7th World Water Forum

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EXECUTIVE SUMMARY

Science & Technology Process

WHITE PAPER

Executive Summary

This White Paper, as a major outcome of the Science and Technology Process, aims at publishing an 'Innovative report for science and technology in water management'. The White Paper will reflect the past, the present, and the future of five key focuses, mentioning related technologies simultaneously. The 5 Main Focuses of the White Paper are as follows : (a) Water efficiency, (b) Resource recovery from water and wastewater systems, (c) Water and natural disasters, (d) Smart technology for water, and (e) Understanding and managing ecosystem services for water.

Main Focus 1. Water Efficiency

Water stress and water scarcity are global challenges with far-reaching economic and social implications. Driven by increasing population, growing urbanization, changing lifestyles and economic development, the total demand for water is rising: from urban centres, from agriculture and from industry. But efficiency gains lie within our grasp, and can put us on track to achieve water security for all.

Security won't arrive by itself. The status quo of single digit incremental efficiency falls well short of the mark. And the imperatives of climate change add urgency to current water crises. Yet right now we possess the tools and experience to design and implement a new paradigm of efficient water use, and scale it up quickly to sustain urban, agricultural, industrial and energy systems everywhere.

This *Policy Brief* shows why, how, where, and for whom water and energy efficiency goals became real:

1. **City Solutions.** *Urban water managers who control water losses and combine firm incentives with flexible innovations can quickly close the projected 40% gap between supply and demand.*

2. **Agricultural Advances.** *Farmers who slash waste throughout irrigation systems can grow more food, and earn more per drop, even with 43% less water.*

3. **Industrial Innovations.** *Corporations that push for internal and external efficiency both increase outputs and reduce exposure to risks, even within zero increases in water supplies.*

4. **Power Shifts.** *Judicious early investment can achieve carbon and energy neutrality, or generate net gains, through efficient water and wastewater processes.*

5. **Smart Systems.** *Advanced water technologies – when nested within rigorous legal, administrative, and economic institutions – enable and accelerate 'smart systems.'*

6. **Standard Metrics.** *More inclusive, exacting, and uniform ways of measuring water will yield efficient outcomes both quickly and affordably.*

7. **Stress Relief.** *The fastest, fairest, cleanest and cheapest path to efficiency involves carefully optimizing water pressure to maintain priorities while eliminating excessive strains.*

These *Seven Keys* ensure vital systems do more with less. Each reveals effective tactics and techniques to reduce leaks and losses, boost food security, increase productivity, conserve (or generate) power, and build resilience to escalating shocks. They highlight what has already been achieved and what can be replicated at scale quickly. Efficiency aligns ecological and economic outcomes so that further waste is not only unacceptable, but also unnecessary.

1. City Solutions

Challenge : For decades, cities grew perverse incentives to waste their water. Water prices that do not reflect the economic value of water. Natural monopolies prevent competitors from driving efficiency. Hard surfaces accelerate runoff to erode, pollute, and overwhelm plants.. As demand rises, water stress will only intensify. How can professionals relieve compound pressures of rapid urbanization, thirsty growth, competing demands, nonpoint source pollution, rising labour costs, escalating emissions, and extreme droughts punctuated by flash floods?

Solution : *Urban water managers who control water losses and combine firm incentives with flexible innovations can quickly close the projected 40% gap between supply and demand.*

Action : Whenever governments set binding targets to reduce water use, water losses or greenhouse gas emissions, they generate a lively market for innovative technology. Consumer demand drove widespread adoption of efficient new household appliances that save water and energy. To accelerate demand, and the innovation it stimulates, leaders must incentivize efficient outcomes through tariffs that reflect water's true value and policies that reward efficiency gains.

Result : With institutional incentives fixed in place, flexible innovations emerge:

- Efficiency in the home comes through rebates to phase out older toilets or appliances in favor of high performance models, but the most successful programs measure outcomes, not inputs.
- Efficiency in distribution networks that harmonize water loss reduction with water pressure control, gives opportunity for programs that help flatten a system's peak demand, create water reserves, and reduce long term capital investment needs.
- Rainwater harvesting links ancient technology with a new urgency to collect and store runoff from rooftops or landscapes using surfaces containers or underground check dams.
- Harmless, nutrient-rich greywater from sinks, showers, and washers can safely irrigate and fertilize turf, flowers, or fruit trees, easing strain on energy-intensive treatment plants.
- Low-impact development designs with nature, rather than against it, to slow, spread, and sink runoff, disperse pollutants, and ease strain on urban infrastructure.
- Advancements in Ground-penetrating radar (GPR) and thermal infrared radiation can 'x-ray' networks to reveal vulnerable areas where a leak is cooler or warmer than the surface it.

2. Agricultural Advances

Challenge : As populations swell in number and income, so does their consumption. Soon we will annually require one billion additional tons of cereals and 200 million additional tons of livestock. For decades we grew more by expanding cultivated lands 12%, and doubling irrigation. But arable land is scarce and irrigation water is capped; its 70% share is shrinking under competing demands. At the same time, hungry soils need replenishing with vital nutrients, some of which are finite resources. So how can we feed ourselves?

Solution : *Farmers who slash waste throughout irrigation systems can grow more food, and earn more per drop, even with 43% less water and use vital nutrients such as nitrogen and phosphorus reclaimed from wastewater.*

Action : Effective agricultural water efficiency (AWE) techniques help farmers match every drop to each crop's needs through precision technologies. These increase yields and quality while reducing costs of fertilizer, water, energy, and greenhouse gas releases. The result is higher profits, reliability, and resilience to drought, deluge, reallocations, or price flux.

Result : AWE may involve many forms, tools, tactics and technologies:

- By combining crop selection, irrigation scheduling, and alternative sources of irrigation water, some regions have been able to reduce irrigation losses 43%.
- Other tools measure soil moisture, assess leaf moisture, deploy conservation tillage, maintain soil fertility, and boost water retention capacity.
- Farmers can now fine-tune the crop development stage; the timing and amount of water applied to the root zone; or water consumed by the crop since the previous irrigation.
- Accurate monitoring– of fertility, crop variety, pest management, sowing date, soil water content, planting density – help systems reach optimal performance, saving water while enhancing yields.
- In-field sensors, geographic information systems, remote sensing, crop and water simulation models, climate predictions are deployed in versatile ways.
- In Korea, AWE cut across spatial, temporal, and political scales, engaging competing stakeholders, to achieve different outcomes:
  - AWE targeted 1,570 reservoirs to monitor real-time flow and storage against drought.
  - AWE rehabilitated 11 reservoirs to secure 0.28 billion tons of water.
  - AWE enhanced performance of 37 irrigation districts in the Yeong-San River basin.

3. Industrial Innovations

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4. Power Shifts

Challenge : Urban, agricultural and industrial water systems are energy-intensive. Nonstop pumps use 95% of the power for distribution; heating and treatment use even more. Water systems often represent the single biggest users of energy. Some drain 20% of the grid. Energy production and distribution, in turn, requires excessive carbon and water, with some plants consuming 5% of water withdrawals from a basin.

Solution : *Judicious early investment can achieve carbon and energy neutrality, or generate net gains, through efficient water and wastewater processes.*

Action : In the water-energy nexus, emerging efficiency for one resource yields comparable gains for the other. Operational reforms may require intensive retraining, energy audits, investments and longer term plans. But delay escalates economic and ecological risks, while action now turns crises into opportunities.

Result : The vicious spiral of rising water/energy demand can be slowed, and even reversed in a positive direction through conservation, loss prevention, stormwater reduction, or repairs to infiltration. The most effective strategies may convert water systems into net energy producers.

- Treatment plants may capture and burn biogas from anaerobic digesters to generate some or all of their own electricity, turning plant into net zero consumers of energy.
- Other technologies may enable industries and agencies to develop closed-loop systems that optimize

water use.

- Significant energy gains come by combining demand response, leak detection, storage tanks, automated meters, and upgrading system pumps, motors, lights, HVAC.
- Micro-hydro may convert pressure and flow in large pipes into electricity, much as a hybrid vehicle harnesses braking power for energy: an alternative to valves that helps regulate pressure.
- Water supply systems can be integrated with a renewable source of energy such as solar cells, wind turbines, and small or run-of-river hydropower.

5. Smart Systems

Challenge : For decades – in order to boost health, growth, and prosperity – public policies set out to provide water at any cost. The heavy asset base these policies delivered were inherently inefficient, contributing to unaccountable waste, and scarcity. The high costs of operating, maintaining, rehabilitating and replacing these systems contributes to a vicious cycle of low cost recovery ratio. Those same decades brought gleaming information communication technology. ICT tools can improve demand response, energy-water nexus, and engagements with family, farm, or factory. But they don't exist in a vacuum, and without non-structural reforms, gains from 'smart' hardware and software may bleed away.

Solution : *Advanced water efficient technologies – when nested within rigorous legal, administrative, and economic institutions – enable and accelerate 'smart systems.'*

Action : Every tool, however innovative, is only as 'smart' as those who wield it. Water professionals achieve efficiency to the extent they anchor and integrate each tool within the non-structural framework.

Result : To reap the full potential gains from smart technology, professionals should nest them within water rights, allocations, tariffs, licensing, regulation, storage, abstraction, energy choices, and markets:

- Advanced Metering Infrastructure (AMI), with 'smart' sensors and signals, lets consumers choose tariffs, while utilities can prioritize usage for special purposes and pricing.
- Smart meters allow time of day billing, reduction of peak demand, leak detection, increased distributional efficiency, non-revenue water reduction, and deferral of capital spending.
- Smart pipes measure water flow and quality to detect strain, temperature or pressure anomalies, so potential leaking can be checked in real time.
- Smart sensors optimize irrigation water by measuring humidity, rainfall, wind speed/direction, soil temperature/moisture, atmospheric pressure, and solar radiation.
- Smart rehabilitation sends image-diagnosing robots to inspect pipes, blasts scaling and rust with an ultra-high pressure water jet, and sprays lining/coating materials evenly inside the pipes.
- Smart green infrastructure – soil, trees, vegetation, wetlands, and open space – can mitigate stormwater runoff and treat it through local storage, reuse or infiltration.
- Smart asset management optimizes capital, operations and maintenance expenditures by providing the desired level of service at the lowest infrastructure life-cycle cost.

6. Standard Metrics

Challenge : A water authority that seeks efficiency from metered clients – housing developments, golf courses, cane fields, manufacturers or power plants –often overlook the single biggest source of waste: itself. 'Non-revenue water' (NRW) reveals the yawning gap between water treated and water invoiced. Loss leaders include: inaccurate billing, deteriorating infrastructure, high pressure, inexact metering, reservoir overflows, excessive flushing, and illegal connections. These are symptoms of much larger mistakes: while estimated losses may be a third to half the input volume, the truth is no one really knows for sure.

Solution : *More inclusive, exacting, and uniform ways of measuring water will yield efficient outcomes both quickly and affordably.*

Action : Too often efficiency is erroneously measured by random or inappropriate metrics. NRW estimates often use simple percentages, which vary wildly by day or season, depending on weather. Paradoxically, when it rains, and demand falls, NRW percentage will appear to have increased; conversely, water loss percentages will appear to decrease in a dry year when demand rises. Both mask the actual physical leaks.

Result : Physical measurement drives efficiency closest to the source with robust and precise indicators.

- The most advanced compares NRW to the length of water mains, or the number of properties or connections, against an optimal level for those metrics, in an Infrastructure Leakage Index (ILI).
- Avoid confirmation or selection bias, 'cherry picking' favorable metrics, categories, inputs, or sources of use.
- High performance dictates that agencies must account not just for some of the water being used in a few random places, but rather all sources throughout the network.
- Rigorous standardized accounting, through the IWA Water Balance, encompasses the measurement and thus management of the system as a whole.
- Meters installed throughout the networks, backed by inspectors with listening devices, help identify the real extent of leaks.
- Modern equipment helps track speed, velocity, and source of noise transmission.

7. Stress Relief

Challenge : Water pressure presents an old, deep challenge of individual vs. collective needs. Centralized, energy-intensive pumps amplify water velocity that only a few may desire, but most don't require. The escalating risk is that excessive pressure compounds stress, leading massive systemic hemorrhaging of water, energy, carbon and money for all. Perversely, the agency itself may elevate pressure for this very reason: more water forced out means more revenues coming in. But such quick gains prove illusory, and erode under the mounting expense as stress opens cracks and widens splits until burst pipes bleed efficiency throughout the system.

Solution : *The fastest, fairest, cleanest and cheapest path to efficiency involves carefully optimizing water pressure to maintain priorities while eliminating excessive strains.*

Action : Care may require investing in time, training, trials, and tests. Yet the effort to optimize pressure yields lasting benefits across every system, urban or rural, ecological or economic, industrial or agricultural. Dramatic efficiency gains may seem silent and invisible, but are substantial, and immediate.

Result : For most water supply networks, and even in some developing countries with intermittent supply, optimal pressure management can be among the most cost effective measures to reduce widespread leakage, deterioration, and waste.

- High pressure increases the size of 'variable leaks', which illustrate a paradox: systems lose more water at night, when communities sleep, than during the day, as demand steadily rises.
- Most networks running at 60-90 m can shift down to the average, yet still quite ample, 20-50 m.
- New electronic, flow modulation, and time controllers can each judiciously reduce pressure by up to two thirds, without compromising the level of service for heavy consumers or fire-fighting.
- Low pressure does not by itself repair or eliminate leaks, but it keeps new ones from forming, and ensures cracks, holes or joints lose water at a far lower rate, by up to 90%.
- Pressure reduction also further scales back systemic and local demands on energy, as well as associated carbon embedded within.

Main Focus 2 : Resource Recovery from Water and Wastewater Systems

Civilizations developed water and wastewater systems with a focus on treatment technology. The goal was simple: pull clean water in, push dirty water out, and make odours disappear as fast as possible.

But our larger and more affluent populations demand far more resources from far fewer supplies. Budgets have shrunk and climate change is forcing cities and industries to reassess every aspect of our resource life cycles.

As a result, leaders have begun to develop a more sophisticated philosophy and methodology of resource recovery and reuse – towards a low-carbon 're-appearing act'. These concepts are neither new nor radical. But they highlight the troubling gap between theory and practice, which prevents us from capturing valuable benefits at a large scale.

A fundamental shift in our approach and mentality can lead us beyond conservation, efficiency, or treatment toward the optimal recovery and reuse of resources. This Executive Summary illustrates why, how, where, and for whom 'waste' is becoming progressively obsolete.

It provides trends, tools, tactics, perspectives, case studies, and solutions. In sum, this paper reframes our water, energy, and nutrients crisis as an opportunity to create enormous value. The keys to success lie in:

1. **Bottom-Line Benefits.** *Resource recovery and reuse dramatically saves electrical currents and financial currency, effectively earning money that can be reinvested elsewhere in water utilities.*

2. **De-carbonization.** *As governments seek to meet greenhouse gas emissions targets, resource recovery and reuse can slash per capita carbon emissions by 4% annually.*

3. **Effluent Mining.** *Apart from water, energy and nutrients, such as phosphorous, resource recovery and reuse extract new wealth from an old pool of other compounds and substances.*

4. **Cyclic Economies.** *Judicious early investments in reuse and recovery help close the loop in water and wastewater systems, eliminate externalities and build resilience to escalating risks.*

5. **Imaginative (Re)Branding.** *Much as 'used cars' are now highly valued as 'previously owned vehicles,' water and nutrients can be judged not by their history but by their quality.*

6. **Linked Outcomes.** *Water reuse may top the agenda, but the hottest topic relating to resource recovery is connected to energy efficiency and recovery in water and wastewater systems.*

7. **Centralized Control.** *While efficiency and conservation gains may come from devolving authority, recovery and reuse take advantage of concentrated water, energy, and nutrients*

The *Keys to Resource Recovery* not only ensure lateral transfer of existing best practices, but raise the bar by enabling new innovations to emerge. Each key reveals the most effective tactics, tools and techniques to generate more energy, enhance food security, increase productivity, secure more water, bring more nitrogen and phosphorous to market, and build resilience to escalating shocks.

In sum, this paper reveals 'waste' as merely a source of food, energy or water. It reminds us that by shifting our fundamental approach to resource recovery and reuse in our systems, 'freedom' really is just another word for nothing left to lose.

1. Bottom-Line Benefits

Challenges : Professionals seeking to recover and reuse the valuable resources from water systems may question its affordability. Financing an overhaul or building a new plant from scratch is daunting. Municipal budgets face fiscal constraints. Even a progressive leader can't justify up-front expenses today, without a clear sense of the return on investment. How can leaders quantify returns – avoided costs, increased savings, new sources of revenue – to ensure gains are easy, clear, dramatic and perpetual?

Solutions : *Resource recovery and reuse generates an electrical current, financial currency, and river currents – natural capital that can be reinvested into the system.*

Actions : Those who make scarce resources 'reappear' can collect and market them. There is high value in energy, nutrients (nitrogen, phosphorous and minerals, including rare earths) and in life's matrix: water.

Results : Water reuse and reclamation have been developed and practised far more than any other recovered resource, to drive end users and utilities alike toward real benefits:

- High quality reclaimed water gains value as drinking water, through monitoring and chemical-toxicology technology, as well as through involvement of different public sectors.
- Recovery of sewage, could earn each European €1.6 per cubic meter; at 50 cubic meters, that equals €80, earning 65% of the value is in water, 12% is in energy, and 23% in nutrients.
- Utilities can earn €1 by eliminating the capital-intensive costs to treat 1 m3 of water, or make it 'ready to be discharged back into nature', earning another €50 per capita per year.

2. Nexus Outcomes

Challenge : Recovered energy from wastewater sounds good in theory. But in practice it must compete with fossil fuels that are cheap, familiar and integrated. Professionals have to adjust infrastructure and institutions to handle biogas or heat. It takes public resources and political will to kick-start markets. Families and firms often require economic incentives to sort and separate waste (including bio-solids) for potential fuel sources, much as they already sort organic material for recycling.

Solution : *Water reuse has traction, but the hottest topic in water and wastewater systems is energy efficiency, production and recovery.*

Action : Systemic changes increase both energy generation and recovery. Most feed into the treatment system, which in turn boosts efficiency, and may even lead to net energy-positive systems.

Results : To recover energy from used water: 1) turn sludge into biogas through anaerobic digestion to create electricity and heat; or 2) concentrate, transport and incinerate the digested product for heat. Both involve trade-offs.

- Water with fermentable organic matter, landfills rich in organics, livestock wastes, food wastes and sludge can be anaerobically digested into biogas (65% methane; 35% carbon dioxide).
- Biogas can be upgraded to compressed natural gas or liquid natural gas for vehicles.
- Within treatment processes, 80% of the chemical energy can be transformed into methane; 35% of the energy in methane can then be converted into electricity, for 28% efficiency.
- More than 500 used water heat pumps, with thermal energy capacity from 10kW to 20MW, in operation.
- China, Finland, Switzerland, and Canada use thermal energy recovery for on- and off-site district heating, sludge drying, and sludge digestion.

3.De-Carbonization

Challenges : Conventional treatment systems don't just pollute water; they choke air. Organic matter in used water is removed, by biological oxidation, to CO2. The residual organic carbon, harvested as sludge, is often incinerated into CO2. And external or internal carbon sources for de-nitrification can result in more greenhouse gas emissions. Energy-intensive 'dissipation' (removal of unwanted characteristics) typically burns fossil fuels, which emit greenhouse gas, which elevates temperatures, which bring drought, floods, and stress in a vicious cycle of rising costs, shocks, fragility and potential collapse.

Solutions : *To meet global carbon reduction targets, resource recovery and reuse offers governments affordable ways to slash annual per capita emissions by up to 4%.*

Actions : Water professionals should also explore harnessing their systems to recover and reuse two increasingly valuable natural assets: clean air and a stable atmosphere.

Results : Recovery of energy and nutrients can help reduce extreme impacts from climate change:

- Replacing natural gas with biogas requires enrichment of methane and removal of carbon dioxide.
- The current 'dissipative' technology demands more energy – up to 1 percent of the total electricity use in industrialized countries – from fossil fuel than is necessary.
- Beyond water and money, resource recovery can annually save each person 140 kWh in electricity, 530 kWh in heat, and 88 kg (1-4% of all sources) in needless carbon emissions.
- Higher returns on cheaper innovations emerge from research, development, and technology.

4. Effluent Enhancement

Challenges : Most technologies don't recover nutrients; they just remove them. And nutrients are rarely of either uniform quality or large quantity. There can be positive or negative consequences of using sludge as fertilizer, as variable levels of mercury and other heavy metals accumulate over time, and risk excess nutrient loads trickling into streams. High start-up and running costs of new recovery plants mean the end products can't compete well at market: it's still cheaper to mine nutrients than recover them.

Solution : *Apart from water, energy and clean air, resource recovery and reuse can extract new wealth from an old pool of nutrients, compounds and substances.*

Action : Treatment plants hold a wealth of nutrients – especially potassium, phosphorus and nitrogen – whose recovery rises with demand for artificial fertilizer, increased yields, food security and irrigation.

Results : Reusing nitrogen at the recovery site can be upgraded to a valuable feed or food.

- 85 percent of all nutrients are linked to agriculture, but other sectors use recovered products too.
- Resource recovery can be as basic and simple as a $20 waterless composting toilet, which can divert urine and faeces into harmless, odour-free ammonia and organic dry 'humanure'.
- Other processes use bacteria to break down sludge, converting human waste into biogas for heating, cooking and generating electricity.
- As agriculture reaches 'peak phosphorous' (90% of which is locked up in five countries) and petroleum-based fertilisers grow scarce, progressive farmers contract for valuable local sludge.

5. Cyclic Economies

Challenge : 100 years is enough. Despite our fast-changing climate, old treatment plants still burn too much carbon, food, water, heat and money. Sanitation destroys nitrogen. We dissipate potential proteins into sewage. We consume 2% of the world's available energy. So while a 20-30% target for waste reduction sounds nice, it is far from full recovery and remains open-ended.

Solution : *Early targeted investments in reuse and recovery can 'close the loop' in our systems, eliminate externalities, and build resilience to escalating risks.*

Action : Components like sulphur, cellulose, metals, and bioplastics will grow valuable with societal acceptance of the cyclic economy.

Result : A truly closed loop demands that we know exactly what resources can be recovered where, how, and for which markets:

- · Research can address and delineate the limits to, and potential of, the cyclic economy.
- · That economy exists in the context of both primary materials it will consume and of those potentially supplied by the reuse loops that will be developed
- · Water professionals must work harder with legislators to construct legal frameworks that clearly define and encourage resource recovery across and within borders.
- · Innovative R&D platforms can spur the cyclic economy within the sector of water use and reuse.

6. Imaginative (Re)Branding

Challenge : Culture can make or break resource recovery. People typically react to excreta with disgust. They fear contact with faecal matter as a source of stinking, bacterial, disease-infested filth. They avoid 'waste' at all cost. Technology alone can't transform public perception, or transform sludge, heavy metals or bioplastics from liabilities into assets. That demands marketing a brand with strong appeal.

Solution : *Just as 'used cars' gain high value as 'previously owned vehicles,' let us judge water, energy and nutrients not by their history but by their quality.*

Action : By dealing honestly with materials, we can surmount 'pushing' new supplies to the 'pull' side of demand. No one complains about aquaculture quality, despite fish whose diet is 50% faecal matter.

Results : The resource paradigm must be cleared from "waste"-related connotations, so that:

- · Rather than past processes, focus on future products – clean energy, water security, organic products, phosphates, nitrogen, biogas, fertilizer, paper, cellulose, rare earths, and other resources
- · Existing 'wastewater treatment plants,' transform into 'resource recovery facilities'
- · End users – industry, farm, school, family, airport – may be more willing to use a recovered resource if shown how it shrinks, stops and reverses damage to their self interest.
- · Integrate concepts of life cycle assessment, strict quality control and hazard assessment.
- · Singapore prioritized Four National Taps: catchment water; imported water; desalinated water; and reclaimed or NEWwater.
- · Nano-technology holds promise if it stops scaring people about unknown aquatic consequences.

7. Appropriate Scales

Challenge Size matters. Some recovered water, energy, carbon or nutrient sources are unsuitable to store or transport over long distances. The plant where energy is produced may be too far from where it will be consumed. Uncritical intervention can lead to unnecessary costs or the loss of energy in transmission. Demographic, physical, economic, labor skills and ecological differences mean resource recovery technology cannot be easily or uniformly transferred. What works here may not succeed there.

Solution : *Context-specific gains come from devolving authority, so recovery and reuse optimise water, energy, clean air and nutrients at the source.*

Action : By assessing goals, as well as local supply and demand, professionals develop tools, tactics and techniques that recover the right resources, in the right way, at the right scale.

Result : The hard, visible, physical plant depends on soft, invisible institutional infrastructure put in place:

- Appropriate technology ensures decentralised and urbanised societies gain efficient supplies.
- Resource recovery is no panacea, target, or goal; it is a means to an end that arises from within.
- Durable outcomes depend on an institution's clearly defined agenda, concrete policies, financial incentives, legal frameworks, strict timeframes and cross-sector partnerships.
- Decentralized and locally situated facilities avoid transport issues (a Swedish system produces biogas next to the bus depot) between resource recovery and usage.

Main Focus 3 : Water and Natural Disasters

In recent years, water related disasters – floods, droughts and storms – have grown frequent, affected 4.2 billion people, caused USD 1.8 trillion economic losses, and accounted for 90% of all natural hazards.

Climate change is not coming. It is here. It's underway. And it will only intensify. Our mitigation depends on green energy sources that reduce greenhouse gas emissions. But our adaptation depends on water.

Water is the medium through which climate change becomes real. No city or nation is immune from extremes of protracted droughts punctuated by sudden urban floods. Negative impacts of natural disasters include loss of life, displaced families and livelihoods, and destruction of billions of dollars in property.

We can't predict the degree, extent or timing of impacts. But water professionals today far better understand our escalating vulnerability, and take steps to reduce risk exposure through building resilience.

This Executive Summary illustrates why, how, where, and for whom natural disasters loom large, and offers tested approaches and techniques to anticipate crises and address them in advance. It reframes unnatural shocks less as crises to manage than as opportunities to thrive. Success comes if we:

1. **Play Offense, Not Defense.** *Don't wait and react to future impacts; adopt a proactive approach to water system reforms that reduce waste, build integrity, and lower exposure to rising risks.*

2. **Make Drought the Norm.** *Consider severe and protracted aridity the new rule, with rainfall the rare exception, in order to reach a new equilibrium heading into perpetually drier future.*

3. **Embrace Floods, Naturally.** *Rather than push runoff elsewhere, ease its intensity by slowing it up, spreading its risks out, and sinking its waters down through low-impact development.*

4. **Help Living Cities Breathe.** *Take the lead in turning urban areas into dynamic living organisms, by linking natural water infrastructure in ways that enhance the built environment.*

5. **Buy Low (Tech), Sell High (Yields).** *Invest early in a menu of affordable and interactive options that generate stable, adaptive outcomes over the many volatile years ahead.*

6. **Reform Institutions.** *Explore drought insurance, dam re-optimization, water rights, internal markets, trade in virtual water, pricing, policy, devolution of authority.*

7. **Link Silos.** *Integrate the water-energy-food-health nexus to achieve higher adaptation, mitigation, and valuation of water across sectors.*

The *Solutions to Resilience* illustrate the value of taking early, deliberate and judicious measures to calmly confront an uncertain and troubling future – a future that has already arrived, is growing ever more volatile, but to which we can adapt.

1. Play Offense, Not Defense

Challenge : Climate flux may take the form of record-breaking snows, enduring ice, and frozen ground that disrupts cities and farms. Conversely, it may bring urban heatwaves, protracted droughts, and cracked and barren soils. Or it may bring increasingly frequent and intense typhoons and hurricanes. The one constant will be changes in hydrologic systems, water resources, coastal zones, and oceans. On the whole, wet tropical regions will get wetter, and the dry regions will likely suffer increases in extent, severity and duration of droughts.

Solution : *Don't wait and react to future impacts; adopt a proactive approach to water system reforms that reduce waste, build integrity, and lower exposure to rising risks.*

Action : Accelerate reforms that have begun to improve the efficiency and integrity of operations, with an emphasis on adaptive, decentralized, natural infrastructure measures that increase the adaptive capacity to absorb shocks.

Results : Climate resiliency emerges through integrating silos of the system into a whole.

- Water efficiency and pressure management efforts ensure both the availability of more and better water, but also builds a tighter linkage between supply and demand.
- Low impact development like swales, permeable paving, wetlands and rain gardens can attenuate urban

flooding and recharge groundwater recharge by slowing, spreading, and sinking runoff.

· Aligning built and natural infrastructure – conjunctive use of groundwater or dam reoperation, for examples, -- can minimize the peaks and valleys of drought impacts downstream.

2. Assume Drought as the Norm

Challenge : Drought is no longer what we thought it was. Once considered the exception, it is increasingly becoming the norm. Few can universally agree on what it means or how to define it. Even scientist and policy makers can't decide whether a drought has begun, let alone when, or if, they can declare it has ended. Quantifying the impacts and providing disaster relief are more difficult for drought than for other natural hazards due to slow, severe, and long-lasting impacts that may run for decades. Also a global temperature increase of 3-4°C may alter run-off patterns and force another 1.8 billion people to live in a water scarce environment by 2080. Droughts may be increasing in frequency, severity, and duration, which make the traditional reactive approach inadequate.

Solution : *Assume severe and protracted aridity is now the rule, with rainfall the exception, in order to plan for and reach a new equilibrium and thrive in a perpetually dry future.*

Action : Mobilize around the causes and effects of drought, promote information exchange, and introduce innovative techniques, trade, and practices that improve food security.

Results : Proactive drought policy options include:

· Securing a risk and early warning system that conducts a vulnerability analysis, impact assessment, and communication plans;

· Include mitigation and preparedness measures that include the application of effective and affordable practices;

· Build universal awareness by investing in aggressive education, since a well-informed public can share responsibility through an inclusive, participatory decision-making processes; and

· Enhance policy governance through stronger political commitment and accountability.

3. Embrace Floods, Naturally

Challenge : By 2050, rising populations in flood-prone cities, climate change, deforestation, loss of wetlands and rising sea levels are expected to increase the number of people vulnerable to flood disaster to 2 billion. Urban flooding affects developed and developing countries alike. The devastating impact of recent deluge, like that which occurred in Thailand in 2011, means more than half of humankind face volatile weather events in cities. Some degree of exposure to flood risks have long been part of our life, but climate change elevates flood events to new extremes. Worse, these dangers are compounded by unregulated urbanization with impermeable land use and development. Hard surface roads, walkways, parking lots and rooftops accelerates the velocity and amplifies the peak intensity of urban runoff, with devastating consequences in cities around the world.

Solution : *Rather than push runoff elsewhere, ease its intensity by slowing it up, spreading its risks out, and sinking* *its waters down through low-impact development.*

Action : Forewarned is forearmed: proactive investments in institutional, technical, and communications capacity to empower developers, officials and residents to anticipate build resilience.

Result : Reduce direct and subsidiary damages by planning urban areas to absorb and adapt to sudden natural hazards, using hardware and software tools.

- Enact codes to build or retrofit urban land development that integrates natural infrastructure with the build environment.
- Mitigate impacts of urban flooding by integrating traditional knowledge and developing and early warning systems.
- Develop flood defence systems such as flood gates, doors, and barriers as well as flood forecasting and observation technologies.
- Improve forecasting, warning systems, and visualization of status that the public can rely on.

4. Help Living Cities Breathe

Challenge : Much of the past century of urban development has involved the construction of hard, and rigid infrastructure – concrete sidewalks, asphalt roadways, steel sewerage, straight gutters – to keep a city on a firm base and push water elsewhere. That made sense in an age of reliable weather patterns and a stable climate. But cities no longer live in that age. The solid framework and foundation have become a liability that elevate temperatures to lethal levels in the urban heat island effect, while runoff backs up into streets, and streets back up into homes, buildings, and water or energy installations. This highlights a vexing water and sanitation challenge: a resource can flow clean, with efficient delivery of healthy and equitable water, yet still be fragile. What was seen as support has now become a corset that inhibits a city's ability to adapt to escalating stress, choke points and natural disasters.

Solution : *Take the lead in turning urban areas into dynamic living organisms, by linking natural water infrastructure in ways that enhance the built environment.*

Action : Enact new codes that reward the rapid development and deployment of green spaces that bring new flexibility, distribute local risks and broad responsibility, and build capacity against the worst.

Result : One constant is our need to adapt, when the only sure thing is a sense of uncertainty.

- To avoid rupture, water systems must go beyond 'robust' and be able to bounce back against stress.
- As a rule of thumb, the economic, societal, or ecological life of a city grows resilient to the extent to it anticipates, minimizes, and de-risks water systems.
- Looking ahead, the success of our 'grey' systems depends on integration with green, 'natural infrastructure.'
- But benefits must be shown to be cost-effective, or superior to traditional built approaches, and the most rigorous outcomes require flexibility.

5. Buy Low (Tech), Sell High (Yields)

Challenge : Cities may desire resiliency through adaptive mechanisms, but complex plans take time. They can prove slow and contentious. Special interests may push for pet projects by geography or sector. And infrastructure – natural or built – may still require expensive tools, blueprints, labor and capital expenditures. How can cash-strapped urban governments come up with the money to bring about the necessary changes?

Solution : *Invest early in a menu of affordable and interactive options that generate stable, adaptive outcomes over the many volatile years ahead.*

Action : Deploy affordable, participatory and user-friendly tools that maximize durable outcomes, distribute risks and responsibilities, engage multiple stakeholders, and shift cities to resiliency.

Result : Where uncertainty breeds fear, transparency builds trust: web- and mobile-based information communications technology (ICT) yields knowledge that can be shared.

- From meters to billing systems to temperature gauges, resilient water managers tap into reliable big data that is cheap, anonymous and available. Sharing it interactively can fast track resilience.
- Repurpose existing tools like cell phones, archival data, and closed circuit TV into hydro-informatics – the symbiosis of ICT and water science – to forewarn and forearm stakeholders.
- University researchers harness GIS and 3-D expressions of 'the Internet of things' to analyse signals for flood or drought anomalies that allow intervention in real-time, before it is too late.
- Other recipes combine basic rainfall data with meter readings, add runoff patterns, control for slope, adjust by surface, flood records, and satellite images. The result: a useful, actionable tool.
- Markets help make interactive technology transfer easier, cheaper, and in some cases free: open platforms integrate water data, link sensors throughout utility networks, or offer water R&D.
- These tools yield results across space and time, helping anticipate floods, hurricanes, or droughts, and focus on where damage potential may be highest, allowing managers to rank threat risks.

6. Reform Institutions

Challenge : Technology advances globally and economically. Wind power desalinates the sea. Deep aquifer pumps 'deposit' seasonal flows into groundwater 'banks'. Conversion of waste streams into water, or energy, can generate a potentially drought proof supply. But engineering alone can't work unless nested within a strong institution. Decision-makers need authority to weigh residential equity against industrial demands. Pricing strategies require stakeholder engagement. Pooling risks and cross subsidies demand a deep and stable reservoir of trust, incentives, outreach and coordination.

Solution : *Explore drought insurance, dam re-optimization, water rights, tiered rates, internal markets, trade in virtual water, drought pricing, and devolution of authority.*

Action : Engage constituents in honest discussions of future risks as a way to justify simple, small-scale, isolated pilot demonstration projects that test and build potential institutional reforms and allow the most effective results to emerge on top.

Results : Public, private and philanthropic institutions have allocated funds for sustainable investment strategies, research, and pilots programs to grow institutional capacity.

- The U.S. coordinates efforts of 13 federal agencies to understand why climate is changing, improve predictions about how it will change in the future, and to use that information to assess impacts on human systems and ecosystems and to better support decision making.
- The Netherlands has begun to address, absorb, and build resilience to water impacts from a rising sea level, while the Rotterdam Approach combines knowledge, action and positioning/marketing.
- Japan's environment ministry explores both the impact of and adaptation to climate change, and seeks to spread knowledge of water through "Wise adaptation"
- Korea launched a 'National Climate Change Adaptation Policy' with other 13 ministries to reform policy in 7 areas through basic alternatives for resilience; including tools that help local governments estimate and address vulnerabilities through Local Climate Change GIS.

7. Link Silos

Challenge: The United Nations' proposed 17 Sustainable Development Goals includes #6: "Ensure availability and sustainable management of water and sanitation for all". At the same time, water underpins all 16 other priorities, and is thus both a target and means to an end. Yet as water professionals see temperatures and sea levels rising, monitor groundwater salinity, watch floods escalating and snowpack melting, they lack political capital to build resilience. Water is still rarely seen as the matrix on which all other sectors depend, and its reveal competition between energy, agriculture, industry, and nature.

Solution : *Integrate the water-energy-food-health nexus to achieve higher adaptation, mitigation, and valuation of water across sectors.*

Action : Build collaborative resilience through reforming water policies, and leveraging financing mechanisms, that align with the goals and interests of key stakeholders.

Results : Water is this century's common currency of life, health, trade, energy, nutrition and climate change security.

- Efficient water use in agriculture lowers the global commodity food price index, and through virtual water trade this builds climate resilience for billions of the world's poorest.
- Secure, reliable, nearby taps allow water-fetching women and children to reinvest spare hours into education or remunerative labor
- Universal access to clean, safe, water and sanitation slashes disease and death from dehydration.
- Low-impact development approaches filter runoff in ways that heal hypoxic dead zones offshore, boosting the wild fishery resources on which 4.3 billion depend for vial animal protein.
- Slashing demand for urban water in half eases strain on power grids and lowers carbon emissions.
- Appropriate resource valuation could reduce energy's hunger for 8-44% of all water withdrawals, and water's thirst for up to 33% of all energy.
- Cutting food waste from field to fork by 40% would enhance global nutrition for billions without demanding more water; conversely drip irrigation could produce more food with fewer drops.

Main Focus 4 : Smart Technology for Water

For millennia Egypt gathered water data from step-like infrastructures. Strategically sited along the river, these durable instruments measured the seasonal pulse of currents; recorded water quantity and quality; calibrated how much flood irrigation would benefit all subjects; determined taxation rates based on flow pattern; and detected early potential for risky extremes of drought or deluge.

The Nilometer may be the oldest information and communications technology (ICT) applied to water.

Pharaoh and farmer alike depended utterly on this 'smart' tool. Each recognized it as a means to their own water security. With time it fortified the social contract through layered scientific understanding.

Since then, our end goals have changed little. We still seek to collect, analyse and share water quality and quantity data in a quest for security. Our urbanizing, water-stressed world demands faster, smarter, more precise knowledge. Vital data supports equitable, efficient and ecologically sustainable governance.

But the means at our disposal – the fast-evolving spectrum of clever, complex, costly, and sophisticated tools – may complicate decisions. This Executive Summary helps professionals leverage ICT to achieve their desired outcomes. We outline the trends, tactics and case studies that can convert more data into more food, energy, security, life. 'Smart' water solutions lie in:

1. **Nexus management.** *Intelligent decision-making at systemic levels can incentivise efficient and sustainable use of water and energy, and reduction of greenhouse gases emissions.*

2. **Transparent Trust.** *The most valuable information needs to be free, so any smart water system must be willing to share information globally and across sectors and segments.*

3. **Open Doors.** *The success of any smart water management lies not only in improving the technology, but also in involving, persuading and preparing multiple stakeholders to adopt it.*

4. **Empowered Options.** *Real time monitoring and diagnosis, as well as automatic controls, can improve the supervision and optimization of water demand-supply management.*

5. **Appropriate Scales.** *To enable robust management of big data, support smart monitoring and metering at scales ranging from basins to households.*
6. **Broad(band) Foundations.** *Rapid, reliable decisions require web and mobile-based networks to monitor, acquire and process real-time data on water level, rainfall, runoff and water quality.*

7. **Driving Efficiencies.** *Smart systems, linked to wise legal and economic institutions, can help professionals achieve water and resource efficiency goals.*

The Solutions to ICT seeks to build on best practices and enable new innovations. Information may be power, but only if anchored by those with the wisdom of to use it. Each solution outlines the most effective ways to generate better results, for more people, in a shorter time, with fewer resources.

1. Nexus Management

Challenge : The world has awakened to the risks of the water-energy nexus. Electricity grids grow thirsty while water grids demand more and more power to convey, heat and treat what flows through tap or toilet. The nexus escalates greenhouse gas emissions, increasing exposure to climate impacts. But solutions too often seem slow, cumbersome and expensive; they tend to be aimed at the supply side of the equation – upgrading pumps, plants and generators – rather than address the real, largest, and fastest growing source of energy embedded in water: the end user. It is unclear whether, where or how best water professionals can engage customers in transforming this vicious spiral into a virtuous force for water security, energy efficiency and carbon reduction.

Solution : *Intelligent decision-making at systemic levels can incentivise efficient and sustainable use of water and energy, and reduction of greenhouse gases emissions.*

Action : Set goals that are widely desirable – like avoiding the unmanageable (and managing the unavoidable) impacts of climate change – then use ICT to build a 'smart water grid' (SWG).

Results : A SWG can take many forms, in response to unique contextual and demographic drivers:

- K-water's SWG is developing new & renewable energy technologies for increasing the efficiency of consumed energy in the water supply system to at least 30%.
- The 'Pecan Street Project' in Austin, Texas is implementing a demonstration complex that combines a smart electricity grid and smart water grid for 4,900 households across 2.8 Km^2, applying AMI, sewage recycling technology and Smart Irrigation for gardening.
- Following crippling drought in 2004-2007, Queensland, Australia, developed a SWG to secure water by balancing flows and stabilising supplies at minimum cost.
- Despite high rainfall, Singapore lacks land to capture and store rain. To address shortages, its SWG aims to secure a stable water supply, predict and respond to rapid changes in the global water situation, establish an R&D center for water processing technology, and foster international and domestic water companies to become the world's leading water hub.

2. Transparent Trust

Challenge : Water is highly transactional. People allocate, ration, charge and pay each other for it. Rural tariffs and urban rates put a premium on privacy. Commercial clients, irrigators, and residential customers feel sensitive about usage patterns; urban water providers and governments fear disclosing non-revenue water and waste. Yet 'smart data' remains largely worthless if locked up alone. It serves no purpose removed from context or currency. Real value and knowledge emerge only when information can be accessed, analysed and used to understand, benchmark, integrate and improve the system as an organic entity throughout watersheds and across the borders of nations sharing river currents.

Solution : *The most valuable information wants needs to be free, so any smart water system must be willing to share information globally and across sectors and segments.*

Action : Set up the network of smart water systems based on who can benefit from data, whether residential customers, downstream stakeholders, industrial corporations or the government itself.

Result : Many innovative, effective assessment technologies have been developed and can motivate users.

· Detect leaks by fixed or portable hydrophones, magnetic flux or linear polarization resistance.

· Smart meters indicate anomalies against baselines; signals can alert company and client alike.

3. Opening Doors

Challenge : Despite many attempts to integrate ICT into urban water supply systems, smart technologies continue to face barriers of sociological, ecological and economic limitations. These include public health fears; cost concerns; database quality; workforce skills; assessment capacity; and the requirements, technologies and costs of inspection.

Solution : *The success of any smart water management depends not only upon improving the technology itself, but also upon involving, persuading and preparing multiple stakeholders to adopt it.*

Action : Rather than present smart meters as a hasty 'done deal,' engage clients and other constituents up front, out in the open, to discuss shared social, economic and ecological benefits: safer working conditions, more accurate readings, billing efficiency, leak detection and reduced emissions.

Results : However contentious or costly public outreach may seem on the front end, it pays long term dividends in trust, savings, compliance and accountability.

· K-water shares the data with the KMA (Korea Meteorological Administration), the MOLIT (Ministry of Land, Infrastructure and Transport of Korea) and other relevant entities, and supports its own employees to check hydrological information through smart phone applications anytime and anywhere.

· The website of K-water provides real-time data about hydrological conditions and closed-circuit television footage from dams and weirs to satisfy the public desire for better services.

· Western Australia launched an ongoing campaign with its customers to explain the need to take more responsibility for water.

4. Empowering Options

Challenge : Climate change impacts will be felt most severely on water availability and quality, affecting human wellbeing, industry, agriculture, ecosystems, economies and regional stability. Negative water impacts are falling hardest on the disenfranchised urban and rural poor.

Solution : *Real time monitoring and diagnosis, as well as automatic controls, can improve the supervision and optimization of water demand-supply management.*

Action : Provide widespread access to data – or even to the tools that generate that data – in ways that shorten the distance between provider and recipient, supply and demand.

Result : Smart systems are emerging in affluent cities and developing rural landscapes alike.

· In Africa, Water for People is harnessing ICT by encouraging end users to alert the government when and where a groundwater pump is broken or contaminated.

· Two-way signals combined with interactive web-mobile alerts allow urban users to see whether they have a leak, where it may be, what to do about it and how fixing it can save money.
· Connectivity increases accountability, encourages end users to take responsibility and improves the performance and responsiveness of governments.

5. Appropriate Scales

Challenge : ICT often seems like a 'one-size-fits-all' package that gets marketed and sold to affluent megacities or large industries. The world may be urban, but cities vary dramatically by region and context. Many water systems – especially older ones, strained to capacity – are limited by small budgets, outdated technology, unskilled human resources and political constraints. Yet these are the very systems that could benefit most from having tools that could empower and integrate stakeholders to achieve water security.

Solution : *To enable robust management of big data, support smart monitoring and metering at scales ranging from basins to households.*

Action : As technology grows more affordable through economies of scale, it falls within reach of more systems to distribute risks and encourage resilience.

Results : The right to water corresponds to the responsibility of those who demand it.
· A decentralized water system used for water supply can be understood as a system where intensively concentrated urban water load is mitigated; a water grid connecting different water supply systems is provided; and a sufficient amount of storage capacity to provide against any emergency situation is secured.
· Smart asset management optimises capital, operations and maintenance expenditures by providing the desired level of service at the lowest infrastructure life-cycle cost.

6. Building Broad(band) Foundations

Challenge : Smart water management never emerges in a vacuum. Any ICT system for water – providing broad access for all stakeholders to high quality hydrological data – must walk before it can run. Egypt's Nilometer grew refined over decades, but even it required institutional capacity to track, record, store and share data through a common language base, with shared access, and constant real-time communication.

Solution : Rapid and reliable decisions require web and mobile-based networks to monitor, acquire and process real-time data on water level, rainfall, runoff and water quality.

Action : Take advantage of public, shared and relational databases or web-based systems. A smart data processing system includes: real-time data processing; a client/server communication network configured with satellite, VHF, CDMA, etc; 24/7 monitoring; closed-circuit television footage from major risk areas; and text message services for risk alerts.

Results :
· Smart sensors optimize irrigation water by measuring humidity, rainfall, wind speed/direction, soil temperature/ moisture, atmospheric pressure, and solar radiation.

· K-water operates a real-time information system to provide data about hydrological conditions; Smart rehabilitation technology sends image-diagnosing robots to inspect pipes, blasts scaling and rust with an ultra-high pressure water jet, and sprays lining/coating materials evenly inside the pipes.
· The system functions to combine real-time data (covering water level, rainfall, water quality, etc.) and video footage of closed-circuit televisions from major dams, weirs or rivers, streams in the country for 24/7 monitoring services.
· Relevant data are collected from sensors installed in monitoring facilities, and transmitted to a communication room, or control room, through either wired or wireless communications technologies.

7. Driving Efficiencies

Challenge : A century of cheap or free water has accelerated the depreciation of water infrastructure, led to systemic unaccountable waste, created a culture of entitlement and caused urban and rural water scarcity. ICT tools hold out the potential to improve demand response, reverse the energy-water nexus into a positive direction, and engage clients to work with the provider rather than against it. But smart technology alone needs institutional reforms to prevent water from bleeding away, silent and invisible.

Solution : *Smart systems, nested within wise legal and economic institutions, can help professional achieve water and resource efficiency goals.*

Action : To reap the full potential gains from ICT, nest them within water rights, allocations, tariffs, licensing, regulation, storage, abstraction, energy choices and markets.

Results : Integrating smart tools help build a more efficient and accountable non-structural administrative framework.

· Advanced Metering Infrastructure (AMI), with 'smart' sensors and signals, lets consumers choose tariffs, while utilities can prioritize usage for special purposes and pricing.
· 'Smart' meters allow time of day billing, reduction of peak demand, leak detection, increased distributional efficiency, non-revenue water reduction, and deferral of capital spending.
· 'Smart' pipes measure water flow and quality to detect strain, temperature or pressure anomalies, so potential leaking can be checked in real time.

Main Focus 5 : Understanding and Managing Ecosystem Services for Water

Rivers have been, and remain, our most vital water infrastructure.

Headwaters collect it. Forests retain it. Meadows control its extremes. Currents deliver it. Eddies produce food from it. Aquifers store its surplus. Wetlands filter it. Wind and sun desalinate it all over again.

What should nature invoice us for this endless hard and productive work on our behalf? Until recently the answer was: 'No charge'. But water professionals have begun to approach this question in radical new ways, developing new valuation tools, and seeking answers with an increased sense of urgency.

Humans tend not to value what comes for free. We claim water is 'priceless' but treat it as worthless. Our cities take reliable upstream flows for granted, and convert downstream flows into open sewers.

That's changing, fast. This Executive Summary illustrates why, how, where, and for whom watersheds yield dramatic benefits – most recently defined as "the direct and indirect contributions of aquatic ecosystems to human well-being" – that enhance what we've built. Successful outcomes emerge if we:

1. **Move Nature from 'Red' to 'Black'.** *Shift aquatic ecosystems across the policy framework from the column of 'fixed liabilities' that we avoid into 'liquid assets' that generate yields.*

2. **Monetise what's Priceless.** *Deploy clear analytical tools that give explicit value to the hidden ways natural infrastructure adds value to society.*

3. **Slow, Spread & Sink It.** *Decompress and decentralize urban runoff techniques to bring back a watershed's former health, rhythm, velocity, and reliability.*

4. **Seek Symbiosis.** *Convert the reactive 'environmental impact assessment' into a proactive evaluation of how much development can benefit from naturally functioning water flows.*

5. **Scale Economies.** *Encourage and reward investments in natural water infrastructure at every level, from backyards to river basins, and rooftops to reefs.*

6. **De-Risk Development.** *Leverage nature as a fast, secure, and cost-effective insurance policy against escalating shocks to our manmade systems.*

7. **Redefine Relations.** *Transform nature, neither our subordinate nor superior, into an equal partner with which to build a mutually dependent, resilient and productive future.*

Solutions through Ecosystem Services illustrate that when we secure, value, and invest in natural capital, it repays healthy long term dividends. Each introduces the most effective ways that 'natural infrastructure' of aquatic ecosystems can support water, energy, and food security, for all, forever.

1. Move 'Nature' from Red to Black

Challenge : The concept of an "aquatic ecosystem" is easy to grasp but hard to classify or define. All too often it gets ranked as a complex problem for scientists to explore and for governments to manage. As a result, otherwise healthy rivers – and the fish, plants and wildlife species within them – loom as a barrier to progress, an obstacle that development must somehow address or overcome or mitigate (or ignore) so that societies may advance. This misperception has turned out to be harmful not only to natural infrastructure, but also dangerous to the cities that utterly depend on it. Can cities really reflect the true value of water for society? Yes.

Solution : *Shift aquatic ecosystems across the policy framework from the column of 'fixed liabilities' that we avoid into 'liquid assets' that generate yields.*

Action : Compare the many gains from the integrity of robust watersheds against the rising costs of replacing them in perpetuity through building new manmade infrastructure.

Results : The most durable and affordable approach to urban development is often the greenest:

- Wetland integrity need not be lost and mitigated but rather reinvested in as an adaptive strategy to reduce impacts from floodwaters, and costs of stormwater treatment.
- Swales along roadsides filter heavy metals and biochemical that generate savings both from avoided costs and more stable and productive aquatic life and food security.
- Breaking down curbs into green spaces slow not only runoff, but also traffic, reducing traffic congestion, urban stress and social risks.
- Centralised stormwater treatment plants finds valuable and complementary support from strategically designed green spaces, especially at crossroads.

2. Monetise what's Priceless

Challenge : Rivers that belong to everyone are too often valued by no one in particular. Constituents in every government, at every level, naturally enjoy goods and services watersheds provide for free; conversely, they resent being asked to pay for them. And while economists can explain on paper the benefits from 'putting a price tag on nature,' they can't win office on promises to raise the cost of water, the cost of food, and the cost of energy for everyone. If restoration of watersheds is desirable for society, can its benefits be monetized, without generating a political backlash? Yes.

Solution : *Deploy clear analytical tools that give explicit value to the hidden ways natural infrastructure adds value to society.*

Action : Present watershed health on a menu of options, demonstrating if, how, where, and why green and low-impact development is less expensive than built up alternatives.

Results : Measuring ecosystem services in monetary terms is crucial for policy implementation:

- New York City happily invested in the integrity of upstream rural headwaters when shown that doing so cost a fraction of a downstream urban treatment plant.
- Businesses and officials in seven Northern Andean cities like Quito, Ecuador and Bogota, Columbia invest matching 'water funds' into upstream watersheds for downstream security.
- South Africa's taxpayers invest in labor intensive projects to remove invasive alien weeds, because doing so generates more water at less cost than built infrastructure.
- The Netherlands is testing a program to compensate farmers who manage their land for the ecological benefits of watershed services.

3. Slow, Spread & Sink It

Challenge : Every country on earth is undergoing rapid industrialization, an unprecedented experiment with unforeseen outcomes. As more than half of humanity lives and works in cities, land use patterns generate undesirable impacts both on and from declining watershed health and stability. Governments easily identified and addressed industrial pipes spewing toxic discharge, but now face a new threat from rain hitting impermeable surfaces. Runoff from tar rooftops, driveways, roads, parking lots, and industrial complexes combine new, unwieldy and potentially lethal non-point source (NPS)_ pollution. This NPS cocktail runs through gutters, and drains into water bodies, as untreated discharge. It steadily poisons rivers with heavy metals, and suffocates life by biochemical oxygen demand, two thirds of which now come from polluted stormwater runoff. Can cities escape pollution that rushes in from everywhere all at once? Yes.

Solution : *Decompress and decentralize urban runoff techniques to bring back a watershed's former health, rhythm, velocity, and reliability.*

Action : Adopt low impact development (LID) and green vegetation cover to intercept, absorb, and store rainfall and runoff in an affordable and aesthetic policy response.

Results : LID harnesses society's goals with natural processes in impervious areas as it:

- Eases both the timing and peak of runoff from extreme storms to reduce the sudden surprise, biochemical loads, heavy metals, and extreme impacts of urban flooding.
- Maintains drinking water supply by decreasing exposure to risks of contaminated stormwater overflows.
- Increases individual property values of sites by improving the exterior aesthetic nature for the community, while lowering the rising plumbing, insurance, maintenance, and treatment costs for all.

4. Seek Symbiosis

Challenge : Decades ago local, city, regional, and federal governments began to adopt various assessment tools that promised to reduce the negative impacts on aquatic ecosystems. These have faltered, due largely to inherent flaws and disincentives. First, they demanded too few and too little in countermeasures, applied too infrequently, coming too late in the planning process. Also, they pitted environmentalists against private interests in an escalating arms race, with officials caught in the crossfire. Finally, in trying to avoid the downside of negative damage to watersheds, they ignored the potential upside of positive benefits from precautionary measures from watersheds. Is there a better way forward? Yes.

Solution : *Convert the reactive 'environmental impact assessment' into a proactive evaluation of how much development can benefit from naturally functioning water flows.*

Action : Low Impact Development (LID) and natural infrastructure approaches include and integrate the development plan to overcome hydrological, social and ecological problems caused by urbanization so that humans can coexist with the ecosystem.

Results : Natural infrastructure doesn't replace built infrastructure; each supports the other:

- Dams benefit from forests and meadows that stabilize soils, maintain snowpack, attenuate floods, store runoff, and hold back erosion upstream.
- Lakes, aquifers, floodplains and wetlands provide water storage and therefore reduce the reservoir size along with the labor, equipment, and mitigation costs to build it.
- Terraced landscapes, green roofs, planted medians, and permeable pavements recharge groundwater, reduce floods, cut sediment loads, capture pollutants, and filter runoff.
- Well-functioning natural watersheds extend the life of hydropower and irrigation technology, and justify their integration through a longer, higher return on investment.

5. Scaled Economies

Challenge : Our manmade infrastructure for irrigation, hydropower, or municipal water was built on a foundation of relatively stable equilibrium, or 'stationarity,' but that no longer exists. Water's quality, quantity, productivity and health is being degraded at every level. Responses are fragmented. Governments mandates are broken into silos. Urban and rural institutions work in isolation. Competing users talk past each other. The lack of coordination breeds delays, distrust, and conflict. And the scope is often narrowed to single issue crises rather than the spectrum of freshwater flows and processes across scales. Can we widen and expand the set of interests to align stakeholders? Yes.

Solution : *Encourage and reward investments in natural water infrastructure at every level, from backyards to river basins, and rooftops to reefs.*

Action : Prioritise a focus on watershed-based outcomes to build policy support, engage water and wastewater operators, and leverage investments in natural infrastructure.

Results : Urban LID policies to integrate retention, infiltration, and circulation can aggregate across groups of actors and collaborative efforts to yield massive regional benefits:

- Frieberg, Germany applies small scale decentralized types of vegetated swale, infiltration basins, bioretention and constructed wetlands in urban land use.
- As part of a national project, Chungcheongnam-do, Korea designs small scale bioretention, infiltration trenches, horizontal subsurface wetlands, and free water surface flows.
- Cities in the UK install green drainage systems to manage runoff and NPS pollutants, leveraging ecological mechanisms that connect water, green spaces, and scenic values.
- Social networks with a wide scope of actors can connect institutions across scales to build trust, share information, identify knowledge gaps, and create nodes of expertise.

6. De-Risk Development

Challenge : Humanity depends on stable watersheds for food, energy, transportation, health and culture. Unfortunately, these life-supporting freshwater systems are extremely complex and now increasingly unstable. After millennia of co-evolution at a literally glacial pace, both nature and societies are being forced to undergo sudden, accelerated and extreme shifts into undesirable states that may be impossible to reverse. Global change is forcing local economies to confront unprecedented risks. If we can't stop or predict disruptive risks, can we absorb and adapt to their inevitable impacts? Yes.

Solution : *Leverage nature as a fast, secure, and cost-effective insurance policy against escalating shocks to our manmade systems.*

Action : Just as auto insurance companies structure rates based on safe driving, so too can underwriters base premiums and risk ratings on policies that encourage 'natural infrastructure' and 'low impact development.'

Results : Public, private, commercial and industrial complexes take locally and demographically appropriate measures to build resilience to a more volatile and unstable water future:

- Makanya, Tanzania is investing in rainwater harvesting, conservation tillage, and other productive and affordable small-scale water innovations to break dryland poverty traps.
- China is investing 100 billion USD over a decade to secure the natural capital of river system services against urban flooding, loss of topsoil, desertification, and ecotourism.
- Korea's 'Four major River Restoration Project' is investing in natural capital to secure supplies, control floods, enhance water quality, boost culture, and develop the region.

7. Redefine Relations

Challenge : Our ancestors carved out and grew civilizations alongside rivers. They saw nature as chaos, and sought to bring order to its hostile and malignant forces of drought, turbulence, and deluge. Their engineers began to subdue, harness, tame and domesticate aquatic ecosystems, halting, diverting and draining currents before they could 'empty' and thus be 'wasted' into the sea. Now younger and more affluent generations seek to reverse these policies. Rejecting the 'anthropocentric' mindset for 'eco-centric' outlook, they demand rivers be liberated, unleashed, left alone to return to a feral, unruly, and wild existence. Both enslavement and neglect are impractical and unaffordable in our increasingly thirsty world.

Solution : *Transform nature from subordinate or superior into a full and equal partner with which to build a mutually dependent, resilient and productive future.*

Action : Learn to use the services of aquatic ecosystems with the same care a craftsman devotes to his tools, in order to build or restore useful works with integrity, diversity, durability, and beauty.

Results : Secure development comes from recognizing people and nature as inextricably linked:

- U.S. coastal cities are embracing policies to improve stormwater runoff, water quality, and resilience through natural infrastructure, especially in schools and public spaces.
- Aquatic ecosystems are disrupted by demands to take water away from rivers, but also by changes in land use that affect the amount and quality of water flowing into them.
- Preservation and regeneration of native open vegetation, or rain gardens, can extend runoff detention time in the sources, connect impervious areas, and improve drainage.
- Minimizing impervious areas through common values can improve infiltration rates, link flows, absorb extreme risks, and enhance runoff quality.
- Managing stormwater runoff through natural sources helps reduce impacts, and dependence on conventional drainage pipes, sewer lines, and treatment ponds.

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