Private Infrastructure Development Group

NATURE FINANCE

Investing in Water-Related and Dependent Infrastructure:

Risks, Considerations, and Opportunities

How Water Risks Shape Infrastructure Performance, Financing, and the Case for Ecosystem Integration

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Contents

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Executive Summary

The world has entered what the United Nations (UN) describes as an era of global water bankruptcy, in which many river basins and aquifers can no longer return to historical baselines. Infrastructure performance depends on the condition of the water systems it relies on. Reliable supply, natural flood attenuation, and catchment filtration are operating inputs, not externalities, and when they degrade the financial consequences flow directly through to operating costs, revenue, reliability, debt service coverage, and asset life span.

This report explores how water risk shapes infrastructure performance, financing, and value, drawing on three case studies across Africa and Asia: the Xuan Mai water supply system in Vietnam, the Cape Town water crisis in South Africa, and the Wuhan sponge city programme in China. Each case study highlights a new solution to infrastructure that was underperforming – not only due to engineering shortcomings, but also because of changes in the natural water systems on which these assets depend. The case studies explore how water-related dependencies can be better understood and considered, and how this should inform the appraisal, structuring and financing of water-related and water-dependent infrastructure in the future.

Water risk is a macroeconomic and macro-fiscal risk: when supply fails or becomes prohibitively expensive, activity contracts, investment retreats, and tax bases erode, while emergency spending and contingent liabilities rise. The overarching finding is that water-system conditions increasingly determine infrastructure performance, yet investment decisions still under-account for them. Four findings stand out:

1. **Grey and green are not evaluated as one system:** Costed as separate line items, the green component looks like an added cost rather than a cheaper alternative, so integrated solutions are systematically undervalued. Green and grey infrastructure should be evaluated as one system.
2. **Residual ecosystem risk sits implicitly with the project:** Where the dependency on upstream natural systems is not explicitly allocated in the contract, the project carries it by default, and it is rarely priced. Residual ecosystem risk should be accounted for explicitly.
3. **Stewardship is uncontracted and structurally underfunded:** In most deals examined, no funded mechanism sustained the catchment, wetland, or flood buffer the asset relies on; Cape Town's recent outcomes bond is an early exception. Where stewardship is unfunded, the resilience attributed to the project is assumed rather than contracted. The catchment should be treated as part of the asset, on contractable terms.
4. **There is no established insurance market for water ecosystem risk:** Acute shocks such as drought, and contamination are not yet routinely transferable: parametric instruments exist but remain one-off and nascent for water ecosystem risk, leaving residual exposure on project and public balance sheets. A dedicated insurance channel for ecosystem risk is needed.

Underlying all four findings is a structural barrier: much of the value created by ecosystem investment takes the form of avoided costs rather than revenue, so even sound investments struggle to attract private capital.

The report sets out a way to make these dependencies visible and priceable. It proposes a seven-step decision framework for infrastructure investors and a set of recommendations organised across three layers: the enabling environment, project design, and how capital is structured. The mechanisms to act already exist, from screening and stress testing to payment for ecosystem services, credit enhancement, and outcomes-based instruments, but they remain marginal because ecosystem dependencies are still treated as peripheral to core appraisal, governance, and pricing decisions.

The question is no longer whether to integrate water and ecosystem conditions into investment decisions, but how quickly institutional practice can make this standard. Acting early protects asset value and public finances; acting only after a crisis, as several of the cases show, is slower, costlier, and sometimes comes too late.

1 Water Risk and Infrastructure Investment

How do water risks cascade through infrastructure systems to create operational failures, cost escalations, and development setbacks - and what does this mean for infrastructure investment?

Water is becoming one of the defining risks for infrastructure investment. Basins that were once predictable are now volatile, and the hydrology that underpins the value of water-related and water-dependent assets is degrading in ways that conventional appraisal does not capture. PIDG and NatureFinance have collaborated to address this challenge. This paper presents a new approach to understanding and pricing water-related risks, with the aim of unlocking additional investment in water-related and -dependent infrastructure.

The approach treats the condition of water systems as a financial variable rather than a background environmental condition, making water and ecosystem dependencies visible within the appraisal, structuring, and governance of deals. The aim is practical: to help investors and financiers assess water risk more accurately, price it where it has previously been ignored, and continue to support investment in the critical water-related and water-dependent assets and infrastructure that economies rely on, rather than retreating from them.

The chapters that follow examine three case studies from Africa and Asia (Chapter 2), demonstrate how ecosystem dependencies can be identified and quantified (Chapter 3), assess available financing mechanisms and the barriers to scaling investment (Chapter 4), present a seven-step decision-making framework for investors (Chapter 5), and outline key recommendations to support the widespread adoption of the paper's findings (Chapter 6).

1.1 The Problem

The global water cycle is becoming more volatile. Rainfall extremes are intensifying, flooding is more frequent, and droughts are growing more severe and prolonged. The Intergovernmental Panel on Climate Change (IPCC) state with high confidence that variability and extremes in the water cycle will continue to intensify regardless of mitigation policy, affecting a large and growing share of the global population.[1,2]

Multiple drivers are converging to accelerate this instability. (1) Climate change is increasing atmospheric moisture content and intensifying precipitation by approximately 2–3% per degree of warming, accelerating glacier melt, disrupting monsoon patterns, and extending dry periods in already arid regions.[1] These dynamics undermine the long-standing assumption that historical hydrology can guide future water planning.[1] At the same time, global **(2) water demand** is projected to increase by 20–30% by 2050, driven primarily by manufacturing, energy production, and household use. This growth is tightening competition in already stressed basins, where a single dry season can trigger restrictions and sharp allocation trade-offs across urban, agricultural, and industrial users.[3,4] **(3) Ecosystem degradation** is further eroding the natural infrastructure that regulates water supply and quality. Wetlands, critical for water storage, filtration, and flood buffering, have declined by 35% since 1970, disappearing three times faster than forests.[5,6] **(4) Governance and policy gaps** compound these pressures. Fragmented water management, weak enforcement, and chronic underinvestment in monitoring and data systems leave infrastructure operators exposed to poorly anticipated shocks.[7]

Together, these drivers increase the risk that some basins transition from intermittent stress into a structural condition where reliability is difficult or impossible to restore. Recent synthesis work describes this state as "water bankruptcy".[8]

The Financial Analogy

Accounting metaphor to understand 'water bankruptcy':

- Checking Account = Renewable water (rivers, lakes, reservoirs, seasonal groundwater).
- Savings Account = Non-renewable stocks (deep aquifers, glaciers, long-residence groundwater).
- Income-Generating Assets = Natural capital that produces water (forests, wetlands, healthy soils).

Water bankruptcy develops in stages:

1. When checking accounts are regularly overdrawn beyond safe limits, savings accounts are drawn down to cover the gap.
2. This is compounded by damage to the income-generating assets that would otherwise replenish both.
3. The net result is water bankruptcy, with damage that is irreversible on human timescales.

Source: Madani (2026). Global Water Bankruptcy. UNU-INWEH.

These risks are not a future problem. Water-related disruptions and risks are already cascading through infrastructure systems, eroding asset performance and straining public finances. These impacts are expected to compound and intensify over the 20–100-year lifetimes of assets in operation or under development today. The operating environment in which infrastructure is appraised is increasingly unlikely to be the environment in which it operates. The following sections examine how these risks transmit through physical, regulatory, and reputational channels, and what they mean for infrastructure investors.

1.2 Risk Filters

The World Wide Fund for Nature (WWF) Water Risk Filter categorises water risks across three dimensions: physical, regulatory, and reputational. This report uses the WWF framework as a classification system, applying an investor lens to how each risk type translates into financial materiality for infrastructure assets and financing structures.

Figure 1: Water Risk Filters

Physical risk	Regulatory risk	Reputational risk
Water Scarcity	Enabling Environment	Cultural Importance
Flooding	Institutions & Governance	Biodiversity Importance
Water Quality	Management Instruments	Media Scrutiny
Ecosystem Services Status	Infrastructure & Finance	Conflict

Source: WWF (riskfilter.org/water)

Physical Risks

Physical water risks arise from changes in the quantity, quality, and the timing of water availability:

- **Water scarcity** occurs when demand exceeds available supply, reducing operational capacity and increasing costs. In India, approximately 40% of thermal power plants are in water-scarce regions and operate, on average, a 21% lower capacity utilisation rate than comparable plants in low or medium water stress areas, due to water shortages limiting operation.[9]
- **Drought** extends scarcity over time, compounding operational risk. In Zambia, where over 80% of electricity comes from hydropower, the 2024 El Niño drought caused blackouts lasting up to 21 hours a day.[10]
- **Flooding, by contrast, damages** infrastructure, disrupts transport and logistics, and contaminates water supplies. In Nepal, September 2024 floods damaged at least 20 hydropower plants, reducing output by over 1.1 GW.[11]
- **Water quality degradation** further constrains usable supply by increasing treatment costs and reducing downstream usability. This is evident in the Ganges basin, where industrial effluents and untreated sewage compromise downstream water treatment processes and irrigation systems.[12]
- Finally, **ecosystem services degradation** destabilises the natural infrastructure that regulates flows, filters pollutants, and buffers extremes. In Vietnam's Mekong Delta, upstream dam construction combined with mangrove loss is driving saltwater intrusion as freshwater flows and natural barriers decline.[13]

Regulatory Risks

Regulatory risks arise from changes in policy, legal, and institutional factors that affect water access, allocation, and compliance costs. Rapid shifts in policies or weak enabling environments can create or increase uncertainty and raise the cost of capital for water-dependent projects and infrastructure. Rising compliance costs can also materially affect project economics. Under the **EU Water Framework Directive,** utilities have had to finance large-scale wastewater treatment upgrades. Projects designed under current regulations may therefore face material unanticipated cost increases if standards tighten during their operating life.[14]

Government Policy Responses to Water Risk

Governments are translating water risk into binding requirements through allocation reform, disclosure mandates, and investment conditions at a pace affecting infrastructure project economics.

- **Water allocation reforms:** Kenya's Water Act (2016) introduced enforceable extraction permits. India's groundwater regulation is tightening with new restrictions affecting industrial users.[15,16]
- **Disclosure requirements:** The EU Taxonomy requires water risk assessment for sustainable finance classification.[14] China mandates 80% of urban areas meet sponge city standards by 2030.[17] South Africa's proposed amendments would restrict development within protected water source areas.[18]

Reputational Risks

Reputational risks arise from stakeholder concerns, community opposition, and media scrutiny largely related to water use, allocation, and environmental impact. For example, Google's planned data centre in Uruguay, requiring an estimated **7.6 million litres per day,** prompted **widespread protests during the 2023 drought,** ultimately forcing the company to redesign the project to eliminate direct water consumption.[19]

1.3 The Impact

Water risks are creating widespread and escalating development challenges. Water-related disasters caused 2 million deaths and USD 3.64 trillion in losses between 1970 and 2019.[20] These impacts are no longer episodic; they are systemic, affecting livelihoods, growth trajectories, and institutional stability.

Social Impacts

Social consequences cascade across scales, driven by inequitable access and heightened competition for water, which can trigger displacement, social unrest, and conflict. At the household level, people in poverty often pay 10-20 times more per litre for water sourced from informal vendors,[21] while women in sub-Saharan Africa spend an estimated 40 billion hours annually collecting water,[22] time lost to education, income generation, and care. As scarcity becomes chronic, displacement and instability increase. Water stress is contributing to population movements and displacement across East Africa, the Sahel,[23] and South Asia, often interacting with food insecurity and conflict. Failing economic systems erode public trust; in Iran, water shortages and mismanagement triggered protests that escalated into broader challenges to government legitimacy.[24] At the international scale, scarcity heightens transboundary tensions, as evidenced by growing strain on agreements such as the Indus Waters Treaty between India and Pakistan.[25]

Economic Impacts

Economic impacts compound these pressures. Water insecurity can reduce growth through productivity losses, agricultural disruption, health burdens, and rising public expenditure. Globally, GDP losses of 6-8% are projected by 2050, rising to as much as 15% in the most severely affected countries.[26] Extreme weather events place acute strain on public finances and are increasingly reflected in sovereign risk assessments; around one-third of rated sovereigns face elevated water-related credit exposure thereby increasing borrowing costs. Disruptions cascade through interconnected systems. Low water levels restrict shipping, and energy security weakens when hydropower reservoirs decline or thermal plants lack sufficient cooling water, triggering rolling blackouts and supply volatility. These shocks propagate through trade, manufacturing, and urban systems, amplifying inflationary pressures and fiscal risk.

Emerging systemic risk frameworks are beginning to quantify these exposures more precisely. **The European Central Bank and Oxford University's Nature Value at Risk (NVaR)[27]** framework estimates the financial risk from ecosystem service degradation at sectoral level, finding that water scarcity and declining water quality represent the most material nature-related risks to Euro area economic output. While currently limited to the Euro area, the methodology signals the direction of regulatory risk assessment globally.

As established in Section 1.1, these impacts cascade and compound over infrastructure asset lifetimes. A basin experiencing intermittent drought today may face structural water deficit within a single asset's operating life, widening the gap between appraisal conditions and operating reality.

Infrastructure and asset impacts

Water risks materially alter infrastructure performance, asset viability, and cost of capital across energy, transport, manufacturing, and urban systems. The relationship is bidirectional: infrastructure development can increase flood risk through land use change and exacerbate water stress through extraction and pollution, creating feedback loops that compound over time.

- **Operational performance** degrades when infrastructure designed for historical conditions and operational practices, physical designs and management expectations fail to evolve. Thermal power plants derate when cooling water is insufficient; hydropower output declines when reservoirs shrink or sediment damages turbines; and treatment facilities struggle when source water quality degrades.
- **Cost escalation** occurs across the lifecycle as projects require additional sourcing, treatment, and resilience investments, while maintenance costs rise due to sediment damage and accelerated repair cycles.
- **Construction delays** lengthen as regulators demand more rigorous assessments of cumulative impacts and climate scenarios.
- **Social license** to operate also erodes where infrastructure competes with communities for limited water resources, with risk intensifying as awareness of infrastructure's role in altering local hydrology grows.
- **Asset stranding** risks further increase as infrastructure designed for historical hydrology encounters conditions that financial markets are increasingly repricing.[28]
- **Credit and insurance** markets are also responding; rating agencies are increasingly incorporating water risk into analysis for water-dependent sectors and water-stressed sovereigns,[29] while investors are now applying water risk screening,[30] reallocating capital away from water-intensive assets in stressed basins.

A cross-cutting constraint applies across all infrastructure types: the resilience dividend that water-secure infrastructure delivers - avoided damages, reduced emergency costs, and sustained service continuity – is not captured in any revenue stream available to the asset or programme that produces it. Without mechanisms to price, insure, and fund ongoing maintenance of both grey and green infrastructure, the value of resilience remains an externality.

These risks do not materialise uniformly over time. Slow burn pressures such as sedimentation and water quality degradation erode assets gradually, while drought curtailments and flood damage impose sudden, acute losses. The interplay between chronic and shock-driven risk shapes how infrastructure and assets should be designed, financed, monitored and governed.

2. Water Risk and Infrastructure Performance

How have water risks shaped infrastructure outcomes in Africa and Asia, and how have different approaches – grey, green, and hybrid – performed under those conditions?

This chapter presents case studies from Africa and Asia illustrating how water risks shape infrastructure performance, financing structures, and investment outcomes across grey, green, and hybrid infrastructure. The case studies are organised around three physical water-risk dimensions: scarcity, flooding, and water quality.

Table 1: Case study overview

Case Study	Geography	Primary Water Risk	Risk Dimensions
Vietnam Xuan Mai Water Supply	Asia	Water quality / scarcity	Physical, regulatory
Cape Town Water Crisis	Africa	Drought / scarcity	Physical, reputational
Wuhan Sponge City Programme	Asia	Flooding	Physical, regulatory

Three Infrastructure Approaches

- Traditional (grey): Dams, desalination, treatment plants, pipelines, embankments.
- Green (nature-based): Watershed restoration, wetland protection, catchment management, invasive species removal.
- Hybrid (integrated): Strategic combination of grey and green infrastructure.

**Also called non-revenue water: water that a utility produces but does not get paid for.*

2.1 Regional Profiles: Africa and Asia

Water risk manifests differently across regions, shaped by distinct climate patterns, infrastructure legacies, governance contexts, and development trajectories.

Africa:
In Africa, the dominant infrastructure risk channels are hydropower vulnerability to hydroclimatic volatility and urban service delivery failure in rapidly growing cities with weak cost recovery for water utilities. The supply baseline is thin and unevenly distributed. Water demand in sub-Saharan Africa is projected to increase by 163% by 2050, nearly four times the global average rate,[32] compounding an existing infrastructure deficit where piped systems are ageing, poorly maintained, and local governments lack the fiscal capacity to fund upkeep until failure forces costlier intervention. Climate extremes are intensifying at both ends of the risk spectrums. At one end, drought frequency in Eastern Africa has doubled since 2005,[33] while at the other, the Horn of Africa transitioned directly from its worst drought in 40 years to severe flooding in 2023–2024.[34] In Southern Africa, the 2024 El Niño drought, the worst in over a century, simultaneously collapsed hydropower generation, devastated staple crop production, and strained fiscal capacity across multiple SADC economies, demonstrating how water scarcity cascades through shared river systems as a regional macroeconomic transmission channel.[35] Flood magnitudes are projected to increase at over 94% of West African monitoring stations.[36] In North Africa, aquifer depletion and competition over the Nile basin are compounding water stress across energy, and agriculture, and are impacting regional stability.[37] Water quality and ecosystem conditions are also deteriorating. Analysis of five African cities found that fewer than 25% of urban populations have access to safely managed water[38] and groundwater beneath Nairobi has declined at 6 metres per decade since 1950[39] as catchment deforestation reduces recharge. Governance is also fragmented across agencies with weak enforcement. Unaccounted-for water averages 50% in urban areas* and water-related conflicts increased 34% between 2022–2023.[40]

Table 2: Examples of water risk impacts on infrastructure in Africa

Project	Water Risk Impact
Kariba Dam (Zambia/Zimbabwe)	2024 drought (declared national disaster) forced plant shutdown, triggering 21-hour blackouts across two economies reliant on hydropower for over 80% of generation[41]. Zambia's GDP growth downgraded from 4.7% to 2.3%.[42]
Konkola Copper Mines (Zambia)	Decade-long toxic runoff contaminated community water sources; UK legal action from 2,500+ villagers against Vedanta (settled 2021), illustrating stranding risk from environmental liabilities.[43]
Water legislation gaps (Continental)	Lack of comprehensive water law increases cost of capital for water-dependent projects.

**Also called non-revenue water: water that a utility produces but does not get paid for.*

Asia:

In Asia, the dominant infrastructure risk channels are asset impairment across water-stressed industrial corridors and accelerating dependence on groundwater where surface systems are at capacity. South Asia is the world's most water-stressed region, with 74% of the population exposed to extremely high water stress.[4] India's per capita freshwater availability is approaching the international scarcity threshold, and groundwater tables are falling by more than one metre per year in many dry areas. Climate change compounds these pressures: Himalayan glaciers are retreating 65% faster than a decade ago,[44] major rivers like the Indus will reach "peak water" by 2050[45], and flood-related disasters have risen 134% since 2000.[46] More than 200 high-risk glacial lakes now threaten outburst risks to an estimated 462 million people by 2030.[47] Water quality and ecosystem condition are severely degraded. Rivers in parts of Asia contain up to three times the global average of bacterial load from untreated human waste[48], while large scale dam construction has fundamentally altered sediment transport across the Mekong, Ganges, and Indus basins[49]. Unprecedented mangrove loss is also reducing coastal flood buffering in megacities. Governance risks and gaps are structural. Upstream flow control particularly by China creates planning uncertainty for downstream nations,[50] many critical basins lack effective transboundary frameworks, and the region faces an estimated USD 4 trillion WASH investment gap through 2040.[51]

Table 3: Examples of water risk impacts on infrastructure in Asia

Project	Water Risk Impact
Thermal power (India)	USD 1.4b in losses and 14 TWh of lost generation in 2016 from water-related shutdowns cancelling over 20% of national electricity growth. Moody's subsequently warned water scarcity could weaken India's sovereign credit profile.[29]
Hydropower (Nepal)	Compounding risks from reduced dry season flows, monsoon sediment, and Glacial Lake Outburst Flood (GLOF) threats.[52]
Semiconductors (Taiwan)	Water-intensive fabrication processes face operational risk in a region experiencing increased drought frequency.
Myitsone Dam (Myanmar)	USD 3.6b project halted in 2011 over environmental and displacement concerns, illustrating stranding risk from social licence failure on water-intensive megaprojects.[53]

Comparative Read: Africa and Asia present distinct but related investment profiles. Africa's water risk is characterised by acceleration with thin buffers. Demand growth is outpacing current system capacity at nearly four times the global rate, and shocks quickly translate into prolonged service failures because utilities and asset owners lack financial resilience. Asia's risk is defined by intensity at scale. Large urban, industrial, and energy systems operate near ecological limits, so risk materialises as asset impairment, retrofit capital expenditure, and reputational conflict in densely populated basins. For infrastructure investors, Africa offers opportunity driven by unmet demand, but bankability, not capital availability, is the binding constraint. Asia offers scope for retrofit, efficiency, and resilience investment opportunities in existing assets, but carries elevated reputational and regulatory risk given visible competition for water across dense populations. In both regions, water risk is no longer a background environmental condition; it is actively shaping infrastructure performance, costs, and long-term viability, reinforcing the case for integrated green and grey approaches as a condition of long-term economic viability rather than separate investment categories.

2.2 Case Studies

The regional profiles above identify where water risks concentrate and how they affect infrastructure broadly. The following three case studies examine specific projects in depth, each representing a different infrastructure approach (grey, green, hybrid), a different primary water risk (quality/scarcity, drought, flooding), and different mitigation solutions to these risks (as outlined in Table 1).

Case Study 1:

Xuan Mai Water Supply, Vietnam:

Surface-Water Switch and Credit Enhancement

Hanoi faces a deepening groundwater crisis driven by decades of over-extraction. Aquifer depletion is causing land subsidence, concentrating pollutants in remaining groundwater, and accelerating saltwater intrusion. In the Red River Delta, 48% of tubewells exceed five times the WHO guideline for arsenic, exposing millions of people to health risks.[54] In response, the Vietnamese government formalised a policy shift toward surface water supply in 2021 as the long-term response.[55]

The Xuan Mai project is a greenfield surface-water system drawing from the Da River. Phase 1A comprises a 150,000 m^3/day treatment plant, 25 km transmission pipeline, and associated infrastructure, with potential future expansion increasing supply to 300,000 m^3/day by 2030.[56] The source-water switch is itself a core risk-management, resilience building, decision: arsenic-contaminated groundwater would require specialised treatment with higher operating costs, whereas the Da River surface water enables conventional treatment with more predictable performance. Energy-efficient pumping (leveraging 100 metres of natural elevation), rooftop solar, and backwash recirculation all reduce operating cost exposure, which is critical in a tariff-constrained market that has stranded water assets elsewhere in Vietnam.[57] Total project cost is USD 125m.[58]

PIDG provided an innovative financing solution through a combination of a guarantee from GuarantCo, its guarantee business, and equity investment from InfraCo, its project development solution. GuarantCo's credit enhancement guarantee (USD 48m), delivering an 11-notch rating uplift (BB to AAA), enabling Vietnam's first 20-year project bond and first water-sector green bond, aligned with ICMA Green Bond Principles. InfraCo committed USD 13m equity across treatment-plant and pipeline SPVs as early-stage development capital. This mobilised USD 112m in local currency debt from domestic institutional investors (Chubb, AIA, Generali, Hanwha Life) without direct government fiscal support, aligning revenues and debt service, avoiding the foreign-exchange mismatch.[60] Policy commitment, technology choice, and the guarantee functioned as mutually reinforcing channels: the policy framework provided the regulatory foundation, the source-water switch reduced treatment complexity, and the guarantee brought local institutional investors into a new asset class for the first time.

On water risk, the design of the project considers changing hydrological conditions with flood design criteria based off future climate projections. In addition, two upstream dependency channels are relevant to long run operating costs: water quality (if upstream vegetation degrades, treatment costs could rise)[59] and sediment control (increased erosion accelerates mechanical wear on the intake). While the design specifications address these risks through seasonal flow buffering and sediment management requirements, there may be an opportunity to go further. A funded mechanism to support the protection or restoration of the upstream catchment – on which the facility's long-term operating costs partly depend – is not part of the current structure. Incorporating such a mechanism could strengthen the project's long-term resilience. The Da is one of the most heavily engineered rivers in Southeast Asia: the largest tributary of the Red River, it carries a five-dam hydropower cascade of close to 7,800 MW,[60] whose reservoirs trap the bulk of its sediment.[61] Upstream, deforestation and farming have raised runoff and erosion. Catchment condition is therefore set by infrastructure and land use decisions well beyond the project's control.

As mentioned above, this points to a wider opportunity. The same catchment supports the Xuan Mai plant, the Da River hydropower cascade, irrigation users, and downstream communities, yet no single party is likley to fund its protection alone because each capture only part of the benefit. A structure that pools contributions across these beneficiaries, such as a payment for ecosystem services (PES) arrangement tied to verified water quality and erosion outcomes, could build a diversified revenue base, which an asset agnostic credit enhancement like the GuarantCo guarantee could in principle support. Delivery would require coordination across actors with different mandates, a multi-beneficiary structure can prove to be more durable in such scenarios.

Case Study 2:

Cape Town, South Africa:
Drought and Catchment Restoration

The 2015-2018 drought pushed Cape Town to the brink of "Day Zero," threatening system-wide supply failure for roughly 4.6 million residents,[62] with direct economic losses estimated at R15b (approximately USD 920m).[63] Invasive alien plants in key catchments compounded the crisis, consuming approximately 55 billion litres per year that would otherwise have reached the city's reservoirs.[64] The crisis forced an unprecedented convergence of government, academia, conservation practitioners, and business, whose comparative analysis revealed that invasive clearing could deliver water at a fraction of the cost of desalination, a finding that would not have emerged under normal institutional silos.

Day Zero was averted primarily through demand-side governance. Restrictions, tariff increases, and public mobilisation cut consumption from approximately 1,100 ML/day to around 500 ML/day. Emergency grey augmentation (temporary desalination, groundwater, wastewater reuse) added only around 14 ML/day, a marginal supplement.[65] The return of winter rainfall in 2018 was the decisive inflection point. In parallel, the Greater Cape Town Water Fund launched a 30-year programme to clear invasive alien plants across priority catchments, establishing that catchment restoration can function as a water-supply intervention with measurable yield.[66] As of March 2025, 63,000 hectares have been cleared, recovering 17.5 billion litres per year toward a 100 billion litre target by 2050. Restored indigenous vegetation reduces pollutant and sediment loads in source water, lowering treatment costs over time.[67]

Three financing channels supported the response: Municipal emergency procurement (R500m – approximately USD 38m to Proxa for three temporary desalination plants on two-year contracts) funded initial supply augmentation, though these delivered less than 3% of the city's emergency water target;[68] the Water Fund (USD 54.3m over 30 years; transitioning to an independent non-profit in 2023) blended philanthropic seed funding with corporate water stewardship contributions from Coca-Cola, PepsiCo, AB-InBev, Nedbank, and Remgro alongside City performance-based contracts;[66] and the City's 2017 green bond (R1b / USD 54m – four times oversubscribed, Climate Bond Initiative-certified) refinanced eligible municipal infrastructure on its balance sheet[69]. The bond and Water Fund operated as complementary instruments: the bond refinanced balance-sheet CAPEX (pressure management, metering, leak reduction) with predictable revenue streams, while the Water Fund financed catchment restoration, which is OPEX-like and maintenance-heavy, with benefits accruing over years and flowing partly beyond the City's own revenue base. At a lifecycle unit cost of R1.2/m^3 (USD 0.07/m^3) against desalination at R14.9/m^3 (USD 0.92/m^3), the programme reports a Benefit Cost Ratio (BCR) of 4.5x.[70]

Yield recovery has been gradual from 2019, but the Western Cape is facing severe drought conditions in 2025, with the Garden Route approaching its own Day Zero. This underscores that the problem is a recurring cycle, not a resolved crisis. This confirms a structural limitation of nature-based approaches: they must be financed well before a crisis, not in response to one. The business case values the ecosystem service at the cost of avoided desalination (approximately R9/kL / USD 0.58/kL), but that reference price has not yet been turned into a contract. The cost per unit, the measured yield, and the priced commodity are all established. Drought pushed water costs from R5/kL to R30-39/kL for desalinated supply. Catchment restoration delivers water at roughly twelve times less. Large water users bear the scarcity premium and gain the most from upstream investment. The building blocks for a contractable instrument exist: a known unit cost, a measurable volume, and a priced commodity.

In March 2026, this obligation was structured for the first time. FirstRand Bank issued the R2.5b (approximately USD 147m) Cape Water Performance-Based Bond, with FirstRand as issuer and RMB as arranger and structurer.[71] It is the first nature outcomes bond issued by a commercial bank in the world, tying investor returns to verified ecological restoration. Rather than launching something new, the bond provides longer-term, five-year funding to an existing The Nature Conservancy (TNC) South Africa project run through the Greater Cape Town Water Fund, on the logic that clearing invasive alien trees yields the most water at the lowest cost. It channels roughly R150m (about USD 8.8m) to that conservation work over five years. The bond drew an investor base: the IFC subscribed for R1.6b (approximately USD 94m) and FSD Africa Investments for R234m (approximately USD 14m), alongside Aluwani, a local South African asset manager. Behind these sat a strong and diversified roster of outcomes-based funders (OBFs), including the FirstRand Foundation and DBSA, around 75% of which had not previously funded nature. The City of Cape Town's main contribution was funding the Greater Cape Town Water Fund which they have been funding for the last six years.

The crisis also exposed distributional weaknesses in the demand-side model: wealthy households bypassed restrictions through private boreholes, undermining collective compliance and destabilising utility finances.[72] No binding mechanism currently prevents recurrence, raising questions about the durability of demand governance outside crisis conditions.[73]

Case Study 3:

Wuhan Sponge City, China:
Hybrid Flood Infrastructure

Wuhan is a major inland megacity on the Jianghan floodplain where the Yangtze and Han rivers converge, exposing it to acute flood risk and water-quality challenges.[74] Rapid urbanisation rendered approximately 70% of the city's surface to impermeable cover, while the number of lakes fell from 127 in 1950 to 40 by 2010, eliminating 228.9 km^2 [75] of natural storage. Waterlogging occurred two to three times annually, causing average damages of approximately USD 800m per event, and four of the city's 11 rivers failed national water quality standards.[76]

The solution was a large-scale hybrid programme combining green/blue infrastructure (permeable pavements, rain gardens, bioswales, and constructed wetlands) with targeted grey upgrades to drainage and pumping. The first phase delivered 389 sponge projects across 38.5 km^2 in two pilot districts, designed to capture 60–85% of annual rainfall.[76] On a replacement cost basis, this approach was estimated to be CNY 4 billion (USD 600m) cheaper than a grey-only alternative. It restored the infiltration and storage functions that urbanisation had destroyed.[77] Two dependency channels are financially material: flood regulation, where permeable surfaces and distributed storage absorb rainfall before it reaches drainage networks, reducing peak flows;[78] and water quality, where bioswales and constructed wetlands filter urban runoff before it enters the river system.

The programme was driven by national policy through pilot-city designation, mandatory standards, and time-bound central subsidies of CNY 400–600m (USD 60–90m) per year for three years.[79] Wuhan committed CNY 10b (approximately USD 1.4b) in public funding.[80] A PPP consortium in Qingshan District delivered 84 projects under a 10-year contract totalling CNY 1.27b (USD 185m),[81] but mobilised only a fraction of targeted private capital. No green bonds, catastrophe insurance, or guarantees were used. The financing stack was predominantly public. Private capital mobilisation fell short because the programme's primary value, avoided flood damage and reduced emergency costs, does not generate a contractable revenue stream; without a mechanism to price and monetise the resilience dividend, the returns were not bankable on commercial terms.

Programme reporting indicates a clear performance validation in 2020: daily precipitation reaching 472 mm in some areas,[83] no serious flooding was reported in sponge districts versus significant waterlogging in untreated areas during comparable 2016 events. The programme scaled from a single-city pilot to a 30-city national initiative. The performance claim rests on programme reporting rather than independent verification, and the counterfactual scenario – what would have occurred in the absence of the interventions – was not clearly established, thereby weakening the evidence base for projecting future success. Long-term performance depends on ongoing maintenance of the green infrastructure, and operation and maintenance financing remains a structural challenge nationally and globally. Without risk-transfer instruments such as parametric flood insurance, the resilience dividend the programme delivers is not captured in any revenue stream: avoided damages and reduced emergency response costs do not flow back to the programme. The residual economic shock from flood events remains on government balance sheets, and the resilience value the infrastructure generates has not been priced or monetised. China's catastrophe insurance pilots in other cities have not yet been integrated with sponge city projects.

Cases Comparative Insight

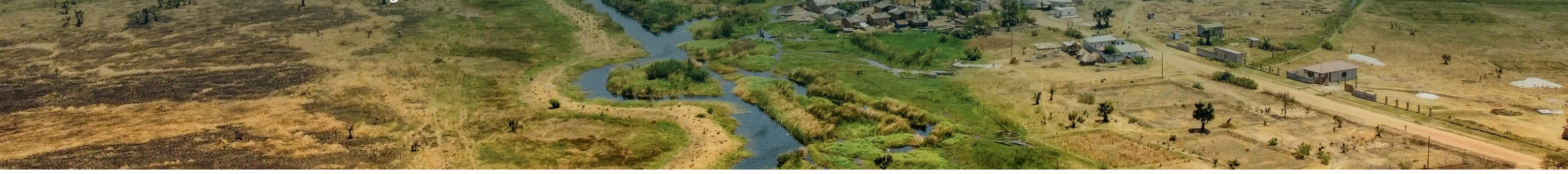
Across all three cases, infrastructure performance depended on underlying water systems that were only partially recognised or entirely externalised at the time of original planning or financing. Vietnam's Xuan Mai project is a direct response to groundwater over-extraction and existing failing infrastructure, yet its long-run operating costs are dependent on the condition of the Da River catchment. Cape Town's reservoirs are similarly dependent on upstream catchment function to sustain yield and water quality. Wuhan's drainage capacity depends not only on pipes and pumps, but on soil infiltration capacity and distributed storage across the urban landscape. In each case, infrastructure underperformance emerged not only from engineering defects, but from changes in the natural water systems. When those systems degraded, asset performance deteriorated. In practice, these dependencies are rarely incorporated consistently into baseline assumptions, monitoring plans, or appraisal risk registers, and are often treated as external environmental conditions rather than core operational inputs.

Over the 20–50-year operating lives of these assets, the water risk conditions they were designed for may change, making these dependencies more, not less, financially material over time, affecting operating costs, reliability, social licence, and asset valuation. Each case maps directly onto the analytical framework in the chapters that follow, illustrating how unpriced water dependencies translate into material performance and investment risk.

3. Ecosystem Services and Infrastructure Resilience

How do ecosystems enhance infrastructure resilience, and can ecosystem services be meaningfully integrated into financial planning?

Chapter 2 showed that infrastructure performance depends on water system conditions rarely accounted for in original planning and financing. In Cape Town and Wuhan, these dependencies became apparent only when crisis forced recognition. In Vietnam, Hanoi's existing water supply is under increasing pressure from over-extraction and shifting environmental conditions. Although the solution's design accounts for ecosystem dependency, no specific mechanism is currently in place to fund or manage upstream watershed conditions. This chapter explains how those dependencies can be identified, evidenced and quantified in ways that support infrastructure appraisal and investment decision making.[82]



3.1 Infrastructure Dependencies on Ecosystem Services

Ecosystem services are the benefits that natural systems provide to human society. For infrastructure, four categories are relevant: provisioning services (freshwater supply), regulating services (flood control, water purification), supporting services (nutrient cycling, soil formation), and cultural services (recreation, tourism). Together, these services underpin infrastructure performance in ways that remain largely unmeasured, unpriced, and external to financial decision-making.[82]

Key Dependency Channels*

- **Water supply and reliability:** Healthy catchments recharge aquifers, sustain dry-season baseflows, store water in soils and vegetation, and, in the case of rainforests, help shape regional rainfall patterns. Degradation reduces yield and increases curtailment frequency.[83,84]
- **Water quality:** Forests, wetlands, and riparian vegetation filter runoff, trap pollutants, and absorb excess nutrients. Degradation leads to sediment and pollutant load rise, raises treatment costs and compliance risk.[85,86]
- **Sediment control:** Vegetation cover and intact soils stabilise sediment and limit erosion, protecting reservoirs and equipment. Degradation accelerates siltation and mechanical wear.[87]
- **Flood regulation:** Permeable soils, floodplains, and wetlands absorb rainfall and slow runoff, reducing peak flows. Ecosystem loss to urbanisation overwhelms drainage and increases damage.[88]
- **Coastal protection:** Mangroves, coral reefs, and coastal wetlands dissipate wave energy and reduce storm surge. Degradation increases storm exposure and recovery times.[89]
- **Heat and evaporation:** Vegetation cools surfaces and moderates reservoir evaporation and thermal stress on infrastructure. Loss of cover increases evaporation and heat-related operational constraints.

**Later sections trace how these dependencies become financially material (3.2), how they can be valued (3.3), and where that value enters project finance decisions (3.4).*

The Panama Canal demonstrates the consequences of treating ecosystem dependencies as invisible. The Canal generates USD 4.9b revenue annually and relies entirely on rainfall to move vessels between oceans.[90] During the 2023–24 drought, transit was restricted from 36 to 24 vessels daily, causing significant losses.[91] This critical dependency on watershed services was never factored into the Canal's economic valuation until the crisis exposed it. The failure to price ecosystem services creates a valuation blind spot. When ecosystems degrade, infrastructure performance declines or completely fails, yet the economic linkage remains invisible until disruption forces recognition.

3.2 Financial Materiality

Ecosystem change affects infrastructure through the dependency channels summarised above. For investment analysis, the objective is to identify when a dependency channel becomes financially material: when it can credibly change operating performance, cost trajectories, operating limits, or long-run viability, ultimately reducing financial returns below the levels assumed at appraisal.

Table 4: Ecosystem risks and financial materiality

Where It Shows Up	What changes in practice	Financial Impact
Service delivery	The asset delivers less, or less reliably (more outages, lower output, weaker quality)	Lower revenue; penalties; higher year-to-year volatility
Costs over time	Running and maintaining the asset becomes more expensive (more treatment, energy, dredging, repairs)	Lower margins; higher operating risk; earlier capex needs
Operating limits	Tighter rules or physical limits (abstraction caps, quality failures, forced curtailment)	Sudden revenue hits; compliance costs; regulatory disputes
Financial resilience	Stress years become more frequent (downtime and cost spikes at the same time)	Greater chance of missing debt payments; higher refinancing needs
Long-term viability	Permanent loss of usable capacity (storage loss, chronic salinity, irreversible depletion)	Lower long-term value; shortened economic life; potential stranding

A dependency channel becomes financially material when it can credibly weaken debt service coverage or project returns under downside scenarios. Crucially, the relevant variables (OPEX intensity, outage frequency, maintenance timing, regulatory compliance) already sit in standard models. The analytical shift is to treat ecosystem condition as a variable input rather than a constant. Where catchment health, sediment loads, or water quality are held fixed, models systematically understate tail risk and overstate expected returns.

For example, under the water quality channel, catchment degradation increases pollutant loads in source water, raising treatment intensity and the risk of regulatory exceedances. Financially, this manifests as sustained OPEX increases, episodic treatment shutdowns or service disruptions during extreme events, and elevated regulatory and liability exposure, reducing operating margins and increasing cash-flow volatility.

Time horizon matters. Some channels crystallise suddenly (flood events, contamination incidents), while others accumulate gradually (sedimentation reducing storage, progressive degradation increasing treatment costs). Slow-moving channels often dominate lifetime losses, particularly once ecological thresholds are crossed and impacts become difficult or impossible to reverse.

Which channels dominate depends on asset type, geography, and investment tenor. While translating these effects into risk-adjusted pricing or stress test thresholds remains largely underdeveloped, dependencies become easier to integrate when evidenced in terms of performance, cost, and reliability impacts.

3.3 Valuation Methodologies

The Natural Capital Protocol and TNFD framework establish a three-tier approach to valuation: qualitative assessment identifies which ecosystem services are material, quantitative assessment measures these in biophysical units while monetary valuation translates selected measures into financial terms. Not all dependencies require monetary valuation; biophysical metrics often suffice for operational decisions.[92,93,94]

Where monetary valuation is required, four method categories are established: **(1) market price and cost-based methods** use observable market data to value ecosystem goods traded directly or estimate what engineered alternatives would cost (replacement cost, avoided cost, restoration cost). **(2) Revealed preference methods** infer values from observed market behaviour, using property prices or visitor expenditure to estimate what people implicitly pay for environmental attributes. **(3) Stated preference methods** use structured surveys to elicit willingness to pay directly, asking respondents to value ecosystem services or choose between alternative scenarios. **(4) Benefit transfer** applies values from existing studies to new sites with similar characteristics, either through direct per-hectare figures or statistical models adjusted with local data.

Each method has inherent constraints, and all monetary approaches struggle with dynamic dependencies: they value ecosystem services at a point in time but cannot easily capture how degradation affects infrastructure performance across asset lifecycles. Infrastructure appraisal relies overwhelmingly on cost-based methods because they produce figures directly comparable to engineering estimates.

The Chapter 2 case studies apply these methods. Cape Town's 4.5x BCR uses avoided cost, pricing restoration against displaced desalination; Wuhan's USD 600m saving uses replacement cost against a grey-only alternative. Vietnam applies avoided-cost reasoning too, but at the level of source selection: switching from arsenic groundwater to surface water avoids specialised-treatment costs.

3.4 Translating Dependencies into Project Finance Variables

Ecosystem dependencies affect infrastructure finance through six main entry points: CAPEX (ecosystem condition shapes asset sizing), OPEX (catchment degradation raises treatment intensity), revenue and throughput (reduced availability lowers volumes), reliability and downtime (scarcity drives curtailments), reserves and contingencies (greater variability increases buffer requirements), and asset life (sedimentation and poor source water accelerate equipment degradation).

Table 5: Mapping dependency channels to financial variables

Dependency Channel	CAPEX	OPEX	Revenue	Reliability	Reserves	Asset Life
Water supply and reliability	X		X	X	X	
Water quality	X	X		X		X
Sediment control		X	X			X
Flood regulation	X			X	X	
Coastal protection	X			X	X	
Heat and evaporation		X	X	X		

4 Financing Ecosystem-Dependent Infrastructure

What financial mechanisms exist to mobilise capital for ecosystem-dependent water infrastructure, and what barriers prevent deployment at scale?

4.1 The Financing Challenge

Water infrastructure faces an estimated at USD6.7 trillion financing gap by 2030.[95] Public sources currently provide 91% of current funding while private capital contributes less than 2%[96].* This mismatch is structural. Financial markets require predictable cash flows within conventional investment horizons. Ecosystem services, by contrast, deliver benefits over extended timeframes with performance uncertainty and attribution challenges. These dependencies also compound over time; degraded water sources increase treatment costs, strain utility revenues, reduce maintenance budgets, and accelerate asset deterioration. As ecosystems degrade, infrastructure risk rises and so does the financing gap.

The challenge is therefore not simply mobilising capital for water infrastructure, but structuring finance to reflect the ecosystem dependencies that determine whether infrastructure performs as designed. The mechanisms reviewed below each address a specific point where this mismatch creates a financing constraint. Some provide credit enhancement where ecosystem-dependent assets cannot otherwise reach market. Some bridge the period before ecosystem performance is measurable. Some create recurring payment streams for land management that sustains asset performance. Others convert acute shock risk into defined liquidity events.

4.2 Financial Mechanisms in Practice

Infrastructure depends on functioning water systems that serve as natural infrastructure, underpinning built assets. Financing structures must therefore account for both the physical asset and the water system it relies on. The mechanisms below are grouped by the financing function they perform.

Mobilising Capital This function enables long-tenor finance for ecosystem-dependent assets with risk profiles that conventional credit markets struggle to price.

- **Green and blue bonds** are use-of-proceeds instruments connecting institutional investors to labelled water infrastructure. The Climate Bonds Initiative has developed a Water Infrastructure Standard enabling projects utilising natural infrastructure to be certified.[97]
  - Impact on financial models: expands access to capital but does not on its own improve Debt Service Coverage Ratio (DSCR) or reallocate underlying ecosystem risk.
  - Key barrier: NbS assets lack the revenue model and operational track record for conventional use-of-proceeds eligibility.

**Assumed the remainder (7%) comprises community financing, philanthropic grants, and bilateral aid*

- **Blended finance and guarantees** combine concessional capital with commercial investment, absorbing risks that private investors cannot price such as policy uncertainty, currency fluctuations, or hydrological variability.[98] The Tropical Forest Forever Facility targets USD 125b to maintain tropical forest cover, demonstrating that blended structures can sustain natural infrastructure at landscape scale.[99]
  - Impact on financial models: by absorbing tail risks, these structures improve DSCR under downside scenarios and reduce cost of capital through credit enhancement.
  - Key barrier: deal-by-deal structuring drives high transaction costs and concessional capital is finite.

Bridging Maturation Gaps This function absorbs the elevated credit risk during the 2-to-8-year period before ecosystem benefits become measurable, allowing commercial lenders to remain engaged through the restoration window.

- **Patient and subordinated capital** (concessional first-loss tranches, subordinated debt, philanthropic grants) sits at the bottom of the capital stack and absorbs the maturation risk that commercial investors cannot price[100]. As ecosystem performance becomes verifiable, commercial capital steps in progressively. The Latin American Water Funds Partnership applies this model across 30+ funds, with philanthropic capital absorbing restoration-phase risk while downstream utilities scale contributions as conditions improve.[101]
  - Impact on financial models: protects DSCR during early years by absorbing maturation risk and lowering effective cost of capital.
  - Key barrier: concessional capital is rationed, and without standardised measurement, reporting, and verification (MRV) protocols, exit timing remains contested.

Stewardship Finance This function creates recurring payment streams for the land management required to sustain ecosystem performance over the asset's operating life.

- **Payment for Ecosystem Services (PES)** creates direct financial flows from downstream beneficiaries to upstream land managers. Water funds institutionalise this by pooling contributions from utilities, businesses, and governments.[102] The Upper Tana-Nairobi Water Fund coordinates the water utility, hydropower company, breweries, and 44,000 smallholder farmers, delivering a 2:1 benefit ratio.[103] The Panama Canal Authority pays upstream farmers for reforestation to protect dry season flows and reduce sedimentation.[104]
  - Impact on financial models: where payment streams are stable, these mechanisms improve DSCR through OPEX reduction, but weak contract structures limit their effect on cost of capital.
  - Key barrier: long maturation timelines, counterparty risk with landholders, and lack of standardised MRV for ecosystem service delivery.*

Shock Liquidity This function provides rapid payouts after acute events, preventing temporary ecosystem damage from compounding into long-term infrastructure impairment.

- **Parametric insurance** provides payouts based on pre-established triggers (wind speed, water levels). The Quintana Roo reef insurance (Mexico, 2018) was the first parametric policy for a natural asset; when Hurricane Delta struck in 2020, the policy paid nearly USD 850,000 within weeks.[105] The model has been replicated across the Caribbean and Pacific.
  - Impact on financial models: does not improve base-case DSCR but protects downside scenarios by transferring shock risk away from the project.
  - Key barrier: basis risk, limited actuarial data for ecosystem assets, and premium affordability in developing countries.

Revenue Stacking This function layers additional income from co-benefit markets onto primary infrastructure cashflows where primary revenues alone are insufficient.

- **Biodiversity and carbon credits** monetise co-benefits such as carbon sequestration from mangrove restoration that simultaneously provides coastal protection. In the Philippines, the RISCO pilot stacks insurance payments with blue carbon credits to finance 4,000 hectares of mangrove protection, expected to generate over USD 10m over ten years.[106]
  - Impact on financial models: provides marginal DSCR uplift but does not materially affect cost of capital unless contracted and predictable.
  - Key barrier: credit markets for water-specific outcomes are thin, revenue volumes are supplementary rather than primary, and market confidence in underlying standards has proven volatile.

**Ecosystem maturation is progressive - watershed interventions reduce sediment within the first growing season; constructed wetlands achieve partial treatment capacity within months, but full performance may take 2-8 years.*

How these instruments combine in practice

The following is an illustrative example. It does not represent a specific project.

Guarantee
Mobilises capital
Partial credit guarantee lifts the bond to investment grade, enabling a 15-year tenor at commercial rates.

→ Enables bond

↕ Reduces exposure

Parametric insurance
Converts shock risk
Trigger at 40% below average dry season flow. Payout within 30 days covers 8 months of debt service, reducing tail risk on the guarantee.

→ Payout protects debt service

Illustrative project
Location: River basin city, South Asia
Asset: Hybrid water supply, USD 85m, 15 years, structured with 30:70 equity debt ratio
Grey: Treatment plant and distribution
Green: Upstream riparian buffer restoration (5 to 8 year maturation)
Key constraint: Green component creates a maturation gap: ecosystem performance not measurable until year 5.

← Bridges gap

Concessional tranche
Bridges maturation
First-loss tranche (18% of capital) covers years 1 to 6, absorbing risk before upstream restoration is

↕ Supplements revenue

← Credits improve economics

Revenue stacking
Improves economics
Carbon and biodiversity credits from buffer restoration yield USD 2.1m over 10 years, supplementing tariff revenue during maturation.

No instrument is sufficient. The guarantee mobilises capital but carries tail drought risk. The concessional tranche bridges maturation but not acute shocks. Parametric insurance converts that tail risk into a defined liability, reducing the guarantee's exposure. Revenue stacking supplements cashflows during maturation, reducing pressure on the concessional tranche. The instruments are interdependent: each changes what the others need to do.

4.3 Cost Competitiveness

The evidence base comparing infrastructure approaches is growing but remains uneven. International Institute for Sustainable Development (IISD) analysis finds that nature-based infrastructure costs approximately 50% less than built alternatives in the cases reviewed.[107] Cape Town's BCR of 4.5x and Wuhan's CNY 4 billion saving over conventional grey drainage are consistent with this pattern. Philadelphia's green stormwater programme was estimated at USD 2.4b over 25 years, compared to USD 9.6b for a comparable grey solution.[108] However, most evidence reflects avoided costs rather than revenue generation. Avoided cost ratios demonstrate economic value but do not directly service debt.

Grey infrastructure remains necessary where ecosystems are irreversibly degraded, capacity is needed within months, land opportunity costs exceed infrastructure savings, or coordination across many landholders makes transaction costs prohibitive. These are constraints on viability, not evidence that grey is inherently cheaper when both options are feasible. Cape Town illustrates the timing constraint. Catchment restoration was by far the cheaper source of water, but it had not been financed ahead of the drought, so it could not deliver supply within the few months the crisis allowed. The city fell back on emergency desalination, which cost far more and still met less than 3% of the emergency target. Grey was not the cheaper option here. It was the only one available in time.

Turning avoided costs into revenue, lessons from other sectors

The model is not new. Other industries have converted avoided costs into contracted revenue for decades. Two examples show the structure works, and why water lags.

- **Energy efficiency (ESCOs).** An energy service company funds and installs efficiency upgrades; then is repaid out of the savings they produce. It is paid from the energy savings, usually guarantees a savings level, and needs little or no upfront cash from the client. The risk sits with the provider: if the measures miss the guarantee, the provider takes the loss. Limit: savings are metered against a clear baseline and land on a single payer, which keeps the contract clean.
- **Early childhood education (pay-for-success).** Investors fund a preschool programme for low-income children, repaid by government from the special-education costs it later avoids. These bonds are designed so that the savings from reduced special-education need are diverted, at least in part, to repay private investors. An independent evaluator found positive effects on school readiness and special-education avoidance, which triggered repayment. Limit: the payer is government, deals are small, and the saving rests on a counterfactual about how many children would otherwise have needed support.

Even where conditions are favourable and economics are competitive, integrated approaches remain marginal due to:

1. **Financial horizon mismatch:** Institutional investors operate on 5–10-year cycles while ecosystem benefits materialise over 10–30 years, making them harder to monetise in project cashflows.
2. **Outcome uncertainty:** Engineering precedent for green infrastructure is limited and ecosystem performance varies with local conditions, biasing procurement toward conventional approaches.
3. **Skills gaps:** Cross-disciplinary teams of hydrologists, ecologists, and conservation finance experts remain rare in infrastructure finance organisations.
4. **Performance attribution:** No agreed basin-level data standards or monitoring protocols exist; each project requires bespoke analysis, driving transaction costs up.
5. **Institutional fragmentation:** Water governance spans multiple agencies with competing mandates and limited coordination.
6. **Risk pricing gap:** No standard method exists to translate ecosystem dependency into cost of capital calculations. Until it can be priced, ecosystem dependency defaults to zero in investment decisions, which is itself a pricing assumption, just an inaccurate one.

4.4 Summary and recommendations

The evidence across chapters 1–4 points to a consistent conclusion: infrastructure performance depends on the condition of the water systems it relies on, and financing that ignores this dependency carries hidden risks and measurable cost. Sections 4.1–4.3 show that the financing challenge is not a lack of viable mechanisms, but a lack of systematic integration. Individual instruments can mobilise capital, bridge maturation risk, support stewardship, or manage shocks, and evidence increasingly shows that ecosystem-based and hybrid approaches can be cost-competitive. Yet these tools remain marginal because ecosystem dependencies are still treated as peripheral to core appraisal, governance, and pricing decisions. As a result, infrastructure financing continues to underweight risks that are already shaping asset performance and long-term value.

The evidence also surfaces a structural barrier. Across the cases, much of the value created by ecosystem investment takes the form of avoided costs, such as deferred desalination, lower treatment expense, or reduced disruption, rather than a direct revenue stream. These avoided costs accrue diffusely across many beneficiaries and do not, by themselves, service debt or pay investors. This may be a core barrier: ecosystem-dependent infrastructure can struggle to attract private capital even where the economics are sound, because the value tends to sit in avoided costs rather than revenue. Part of the financing challenge could therefore be converting those avoided costs into contractable revenue.

The implication is not that new instruments are required, but that existing investment and appraisal practices must change. The following recommendations focus on where decision-makers can intervene to reduce mispricing, lower transaction costs, and make ecosystem-dependent infrastructure financeable at scale:

- **Screen for ecosystem conditions alongside engineering feasibility.** Where catchments are restorable, rights are secure, and coordination is feasible, ecosystem approaches can reduce capital requirements and improve long-term performance.
- **Build partnership capabilities as core institutional capacity.** Every mechanism examined in this report required multi-stakeholder coordination; building this deal by deal does not scale.
- **Recognise hybrid value.** Appraisal processes that evaluate grey and green independently will systematically undervalue integrated solutions, including the adaptive flexibility that ecosystem infrastructure provides over asset lifecycles where water risk conditions are likely to worsen.
- **Advocate for standardisation of monitoring protocols and performance benchmarks.** Without these, ecosystem-dependent financing remains uneconomic at small scale, and the key question for scaling adaptation finance is whether credit enhancement models can be standardised rather than structured deal by deal.
- **Embed full lifecycle costing in project appraisal.** Capital expenditure alone understates the true cost where ecosystem conditions are likely to worsen. Appraisals should account for ongoing maintenance of grey and green components, contingency for climate and biodiversity risk, and scenario testing against worst-case conditions over the asset's operating life.

Chapter 5 translates these findings into a decision framework for infrastructure investors.

5. Decision Framework for Infrastructure Developers and Investors

How can investors and developers identify, assess, respond to, and price water-related risks when financing and structuring infrastructure projects?

**Existing frameworks (TNFD LEAP, NGFS, OECD, ENCORE, WWF Water Risk Filter, WRI Aqueduct) equip investors to assess and disclose water and nature dependencies but stop at diagnosis. This framework's contribution is to carry that diagnosis through to pricing, deal terms, financing structure, and lifecycle governance, drawing on those tools at Steps 3 and 4 rather than duplicating them.*

5.1 How This Framework Works

Chapters 1 through to 4 established three core findings: **(1) that water risks materially** affect infrastructure performance, **(2) that outcomes depend on ecosystem conditions** that are rarely accounted for in financing, and **(3) that financial mechanisms** to address these dependencies are emerging but not yet mainstream. This chapter translates those findings into a seven-step decision framework for infrastructure developers and investors.* Each step produces a defined output that feeds the next. While the steps are presented sequentially, the framework is iterative and insights from later steps may require revisiting earlier assumptions as evidence improves or conditions change.

Table 2: Seven-step decision framework

Step	Action	Description
1	Identify Approaches	Explore the full range of grey, green, and hybrid response options
2	Select Response	Choose between approaches based on risk, resilience, and lifecycle economics
3	Assess Risks	Determine material water ecosystem dependencies and their financial materiality
4	Price	Quantify financial impact so ecosystem dependencies are visible in the investment decision
5	Translate into deal terms	Operationalise pricing into enforceable contractual provisions
6	Structure	Match risk profile to financing instruments that absorb or transfer dependencies
7	Govern	Ensure assumptions remain valid over the asset's 20–50-year life

Step 1: Identify Approaches

Before assessing risk, the development and investment teams must understand the full set of response options available. Grey infrastructure provides engineered solutions with well-understood cost profiles. Green infrastructure works with ecosystem processes, often at lower capital cost but with longer maturation periods and performance uncertainty. Hybrid approaches combine both, using grey assets to meet near-term capacity needs while green components manage ecosystem conditions that determine long-term performance. The appropriate choice depends on the dependency profile, time horizon, governance context, and whether ecosystem restoration is feasible within the project timeline. Step 1 establishes the option set. Step 2 selects a response from that set, and Step 3 assesses the water ecosystem dependencies of the selected approach and their financial materiality.

Step 2: Select Response

The selection should be based on three considerations: (i) test each approach against forward-looking climate and land-use (ii) placement after projections and before assess whether adaptive capacity is built in (e.g. modular expansion, switchable supply, nature-based buffers); (iii) and a lifecycle cost comparison that looks beyond upfront CAPEX to whole-of-life economics. At selection stage this comparison rests on an indicative view of ecosystem degradation; the formal trajectory assessment follows in Step 3 and the quantified degradation scenarios in Step 4. Consistent with the framework's iterative design, the selection is revisited as that evidence firms up.[109]

Where green or hybrid options are favourable on cost, the selection must also weigh their delivery complexity. Unlike grey assets, which are built within a defined site boundary and a single owner, ecosystem-based options often operate at landscape scale, depend on many landholders, and require coordination across actors with different mandates and time horizons. This raises transaction costs, lengthens delivery timelines, and creates the collective action. A green option can be cheaper on a lifecycle basis yet still fail if these conditions cannot be met. Where the comparison does not justify a green or hybrid component, or where the coordination required is not achievable, grey infrastructure remains the appropriate response. The framework's contribution is ensuring that residual ecosystem risk is well documented and monitored through Step 7.

Table 6: Conditions assessment for ecosystem-integrated approaches

Favourable Conditions	Unfavourable Conditions
Ecosystem restorable within project timeline	Ecosystem irreversibly degraded
Demonstrated lifecycle cost advantage	Immediate capacity need (under 2 years)
Secure water rights and land tenure	Water rights contested; no resolution path
Multi-stakeholder coordination feasible	Extreme institutional fragmentation
Concessional capital available for maturation	No patient capital available
Performance attribution credible	Attribution impossible

Step 3: Assess Risks and Financial Materiality

This step determines whether the project has material water ecosystem dependencies and how those dependencies behave under the response selected in Step 2. Three tasks are involved:

1. **First, map the dependency:** Identify the specific ecosystem service the project relies on, assess its current condition, and project its trajectory over the asset's life. TNFD's LEAP framework, NGFS's Conceptual Framework for Understanding Nature-Related Risks and Supervisory Framework for Assessing Nature-related Financial Risks developed by the OECD provide structured methodologies for this analysis.[110,111] Supporting tools could include the WWF Water Risk Filter (basin-level risk, scenarios to 2050),[112] WRI Aqueduct 4.0 (13 indicators, three climate scenarios to 2080),[113] ENCORE (sector-level dependencies and impacts on nature),[114] and the World Bank's Climate and Disaster Risk Screening tools.[115]
2. **Second, rank and translate to financial variables:** Chapter 3's six entry points (CAPEX, OPEX, revenue, reliability, reserves, asset life) provide the translation framework. It also helps to identify how risk enters the project's finances, because different routes require different responses:
   - Gradually rising costs (credit risk): catchment degradation slowly increases treatment intensity, eroding debt service capacity. Response: scenario stress testing.
   - Sudden shocks (liquidity risk): flood, drought, or contamination disrupts operations, creating acute cash flow gaps. Response: insurance, reserves, or parametric triggers.
   - External environment changes (regulatory risk): government reforms water allocation or reclassifies water rights. Response: contractual protection.

   Most projects face a combination, but one route typically dominates, and identifying it determines where the strongest response is needed.[116]
3. **Third, assess materiality and time horizon:** A dependency is material when it can credibly weaken DSCR, trigger covenant breach, shorten asset life, or require unplanned CAPEX. Three dynamics matter: gradual escalation, where upstream conditions worsen incrementally beyond standard inflation assumptions; irreversible tipping points, such as aquifer compaction or reservoir sedimentation;[117] and amplification, where loss of natural buffers actively increases the severity of the hazard they used to attenuate.[118]

Step 4: Price Water Risk into the Financial Model

Most financial models treat water input conditions as constant. Four approaches can reveal and quantify the exposure; the strongest analysis combines two or more as cross-checks.[119]

Scenario stress testing constructs two to three degradation and climate shocks scenarios and traces the impact through every affected variable in the financial model. The OECD's three-step methodology provides the analytical structure.[120] In practice, this means adjusting the OPEX line, revenue assumptions, or maintenance schedules to reflect each scenario, then observing the effect on DSCR and covenant headroom.

Shadow water pricing calculates the gap between what users pay for water and what it actually costs when the full range of ecosystem services is included. The Water Risk Monetizer can calculate this gap using facility coordinates, water volume, and basin conditions.[121] WWF's WAVE tool offers a complementary approach, converting basin scores into present and projected financial impacts at site level.

Water market price discovery applies where tradeable water rights exist. In most emerging markets, water rights are not tradeable, so the other three approaches must substitute.

Credit risk integration: Rating agencies and central banks are increasingly incorporating water exposure into credit assessments. For investment committees: check whether the sector is flagged as water-exposed, assess whether the dependency could affect the credit profile at refinancing, and consider whether proactive disclosure strengthens positioning with ESG-sensitive investors. Standardised nature scenarios are not expected until end of 2026; bespoke stress testing is the operative approach[122].

Checklist for the investment committee: At the end of Step 4, the team should ideally be able to answer:

- What is the DSCR under moderate and severe ecosystem degradation scenarios?
- At what point does degradation breach the minimum DSCR covenant?
- How large is the gap between current water cost assumptions and the risk-adjusted cost, and what does this imply for the OPEX line?
- Has ecosystem condition been tested as a sensitivity variable alongside interest rates, demand, and construction cost?
- What reserves or covenant adjustments are needed to accommodate the downside range?

Investment decision gate: Given the ecosystem-adjusted base case and downside scenarios, does the projected return still meet the investment's minimum return requirement? If not, what would need to change in pricing, structuring, or scope to close the gap?

Step 5: Translate Dependencies into Deal Terms

Analysis only matters if it is embedded in the deal. Without it, water risk is understood but not acted on. The translation works across three areas:

First, reflect the dependencies in the financial model. The degradation scenarios from Step 4 should inform base-case assumptions. This means ensuring OPEX and revenue assumptions reflect a realistic range of ecosystem conditions, reserves are sized to accommodate that range, covenants are set with enough headroom to remain workable under plausible downside conditions, and ecosystem condition appears in the sensitivity analysis as a variable in its own right.

Second, allocate ecosystem risk explicitly in the contractual structure. For each material dependency, determine who bears the risk if conditions change, and whether that allocation is explicit or implicit. In many current structures, the project company absorbs ecosystem-driven cost increases silently because they are not addressed in the offtake, O&M, or insurance arrangements. Making the allocation explicit could involve tariff or pricing provisions that reflect changing input conditions, availability or performance clauses that account for water-related disruption, insurance or contingency arrangements for acute events, or upstream management agreements where feasible. Where no contractual allocation is practical, the dependency remains as residual risk and should be reflected in return expectations.

Third, distinguish between inside-boundary and outside-boundary. Some ecosystem dependencies can be addressed through design. Others sit outside the boundary and cannot be controlled directly. For these, the investment team should assess whether the risk has been addressed through the financial model or contractual structure, or whether it remains unmitigated. Unmitigated outside-boundary risks should be disclosed in the investment memo and reflected in the deal's risk profile. Governance durability is a direct input into credit risk: where enforcement is weak or institutional arrangements unstable, financial protections should be sized accordingly.

Step 6: Structure the Response

This step selects the financing instruments to deliver the deal terms from Step 5. The choice depends on the dependency profile: water funds and PES for chronic water quality risk with restorable catchments; parametric insurance or contingency reserves for acute flood or drought exposure; environmental impact bonds or outcomes-linked debt where ecosystem economics are strong but revenues absent; and guarantees or blended concessional structures where unfamiliar risk blocks commercial pricing. Where concessional capital absorbs ecosystem maturation risk (typically 3 to 15 years), first-loss tranches of 25 to 35% with temporal step-down are indicated.[123]

Step 7: Govern Over the Asset Lifecycle

Ecosystem dependencies evolve over 20-50-year asset lives. A catchment healthy at financial close can degrade. A regulatory framework can change. Communities sustaining land management can lose the incentive to continue. Governance must ensure the institutional, legal, and monitoring architecture is durable enough for the investment to remain sound as conditions shift.

Regulatory durability: are the ecosystem services the project depends on protected by law, and is that protection enforced, resourced, and politically durable? International designations such as Ramsar provide a baseline[124], but formal designation is not the same as functional protection. Sovereign regulatory risk is real; Chile's 2022 reform reclassified water from private commodity to national public good.[125]

Maintenance and contingency provisions: operational budgets for both grey and green infrastructure should be contractually ring-fenced, not subject to annual discretionary allocation. The Wuhan case demonstrated that green infrastructure degrades to grey performance when maintenance budgets are cut. Insurance or contingency reserves for climate and biodiversity risk should be structured at financial close and governed as covenant obligations, not revisited ad hoc when conditions deteriorate.

Community governance: where the project depends on upstream communities, those communities are governance partners, not consultation subjects. FPIC (IFC PS7, ADB ESS7) should apply to ecosystem management arrangements, not only to the physical infrastructure. PES and watershed management contracts require clear property rights or recognised customary use rights.[126]

MRV and adaptive triggers: monitoring should track hydrological indicators (flow, sediment, water quality), ecological indicators (vegetation, species), and financial indicators (treatment costs, downtime, reserve drawdowns). Adaptive triggers established at financial close enable predefined decisions to be implemented based on catchment conditions and associated risks. For example, if catchment conditions deteriorate beyond an agreed threshold, a pre-funded response mechanism is activated. If treatment costs exceed the moderate scenario for two consecutive years, an independent assessment is commissioned. If water quality at the abstraction point exceeds design parameters, the issue is escalated to the guarantee provider. If the allocation framework changes materially, the underlying revenue assumptions are reviewed and renegotiated.

At refinancing or exit, ecosystem conditions should be reassessed against the original appraisal assumptions, as deterioration directly affects asset valuation, credit terms, and transferability to the next holder.

6. Recommendations for Infrastructure Investors and Financiers

Where can infrastructure investors and financiers intervene to reflect water and ecosystem dependencies in how capital is appraised, structured, and governed?

The preceding chapters show that water and ecosystem dependencies are financially material yet routinely unpriced. Acting on this does not require new instruments so much as changes to how investors, financiers, and development finance institutions appraise, structure, and govern deals. The following recommendations are organised across three layers: the enabling environment in which assets operate, the design and appraisal of individual projects, and the way capital is structured.

6.1 Enabling environment

- **Treat water risk as systemic.** Water risk affects sovereign credit, sub-sovereign fiscal capacity, and the pricing of private debt, equity, and insurance, yet these channels are usually assessed in isolation. Financiers should bring water risk into country-level engagement with finance ministries and co-investors, not only into project appraisal, treating it as a shared fiscal concern across all three levels.
- **Make coordination a standing capability.** Every mechanism in this report required coordination across utilities, land managers, communities, governments, and investors, and building this from scratch on each deal keeps transaction costs high and prevents replication. The deeper constraint is often that local and municipal governments lack the capacity to sustain coordination over time. Financiers should support standing convening architecture, shared basin data, governance frameworks, and MRV protocols, with capacity building at the municipal and catchment level designed in from the outset.

6.2 Project design

- **Treat ecosystem condition as a financial variable.** Ecosystem health affects the same variables that determine returns, but models usually hold it constant, understating risk and overstating returns. A two-step process helps: a concept-stage screen for whether performance depends on water availability, quality, or protection, and, for projects that pass, an ecosystem condition assessment and DSCR stress test under forward-looking degradation scenarios run inside the financial model.
- **Appraise grey and green as one system.** Where green and grey are costed as separate line items, the green component always looks like an added cost rather than a cheaper alternative. Appraisal should evaluate them as one system with unified performance targets, placing the burden of justification on the grey-only option where the integrated approach is cheaper over the asset life.
- **Fund the ecosystem dependency or disclose it.** While examples such as water funds, PES schemes and the Cape Town catchment programme demonstrate how capital can be channelled towards upstream protection, such approaches remain niche rather than mainstream. Projects claiming resilience from upstream natural infrastructure should either include a funded stewardship mechanism, such as a PES contract or water fund contribution, or disclose the unfunded dependency as residual risk, with a risk-adjusted degradation scenario presented to investment committee alongside the base case.
- **Anticipate degradation before it forces recognition.** The gap between appraisal assumptions and operating reality tends to widen silently until a crisis forces recognition. Pre-agreed thresholds defined at close, treatment-cost breaches that trigger review, water quality deterioration that activates pre-funded remediation, and mandatory reassessment at refinancing or exit, should be written in as covenant-level obligations, supported by a

6.3 Financing

- **Finance the full lifecycle, not just the build.** Water-dependent infrastructure has three financing needs, not one: (1) construction, (2) sustaining the operating environment by maintaining grey and green components and stewarding upstream systems, and (3) risk transfer for residual shocks. Most deals address only the first. Every deal should answer, before close, who finances construction, who finances upstream stewardship over the asset life, and what mechanism converts acute shock risk into a defined liquidity event. Where the second and third go unanswered, the deal is implicitly transferring those costs to the public balance sheet.
- **Make what works replicable.** The Xuan Mai guarantee showed what well-structured credit enhancement can achieve: a large rating uplift, a first long-tenor local-currency bond, and local institutional capital mobilised without foreign-exchange exposure. Scaling depends on identifying which elements transfer to comparable regulatory and market settings. Financiers should standardise the transferable elements into a template and test it on a small number of upcoming deals, building the evidence on whether credit enhancement for ecosystem-dependent assets can scale through standardisation rather than bespoke design.

Evidence across Chapters 1 through to 6 points to a consistent finding; infrastructure performance depends on the condition of the water systems it relies on. Financing that ignores this dependency carries risk that is measurable but routinely unmeasured. Bankable infrastructure must be financed across all three functions, not just construction – building it, sustaining the operating environment that keeps it performing, and transferring residual risk. When appraisal prices only the build cost, it systematically understates lifecycle exposure and overstates returns. The question is no longer whether to integrate water ecosystem conditions into investment decisions, but how quickly institutional practice can translate this into standard deal structuring.

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