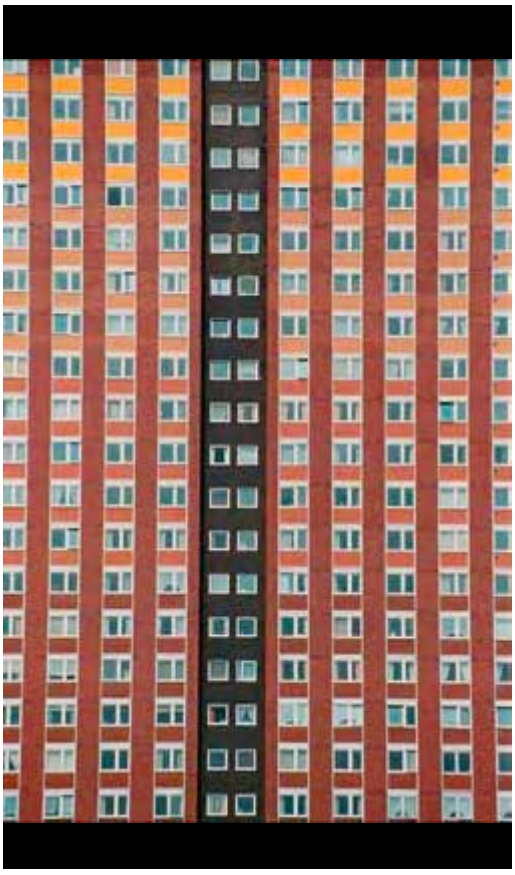
CITIES

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

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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

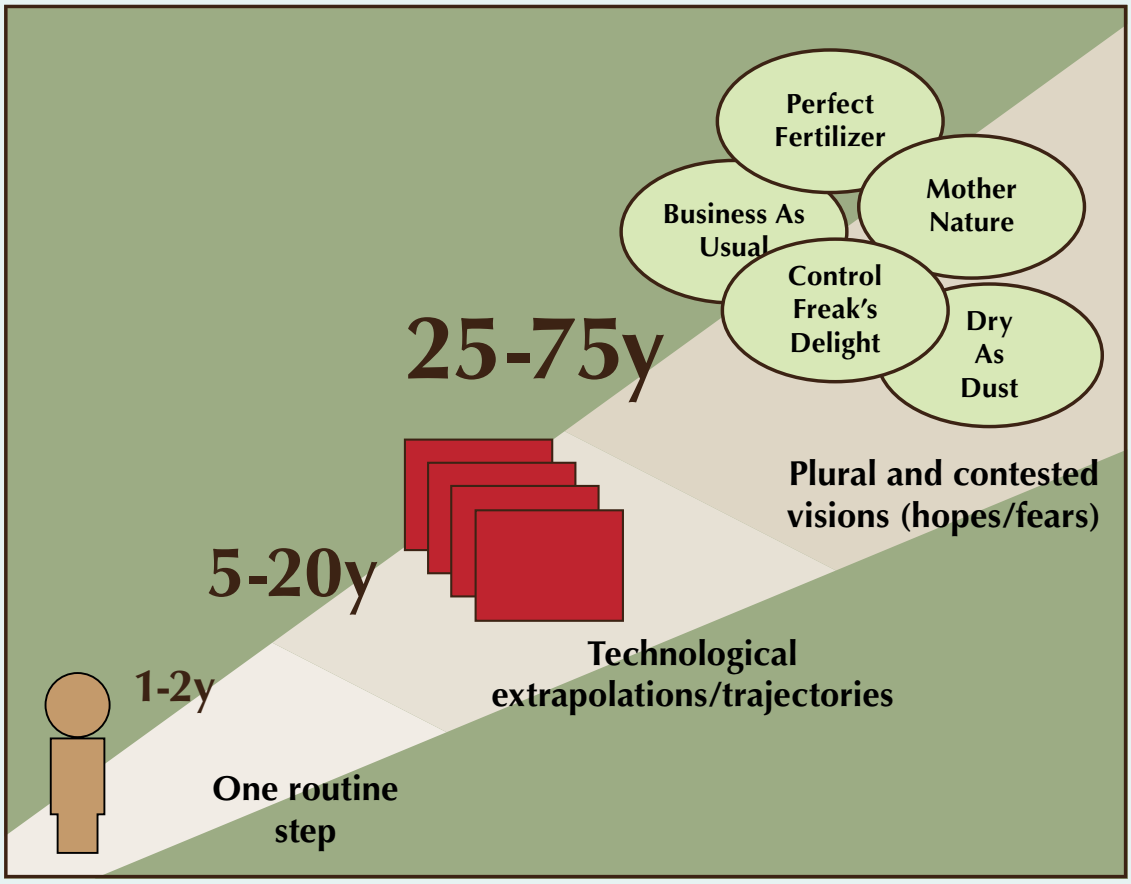

Figure ES1:
Framing the "big picture" of how the city might evolve to become a force for good in its environment with, first, the plural (and contested) visions of the distant, inter-generational futures for the city's water infrastructure (green oval domains), second, the technological alternatives (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 compliment, 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	DHV's re-engineering of Soerendonk Sewage Treatment Plant generates rhythmic flow variations to enhance watershed ecosystem services	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}).