Co-sponsored by

ICG Infrastructure Client Group

National Infrastructure & Service Transformation Authority

The Green Construction Board

Delivered by

Built Environment Connective



The evidence base for systems change

Fifteen case studies informing the Infrastructure Systems Review

Introduction

The evidence base for systems change: 15 case studies informing the Infrastructure Systems Review.

The performance of the built environment shapes daily life, public services and economic activity. It is critical to long-term national outcomes including growth, resilience, climate adaptation and nature recovery.

However, while the built environment is connected, many important decisions are fragmented. This can leave value unrealised and shift costs and risks to other organisations, places or generations, and matters more as resources tighten and demands grow.

In July 2025 the Built Environment Connective published 'Connect to Change', a manifesto calling for systems thinking – to improve the decisions that determine how scarce resources are used, risks are managed and infrastructure performance is improved over time.

It argued: systems approaches make good business and economic sense. They create opportunity to plan and deliver future projects better, and also to create more value through better stewardship of the existing built and natural systems on which the UK depends. Systems approaches could improve outcomes across the built environment.

Connect to Change recommended a study, the Infrastructure Systems Review, to better understand how our built environment performs as a system of systems; address interconnected challenges; identify how to deliver improved outcomes, in particular sustainable growth; and maximise value gained from investment.

The Infrastructure Client Group, the National Infrastructure and Service Transformation Authority and the Green Construction Board recognised the need for new approaches to decision-making, planning, delivery and management of the built environment. They have co-sponsored and shaped the review.

Primary evidence

The review has highly practical foundations. These 15 case studies are its primary evidence. They span a range of places, sectors, scales and lifecycle stages.

The case studies and their interpretation were challenged through the following activities:

Expert reviews: Expert and practitioner reviews challenged assumptions, tested findings and assessed their wider relevance.

Workshops: Workshops with government, regulators, clients, investors, industry, academia and civil society tested emerging conclusions, identified common patterns and supported the interpretation of evidence.

Senior stakeholder engagement: Senior stakeholders provided a broad perspective and constructive challenge for the overall narrative and recommendations.

Success factor assessment: The assessment tested and refined the conditions that enable systems approaches to improve decisions and outcomes.

Economic analysis: The analysis assessed the mechanisms through which systems approaches can create value.

It has been a substantial voluntary undertaking, involving individuals and organisations across the whole of the Built Environment Connective. We thank everybody who has contributed their time, expertise and constructive challenge to this process.

Each case study was developed using a common structure covering scope, outcomes, systems, interventions, economic assessment, systemic assessment and recommendations. This allows evidence to be compared across different sectors and places, and helps distinguish the context, systems approach, interventions, value evidenced or anticipated, and lessons that can be generalised.

The evidence includes both cases where systems approaches contributed to improved decisions and outcomes, and cases where fragmented decision-making, weak integration or unmanaged interdependencies contributed to avoidable cost, delay, risk or lost value. The value identified in the evidence therefore includes both realised benefits and losses that could have been avoided.

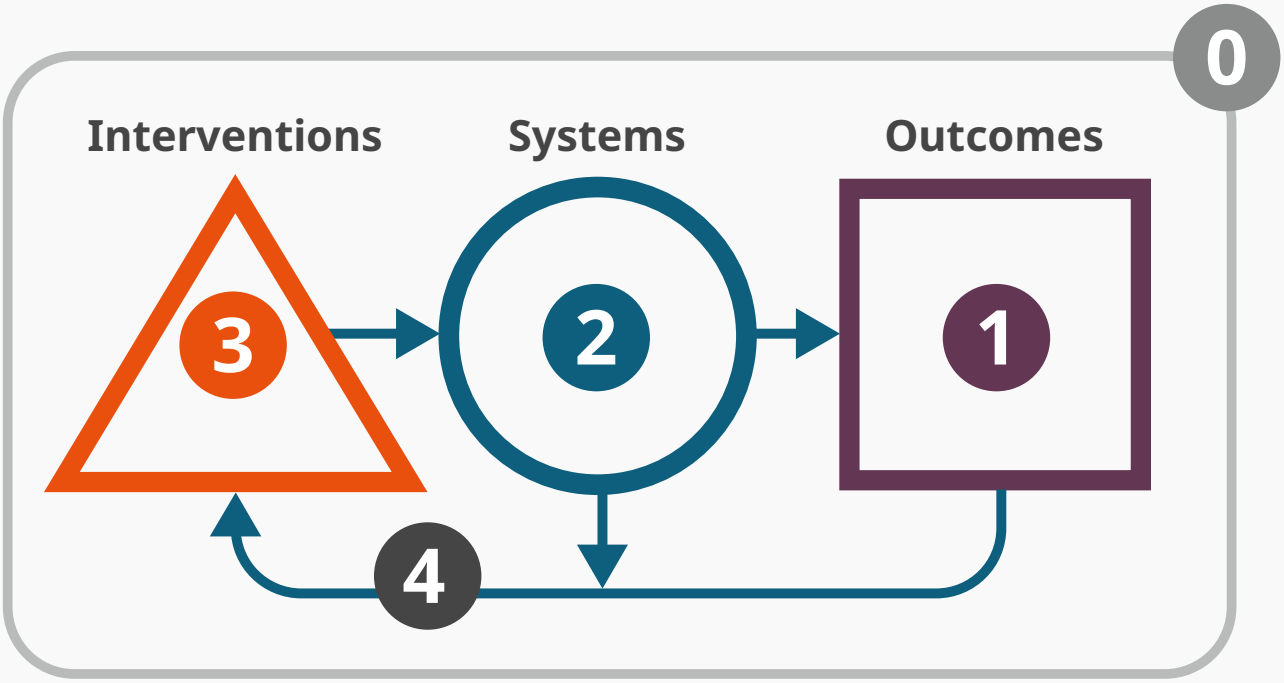
The case studies differ in the maturity and strength of their evidence. Nonetheless, across them, recurring themes emerge:

- Better system understanding can improve consequential decisions.
- Significant opportunities lie in the stewardship of existing systems.
- Realising value depends on organisations being able to act across boundaries.

The Infrastructure Systems Review will examine these patterns, assess their wider relevance and translate them into recommendations for national policy and practice.

Systems to outcomes

The framework set out in 'Connect to Change' illustrates a way of applying systems approaches to improve decisions and outcomes. It informed the analytical approach across all of the case studies, and recurring patterns across them confirm its relevance to different contexts.



0

Know your scope
Define the scope of the decision, the system you are seeking to influence, the boundaries that matter and the stakeholders who need to be involved.

1

Focus on the outcomes
Clarify the outcomes sought, understand the gap between current and desired performance, and use those outcomes to compare options, make trade-offs and guide decisions.

2

Understand the systems
Understand how outcomes depend on the relevant physical, organisational and digital systems, including the interdependencies and external influences that shape their performance.

3

Drive effective interventions
Use the interventions most likely to improve outcomes, including physical, operational, digital, behavioural, governance and nature-based interventions. Focus effort where it can make the greatest difference.

4

Observe, learn and adapt
Monitor outcomes and system performance, test assumptions, learn from experience and adapt interventions as conditions and evidence change.

Foreword

Achieving better outcomes requires different ways of thinking and working. These case studies signal how.



Jason Tucker
Chair, Infrastructure Client Group

Never in recent times has infrastructure been so much in the public and political eye.

It is better recognised now than at any point in my lifetime that infrastructure enables and underpins social and economic growth; that it is inseparable from the environmental, biodiversity and climate emergencies; and that its effectiveness, security and reliability are fundamental to national resilience.

Sustaining the country's existing infrastructure inventory and investing in its future – with £725 billion of planned public and private funding over the coming decade – presents complex questions and requires complex trade-offs. We ignore them at our peril.

Our critical infrastructure is systemically interconnected. We must better understand how – both to avoid unintended consequences, and to realise co-benefits where we can. We require systems awareness and skills to improve performance, productivity, outcomes and value despite resource constraints and the challenges presented by an increasingly turbulent, uncertain, novel and ambiguous world.

This is the nettle that the Infrastructure Client Group has grasped in co-sponsoring the Infrastructure Systems Review with NISTA and the Green Construction Board. Between us, we have the ability to set the direction for the infrastructure value chain, and create the conditions for it to work differently, to achieve better results.

We have done this before. The ICG was founded in 2010 to implement the recommendations of the 'Infrastructure Cost Review', published by HM Treasury, to reduce waste and cost, and improve efficiency and value. The ICG commissioned the 'Infrastructure Carbon Review', which HM Treasury published in 2013 – showing the correlation between carbon and cost, and setting out a clear hierarchy of actions to reduce them both.

Looking back over the last decade and a half, it is clear what impact the cost and carbon reviews, and the workstreams they unleashed, have had on the way the whole value chain thinks and behaves. It is also clear that change has come about as a result of leadership. Clients have rallied behind specific recommendations, developing standards, specifications and guidance, adjusting commercial arrangements, embracing technology, reporting progress and sharing best practice. Government has set policy and shaped regulation.

Infrastructure cost and carbon are ongoing journeys – but they have become embedded in business as usual throughout the infrastructure industry.

Naming of the Infrastructure Systems Review is deliberate. We are placing it in that lineage. But we think it will have a materially greater impact on the infrastructure industry than its predecessors.

The cost and carbon reviews generated unified approaches for tackling issues that were to a large extent known. The systems review is equipping us to address unknowns associated with infrastructure's biggest and most pressing challenges. It recognises the necessity of connecting and coordinating

“Sustaining the country’s existing infrastructure inventory and investing in its future presents complex questions and requires complex trade-offs. We ignore them at our peril.”

organisations, sectors and information. It will provide the insights, strategy and recommendations to do so.

The Infrastructure Systems Review has been shaped through colossal cross-industry collaboration and consultation, with literally hundreds of contributors and reviewers. But at its core are 15 detailed case studies – real experience on existing systems, delivery programmes and strategic propositions that reveals strengths and successes, weaknesses and shortfalls in applying systems thinking and systemic approaches to infrastructure. Academics and system specialists have been involved alongside practitioners in a process of rigorously examining each case study and capturing its lessons.

A critical strength of the review is that it is not theoretical. The case studies root it in reality.

They represent diversity of sectors, geographies, scales and lifecycle stages. Yet out of that diversity, 10 clear insights have emerged. We have tested them on members of the ICG executive board, representing 20 of the UK’s largest infrastructure clients. There is unanimous agreement: the insights are practical and valuable:

1. Better system understanding leads to better decisions.
2. Clear outcomes help decisionmakers make better choices.
3. Better decisions require the right boundaries.
4. Effective interventions address underlying causes, not just symptoms.
5. Some of the greatest opportunities lie in the stewardship of existing systems.
6. Natural systems can function as productive infrastructure.
7. Shared understanding enables coordinated decisions and action.
8. Systems approaches require collaboration, trust and adaptive learning.
9. System integration must be managed throughout delivery, not left to the end.
10. Authority, governance and incentives determine whether value is realised.

There are few areas in which applying the insights and principles of the Infrastructure Systems Review won’t unlock better outcomes – from carrying out everyday operational, asset management and capital delivery activities, to addressing wicked problems.

I encourage everyone to read these case studies for themselves. Individually, each is instructive and offers immediately useful lessons.

I urge you next to read the Infrastructure Systems Review when it is published at the start of 2027. Initiating and driving systems change across UK infrastructure is itself a systemic challenge, needing coordination, collaboration and concerted effort. The ICG will provide leadership and exert influence where we have jurisdiction, and support those beyond.

The future performance of our built environment, and the outcomes it delivers for society, nature and the economy – for all of us – requires systemic coordination and trade-offs. A decision to ignore this is, paradoxically, still a decision – but one likely to produce outcomes we won’t like.

These case studies show how we can decide to take better control, and achieve the outcomes we want.

Case studies

01

A17 Cross Keys Bridge

System: An historic bridge within the regional transport network.
Systems contribution and value: Broadened framing from bridge condition to service availability, reliability and recovery. Potential to reduce disruption costs, improve network resilience, and support freight, economic and community connectivity.

02

Anglian Water Reservoirs Programme

System: Fens Reservoir and regional water resources.
Systems contribution and value: Introduced a requirements hierarchy, common database, ownership and change control as a basis for scope and programme decisions. Improved requirements clarity and traceability, reducing scope creep, rework and investment risk.

03

Connecting the Culm

System: River Culm catchment.
Systems contribution and value: Reframed flood risk and environmental challenges at whole catchment scale, co-creating a coordinated 25-year intervention portfolio. Potential to reduce flood risk and transport disruption, with wider environmental and social co-benefits.

04

CReDO

System: Cross-sector infrastructure resilience.
Systems contribution and value: Shared data and cascade-risk modelling improved visibility of interdependencies and supported early resilience planning. Modelled potential benefits include better-targeted investment, reduced losses and improved continuity of critical services.

05

Crossrail integration

System: The transition from delivery to operation of a new metropolitan railway.
Systems contribution and value: A client-led programme 'reset' was initiated to overcome integration challenges, employing best-for-programme triage and commercial innovations. It supported programme recovery and strengthened operational readiness.

06

Electricity Transmission Partnership

System: Transmission delivery ecosystem.
Systems contribution and value: Employed long-term portfolio partnering, performance-linked future work and multi-level governance, with the aim of reducing delivery fragmentation and bottleneck risk, and supporting investment in delivery capacity, capability and resilience.

07

Hastings Landslide

System: Coupled cliff stability, property and risk-financing.
Systems contribution and value: Reframed risk in terms of the cliff system, rather than individual properties, integrating geotechnics, monitoring, planning, finance and community action. Developed lower-cost intervention options with the potential to restore property value.

08

Integrated Catchment Systems

System: Integrated river catchments.
Systems contribution and value: Participatory mapping, integrated modelling and shared data improved understanding of boundaries, stakeholders, cause-effect relationships and trade-offs. Identified opportunities for coordination and co-funding.

09

London's Thames Crossings

System: Cross-river transport.
Systems contribution and value: Proposes development from existing investment approaches, in which repairs and maintenance are coordinated between boroughs, to a fuller system approach that supports them in protecting cross-river connectivity, efficiency and resilience.

10

Oxford-Cambridge Growth Corridor

System: Cross-sector regional development.
Systems contribution and value: Outcome-led framing and systems mapping made cross-sector dependencies, sequencing needs, gaps and trade-offs visible before major choices. Identified opportunities to reduce coordination failure and de-risk cross-sector investment.

11

River Intervention and Systems Model

System: Great Ouse catchment and water resource.
Systems contribution and value: Modelled interventions considering water, land and ecology, to find balance between different user needs. Illustrated potential impacts on water security, water quality, reservoir and treatment costs, carbon, flood risk and biodiversity.

12

Strategic Nature Network

System: UK natural infrastructure
Systems contribution and value: Reframes nature as productive infrastructure and proposes a connected Strategic Nature Network, with the potential to improve ecological resilience, reduce climate and environmental risks, and increase value from existing public and private investment.

13

Thames Estuary 2100

System: Thames Estuary tidal flood-risk management system.
Systems contribution and value: Shift to adaptive pathways, estuary-wide management and system-level intervention timing. Reported examples include deferred high-cost interventions, improved maintenance timing, reduced whole-life flood-risk cost and supported co-funding..

14

Transpennine Route Upgrade

System: Transpennine rail delivery.
Systems contribution and value: Established enterprise governance, requirements architecture, and whole-railway integration for scope, interface and readiness decisions. Potential to reduce integration risk, late change and rework.

15

Wye-Usk Transition Lab

System: Wye-Usk – socio-ecological and economic.
Systems contribution and value: Shared diagnosis, convening and trust-building developed common priorities for project, finance and governance development. Strengthened collaboration and developed a pipeline of potentially investable landscape-scale interventions.

01



A17 Cross Keys Bridge

This is one of 15 case studies informing the Infrastructure Systems Review.

System: An historic bridge within the regional transport network.

Systems contribution and value: Broadened framing from bridge condition to service availability, reliability and recovery. Potential to reduce disruption costs, improve network resilience, and support freight, economic and community connectivity.

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Summary

Cross Keys Bridge is a Grade II listed hydraulic swing bridge, opened in 1897, carrying the A17 across the River Nene at the Lincolnshire/Norfolk border. It provides the only road crossing at this location, with the nearest alternative around 10km away at Wisbech.

The bridge forms part of the major road network corridor linking the East Midlands with East Anglia and is one of only two principal routes connecting the A1 to Norfolk. It supports nationally significant freight movements serving agriculture, food manufacturing and logistics, seasonal tourism to the Norfolk coast. Cross Keys carries 16,000-18,000 vehicles per day, including 2,500-3,000 HGVs.

As a swing bridge, which opens to allow passage of larger vessels, it also enables river navigation.

Regular openings for river traffic, combined with age-related structural deterioration, maintenance requirements and wider A17 capacity constraints, impact the performance and resilience of the transport network. Closures or restrictions require road traffic diversions via Wisbech, increasing journey times, costs and disruption for businesses, commuters and visitors, and increasing carbon emissions.

The bridge represents a major single point of failure for the regional transport network and economy. Rather than viewing it as an isolated highway asset, it should be considered part of a wider transport and economic system, supporting a place-based resilience approach that prioritises coordinated investment, proactive maintenance and reduced whole life costs.

Regular openings for river traffic, combined with age-related structural deterioration, maintenance requirements and wider A17 capacity constraints, impact the performance and resilience of the transport network.

Scope

This case study defines the scope of Cross Keys Swing Bridge as both a critical infrastructure asset and a point of interaction between multiple transport, economic and community systems.

Geographically, it focuses on the A17 crossing of the River Nene at the Lincolnshire/Norfolk boundary, with recognition of its wider relationship to the regional highway network, including the A47. Its physical scope includes the bridge structure, carriageway, footway, safety features and hydraulic swing mechanism.

Functionally, the bridge provides a strategic road connection, supports nationally significant freight movements, seasonal tourism and river access to the ports of Wisbech and Sutton Bridge. It is also an important local transport link despite limited provision for active travel.

The study considers the bridge's influence on labour market connectivity, agri-food supply chains, tourism, port activity and access to essential services. It also examines interventions ranging from maintenance and operational improvements to wider corridor enhancements and long term replacement options.

Outcomes

Cross Keys Bridge and its associated services should support the safe, reliable and efficient movement of people and goods while maintaining navigational access on the River Nene. An outcomes based approach reframes the bridge from a vulnerable asset to a critical component of a wider transport, economic and community system that must deliver connectivity, resilience and economic stability.

The desired outcomes are to maintain dependable east/west movement along the A17, protect access for communities and emergency services, support freight and agri-food supply chains, sustain tourism and port activity, and improve safety and inclusion for all users, including pedestrians and cyclists.

At place level, outcomes include access to employment, education, healthcare and services; reliable freight and agricultural supply chains; a positive visitor experience supporting the economy. Outcomes align with national objectives for productivity, resilience and net zero by reducing friction in strategic journeys, maintaining connectivity under climate stress, and avoiding unnecessary carbon from unreliable operations and diversions.

These outcomes make clear the bridge's strategic importance. It represents a potentially significant single point of weakness. Structural limits, narrow geometry, swing operations, and exposure to flooding and severe weather could all result in failure of the bridge. It represents a risk hot spot within the context of wider A17 constraints affecting network reliability.

When performance deteriorates, impacts extend beyond the asset. Restrictions or closures force long diversions, increasing journey times, costs and emissions while weakening labour market connectivity, disrupting business operations and supply chains, and reducing resilience in a region with few alternative routes. A prolonged closure would affect residents and workers, delay emergency response, interrupt agricultural logistics, reduce visitor activity, and place pressure on alternative crossings and local roads not designed for sustained strategic traffic volumes.

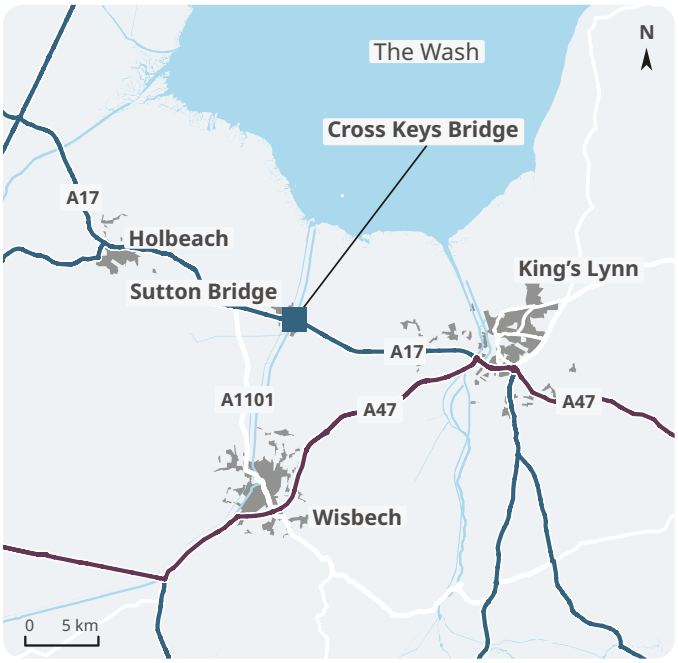
A systems approach defines interventions not simply to preserve the structure, but to secure the outcomes it enables across the wider network and economy. This shifts focus to measurable service performance, including network availability, journey time reliability, navigation access,

Cross Keys Bridge

Regional importance



Local detail



1897
year opened

16-18k
vehicles carried per day

2.5-3k
HGVs carried per day

Cross Keys Bridge at a glance

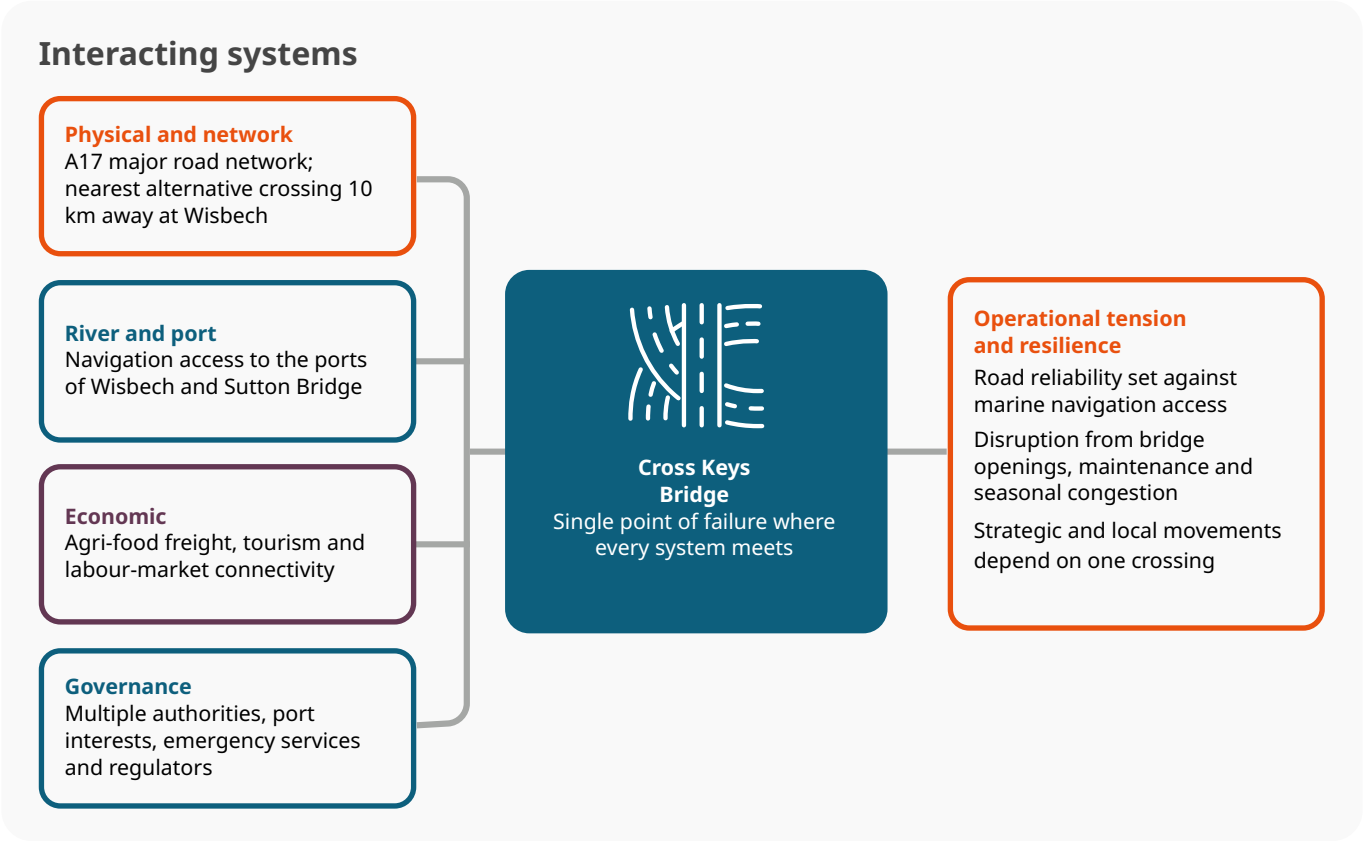
Location and overview
- Located on A17 at the River Nene crossing
- Nearest alternative crossing 10km away at Wisbech
- A17 is a primary east–west corridor
- Linking the East Midlands to East Anglia
- One of only two main routes connecting the A1 to Norfolk

Structure and challenges
- Grade II listed hydraulic swing bridge
- Major weakness on the network
- Single point of failure for local and strategic movements.
- Constraints: structural capacity limits; no segregated active travel; swing bridge openings for vessels; maintenance closures; seasonal congestion

Critical functions
- Supporting freight movements for agriculture, food processing and agri-logistics
- Carrying seasonal tourism traffic to Norfolk's north coast
- Enables river traffic to reach the ports of Wisbech and Sutton Bridge

Systems overview

Cross Keys Bridge operates within a multi-layered transport, economic and governance system.
- **Physical and network system:** the bridge carries the A17, part of the major road network.
- **River and port system:** maintaining navigation access to the ports of Wisbech and Sutton Bridge, creating operational tension between road reliability and marine access.
- **Economic system:** supporting agri-food freight, labour market connectivity, tourism and local business activity across South Lincolnshire, West Norfolk and surrounding areas.
- **Governance system:** responsibilities and impacts are spread across multiple authorities, port interests, emergency services, regulators, businesses and residents.



and recovery from incidents. It also supports proactive maintenance, improved condition monitoring, obsolescence planning, and coordinated working between highway, navigation and emergency stakeholders to anticipate disruption, reduce its frequency, and manage it more effectively when unavoidable.

Critical success factors
Success should be measured through outcome focused indicators: fewer unplanned closures; improved journey time reliability; reduced diversions; maintained emergency access; reduced disruption to freight, tourism and port traffic; improved safety for all users; and greater resilience to flooding and deterioration.

At programme level, success is also shown through lower whole life disruption costs, stronger user confidence, and tangible contribution to regional growth, resilience and lower carbon travel outcomes.

Systems

Cross Keys Bridge operates within a multi-layered transport, economic and governance system rather than as a standalone asset. It sits at the intersection of the A17 corridor, River Nene navigation, local and regional economies, and communities relying on the crossing for access to jobs, services and markets.

Because the bridge is both a route and a node, any change in performance creates ripple effects through traffic reassignment, journey reliability, business activity and accessibility. However, addressing the systemic importance of the bridge is complicated by organisational silos: The bridge sits at the boundary of three counties – Lincolnshire, Norfolk, and Cambridgeshire – requiring coordination between different local highway authorities, each with different priorities.

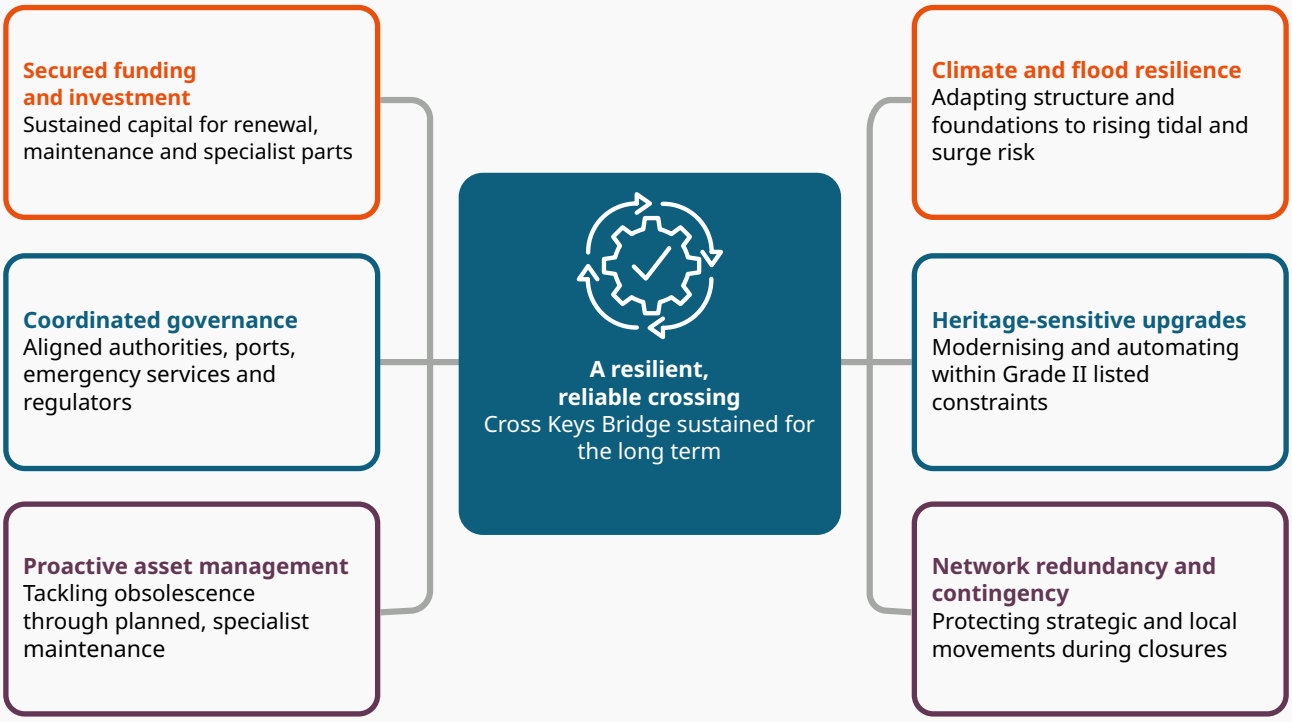
The principal systems are fourfold.

- **The physical and network system:** the bridge carries the A17, part of the Major Road Network and one of only two main routes linking the A1 to Norfolk, with the nearest alternative crossing around 10km away in Wisbech.
- **The river and port system:** as a movable bridge it must maintain navigation access to the ports of Wisbech and Sutton Bridge, creating tension between road reliability and marine access.
- **The economic system:** the route supports agri-food freight, labour connectivity, tourism and business activity across South Lincolnshire, West Norfolk and surrounding areas.
- **The governance system:** responsibilities are shared across highway authorities, navigation interests, emergency services, regulators, businesses and residents.

These systems operate within constraints including structural and geometric limits, flood and climate risk, seasonal peaks, heritage considerations, and the need to balance strategic traffic, local access, freight, tourism, navigation and active travel. These interacting pressures mean decisions in one area can generate consequences elsewhere.

A systems approach makes these interdependencies visible and supports interventions that improve whole system performance rather than preserving the structure alone. This focuses on service outcomes such as availability, reliability, recovery time and diversion readiness. It strengthens governance and reduces the wider economic and social costs of disruption.

Success factors



Alongside physical works, system wide actions are required, including coordinated closure protocols, agreed diversion strategies, clearer communication with users, and alignment with wider A17 management.



10km

Nearest alternative road crossing

Interventions

Interventions should focus on improving whole system performance rather than treating Cross Keys Bridge as an isolated structure. This means combining measures that address the bridge's physical and operational vulnerabilities – its ageing listed fabric, narrow geometry and exposure to flooding, plus measures that address both heavy A17 traffic and river navigation, and that reduce disruption across the surrounding network and dependent economic activity.

The aim is to protect service continuity, manage risk proactively, and balance reliability, heritage, safety and navigation requirements.

In the short term, priority measures include risk based maintenance, renewal of critical hydraulic and mechanical components, improved spares and obsolescence planning, condition monitoring, and targeted safety improvements. Medium term measures could include junction improvements on approaches, better provision for walking and cycling, and improved integration with wider corridor operations. Longer term options may include major refurbishment, a parallel crossing, capacity enhancement, or structural replacement where this improves resilience and performance.

Alongside physical works, system wide actions are required, including coordinated closure protocols, agreed diversion strategies, clearer communication with users, and alignment with wider A17 management. Together, these should reduce closures, improve reliability, strengthen resilience to extreme events, and lower the wider economic and social costs of disruption while supporting more coordinated governance based on shared service outcomes.

Cross Keys Bridge vulnerabilities, constraints and challenges

Current vulnerabilities

- Ageing structure and mechanical/ hydraulic systems
- Structural capacity limits
- Exposure to flooding and extreme weather
- Heritage constraints, reliance on specialist parts/maintenance

Operational constraints

- Single crossing point and narrow geometry
- High traffic demand (18,000 vehicles per day)
- High HGV demand (18%)
- Seasonal variations
- 3–4 bridge openings for river traffic per day (uncertain demand)
- Planned maintenance closures, and limited alternative routes

Long-term resilience challenges

- Increasing traffic and HGV demand
- Seasonal tourism peaks
- Climate change impacts
- Rising maintenance burden
- Parts obsolescence
- Risk of longer and more frequent disruption events

Economic assessment

Improving Cross Keys Bridge would generate significant economic benefits by reducing the risk and cost of disruption on a critical section of the A17, strengthening connectivity between agri-food production, processing, logistics and port activity, and improving access to jobs and services across county boundaries. The strongest economic case is likely to arise not only from conventional transport benefits but from avoided disruption and protection of wider system performance.

Baseline – do minimum
Under a reactive approach, costs accumulate through increasing maintenance visits and emergency repairs as components age, alongside growing user disruption from restrictions, closures and diversions. These costs include lost time, higher vehicle operating costs, logistics inefficiency, missed appointments, reduced visitor spend and higher emissions. Because alternative routes are long and often unsuitable for sustained diversion traffic, even short closures generate disproportionately high economic, social and environmental costs. The do minimum case also carries the risk of a major failure event resulting in prolonged closure, significant repair costs, and reputational and heritage impacts.

Economic impacts
Upgrading or replacing the bridge would reduce the frequency and duration of closures and restrictions, generating benefits through journey time savings, improved reliability, lower vehicle operating costs and reduced diversion mileage. These effects also deliver external benefits linked to decongestion, safety, emissions, air quality, noise and infrastructure wear. For appraisal, monetised impacts are likely to include travel time savings, vehicle operating costs, reliability benefits, selected externalities and infrastructure carbon. The freight function is particularly important as more dependable HGV journeys would improve supply chain efficiency, reduce logistics costs and support time sensitive sectors such as agriculture and food processing.

Lessons learnt are transferable across similar assets: critical crossings should be managed as service platforms rather than isolated structures, with clear availability and recovery targets, and appraisal based on whole system impacts.

Wider economic impacts
The bridge supports economic performance beyond direct user benefits. Greater reliability on the A17 would strengthen links between production areas, processing centres, logistics hubs and the ports of Wisbech and Sutton Bridge, maintaining market access and productivity in logistics dependent sectors. Improved east/west connectivity would expand labour market catchments across Lincolnshire and Norfolk, supporting recruitment, workforce flexibility and access to employment. Sustained road and river access would support port activity and multimodal connectivity. Reducing disruption risk also improves business confidence and investor certainty, supporting growth including housing, employment land and agri-tech development.

Social and non-monetised impacts
Beyond monetised benefits, improvements would deliver social value by reducing rural isolation, improving access to healthcare, education, employment and retail, and

Recommendations framework

Recommendation theme	Lead audience	Action focus	Intended outcome
A17 corridor resilience strategy	Local authorities, funders and strategic partners	Assess diversion resilience and longer-term crossing options	Reduced single point of failure and stronger regional connectivity
Long-term resilience planning	Local authorities, funders and strategic partners	Include resilience in forward investment pipeline planning	Clearer long-term investment direction
Whole-system appraisal	Government / HM Treasury	Include disruption, freight, carbon and distributional effects in critical asset business cases	Investment decisions reflect the full consequences of failure
Outcome-led approvals	Regulators and heritage bodies	Engage early to balance heritage protection with operability, maintainability and resilience	Reduced approval risk and improved long-term function
Service-led asset management	Asset owners and funders	Use availability, unplanned closure and time-to-repair metrics to trigger proactive investment	Fewer closures, faster recovery and lower whole-life disruption costs
Cross-sector resilience	Highways, navigation, emergency services and local partners	Create scenarios, common expectations, comms protocols and alternative diversion plans	More coordinated response to disruption and clearer shared accountability

enhancing reliability for emergency services. Safer, more dependable journeys improve community resilience, while better walking and cycling provision can support inclusion. These impacts strengthen the case by reducing vulnerability in areas with limited alternative routes and reinforcing the crossing as an essential service link rather than simply a transport asset.

Systemic assessment

This case study highlights systemic issues that reduce value for money in managing ageing infrastructure, particularly where a single asset supports multiple services and sectors. It identifies key inefficiencies and barriers.

Siloed appraisal and funding can underweight disruption, carbon and resilience impacts borne by businesses, emergency services and communities. Performance is often measured in terms of condition rather than service, meaning condition grades alone may not trigger timely investment; service metrics such as availability, reliability and repair time provide stronger decision signals.

Movable bridge capability gaps, including specialist skills, parts obsolescence and long lead times, can increase downtime without proactive planning. Heritage constraints are sometimes treated as a barrier rather than an integrated design parameter that can enable more resilient solutions. Weak cross border coordination can delay decisions and increase long term costs where impacts span administrative boundaries.

Several transferable lessons emerge.

- Resilience decisions should be framed around service outcomes and whole system costs rather than maintenance budgets.
- Rural crossings can be nationally significant because diversion impacts are high and small investments can prevent disproportionate disruption.
- Integrating transport, navigation and heritage from the outset reduces programme risk.
- Using consistent metrics such as availability, disruption days avoided, carbon avoided and failure cost avoided supports better national prioritisation.

Recommendations

Lessons learnt are transferable across similar assets: critical crossings should be managed as service platforms rather than isolated structures, with clear availability and recovery targets, and appraisal based on whole system impacts including disruption, carbon and emergency access. This avoids under investment that can later manifest as high cost, high disruption failure. Recommendations are:

- Develop a coordinated A17 corridor resilience programme, including diversion route improvements and assessment of long term crossing options, to address this potential single point of failure and support economic growth.
- Prepare a long term resilience phased plan moving beyond reactive maintenance. It should define required service levels over 30-50 years, assessing risks from ageing assets, flooding, extreme weather, traffic growth and obsolescence. It should set trigger points for refurbishment, strengthening or replacement, including whole life option appraisal.
- Establish a multi-agency resilience group to coordinate highway, navigation and emergency stakeholders, with agreed closure protocols, diversion strategies and communications.
- Develop business cases to capture disruption, resilience and carbon impacts, including rural distributional effects.
- Shift from asset management to service-led performance using availability, reliability and repair time to trigger proactive investment.
- Initiate early engagement with heritage bodies to find and enable solutions that balance protection with long term operability and resilience requirements.

02



Anglian Water Reservoirs Programme

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Fens Reservoir and regional water resources.

Systems contribution and value: Introduced a requirements hierarchy, common database, ownership and change control as a basis for scope and programme decisions. Improved requirements clarity and traceability, with potential to reduce scope creep, rework and investment risk.

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Summary

Anglian Water (AW) is developing two nationally significant water supply reservoirs in the east of England to strengthen water resilience in response to climate change, population growth, and increasing environmental pressures. This case study examines how the Reservoirs Programme is applying requirements engineering and management (RE&M) to embed systems thinking and optimise outcomes for people, places, the environment, and water resources.

The programme spans multiple interconnected systems, including communities, land use, agriculture, water networks, and infrastructure. It supports key UK priorities such as economic growth, net zero, climate adaptation, and environmental enhancement. A systems thinking approach recognises that successful outcomes depend on understanding and managing the relationships between these elements to create benefits greater than those achieved by components in isolation. To support this, RE&M has been adopted from the earliest stages of project development to define desired outcomes, analyse needs and constraints, and maintain alignment between stakeholders, project objectives, and delivery solutions.

By providing a structured, traceable framework for connecting needs, outcomes, and interventions, RE&M helps ensure that proposed solutions are viable, feasible, and capable of delivering intended benefits. This approach increases confidence in achieving project objectives while supporting better value and more effective investment decisions given a full understanding of their consequences.

From the early stages of the project, RE&M has established a strong foundation for achieving the seven key success factors associated with systems thinking.

Major infrastructure programmes often underperform because objectives, needs and requirements become disconnected over time. This case study demonstrates how RE&M can provide a scalable and practical mechanism for improving infrastructure productivity, reducing delivery risk, and increasing confidence in achieving desired outcomes.

Scope

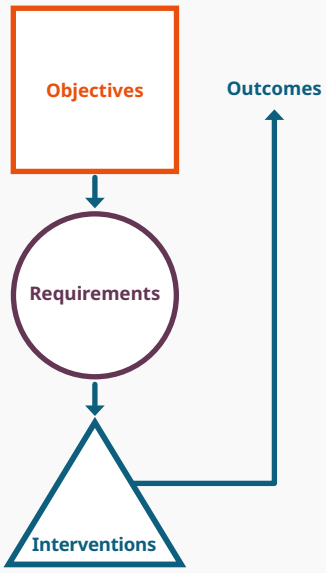
The AW reservoir programme will deliver two nationally significant, once-in-a-generation water resource projects in East Anglia. It includes the infrastructure needed to abstract, store, treat, and transfer water across the AW and Cambridge Water regions, supplying up to 253 million litres per day to 750,000 homes. This study focuses on the Fens Reservoir, though the approach also applies to its sister, the Lincolnshire reservoir. Together, the projects will improve resilience to climate change, population growth, and environmental pressures.

In the early concept stage, AW adopted a systems-thinking approach, working closely with stakeholders and regulators to define clear outcomes. These aim to deliver benefits beyond water supply and are shaped by corporate policy and regulatory requirements. Engagements identified important strategic interactions, including:

- Establishment of a strategic partnership, Future Fens Integrated Adaptation. It brings together stakeholders involved in managing water across the landscape and across sectors, to determine the actions they can jointly take to secure a vibrant future for the Fens.
- Engagement with the Department for Environment, Food and Rural Affairs' (Defra) Water Delivery Task Force and regulators, to chart the path between environmental compliance and supporting growth.
- Engagement with the Regulators' Alliance for Progressing Infrastructure Development (RAPID) to promote the development of national water resources infrastructure that is in the best interests of water users and the environment. This has yielded a transparent, gated governance process.

Figure 1. Requirements hierarchy

Owner	Requirements level	Examples
Government and regulators (Defra, OFWAT, EA, NE, DWI, etc.)	**Level 0: Statutory duties**	Government and regulators
Anglian Water (Reservoirs Programme Board)	**Level 1: Corporate objectives and commitments**	Business purpose; strategic direction statement; WRMP; PR24; ACWG design principles
Sponsor	**Level 2: Needs and benefits**	Deployable output; operational constraints; sustainability targets
Programme/Project teams	**Level 3: Functional, performance and commitments**	System definition & scope; DCO and other site-specific commitments



These engagements have helped define the desired project objectives and outcomes, and limit conflicting regulatory interpretations.

This case study examines the use of RE&M to ensure project outcomes are delivered through effective interventions. RE&M helps manage constraints, existing and new systems, key interfaces, and stakeholder requirements. The programme has established a structured, traceable hierarchy that clearly defines and cascades objectives to drive successful project interventions, illustrated in Figure 1.

The hierarchy provides a clear line of sight from corporate objectives to the interventions delivered. As a result, all programme activities can be linked directly to an objective, ensuring investment is justified and value-driven.

By working top-down – defining desired outcomes, identifying systems, then determining necessary interventions – the project focuses on delivering only what is required.

RE&M is widely used in sectors such as rail and aviation but is not yet common practice in the water industry. To improve efficiency and productivity through cross-sector learning, the AW Reservoirs Programme is applying RE&M to define and manage the diverse stakeholder needs, aspirations, and physical constraints associated with the project.

The study focuses on the use of RE&M during the early project phases to define outcomes, systems and interventions, enabling robust, defensible and mutually beneficial solutions. It does not explore the details of regional and regulatory engagement activities and, given the current stage of the programme, cannot yet quantify the actual achievement of outcomes.

Several studies have demonstrated that RE&M results in better cost and schedule performance, improving certainty of delivery in a sector where confidence in delivering outcomes within budgetary and programme constraints needs improving.[1]

Outcomes

Given the stage of the Reservoir Programme development, actual outcomes are as yet unknown. However, to understand the desired outcomes it is essential to conduct a robust needs and benefits assessment to define the project objectives. The fundamental need for the Fens reservoir was defined in the AW Water Resources Management Plan, 2024, the need for which is driven by population growth, climate change and environmental constraints, detailed in Figure 2.

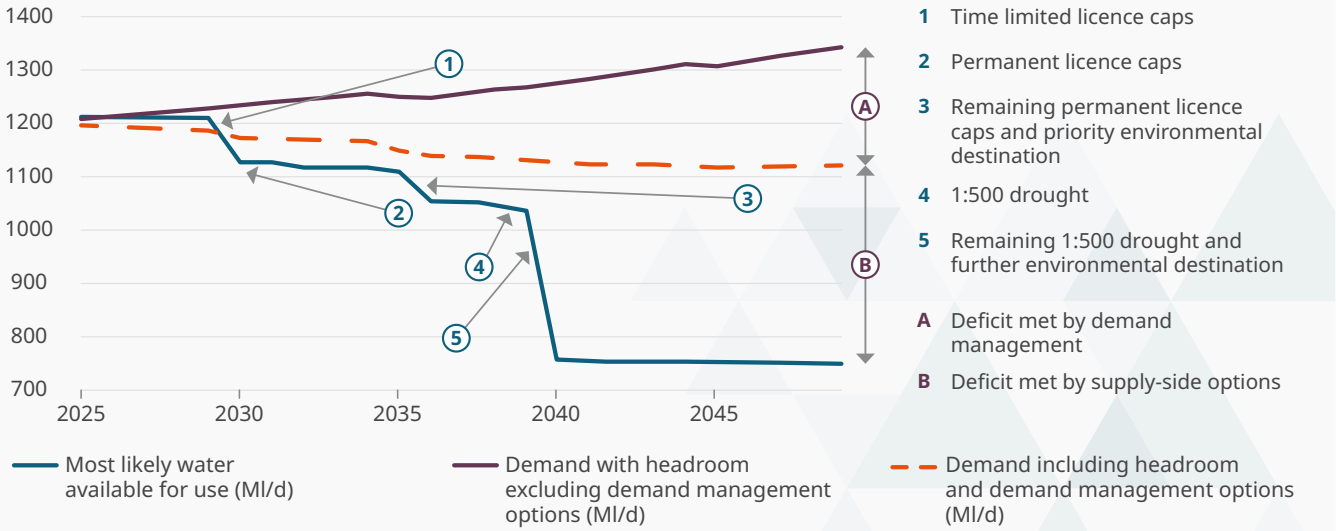
In addition, corporate and regulatory demands require improved outcomes for people, nature and place, all to be delivered within customer affordability limitations.

Implementing RE&M directly assisted with the clarification and definition of these complex interfaces, creating a hierarchy (Figure 1) that will provide a clear line of sight to the desired outcomes and provide assurance for the sponsor, developer, regulators and investors.

This hierarchy was created by remapping and 'systemising' the programme objectives document, previously created by the programme sponsor. This exercise created a hierarchy of objectives, benefits and requirements. The project sponsor used the hierarchy to define project benefits, set specific requirements and determine necessary interventions.

1 Systems engineering for intelligent transportation systems: Section 2.6, cost and schedule impacts of systems engineering. US Department of Transportation, Federal Highway Administration. ops.fhwa.dot.gov

Figure 2. Regional water supply challenges



Level 1 objectives are shown opposite.

Although generic in nature, the objectives clearly state national missions and aspirations around growth, net zero, resilience and productivity that can be cascaded from executive level to all levels involved in defining and delivering required interventions. They support the definition of detail and analysis of trade-offs between potentially competing objectives such as carbon reduction, the creation of economic value and customer affordability. They also focus attention on creating alignment between interventions to maximise the intended overall benefit.

Setting objectives in this way has

- created a database of objectives and benefits to enable the development of requirements that can be tested, adopted and changed in a transparent and clearly governed environment.
- enabled clear levels of accountability and delivery responsibility.
- provided consistent 'guardrails' within which the team can operate and make decisions, while understanding where potential deviations from defined requirements should be escalated and/or follow systematic change control.
- embedded a systems approach.

The last point is demonstrated by assessing project performance against the seven 'success factors' used to appraise all of the Infrastructure Systems Review case studies. They are represented in Table 2, over page.

Systems

The Fens Reservoir system outlined in Figure 4 will operate within a number of wider systems including physical/geographical, organisational, commercial, environmental, social, regulatory and many others. The physical system of the Fens Reservoir spans approximately 50km north to south, from a river abstraction on the River Nene near Peterborough to supply points near Cambridge (Cambridge Water) in the south, and near Chatteris (AW) in the east. Interfaces are with the ground (geology and groundwater) and surface water systems. There are also multiple infrastructure system interfaces including homes, businesses, highways, railways and utilities.

The resulting interventions (comprising the project) will be developed, delivered and operated within a complex regulatory environment that needs to be clearly understood and defined. This will significantly influence the technical solutions that drive water supply, social and environmental outcomes.

The project will be delivered via a specified infrastructure project regulations[2] (SIPR) commercial model that includes developers (water companies), investors, infrastructure provider and main works contractors. Commercial arrangements will need to ensure appropriate reward for each organisation whilst providing the customer, via the regulators (Ofwat[3] and RAPID[4]) value for money: the project needs to be both investible and affordable.

Collating the intervention/project requirements in a single database provides consistency, visibility and transparency across the entire project team. This minimises silos, ensures that solutions are focused on common constraints that can be both competing and complementary, and provides visibility of the many potential trade-offs. The early requirements capture has focussed on the needs of these physical, regulatory and commercial stakeholders.

Understanding and bringing the systems together through requirements will ultimately define the nature, design and delivery of the interventions. Interventions will be components of the 'system-of-systems' delivering the desired outcomes within defined budgetary and programmatic constraints.

The RE&M process enables a systematic process for identifying the 'systems of interest' to the programme – those that the interventions will need to modify to achieve objectives and outcomes. It also enables the subsequent management and assurance to support delivery of the interventions.

Interventions

Having established the programme objectives and system definitions, the project team has a strong foundation for identifying and defining the interventions required to deliver the desired outcomes. This structured hierarchy enables robust scope control and provides confidence that all necessary interventions are captured.

Given the scale and multidisciplinary nature of the team, a consistent approach to requirements development is essential. The RE&M process decentralises requirements capture, allowing all team members to draft and submit requirements directly into the requirements management tool. Requirements are generated through internal activities, including surveys, planning and design, as well as external engagement with regulators, stakeholders and the public. The RE&M process provides a systematic framework for identifying, managing and assuring requirements throughout programme delivery.

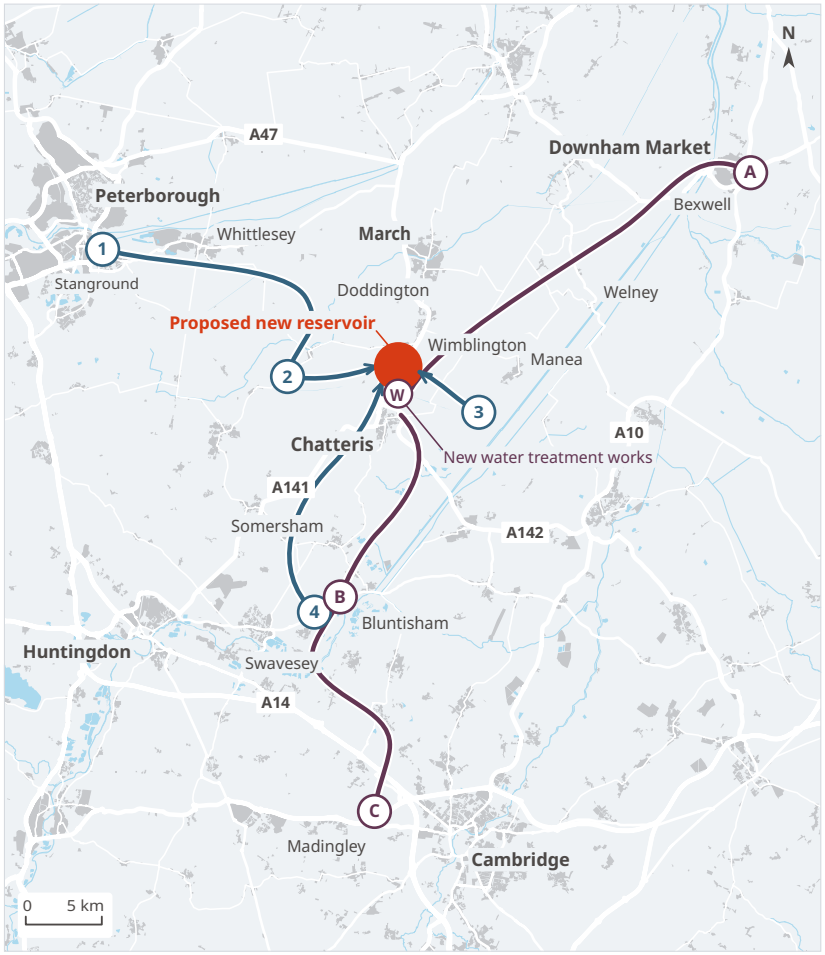
Level 1 and Level 2 requirements have been derived from legislation, corporate business plans and the Water Resources Management Plan 2024. They have been approved through corporate governance processes. Level 3 requirements are developed through a controlled process of identification, capture, review, adoption and change management.

The requirements baseline will be maintained through delivery and handover, with validation and verification

2 Specified Infrastructure Project Regulations (SIPR) is a commercial arrangement being widely adopted across the water industry that enables an infrastructure provider to finance and develop an asset, and to own the asset (through a license) for the duration of a defined license period.
3 Ofwat is the economic regulator of the water sector.
4 Regulators' Alliance for Progressing Infrastructure Development (RAPID) – has been established to accelerate the development of new water infrastructure and design future regulatory frameworks. The joint team is made up of the three water regulators Ofwat, Environment Agency and Drinking Water Inspectorate.

Fens Reservoir system

Anticipated physical extent



Water to reservoir

1. Water from the River Nene and its Counter Drain transferred to the reservoir via the Middle Level system
2. Water from the River Nene and the Middle Level system transferred to the reservoir
3. Water from the Ouse Washes (River Delph) transferred to the reservoir
4. Water from the River Great Ouse transferred to the reservoir

Treated water into supply

- (A) Treated water transferred to Anglian Water supply at Bexwell
- (B) Treated water transferred to Cambridge Water supply at Bluntisham
- (C) Treated water transferred to Cambridge Water supply at Madingley

Key

- → Water to reservoir
- → Treated water into supply

Level 1 objectives

FR-01 Performance
Provide and maintain sufficient water supply

FR-02 Compliance
Comply with applicable legislation and standards

FR-03 Affordability
Maintain customer affordability

FR-04 Safety & Security
Maintain and promote safety, health, wellbeing and security

FR-05 Operational Resilience
Provide a resilient water supply system

FR-06 Carbon and Climate
Deliver a climate resilient and carbon-efficient project

FR-07 Environment
Maintain and enhance the environment

FR-08 Social Value
Create positive social and economic Value

providing assurance of compliance and demonstrating achievement of programme objectives and outcomes.

The interventions are expected to include:

- a non-impounding water supply reservoir
- operational changes to adjacent water systems
- modification of existing infrastructure
- recreational facilities
- creation of environmental habitats
- employment and educational opportunities for local communities.

These interventions will be developed in parallel, with clear traceability showing how each contributes to programme outcomes and objectives within an integrated system.

Economic assessment

The reservoirs programme operates at the interface of natural water sources, existing distribution networks, and a broad range of physical, regulatory, commercial, environmental and social systems. These interconnected systems create multiple interfaces, competing objectives and constraints that must be managed simultaneously.

A key economic challenge is that the benefits of effective RE&M are distributed across the programme, while the effort to define and maintain requirements is incurred early in development. RE&M addresses this information gap by providing a structured process that maintains a clear line of sight between objectives, benefits, requirements and interventions, improving decision-making and maximising programme-wide value.

The principal intervention has been the adoption of RE&M from the earliest stages of programme development. This has established a traceable hierarchy linking corporate objectives, programme benefits, requirements and delivery interventions. Consequently, all programme activities can be directly linked to strategic objectives, improving investment justification, governance and accountability.

Although the programme is still at an early stage and long-term outcomes cannot yet be quantified, several benefits have already been realised:

- Executive objectives were remapped to distinguish statutory requirements, core outcomes and desirable enhancements, improving accountability and reducing the risk of conflicting priorities.
- Formal requirements elicitation established transparent scope and cost baselines, strengthening governance and limiting uncontrolled change.
- Clear requirements and system constraints focused teams on agreed outcomes, enabling earlier escalation of strategic issues and improved risk identification and mitigation.
- SMART requirements created a single source of truth, reducing ambiguity, limiting siloed decision-making and promoting consistent stakeholder understanding.
- The requirements process improved decision quality by helping teams differentiate essential requirements from desirable enhancements.
- Standardised workflows and governance processes established a consistent approach to requirements development, change management and assurance, improving efficiency.
- RE&M provides traceability from regulatory and sponsor objectives to project delivery, supporting assurance that interventions remain aligned with intended outcomes.
- The approach is expected to strengthen confidence among shareholders, regulators and investors by demonstrating continued alignment with agreed strategic objectives.
- Requirements-based acceptance criteria support a common assurance process across stage gates, reducing duplication in verification and validation activities.

Major programmes often struggle when objectives, outcomes, and requirements become disconnected. RE&M provides a scalable, cross-sector framework for maintaining alignment, reducing delivery risk, and improving infrastructure productivity.

Further benefits are expected as the programme progresses. The established hierarchy of objectives, requirements and interventions will underpin validation, verification and delivery assurance, helping maintain alignment throughout development, delivery and operation.

While the programme is not yet mature enough to quantify realised economic outcomes, evidence to date indicates that RE&M has improved governance, transparency, accountability and decision-making. Its principal economic value is expected to arise from reduced delivery risk, avoidance of costly rework and scope changes, better alignment across systems and stakeholders, and increased confidence that strategic outcomes will be delivered efficiently and effectively.

Systemic assessment

Implementing RE&M provides a structured approach to identifying, documenting and managing stakeholder needs, while increasing confidence in achieving successful delivery. Its core purpose is to reduce rework, align teams around clear objectives, manage project risks, and ensure outcomes deliver real value to customers and stakeholders. It does so by:

- Reducing rework and cost, by identifying and resolving unclear or misunderstood requirements early, when changes are significantly less expensive.
- Improving communication through a single source of truth and shared terminology, ensuring alignment between technical teams and non-technical stakeholders.
- Controlling scope creep, by introducing disciplined change management, where proposed changes are assessed for

Systemic assessment

The programme has been assessed against seven 'success factors' and scored on a four level scale:
0 – Not met | 1 – Partly met | 2 – Mostly met | 3 – Fully met.

Success factor	Assessment	Rationale
1. Outcome clarity	**3**	The programme has a clearly defined hierarchy of objectives > outcomes > requirements. Scope boundaries, governance and traceability are explicit and formally managed.
2. Systems capability	**3**	Requirements engineering is itself a systems discipline. The programme explicitly identifies physical, regulatory, commercial, environmental and social systems and their interactions.
3. Leverage focus	**2**	The intervention focuses on requirements management, which is a genuine leverage point influencing later design and delivery outcomes. The programme needs to further identify how specific leverage points will be identified and prioritised.
4. Authorising leadership	**3**	Corporate governance structures are evident and requirements are formally approved and controlled. Leadership has clearly authorised the approach and embedded it into programme governance.
5. Incentive alignment	**2**	The specified infrastructure projects regulations commercial model recognises the need to balance customer value, investor returns and regulatory objectives. Further development required to ensure that incentives can be systematically aligned around whole-system outcomes.
6. Decision quality	**3**	The entire requirements engineering process is designed to improve decision quality through evidence, traceability, governance and change control. The single source of truth is a major strength.
7. Adaptive learning	**2**	Validation, verification and change management mechanisms exist. There is relatively little evidence yet of learning loops operating over time because the programme remains at an early stage.

cost, effort, risk and business value before approval.
- Ensuring compliance and business alignment, by linking requirements to regulatory, legal, investor, and organisational objectives.
- Supporting traceability and testing, by tracking requirements from origin through development and verification, ensuring all essential features are delivered and validated.
- Capturing organisational knowledge in a structured, reusable format that remains available despite changes in personnel or suppliers.

Major programmes often struggle when objectives, outcomes, and requirements become disconnected. RE&M provides a scalable, cross-sector framework for maintaining alignment, reducing delivery risk, and improving infrastructure productivity. Better infrastructure outcomes are achieved through the effective definition, integration, and management of outcomes, requirements and interfaces.

Recommendations

Implement RE&M from the earliest project phases. Early adoption enables project objectives to be clearly defined, tested, and agreed before major investment decisions are made. It establishes a baseline for solution development, reducing the tendency to move prematurely into design and thereby minimising rework. It also avoids the need to retrospectively define objectives when conflicts and trade-offs emerge. It promotes a systematic approach that demonstrates how proposed interventions contribute to desired outcomes – an important factor in securing regulator and investor confidence.

Make RE&M a core project discipline. RM should be maintained throughout the project lifecycle, from concept development through construction and handover. This provides a clear justification for each intervention, defines and controls project scope, supports risk management, and demonstrates delivery against agreed objectives. It also promotes consistency and stakeholder engagement, establishes a robust baseline for change control, reduces rework caused by poorly defined requirements, and creates a lasting assurance record.

Measure outcomes effectively. Projects should include an embedded framework to assess whether actual outcomes achieve the intended benefits and objectives, enabling evidence-based evaluation of success.

Secure leadership engagement. Project promoters, sponsors, and senior executives should remain actively engaged in the RE&M process to ensure strategic alignment, informed decision-making, and sustained organisational commitment throughout delivery.

03



Connecting the Culm

This is one of 15 case studies informing the Infrastructure Systems Review.

System: River Culm catchment.

Systems contribution and value: Reframed flood risk and environmental challenges at whole catchment scale, co-creating a coordinated 25-year intervention portfolio. Potential to reduce flood risk and transport disruption, with wider environmental and social co-benefits.

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Summary

The River Culm is a principal tributary to the River Exe. It has a large catchment that is ecologically degraded. The lower Culm suffers from poor water quality and is prone to flooding.

The Connecting the Culm (CtC) partnership and its catchment-scale programme of interconnected actions uses nature-based solutions (NbS) to improve the resilience of critical transport infrastructure and the communities that rely upon it. The CtC project is based in the South West and is critical for regional connectivity and resilience. It spans local authority boundaries and involves multiple stakeholders who traditionally have not worked together. Since its start in 2019 the project has accrued £3 million in funding.

The South West peninsular, Devon and Cornwall, is especially vulnerable to climate change and faces interlinked issues from agricultural runoff, habitat decline, drought and flooding. The Great Western Railway has been closed by flooding annually since 2008. The M5 motorway is also at increased risk of disruption from flooding. With only one primary rail route in/out, and limited high capacity road connectivity, this has severe economic and social impacts for the region, with the effects of disruption cascading through the national transport network.

Challenges of flooding, water quality and degraded habitats arose "because the river has often been treated by policy-makers, land managers and individual residents as a series of disconnected units with disparate functions".[1] The focus of the case study is therefore on the project's central challenges and enablers: community co-creation, local authority cooperation and whole catchment planning. It demonstrates a fundamental use of systems thinking.

CtC began by applying adaptation pathway principles to identify infrastructure 'tipping points' in the 300km^2 catchment, from which the most effective NbS could be modelled. The co-creation of a 25-year blueprint with stakeholders, land managers and communities followed, setting the ambition and laying the foundations for installing multi-objective, co-designed NbS. This unlocked multiple synergistic interventions to improve wellbeing, cut peak flooding by up to 20%, reduce flood damage by an estimated 11%[2], and save the rail industry at least £96,000 pa in flood disruption costs.

Scope

CtC is a long-term integrated programme of activities within the 300km^2 River Culm catchment. This is the 'system of interest'. CtC's scope encompasses the catchment and all the systems affecting and affected by the Culm.

The area is home to ~30,000 residents and is earmarked for construction of an additional 5,000 homes. It also includes nationally important wildlife habitats that support endangered and protected species. CtC's approach is based around three pillars:

- Co-creation
- Nature-based solutions (NbS)
- Climate adaptation.

It aims to improve the wellbeing of people and nature by addressing flooding, drought, water quality, soil quality, biodiversity and infrastructure resilience as interconnected issues requiring joined-up interventions.

The catchment crosses administrative boundaries and the project is led by the Blackdown Hills National Landscape, in partnership with The Department for Environment, Food and Rural Affairs (Defra), Devon County Council, Mid Devon District Council, Somerset Council, the National Trust, National Highways, Network Rail and the Environment Agency. The project has additionally worked with local communities and over 80 landowners to co-design NbS.[3]

CtC's temporal and geographic scope has produced a 25-year blueprint for management and investment that includes all upstream land and tributaries that drain into the River Culm. This uses scenario forecasting and network mapping to identify intervention areas that would collectively deliver synergistic benefits from NbS and new governance solutions.

Fragmented responsibilities for interdependent issues within the catchment necessitate a systems approach. Interdependencies and systemic effects exist across scales, from local to national, as activity within the catchment affects national infrastructure resilience. Although no single named systems method has been applied, systems thinking principles are embedded implicitly throughout CtC's inclusive participatory workshops and mapping activities, its collaborative governance structures and its joined-up catchment-scale approach to intervention planning.

Challenges of flooding, water quality and degraded habitats arose because the river has often been treated by policy-makers, land managers and individual residents as a series of disconnected units with disparate functions.

1 JBA Consulting (2023) Creating a better future for the River Culm | JBA Consulting. Available at: https://www.jbaconsulting.com/projects/creating-a-better-future-for-the-river-culm/
2 Connecting the Culm (2021) How is the River Culm performing? Available at: https://connectingtheculm.com/how-is-the-river-culm-performing/
3 Green Finance Institute (2018) Investment Readiness Toolkit – Milestone 5: Develop Business Case and Financial Model – Connecting the Culm. Available at: https://hive.greenfinanceinstitute.com/gfihive/toolkit/developing-a-business-case-and-financial-model/connecting-the-culm/

Figure 1. CtC blueprint policy and strategy map



How the Culm valley may look when CtC achieves maturity



Outcomes

Desired system outcomes are:

- a healthy, efficient and effective catchment that provides flood and drought resilience for critical infrastructure and communities
- a range of co-benefits including biodiversity and carbon storage, supporting a resilient local economy.

Residents, community organisations, businesses and statutory authorities co-created a shared vision:

"The River Culm will be celebrated as a lifeline that connects people with each other and with nature. Land across the catchment will be managed to protect and enhance the river, whilst sustaining people's livelihoods. Throughout the seasons and as the climate changes, the River Culm will have space to flow naturally and safely. The water will run clear, wildlife will flourish, and people will easily access and enjoy all of these benefits."[4]

Actual system outcomes at present are different. Human activity has changed the natural landscape, including tree removal and soil compaction, causing rain in the upper catchment to rapidly flow into the river, carving deeper channels, eroding farmland, lowering water quality, damaging aquatic ecosystems and increasing flood risk.

Water quality is further affected by farmland runoff and ageing sewer systems. All 11 water bodies in the Culm catchment are failing under the Water Framework Directive.[5] The Great Western Railway line has flooded more than 14 times since 2008 at the Hele crossing, at the extreme low end of the catchment, disrupting the main rail route serving Devon and Cornwall.

Desired outcomes are enhanced resilience to flood and drought, improved water quality and biodiversity, support for the use of NbS, and the involvement of local residents in decision-making.[6] The blueprint seeks to return the river to 'good' ecological condition, make around 200 properties and businesses more resilience to flooding, restore 3,000ha of degraded habitats[7], generate £2.6 million in carbon benefits[8], and reduce flooding at the Hele crossing by up to 10 hours per flood event.[9] This is achieved by overcoming fragmented management to co-create an integrated long-term plan.

Realisation of actual outcomes will be a long-term process. However, intermediate outcomes include the participation of over 80 landowners in the co-design of NbS intended to slow water flow and improve the quality of soil and water. The CtC project has created 172 leaky woody dams to retain and slow water flow in the upper catchment, and around 2,000m^2 of temporary water storage through landscaping to create scrapes and swales.

Beyond the system boundary, the catchment is influenced by climate change, national policy, agricultural markets, housing requirements, NbS funding mechanisms and regional transport demands.

The project has succeeded in engaging residents, communities and stakeholders across the catchment. In 2025, the Connecting the Culm Community Interest Company (CIC) was formed. The CIC can step in to support the Blueprint in ways that local authorities and statutory bodies cannot, for example by entering long-term private green finance arrangements, raising and holding funds, and leasing or buying land.

While the physical measures separately provide benefits to water retention, soil quality and habitats, the additional contribution of systems thinking allows them to be planned and implemented in a way builds stakeholder support and coordination, and allows their effects to combine at catchment scale.

Systems

The 300km^2 River Culm catchment spans south Somerset, and mid and east Devon. It is approximately 87% agricultural, 9% woodland and 4% built environment. Natural elements of the system include waterways, soils, hedgerow networks, woodlands, wetland habitats and aquatic ecologies. The built environment includes farms, communities, their supporting infrastructure, the M5 motorway and Great Western Railway.

These elements interact across landowner and governance boundaries. For example, upstream land management affects soil quality, water runoff, flood characteristics and the downstream resilience of transport services. The treatment of these as disconnected issues is an underlying cause of the barriers to achieving the desired outcomes.

Beyond the system boundary, the catchment is influenced by climate change, national policy, agricultural markets,

4 Groom, Clare (2022) Connecting the Culm – bringing vision to life. Available at: https://blackdownhills.org.uk/news/connecting-the-culm-bringing-our-vision-to-life/
5 Connecting the Culm (2023) The Water Framework Directive – results for the Culm. Available at: https://connectingtheculm.com/water-framework-directive/
6 Blackdown Hills National Landscape (2018) Connecting the Culm. Available at: https://blackdownhills.org.uk/project/connecting-the-culm/
7 Green Finance Institute (2024) Financing Natural Flood Management. Available at: https://connectingtheculm.com/wp-content/uploads/2024/04/GFI-Financing-NFM-Full-Report-2024-compressed.pdf
8 Connecting the Culm (2022) Green Finance for the River Culm. Available at: https://connectingtheculm.com/green-finance-for-the-river-culm
9 Network Rail (2024) Annual State of Nature Report. Available at: https://www.networkrail.co.uk/wp-content/uploads/2026/01/Annual-State-of-Nature-report-2024.pdf

housing requirements, NbS funding mechanisms and regional transport demands.

Systems approaches are manifest in co-creation with local stakeholders, co-ordination of governance agencies and catchment-scale modelling. They influence systemic understanding through the blueprint for the River Culm and the 'Potential areas for improved resilience (PAIRS)' framework.

The blueprint was developed through participatory workshops and interviews, producing a policy map (Figure 1), coordinating a portfolio of work across the catchment and enhancing integration of public and private sector actors. For example, encouraging housing developers to collaborate in catchment flood risk management supports action beyond legislative requirements for neutral flood risk impact.[10] Such collaboration is required when costs of improvement fall to landowners upstream, and benefits are seen to be accrued by those downstream.

The PAIRS framework combined geomorphology, hydrology, land surveys, expert knowledge and local lived experience to identify NbS intervention points. It forms an information/data layer of the system of interest – the catchment.

Three scenarios (restoring soil to reduce runoff, creating features that intercept runoff and riparian tree and hedge planting) were considered to identify the best programme of intervention to achieve the desired outcomes, rather than deciding on a site-by-site basis.

By combining datasets on soil, land use, runoff, habitats and rivers, modelling identified areas where interventions can deliver greatest impacts. This enabled the mapping of opportunity areas that can deliver multiple significant impacts, allowing for the prioritisation of interventions that deliver resilience alongside environmental benefits. This understanding underpinned access to Environment Agency flood grant in aid (GiA) funding for NbS that delivers further environmental and societal benefits.

Collectively, the systems thinking principles that underpin the blueprint and PAIRS framework unlock value by advancing understanding, facilitating collaboration, addressing root causes and directing potential investment at interventions that deliver multiple and synergistic benefits to the natural and built environment.

Interventions

The PAIRS framework and blueprint are key to the design and implementation of interventions. The process begins by working with key stakeholders, including infrastructure operators, to understand the desired outcomes, such as a 20% reduction in peak flooding. The best combination of NbS can then be identified through modelling of options.

By adopting a holistic catchment-wide perspective, founded on place-based community co-creation, the project was able to design a portfolio of nature-based interventions in a single, coherent, joined-up programme. As part of the longer term two-year blueprint, over 1,000 interventions have been implemented, valued at £1 million.

Examples of specific interventions considered are shown in Table 1. But the added value emerges from their interaction and synergy. It is important to note that these NbS are expandable and scalable, should environmental conditions or desired outcomes change, in ways that traditional 'grey' infrastructure interventions are not.

Interventions are split into two strands:

- Headwater NbS to slow runoff and increase infiltration (for example, woodland planting and soil management)
- Floodplain reconnection for railway resilience (slowing water flow through vegetation and temporary storage)

Assessment of the portfolio of nature-based interventions in the blueprint suggests the cumulative result would see an overall eight hour reduction in the duration of railway flooding incidents at the Hele crossing. This represents a significant improvement in performance and transport resilience.

Economic assessment

There is no direct conventional comparator that would deliver the same outcomes as CtC. However, business as usual would likely mean reactive disruption management and/or separate, asset-specific interventions. Addressing risks while leaving upstream causes and wider downstream benefits out of the economic investment case can be inefficient or even ineffective. For example, carrying out interventions to improve downstream soil quality while ignoring the upstream causes of its degradation could be costly and futile. Failing to value and capture the wider benefits of an intervention in its business case may constrain access to finance. As climate risks increase, the cost of action or inaction are likely to also rise.

The benefit of adopting a holistic, catchment scale approach across local authorities becomes clearer when looking at traditional, discrete interventions implemented to deliver similar outcomes.

Valuing biodiversity gains, habitat improvements and the health benefits of access to nature can be challenging. While flood resilience is only part of CtC's aims, it is nevertheless the area of impact where traditional economic appraisal may facilitate easier comparison to business as usual. In 2020 the government committed £5.2 billion to flood defence between 2021 and 2027 and Network Rail, as an owner of at-risk assets in the Culm catchment, committed £2.8bn between 2024 and 2029 to make the railway more resilient to climate change impacts.[11]

A systems approach supported catchment-wide modelling that links upstream and downstream interventions and outcomes, while the PAIRS framework prioritised a portfolio

10 Connecting the Culm (2025) Forum #7 – Managing water for nature and people. Available at: https://connectingtheculm.com/connecting-the-culm-forum-7/

11 Network Rail (2024) Weather Resilience and Climate Change Adaptation (WRCCA) Summary of Regional plans for 2024-2029. Available at: https://www.networkrail.co.uk/wp-content/uploads/2024/04/CP7-WRCCA-Plans-combined-summary-of-all-regions-April-2024.pdf

Table 1. Examples of considered interventions

Interventions	Impacts
Restoring hydrological function to spring-line and valley mires	Providing a range of ecosystem service benefits including flood attenuation and carbon storage in peat rich soils
Damming streams and drainage channels using natural woody debris to create attenuation ponds and silt traps	Reducing flood peaks and reducing downstream sedimentation
Innovative flood alleviation features on land associated with new, large developments	Showing how multi-use green infrastructure is deliverable, and unlocking significant co-benefits
Coppicing and laying bank-side trees to imitate beaver activity	Improve water oxygen levels and reduce livestock disturbance of the river bed
Reconnecting the river to its floodplain and restoring more natural floodplain function on intensive agricultural land, by re-creating floodplain attenuation features,	Restoring wetland habitat and unlocking other ecosystem service benefits such as carbon sequestration and biodiversity; enhancing access and recreation
Restoring agricultural soils	Enabling them to achieve their natural hydrological function
Restoring historic leat systems and ponds that hold flood-peak waters	Improving flood resilience and generating renewable electricity at their outlets

Table 2. CtC Systemic assessment

CtC has been assessed against seven 'success factors' and scored on a four level scale:
0 – Not met | 1 – Partly met | 2 – Mostly met | 3 – Fully met.

Success factor	Score	Discussion
Outcomes clarity	**3**	Outcomes are co-produced with diverse stakeholders and clearly stated in the blueprint. These are accompanied by medium- and long-term objectives which measure outputs as leading indicators of desired outcomes.
Systems capability	**2**	Definition of boundaries, co-production approaches and shared representations support system capability, with a holistic approach to catchment management fundamental to the project. Specific system approaches and capabilities are implicit.
Leverage focus	**2**	Despite the previous score, the blueprint and PAIRS modelling explicitly address leverage points and trade-offs to identify a portfolio of interventions with synergistic benefits. There is less clarity on the project's approach to paradigms, mindsets, incentive structures and behaviours that drive the observed actions and resulting symptoms.
Authorising leadership	**3**	The project's partnership model facilitates working across local authorities, while co-creation activities are designed to work across system boundaries, organisations and lifecycle stages.
Incentive alignment	**3**	CtC utilises system-level outcome performance measures and approaches that reinforce collaboration across diverse stakeholders. Consideration has been given to incentives and funding arrangements that support these outcomes, such as landowner payments for resilience gain units related to additional water storage and vegetation roughness.
Decision quality	**2**	Through the PAIRS modelling, decisions are made with transparent links to the desired outcomes of the project.
Adaptive learning	**2**	While the project has demonstrated the ability to experiment, learn and adapt, the formalisation of these processes is less clear.

of measures, providing an alternative to fragmented, piecemeal approaches to siloed asset protection and outcome delivery. It engaged and motivated multiple beneficiaries around shared outcomes, identifying a wider scope of potential funding sources and mechanisms, enabled by the formation of the CtCCIC.

A traditional 'grey' infrastructure solution was originally proposed by Network Rail, rebuilding two bridge structures to prevent overflow onto the railway, but this remains unfunded by the Department for Transport, hence Network Rail investigating 'green' solutions with CtC.

In 2022, CtC commissioned JBA Consulting to assess the economic value of a wider programme of NbS in the catchment (ie, a greater number of interventions than currently being implemented). This concluded that the time the rail line is closed to traffic could be reduced by up to 10 hours, delivering an annual benefit of £96k in terms of avoided disruption costs. Disruption from one in 10 year flood events would be reduced from six hours at present to just one hour.

Benefits to property, agricultural performance, biodiversity, water quality and health are yet to be economically assessed.

Starting in 2019, CtC was provided with 60% of its initial £1 million funding under the EU Interreg 2 Seas 'Co-Adapt' programme. The CIC is currently exploring new green finance mechanisms to support delivery of the blueprint, which is projected to cost £36 million over the next 20 years.[12] Around £15 million of this may come from publicly funded agri-environment schemes, with the balance from blended public/private sources. The systems approach has translated individual, disparate costs and investment opportunities into a single programme with synergistic and wider benefits than if they were they pursued separately. It demonstrates the potential to deliver a broader value stack from an integrated portfolio, attracting coordinated investment from diverse beneficiaries.

Systemic assessment

Systemic inefficiencies arise because catchment processes do not align with administrative boundaries.

The current system requires upstream actors to fund interventions for the benefit of downstream stakeholders and communities, including national networks. It disincentivises action by those who are closest to the root of the problem because they bear the cost but receive little reward. This then requires those at risk downstream to protect or improve their assets, which they do in silos. This is to the detriment of the whole system, and the loss of opportunity to generate synergistic co-benefits.

Approaching the Culm's problems at catchment scale, and joining up across organisational boundaries, allowed for better consideration of causes and effects, and the development of more effective interventions. It built relationships, trust and legitimacy, leading to effective co-creation. Shared mapping and a portfolio of interacting intervention and investment opportunities supports conversations about their ability to deliver better value than isolated actions.

Systems capability could be considered a binding constraint due to the lack of explicit reference to systems approaches and tools. However, CtC has utilised systems thinking implicitly and as part of its underpinning mindset.

Tools can facilitate and support a systems approach, but this project demonstrates they are not always necessary. Systems thinking capability should be developed first, before selecting the most appropriate tools.

Additionally, more efficient and effective funding can arise through valuing stacked benefits across temporal and organisational boundaries. Decision making is more efficient and effective if it goes beyond short term, site level neutrality to catchment wide benefit. This requires mechanisms that allow stakeholders to co-invest and take long-term financial decisions and responsibilities.

Recommendations

The Connecting the Culm case study suggests that place-based solutions should start with a clear understanding of the desired outcomes and the root causes of the problem, not just visible symptoms and traditional, pre-determined interventions.

By defining desired outcomes, such as reduced peak flows and increasing infrastructure resilience, and understanding the behaviour of the whole catchment, the PAIRS approach enabled identification of the combination of interventions required to deliver them.

It is necessary to work with stakeholders at the earliest opportunity. Co-creation with landowners, national infrastructure operators, farmers and local communities helped CtC understand key tipping points, what needs to change and what interventions are feasible.

Efficiency should be judged against place based outcomes rather than narrow asset-specific performance. Effectiveness is as important, if not more so. Iterative co-design helps identify and recalibrate opportunities with landowner insights.

Replication is not about implementing specific systems tools, nature-based solutions or funding mechanisms. A systems mindset is the transferable key learning point. The definition of boundaries through critical reflection, the motivation to work across silos, the construction of willing coalitions, an understanding of interdependencies, and shared decision making are all embodied in this mindset.

Strong, systems-oriented leadership is critical. Replication relies on developing these capabilities within institutions.

12 Connecting the Culm (2026) Green Finance. Available at: https://connectingtheculm.com/green-finance/

04



CReDO

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Cross-sector infrastructure resilience.

Systems contribution and value: Shared data and cascade-risk modelling improved visibility of interdependencies and supported early resilience planning. Modelled potential benefits include better-targeted investment, reduced losses and improved continuity of critical services.

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Summary

Climate change is increasing the frequency and severity of extreme weather events, exposing the interdependent nature of UK infrastructure systems, including energy, water and telecommunications. Historically, these systems have been planned and operated in silos, limiting visibility of cascading risks. This has led to reactive interventions, inefficient investment, and avoidable economic and societal costs.

This case study demonstrates how applying systems approaches across interconnected infrastructure can improve resilience outcomes per pound by targeting investment and operations at critical interdependencies between systems. Rather than optimising assets in isolation, systems approaches enable coordinated decision-making that focuses on whole-system performance.

CReDO (Climate Resilience Decision Optimiser) is a cross-sector digital twin and decision-support platform that enables infrastructure operators to understand how risks and failures can propagate across connected systems. By combining cross-sector modelling of interdependencies, secure data sharing, and scenario-based analysis, it enables infrastructure operators to identify system-critical vulnerabilities, prioritise high-impact interventions, and coordinate actions across organisations. Evidence from its application indicates significant potential value by enabling reductions in cascade failures, more effective targeting of investment, and improved service continuity.

The case study also highlights that realising this value depends not only on technical capability, but on changes to governance, incentives and data sharing arrangements. It demonstrates a pathway from innovation to implementation, showing that the primary constraint on infrastructure resilience is not the scale of investment, but how effectively it is targeted across interconnected systems.

Scope

The CReDO Beta project is a live initiative funded through Ofgem's Strategic Innovation Fund and led by UK Power Networks, focused on improving the climate resilience of the UK's critical infrastructure at a system-of-systems level. It builds on the earlier CReDO demonstrator and has evolved into CReDO+, a scalable decision-support capability for cross-sector planning and operational coordination.

The system of interest is national in scale, spanning interconnected electricity, water, telecommunications and gas networks. It includes physical infrastructure assets and their interdependencies, the operational coordination between infrastructure operators, and the supporting data ecosystem (which is treated as a system in its own right) comprising the data, models and governance arrangements used to understand and manage climate risk.

Climate hazards in scope include flooding, extreme heat and high wind events. Broader regulatory reform and full national deployment are outside scope, though relevant to future scaling.

CReDO applies systems approaches through the development of interdependency models, probabilistic risk analysis, and simulation of cascading failures across sectors. It integrates climate projections, infrastructure topology, and interdependencies with economic and service impact data to support coordinated decision-making.

Key stakeholders include infrastructure operators, regulators (including Ofgem, Ofwat and Ofcom), government departments (Environment, Food and Rural Affairs; Energy Security and Net Zero; Science, Innovation and Technology; Cabinet Office), and delivery and research partners.

At the outset, resilience planning was constrained by limited visibility of interdependencies, weak incentives, and siloed investment decisions, necessitating a systems-based approach to improve whole-system outcomes.

Outcomes

The CReDO platform will enable improved infrastructure resilience outcomes in real-world terms, including reliable provision of essential services, coordinated investment ahead of extreme events, protection of vulnerable users, more efficient use of capital, and reduced long-term economic and societal risk. These outcomes align with national priorities for resilience, productivity and climate adaptation.

Baseline (pre-CReDO outcomes)
Under conventional, siloed approaches, infrastructure operators planned and invested independently within sector boundaries, focusing on asset-level risks rather than system-wide performance. Interdependencies were not systematically identified, and cascading failures were poorly understood.

In practice, this led to ineffective targeting of resilience investment, duplication of resources, and prolonged service outages with higher recovery costs.

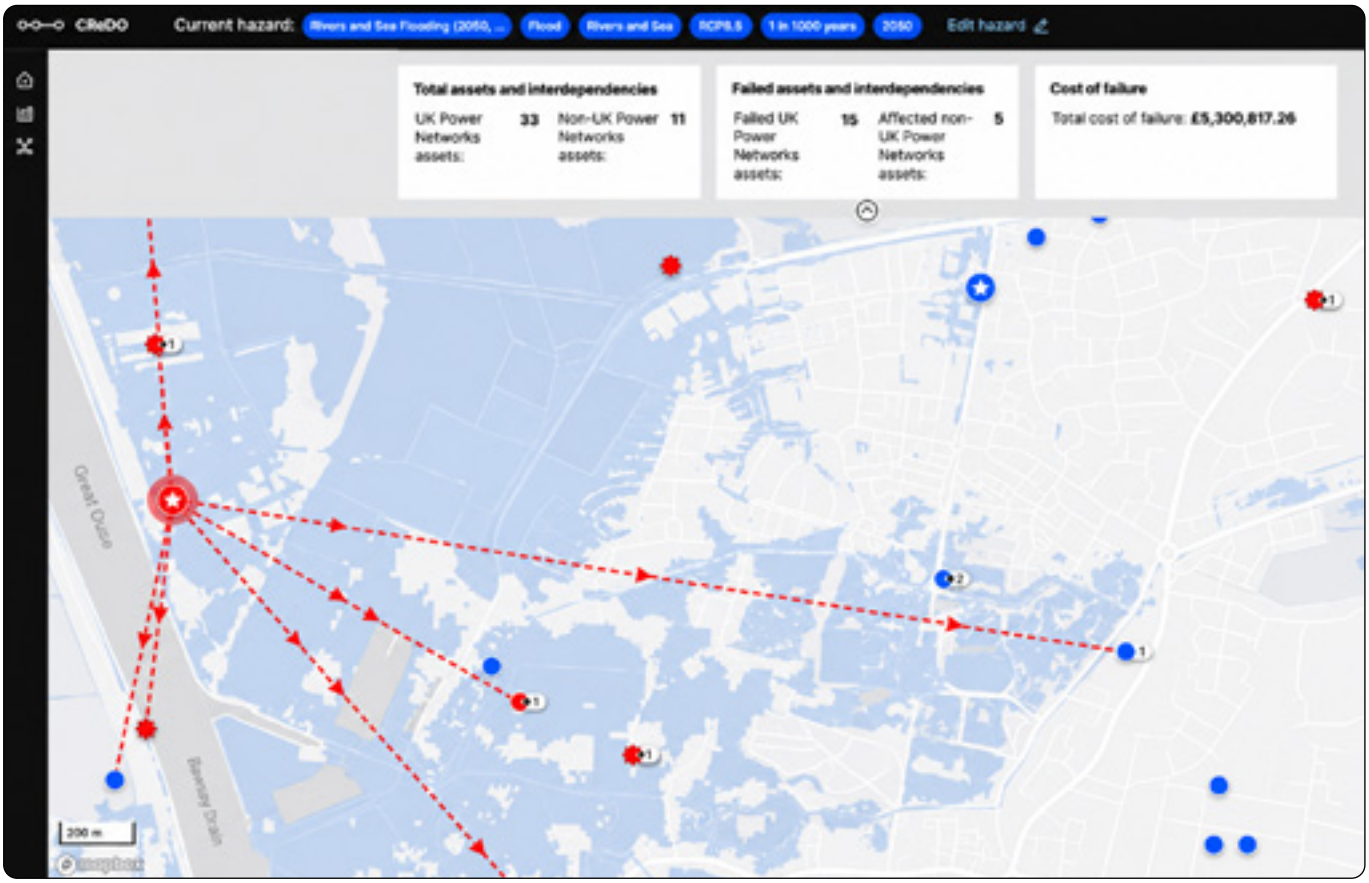
Storm Arwen (2021) illustrates these limitations. The storm left ~1,000,000 homes and businesses without electricity, with ~40,000 still without power after three days and restoration taking up to ten days. Economic impacts were estimated at >£250 million. Power outages also disrupted telecommunications, highlighting how infrastructure resilience depends on understanding cross-sector interdependencies. The event exposed the gap between asset-level resilience and system-level outcomes, where limited visibility of cascading risks hindered effective coordination and prioritisation of interventions.

Outcomes enabled by CReDO
CReDO improves outcomes by enabling a system-level view of infrastructure performance, leading to:

- **Better-targeted investment:** identification of system-critical assets and prioritisation of interventions with the greatest cross-sector impact
- **Reduced cascade failures:** improved understanding of interdependencies and earlier identification of high-risk failure pathways
- **Improved service performance:** reduced customer interruptions/minutes lost; greater continuity of services
- **Enhanced coordination:** shared situational awareness of upstream and downstream risk, and more effective deployment of resources across organisations



CReDO map views. Top: Energy sites (blue circles) and customers and other-sector infrastructure (black diamonds). Bottom: Cascading risk from river and coastal flooding.



CReDO infrastructure interdependencies

Benefit category	Net present value (£ million)
Avoided infrastructure repair and recovery costs	£390
Avoided service disruption impacts on customers and businesses	£622
Environmental benefits	£42
Avoided cascading failures across interconnected infrastructure networks	£3,350
Total benefits	£4,404

Improvements can be achieved as better information and coordination influence planning and operations.

Additional value from systems approaches
Systems approaches deliver additional value beyond conventional interventions by improving how decisions are made, not just what is done. While traditional approaches can strengthen individual assets, they often miss opportunities to address the drivers of system behaviour.

CReDO demonstrates that explicitly analysing interdependencies enables materially better outcomes per pound by targeting high-leverage interventions:

- A coordinated £1.1 million investment in a local flood scenario could avoid £17.2 million in damages, significantly outperforming uncoordinated action[1]
- National-scale analysis indicates potential benefits of around £4.4 billion, largely arising from avoided cross-sector disruption[2]

This additional value arises from improved targeting of investment, shared evidence for decision-making, and coordinated action across organisational boundaries.

Stakeholder outcomes
- **Infrastructure operators:** improved decision-making and reduced outage costs
- **Government and regulators**: stronger evidence base for resilience standards and investment
- **Society:** improved service continuity, particularly for critical and emergency services

Trade-offs and lessons
Early implementation required significant effort to establish trusted data sharing and collaboration frameworks. Benefits accrue across sectors while costs may fall unevenly, highlighting ongoing incentive alignment challenges. Full value depends on embedding systems capability into routine decision-making.

Progress toward realised outcomes
CReDO has progressed from demonstrating capability to influencing planning and early operational decisions through a minimum viable product (MVP) trial within the CReDO+Beta project. While not yet business-as-usual, early applications are already informing asset strategy and investment planning.

Systems

CReDO treats the built environment as a system of systems, recognising that infrastructure performance arises from interactions between physical assets, organisations, digital infrastructure and information flows, rather than individual networks in isolation.

System structure
The system comprises three interconnected layers:

- **Physical systems:** energy, water, telecommunications and gas networks, their assets, and exposure to climate hazards
- **Organisational systems:** infrastructure operators, regulators, emergency responders, and coordination forums
- **Digital systems:** data standards, secure sharing mechanisms and interoperable infrastructure, secure compute environments, models and analytics used to understand and manage risk

The data ecosystem itself is treated as a system, with its own dependencies, governance requirements and failure modes.

System dynamics and root causes
System mapping identified that resilience failures were driven less by individual asset fragility and more by structural factors, including limited visibility of interdependencies, fragmented governance, misaligned incentives, and lack of mechanisms to value cross-sector outcomes. These conditions lead to suboptimal performance despite significant investment.

1 UK Power Networks, Anglian Water, BT Group, Connected Places Catapult and partners. Identifying the Expected Impacts of CReDO. Digital Twin Hub. Available at: Identifying the Expected Impacts of CReDO. https://digitaltwinhub.co.uk/download/identifying-the-expected-impacts-of-credo-report/
2 Energy Networks Association. CReDO Beta (Project 10061361). Smarter Networks Portal. Available at: CReDO Beta Project Page (Accessed: 7 August 2026) https://smarter.energynetworks.org/projects/10061361/

Systems approaches and leverage points
CReDO applies connected, cross-sector models to reveal failure modes and leverage points:

- **information flows:** improving visibility of interdependencies and risks
- **system-critical assets:** prioritising based on cross-sector impact
- **investment sequencing:** coordinating interventions across networks
- **decision-making:** aligning operational, regulatory and strategic choices around shared evidence

In practice, the most challenging leverage points to address have been those related to incentive alignment and authorising leadership, where institutional constraints limit the ability to act on system-level insight.

Unlocking value and improving performance
By improving system understanding, CReDO enables comparison of intervention options at whole-system level, more efficient use of existing infrastructure, and a shift from reactive response to targeted long-term resilience investment. This is already influencing strategic discussions across operators and regulators.

Key insight
Improving infrastructure outcomes depends on understanding and managing interdependencies across systems, with digital infrastructure enabling better decisions about where and how to invest in physical resilience.

Interventions

To engage with the CReDO digital infrastructure, organisations securely share relevant infrastructure and operational data, collaborate on modelling interdependencies and climate risks, and use the resulting insights to inform planning, investment and response decisions.

CReDO provides capability and decision-support interventions to influence how infrastructure systems are planned, prioritised and operated. It is currently at MVP stage, with early user trials demonstrating how improved decision-making can be embedded in practice.

Nature of interventions
- Development of a secure, cross-sector digital platform
- Establishment of structured, outcomes-focused data-sharing arrangements
- Implementation of interdependency-based risk modelling across networks
- Integration of economic and service-based cost–benefit analysis at system level

These interventions are designed to improve decision quality and coordination, enabling more effective use of existing infrastructure and better targeting of future investment.

Inputs
- Securely shared asset and network data
- Climate hazard and environmental datasets
- Economic, service performance and customer impact data
- Expert judgement and historical performance information

Outputs
- System-level risk and vulnerability maps
- Simulations of cascading failures
- Prioritised resilience intervention infrastructure targets
- Quantified evidence to inform planning and investment

Impact on the system
These interventions enable a shift from reactive, organisation-specific response to coordinated risk management, supporting shared situational awareness and more effective deployment of resources.

Difference from conventional approaches
Compared to siloed practices, interventions are informed by system-wide interdependencies, prioritised based on whole-system outcomes, and supported by structured, secure data sharing. Success is measured in terms of avoided disruption and improved service continuity rather than asset-level performance alone.

Economic assessment

This assessment considers the economic case for adopting a systems-based approach to climate resilience planning. It examines how improved visibility of infrastructure interdependencies can address market failures and support more effective resilience investment decisions.

Coordination failure and information gaps
Infrastructure operators typically make decisions on investments within organisational and sector boundaries, with limited visibility of interdependencies across networks. As a result, the costs and risks arising from cascading failures are not fully reflected in investment decisions, while limited data sharing and cross-sector coordination can prevent the most effective resilience interventions from being identified and prioritised. CReDO addresses these information and coordination failures by providing a shared understanding of infrastructure interdependencies and climate-related risks.

Theory of change
CReDO combines infrastructure, climate and economic data to identify interdependencies and potential failure cascades across infrastructure networks. This improves understanding of system-wide risks, enabling organisations to share information, coordinate decision-making and target resilience investment towards the most critical assets and interventions. This leads to more effective resilience planning, reduced service disruption and lower economic costs arising from climate-related infrastructure failures.

Quantified and indicative benefits
Evidence from CReDO pilot applications suggests that a systems-based approach to resilience planning can deliver significant economic benefits by improving how resilience investment is targeted. In a local flood resilience scenario, modelling found that £1.1 million of investment could avoid £17.2 million of damages by accounting for infrastructure interdependencies and cascading failures. At a national scale, modelling estimates total benefits of approximately £4.4 billion, with the largest share arising from avoided cascading failures across interconnected infrastructure networks.

The assessment indicates that CReDO improves the targeting of resilience investment, enabling greater economic benefits to be achieved from a given level of expenditure.

Assumptions and limitations
The assessment is based on cost-benefit analysis comparing a CReDO-enabled, system-level approach to resilience planning with conventional sector-based decision-making. Benefit estimates are derived from modelling of flooding impacts and infrastructure interdependencies in the Kings Lynn area, which were subsequently scaled to estimate potential national impacts. The analysis follows established regulatory appraisal approaches and presents results as net present values over the 63-year appraisal period.

As CReDO is currently at MVP stage, the results should be regarded as indicative rather than predictive. Estimates are sensitive to assumptions regarding infrastructure interdependencies, cascading failure effects and the extent to which organisations adopt system-level decision-making in practice. Cross-sector benefits represent the largest component of total benefits and therefore depend on assumptions regarding infrastructure interdependencies and cascading failure effects

Systemic assessment

CReDO highlights a set of persistent system-level barriers that limit infrastructure performance and increase long-term costs. These barriers are structural and interdependent, meaning progress in one area can unlock benefits across the system.

1. Governance and leadership
Infrastructure systems are governed primarily within sector boundaries, limiting the ability to take decisions at a whole-system level. While technical insight can identify optimal interventions, acting on this insight is constrained by fragmented authority and the challenge of coordinating decisions across organisations. However, CReDO has demonstrated that cross-sector governance is achievable, bringing together infrastructure operators, regulators and delivery partners around shared resilience objectives and common evidence.

2. Incentives and appraisal frameworks
Funding and regulatory frameworks are typically aligned to sector-specific outcomes, with limited mechanisms to recognise or reward cross-sector benefits. As a result, high-value interventions that reduce system-wide risk can be under-prioritised. CReDO has helped quantify these previously hidden benefits, providing evidence that whole-system approaches can deliver significantly greater value than siloed decision-making.

3. Data and decision-making capability
Effective system-level coordination depends on trusted data sharing and the ability to translate system insight into operational and investment decisions. While challenges remain, CReDO has demonstrated that secure cross-sector data sharing, interoperable modelling and collaborative analysis can be achieved in practice.

CReDO therefore demonstrates that the principal barriers are no longer technical, but institutional: embedding these proven capabilities into routine governance, investment and regulatory practice.

Recommendations

The recommendations below are presented in order of priority. Together they describe the actions required to translate proven systems-based capabilities into business-as-usual infrastructure resilience planning and investment. The highest priorities focus on enabling organisations to act on system-level insight; subsequent recommendations support the institutional, technical and regulatory conditions required for scaling.

1. Enable system-level decision-making across boundaries
Mechanisms are required to support decision-making at system level, including enabling coordination across organisations and resolving cross-sector trade-offs.

2. Align incentives with system outcomes
Funding and regulatory frameworks should reward whole-system performance, ensuring investment reflects where value is realised across the system rather than within individual organisations.

3. Embed interdependency analysis in regulation
Resilience investment should be assessed using system-level evidence, including cross-sector impacts and avoided cascade failures, ensuring that high-value interventions are not overlooked within siloed appraisal frameworks.

4. Treat shared data as critical infrastructure
Secure, purpose-driven data-sharing capability should be recognised as essential infrastructure to enable coordinated decision-making across sectors.

5. Align resilience standards around outcomes
Resilience standards should shift from asset-based compliance toward service and outcome-based metrics, aligned across sectors to support coherent planning and investment.

6. Enable scaling of systems-based capability
Create the conditions for proven systems-based approaches and decision-support capabilities to transition into business-as-usual adoption and be applied across sectors and geographies where they deliver value.

Taken together, these actions would enable systems approaches to move from isolated applications to standard practice, improving cross-sector coherence, targeting investment more effectively, and reducing long-term fiscal risk.

Success factors
All 15 Infrastructure Systems Review case studies were assessed against a set of seven success factors. The table, right, provides a high-level assessment of CReDO's development and deployment.

Systemic assessment

CReDO has been assessed against seven 'success factors' and scored on a four level scale:
0 – Not met | 1 – Partly met | 2 – Mostly met | 3 – Fully met.

Success factor	Level	Description
1. Outcome clarity	**3**	Outcomes stated in real-world terms rather than outputs, and key actors describe them consistently. System scope is clear, including what is in and out of scope, and which external effects matter. Trade-offs between outcomes are explicit, with clear priorities, tolerances, and non-negotiables. Legitimacy is established, with outcomes and trade-off rules agreed through an appropriate process with those most affected. Constancy of purpose is maintained over time, with outcomes changing only deliberately and with clear justification.
2. Systems capability	**3**	Systems capability exists across the endeavour, with people, roles, and routines able to apply systems approaches in practice. System boundaries are actively worked with, including identifying and managing interfaces, dependencies, and external impacts. Shared representations of the system exist, such as maps, models, or causal narratives, and are used by different parties to reason together. Information and sensing are sufficient to maintain shared representations over time, including access to data, feedback and monitoring.
3. Leverage focus	**3**	Interventions are chosen to change underlying system behaviour. Feedback and delays that shape system behaviour are explicitly identified and influence the choice and timing of interventions. Structural drivers such as incentives, information flows, rules and constraints are considered alongside (or instead of) asset-based or capacity-led solutions. Unintended effects and lock-in are considered, including how interventions may reinforce path dependence or create new problems.
4. Authorising leadership	**2**	Authority is clear, with defined decision rights and escalation routes that enable cross-boundary decisions to be made and upheld. Governance facilitates working across system boundaries and supports system-level choices; trade-offs are resolved. Boundary-spanning leadership actively co-ordinates organisations, disciplines and lifecycle stages so that they can act on the system as a whole. Complexity and variety are managed across levels; decisions are taken at appropriate scales. Risks are realistically assessed and managed; resilience is built into the plans and the system.
5. Incentive alignment	**2**	Contracts and funding arrangements encourage behaviour that supports whole-system outcomes. Performance measures reward contribution to system outcomes and interface performance. Accountabilities and risk ownership sit with those able to influence outcomes, so problems are surfaced early. Behavioural and reputational incentives reinforce collaboration and early problem-solving.
6. Decision quality	**3**	Decision processes use clear criteria linked to outcomes, with assumptions, evidence, and trade-offs made explicit. Bias and undue influence are actively mitigated through challenge, independent scrutiny, and consideration of relevant external evidence. Decision roles and escalation are clear, so decisions are taken at the right level and are not avoided, deferred, or endlessly recycled. Timeliness is appropriate to the situation, with decisions taken early enough for systems insight to prevent avoidable cost, delay or lock-in.
7. Adaptive learning	**2**	Learning mechanisms are in place to test assumptions and monitor how the system is actually performing, including the use of evidence and leading indicators. Adaptation occurs in response to learning, with plans, interventions, or decisions changing when evidence shows they should. Experimentation is used where uncertainty is high, including safe-to-fail approaches that allow rapid learning without disproportionate risk. Learning culture supports early issue-raising and honest reflection; bad news travels quickly; experience is not lost across boundaries or phases.

05



Crossrail integration

This is one of 15 case studies informing the Infrastructure Systems Review.

System: The transition from delivery to operation of a new metropolitan railway.

Systems contribution and value: A client-led programme 'reset' was initiated to overcome integration challenges, employing best-for-programme triage and commercial innovations. It supported programme recovery and strengthened operational readiness.

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Summary

Crossrail, now the Elizabeth line, converted a clear socio-economic objective into a rail programme combining civil engineering, tunnelling, digital systems, rolling stock, operations and supply-chain development.

The objective was to increase London rail capacity by about 10% and bring 1.5 million more people within 45 minutes of central London. The delivery solution joined existing Great Western and Great Eastern corridors through a new high-capacity central tunnel, requiring new trains, new stations, control systems and integration of legacy and modern signalling environments.

Crossrail drew on London tunnelling capability developed through earlier projects, notably the Jubilee Line Extension, and expanded capability for later schemes including the Northern Line Extension and Thames Tideway Tunnel. Civil construction and tunnelling formed a repeatable systems capability, supported by specialist training, deep-tunnel methods, skilled employment and a supply chain able to work across multiple packages.

The railway systems integration challenge was recognised from early stages.

Crossrail invested in systems engineering and off-site integration facilities. However, the programme underestimated the time required to integrate, test, assure and operate a software-intensive railway at full scale. Dynamic testing began in March 2018 while build activity continued. Close-headway testing was not safely assured until June 2019. Opening followed software correction, proving, operational readiness and trial running in May 2022.

Work to assess project benefits, carried out by TfL post-opening, indicates that the demand and regeneration case remains strong and relevant despite delivery overruns.[1] The central lessons concern preparation for and management of integration, assessment of complexity, and governance of integration risk.

Scope

The scope of this case study encompasses the large and complex range of assets and disciplines involved in creating, integrating and commissioning a major railway. The Elizabeth line connects Reading and Heathrow in the west through central London to Shenfield and Abbey Wood in the east and south-east.

The project aimed to provide a step change in rail capacity without creating a wholly segregated railway. The programme reused Network Rail corridors on the Great Western Main Line and Great Eastern Main Line while building a new high-frequency tunnelled section through London. Reuse of existing corridors avoided wider replacement of operating railways and created interfaces between infrastructure, trains, signalling, stations and operations.

The civil works show Crossrail as part of a wider infrastructure capability system. Jubilee Line Extension tunnelling experience supported delivery, while Crossrail added capability through sustained employment, the Tunnelling and Underground Construction Academy, training and supply-chain mobilisation.

The integration phase required different capability. The train fleet needed conventional operation on outer routes and automatic operation in the central section. The delivery organisation therefore needed to move from a civil engineering centre of gravity toward systems integration and software assurance. That transition occurred later than programme conditions required.

Outcomes

Crossrail was planned to open central-section passenger services in December 2018, within a funding envelope of about £14.8 billion. Passenger services opened in May 2022, around three and a half years later than planned, with approximately £4 billion of additional cost. In broad terms this represented a delay of around 35% on the planned delivery period and a cost increase of around 27% against the 2010 baseline.

The delay developed in a programme that had recognised integration complexity. Crossrail had systems engineering, progressive assurance and the Crossrail Integration Facility. The gap lay in the planned duration and sequencing of integration, testing and assurance. Build completion, dynamic testing, software correction and operational readiness overlapped more than planned. Programme reporting continued to carry an on-time, on-budget recovery narrative while testing evidence showed the railway required more integration cycles before passenger service.

The National Audit Office identified related issues in 2019, including compressed schedule, contractual model, loss of downward pressure on costs and absence of a realistic plan. The 2021 NAO progress update found that the revised 2019 schedule and budget had been unachievable because the programme was further from completion and more complicated than Crossrail Ltd and sponsors understood.[2,3]

The construction phase created capability benefits. Tunnelling and underground station works required management of excavations, settlement, existing infrastructure, ground risk, logistics and specialist labour. That capability drew from earlier London programmes and flowed into later projects.

The recovery programme from 2019 demonstrated adaptive systems thinking. Crossrail strengthened client-side systems integration, created the plateau, and brought client, suppliers, operator and maintainer into a joint defect triage and decision process. Commercial amendments supported a one-team approach focused on rail service readiness. This resulted in a significant acceleration of progress. It would clearly have been better if these measures had been in place from the start.

1 Transport for London: Elizabeth line – benefits framework https://tfl.gov.uk/cdn/static/cms/documents/tfl-elizabeth-line-benefits-framework.pdf
2 National Audit Office, Completing Crossrail, 3 May 2019.
3 National Audit Office, Crossrail - a progress update, 9 July 2021.



Route and service facts

41
stations — 10 new • 118km • 19 boroughs

21km
of twin-bore tunnels under central London

70
purpose-built trains • 1,500 passengers per train

24tph
Paddington to Whitechapel

Signalling and train control architecture



TPWS

Supports conventional lineside signals, automatically applying the brakes if a train passes a protected red signal or approaches certain hazards too quickly.



ETCS

Used on the Heathrow route, ETCS displays permitted speed and movement limits in the cab, continuously supervising speed



CBTC

Used in the central section, CBTC maintains safe train separation and supports automatic acceleration, braking and precise station stopping, enabling frequent services.

The recovery programme from 2019 demonstrated adaptive systems thinking. Crossrail strengthened client-side systems integration, created the 'plateau', and brought client, suppliers, operator and maintainer into a joint defect triage and decision process.

Integrating complexity: collaborative 'plateau'



Leadership · Collaboration · Trust
Best practice · Agile · Focused

Technical and programme integration

Defect triage · Software correction · Operational priorities
Shared decisions focused on the whole railway

Membership

Crossrail project team

Signalling
Rolling stock
Testing and commissioning
Assurance

Operators

Transport for London
MTR
Network Rail
Heathrow

Major suppliers

Alstom
Siemens

Systems

The signalling and train control architecture illustrates the systems-economic trade-off. Crossrail had to connect existing railway corridors in the west and east with a new high-frequency central section.

- The Great Western route included legacy train protection arrangements and the Heathrow branch required ETCS (European Train Control System, a digital signalling system).
- The central section required metro-style performance, platform screen door integration and automatic operating functions unavailable from mainline ETCS products at that stage. It instead employed a CBTC (Communication-Based Train Control) system.
- The Great Eastern route continued to use TPWS (the Train Protection and Warning System common across the UK rail network) and was expected to remain outside ETCS for many years.

The resulting architecture required Elizabeth line trains to support three signalling environments: TPWS on the eastern legacy network, ETCS on the western and Heathrow side, and CBTC in the central operating section. These systems had to transition automatically and reliably so drivers could operate an end-to-end railway without interruption. Speed, control and protection information had to appear through an integrated driver-machine interface, with trainborne and trackside electronics enabling the correct system at the correct location.

It was judged that integrating different systems into a common train and operating model offered a preferable route to either the wholesale resignalling of the outer networks, or reduction of the central-section performance specification. The programme understood the system interfaces. The underestimated element was the time needed to test, prove and assure the integrated railway once train, trackside, station, control centre and operating processes came together.

Interventions

From 2019 onwards Crossrail moved from a construction completion model toward a whole-system recovery model. The client called on senior management from major contractors to participate directly in bringing the railway into operation. Bombardier proposed the plateau approach, based on techniques used in aerospace to bring suppliers together around final system proving.

Crossrail asked engineering consultant WSP to mobilise an augmented systems integration team of more than 20 people. WSP helped establish and lead the plateau, with representatives from Crossrail, Siemens, Bombardier, MTR, Network Rail and Rail for London. The purpose was to create a structured environment for defect triage, software correction, operational prioritisation and best-for-programme decisions.

The plateau addressed a common management challenge in complex software systems: the first supplier allocated an issue may not be the owner of the root cause. Faults were investigated, reallocated and resolved through a shared whole-system process. The shared process reduced friction where suppliers might otherwise optimise for completion of

Programme milestones

2015
CONSTRUCTION
Last tunnel boring machines buried at Farringdon

Jun 2017
ROLLING STOCK
Class 345 trains in Great Eastern service

Jun 2017
SYSTEMS
Central Operating Section track complete (except Whitechapel – East)

Oct 2017
SYSTEMS
Supervisory control and data acquisition live at the Route Control Centre

Nov 2017
SYSTEMS
First Class 345 train hauled by locomotive into the Central Operating Section

Dec 2017
SYSTEMS
Westbourne Park connection commissioned

Feb 2018
SYSTEMS
Traction power commissioned in Zones 1 and 2

Mar 2018
DYNAMIC TESTING
Daytime dynamic testing begins

May 2018
SYSTEMS
Traction power commissioned in Zones 3 and 4

2018
SYSTEMS
High-voltage non-traction power commissioning

Jan 2019
DYNAMIC TESTING
Plateau formation

Jun 2019
DYNAMIC TESTING
Multi-train close-headway testing begins

Dec 2020
DYNAMIC TESTING
Bond Street — Station Completion 1

Mar 2021
TRIAL RUNNING
Start of trial running, ramping up from 4 to 12 trains per hour

Nov 2021
TRIAL OPERATIONS
12 trains per hour, maximum 20 people per train

Jan 2022
TRIAL OPERATIONS
Volunteer trials involving 2,000 people

May 2022
PASSENGER SERVICE
Passenger service, central section

Nov 2022
PASSENGER SERVICE
Through running

May 2023
PASSENGER SERVICE
Full service

individual scope rather than safe and economic operation of the integrated railway.

The integrated team structure created a route for decisions previously slowed by contract boundaries, supplier interfaces and separate assurance processes. Client, supplier, operator and maintainer representatives could review defects against railway-level consequences, agree priorities, align software release and test plans and manage operating restrictions.

The plateau approach initially addressed the railway systems integration issues, but the same technique was applied for Crossrail's stations, to address integration of the complex digital systems supporting the station infrastructure and station control rooms.

Economic assessment

The economic assessment should distinguish between the rationality of the original architecture and the cost of proving the architecture late in delivery.

Crossrail accepted integration complexity because the business case depended on reuse of east and west rail corridors, a high-capacity central tunnel and a through-running service. A fully standardised solution would probably have required wholesale resignalling of the outer networks or a lower-performance central section. Both choices would have changed the economics and potentially reduced the benefits case.

The adopted architecture avoided large interventions across the wider rail network and transferred complexity into trainborne systems, signalling transitions, software interfaces, control centre integration, testing and proving.

Risks were recognised, but the programme underestimated the resources and time required for integration. The magnitude of the risk may have been revealed if an attempt had been made to quantify and contrast the complexity of the two approaches, rather than the prima facie costs.

By 2018, dynamic testing had begun while construction and fit-out activity continued. Remaining work required repeated cycles of software updates, test evidence, assurance review, operational rehearsal and defect closure.

The economic impact was material. Against the 2010 funding envelope of about £14.8 billion, the programme required around £4 billion of additional expenditure and opened about 41 months late.

Cost growth and schedule delay do not automatically demonstrate poor value for money. TfL benefits reporting indicates strong early demand, housing and employment signals, supporting the view that the completed railway continues to deliver benefits despite additional expenditure from delay.[4]

The NAO findings support a further policy lesson. Systems integration uncertainty should be treated as a distinct programme risk. Future business cases should include ring-fenced cost and schedule allowances for integration, testing, assurance and operational readiness. Consumption of these allowances should be monitored separately from construction contingency and reported through programme governance.

Separate visibility of integration contingency consumption would have given earlier warning of variance between planned and actual integration progress. Earlier warning would have supported earlier resource mobilisation, more realistic forecasting and timely sponsor decisions. The point is governance of uncertainty as much as size of contingency.

The practical Green Book implication is that ring-fenced systems integration allowance should be a managed control. Programme boards should see planned burn-down of integration contingency against evidence from defect closure, trial operations, software maturity, safety assurance and operator readiness. Variance against that burn-down would identify cost and programme pressure earlier than aggregate reporting. That visibility would support earlier choices on scope, resources, opening strategy and sponsor funding, while protecting value for money by preventing construction progress from masking operational readiness risk.

The assessment should also recognise capability benefits. Crossrail expenditure sustained tunnelling expertise, training capacity, specialist labour and supply-chain capability used by later schemes. Conventional appraisal can miss this portfolio value because benefits accrue across programmes rather than solely to the project being assessed. Meanwhile, the one-team approach reduced transaction costs within the recovery programme by moving defect ownership, software release planning and operational workarounds into joint resolution.

Systemic assessment

Crossrail demonstrates two forms of systems capability. The civil engineering programme drew on accumulated London tunnelling knowledge and developed it further. Deep excavation, logistics, ground movement, adjacent assets, utilities interfaces and work under a dense city were managed through a tunnelling ecosystem with training, apprenticeships and labour mobility across packages.

The railway systems phase required a different operating model. Crossrail had invested in the Crossrail Integration Facility (CIF) in 2015, creating an off-site testing and simulation environment that acted as a virtual railway. The CIF allowed engineers to integrate software and data from multiple suppliers before physical implementation and later supported operator training, control room familiarisation and degraded-mode rehearsal.

Conventional appraisal can miss portfolio value because benefits accrue across programmes.

4 Elizabeth Line post-opening evaluation, TfL https://content.tfl.gov.uk/elizabeth-line-post-opening-evaluation-full-report.pdf

Crossrail should have been seen as a system integration programme, with civil engineering as a means to an end, not an end in itself.

Programme challenge emerged because the organisation remained weighted toward construction delivery as the dominant risk shifted toward integration, operational readiness and assurance. The on-time, on-budget mantra supported recovery effort and milestone discipline, but also reduced visibility of the scale of remaining integration work until late in the programme. The later reset recognised the changed nature of the task.

The Crossrail CEO for the final phase of the project has argued[5] that Crossrail should have been seen as a "system integration programme, with civil engineering as a means to an end, not an end in itself". If supported by sufficient bandwidth to consider systems integration issues in parallel with the real and pressing civil engineering issues, this could have resulted in both a more accurate assessment of and mitigation of the integration issues to come. Such a shift of mindset may be regarded as applying systems thinking to the programme as well as to the delivered system.

The plateau, enhanced systems integration function, CIF, operator involvement and revised commercial arrangements created a new delivery system. The programme moved from managing assets and contracts toward managing the performance of an integrated operational railway. The one-team model enabled defects to be triaged by railway impact, allocated across supplier boundaries and resolved through shared operational priorities.

The chronology of London infrastructure delivery also matters. The Jubilee Line Extension created experience in deep mined and bored tunnelling, station construction, settlement control and delivery beside operational assets. Crossrail converted this experience into a larger industrial programme, including the Tunnelling and Underground Construction Academy at Ilford, apprenticeships, common methods and repeatable safety practices. Later programmes, including the Northern Line Extension and Thames Tideway Tunnel, benefited from the workforce, methods and institutional memory created.

The project therefore demonstrates a systems principle with direct economic consequences: building components, proving an operational railway and sustaining an industrial capability are different system tasks. Each requires governance, skills, resources, risk allowances and incentives.

Recommendations

Crossrail provides a balanced lesson for future programmes. The tunnelling and civil works phase shows the value of sustained infrastructure capability across a portfolio of projects. TfL benefits reporting also indicates that post-opening outcomes can remain strong despite delivery overruns. The railway systems phase shows the need to plan the transition from construction to integration before late-stage testing exposes the duration of system proving.

Major programmes should include an explicit assessment of the complexity of the options being considered at option selection. The costs associated with this complexity including testing, assurance, transition, operational readiness and residual restrictions should be estimated, looking at other sectors for comparable experience. These costs should be taken into account when selecting options.

Where integration is selected over standardisation, the business case should state why this is economically preferable to a simpler architecture, what risks transfer into later stages, and how they will be funded and governed.

Business cases for programmes with significant systems integration requirements should include ring-fenced cost and schedule allowances for integration, testing, assurance and operational readiness. These allowances should be reported separately from construction contingency and protected for that specific purpose.

Appraisal should include what-if scenarios for slower defect closure, additional test cycles, delayed software maturity, extended operational readiness and delayed assurance. Scenario outputs should inform risk allowance, governance triggers and sponsor reporting.

The process of integrating the system should run throughout the lifecycle of the project and all parties to the project should understand that their work must contribute to successful integration. Client governance should include a planned transition from civil engineering delivery methods to those appropriate for systems integration and operational readiness, with skills, reporting, incentives and decision rights adjusted before dynamic testing becomes the controlling activity.

The client must retain prime systems integrator accountability because only the client can take some of the decisions that will be required when getting the parts of the system to work together. To do this, the client needs to hold the risk contingency and have a properly resourced systems integration team.

Contractors should have whole-system incentives during final integration and bug fixing, so defects are triaged on a best-for-programme basis. Minimum viable product thinking should distinguish functionality required for safe benefit realisation from functionality that can follow opening without undermining reliability or safety.

5 Wild, M. (2023). "Project leadership: Getting Crossrail back on track." Crossrail Project 2019-2023: Completing the Elizabeth Line.

06



Electricity Transmission Partnership

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Transmission delivery ecosystem.

Systems contribution and value: Employed long-term portfolio partnering, performance-linked future work and multi-level governance, with the aim of reducing delivery fragmentation and bottleneck risk, and supporting investment in delivery capacity, capability and resilience.

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Summary

The Electricity Transmission Partnership (ETP) is National Grid Electricity Transmission's £8 billion delivery model for accelerating substation infrastructure across England and Wales. It is expected to support around 130 substation projects and forms part of the wider RIIO-T3 investment programme to modernise the electricity transmission network and support the clean energy transition.

This case study considers a nested system. The wider system is the transmission network, because its performance affects clean power, energy security, economic growth, resilience, connection access and long-term consumer value. Within that, the ETP is a system intervention: it changes the commercial, organisational and behavioural arrangements through which National Grid expands substation infrastructure.

The case study examines how changing the delivery ecosystem can improve the transmission system's ability to deliver wider public outcomes.

The ETP moves away from shorter-term, project-by-project procurement towards long-term regional and national partnerships, performance-linked access to future work, co-creation, systems-based governance and partner growth and investment planning. Its value lies in strengthening delivery capacity, delivery-partner and supply-chain confidence, workforce planning, regional capability, portfolio learning and integration with adjacent delivery routes.

The case study shows that better outcomes per pound may come not only from better asset design, but from changing the delivery system that enables the physical network to be built at the scale and pace required.

Scope

The case study focuses on the ETP as a delivery-system intervention within the wider electricity transmission system. The scope draws four boundaris:

- Geographic – England and Wales, where National Grid Electricity Transmission owns and maintains the transmission network.
- Technical – primarily substation infrastructure, recognising that substations are critical nodes connected to overhead lines, underground cables, generation, storage, demand growth and distribution networks.
- Delivery – National Grid, regional delivery partners, national partners, the wider supply chain, workforce capability, long-lead items, commissioning capacity, governance and behavioural expectations. 'Connection customers' means generation, storage and demand projects seeking access to the transmission system. 'Delivery partners' and 'supply chain' mean organisations involved in designing, building, commissioning and supporting ETP substation infrastructure.
- Wider organisational – including Ofgem, NESO, government, local authorities, connection customers, communities and consumers. Adjacent delivery vehicles and asset routes matter where they interact with the ETP's behaviours, governance and resource requirements, especially where they compete for limited skilled labour, long-lead items and specialist capability.

The case study shows that better outcomes per pound may come not only from better asset design, but from changing the delivery system that enables the physical network to be built at the scale and pace required.

The case study proceeds from the current policy and regulatory context in which additional transmission capacity is required to support clean power, electrification, energy security, resilience and growth. It does not test the legitimacy of that national direction, nor compare the ETP in detail with alternatives such as distributed local generation or a wholly National Grid-owned delivery model.

It assumes public benefit where transmission investment enables lower avoidable constraint costs, faster connection of clean generation and demand, reliable system access, regional economic activity and long-term consumer value.

Outcomes

The desired outcome is a transmission network that can support clean power, net zero, energy security, economic growth, electrification, resilience and long-term value for consumers.

For National Grid and the wider energy system, this means greater transfer capacity, maintained reliability, faster and more reliable connections, and improved connection capacity and access for clean generation, storage and major demand.

For consumers and society, it means lower avoidable constraint costs, more resilient energy infrastructure, support for economic growth and a stronger platform for decarbonisation.

The gap in the current system is not only a physical capacity gap. It is also a delivery capacity gap. Connection customers (including generation, storage and major demand projects, such as data centres) want and expect timely access to the grid. Communities experience uncertainty about the design, timing, delivery and impacts of future infrastructure. Delivery partners and the wider supply chain face fragmented pipelines that make it harder to invest in people, plant, equipment and specialist capability. Workers experience unstable or highly mobile employment patterns, including long-distance travel and time away from home. The wider environment is affected when clean generation cannot be connected or must be constrained because the network has insufficient capacity.



The challenge is to deliver £8 billion of new substations against a backdrop of supply chain constraints, and achieve strongly positive economic, social and environmental outcomes while doing it.

The ETP is intended to improve outcomes by creating a more capable delivery ecosystem for substation infrastructure. The direct output is delivery of a portfolio of substation projects. The additional systems value comes from how that portfolio is organised: long-term regional and national partnerships, sustained portfolio visibility, performance-linked access to future work, co-creation, behavioural governance and growth, and investment planning.

The ETP is expected to improve outcomes at several levels.

At the transmission-service level, it strengthens the delivery route for infrastructure that enables capacity, reliability, system access and future connection capability.

At the public-outcome level, it supports clean power, net zero, energy security, economic growth, resilience and long-term consumer value by helping the network keep pace with changing generation and demand.

At the delivery-system level, it seeks to reduce fragmentation, repeated mobilisation, inefficient sequencing and reactive procurement of scarce capability.

The model is also intended to improve integration between National Grid, regional partners, national partners, the wider supply chain and adjacent delivery routes.

These changes matter because the value of the ETP is not only the delivery of individual substation projects. Its wider value is the creation of a more predictable and capable delivery ecosystem for the transmission programme. Greater certainty over future workload will lead to stronger supply chain confidence, better regional capability, clearer accountabilities, better portfolio learning and improved conditions for investment in skills, equipment and capacity.

The ETP is still new, so final outturn evidence on cost, schedule, productivity, quality, safety, carbon, wellbeing and service performance is not yet available. The authors' case therefore makes a forward-looking but bounded claim: the ETP is a systems-oriented enabling mechanism for efficiently and effectively delivering the substation element of the wider RIIO-T3 investment programme, not yet a fully proven source of quantified benefits.

Systems

Electricity transmission should be understood as a system of systems.

The physical system includes substations, circuits, transformers, overhead lines, underground cables, generation, storage and demand connections.

The intended outputs are a more organised, scalable and resilient delivery system: faster mobilisation, reduced procurement fragmentation, stronger delivery-partner and supply-chain confidence, improved regional coordination, better portfolio learning and clearer performance accountability.

The delivery system includes National Grid, regional delivery partners, national partners, the wider supply chain, workforce capability, long-lead items, construction sequencing and commissioning expertise.

The governance and economic system includes the RIIO-T3 regulatory framework, Ofgem's role as economic regulator, NESO's role in whole-system planning and operation, commercial models, procurement rules, performance measures, consumer bills and delivery-partner investment decisions.

The information system includes network planning, project sequencing, supply chain visibility, performance reporting, behavioural insight and regional business planning.

The logic that has made this work begins with the outcomes the transmission system is expected to support, then works backwards to identify the conditions needed to deliver those outcomes. This distinguishes between the physical electricity system, the delivery ecosystem, the commercial and governance system, and the outcome system experienced by connection customers, consumers, communities, workers and the wider economy.

This perspective identifies delivery capacity as a binding system constraint. Network expansion depends not only on asset design, planning consent or regulatory funding approval, but on whether the delivery ecosystem has the confidence, capability, incentives and coordination required to build complex infrastructure at pace. The ETP is not operating in isolation: adjacent electricity delivery routes and other sectors draw on many of the same specialist skills, long-lead items, commissioning resources and delivery partners. The mobilisation of the ETP has occurred alongside wider industry reforms, demonstrating the importance of delivery models that can adapt to external change while maintaining delivery momentum.

The identification of procurement and commercial strategy as a leverage point was not retrospective. National Grid created a dedicated task force, later formalised as a procurement strategy team, to examine how the delivery model needed to change. The task force considered the problem through a systems lens: not simply how to procure substation works, but how to create the capacity, confidence, behaviours and investment conditions needed across a constrained delivery market. Its separation from normal office arrangements was a practical and symbolic choice, creating space to step outside business-as-usual processes.

The same systems logic shaped governance and assurance. Regional ETP boards act as coaching forums for projects, helping them surface risks, improve decisions and resolve issues earlier. The national ETP board acts as a coaching supervisor to those regional boards, while also identifying matters to address once across the portfolio. This creates a route for system-wide learning, such as standardising lower-carbon and more efficient solutions, or designing out safety concerns across all relevant projects.

Interventions

The core intervention was the creation of the ETP as a new delivery model for substation infrastructure. It is a combined commercial, organisational, governance, capability and behavioural intervention whose purpose is to strengthen the system's ability to deliver infrastructure at scale and pace.

National Grid appointed regional delivery partners to support substation delivery across defined areas, with national partners providing additional capacity and resilience. The partners were already part of a National Grid framework, with the change made contractually through a deed of variation. The model is being operationalised through long-term partnering, co-creation, systems-based governance, behavioural change, and growth and investment plans. It draws on Project 13 principles, which promote enterprise-based delivery: long-term, integrated relationships focused on whole-life outcomes rather than transactional, project-by-project contracting.

The ETP also changes governance and assurance. Regional ETP boards support projects through a coaching role. The national ETP board supports the regional boards and addresses issues that cut across the whole portfolio, allowing common risks, opportunities and design choices to be dealt with once and then applied repeatedly. This acts as a learning system, allowing system-wide improvement.

The intended outputs are a more organised, scalable and resilient delivery system: faster mobilisation, reduced procurement fragmentation, stronger delivery-partner and supply-chain confidence, improved regional coordination, better portfolio learning and clearer performance accountability.

The intervention differs from conventional practice because it treats the portfolio as a connected delivery system requiring long-term capacity, aligned incentives, shared behaviours, active learning and portfolio-level assurance. Realising the full benefits of the model will require enterprise behaviours to be consistently embedded throughout participating organisations. While strategic alignment has been quickly established at leadership level, long-term success depends on translating those principles into day-to-day decision-making, behaviours and relationships – an area that continues to be developed as the model matures.



Network expansion depends not only on asset design, planning consent or regulatory funding approval, but on whether the delivery ecosystem has the confidence, capability, incentives and coordination required to build complex infrastructure at pace.

The ETP delivery system

Working backwards from outcomes to the conditions needed to deliver them

Wider public outcomes

Clean power and net zero | Energy security | Growth | Resilience | Long-term consumer value

Enabled by

Electricity transmission system performance

Capacity and reliability | Faster connection access for generation, storage and demand
Reduced avoidable constraint costs

Depends on

Substation infrastructure delivered at scale and pace

£8bn delivery model; around 130 expected projects | Long-lead items | Skilled workforce
Construction sequencing | Commissioning | England and Wales | Part of RIIO-T3

Shaped by

ETP delivery-system intervention

Long-term regional delivery partners and national partners | Growth and investment plans
"Yours to lose" model: performance-linked future work | Co-creation

Changes

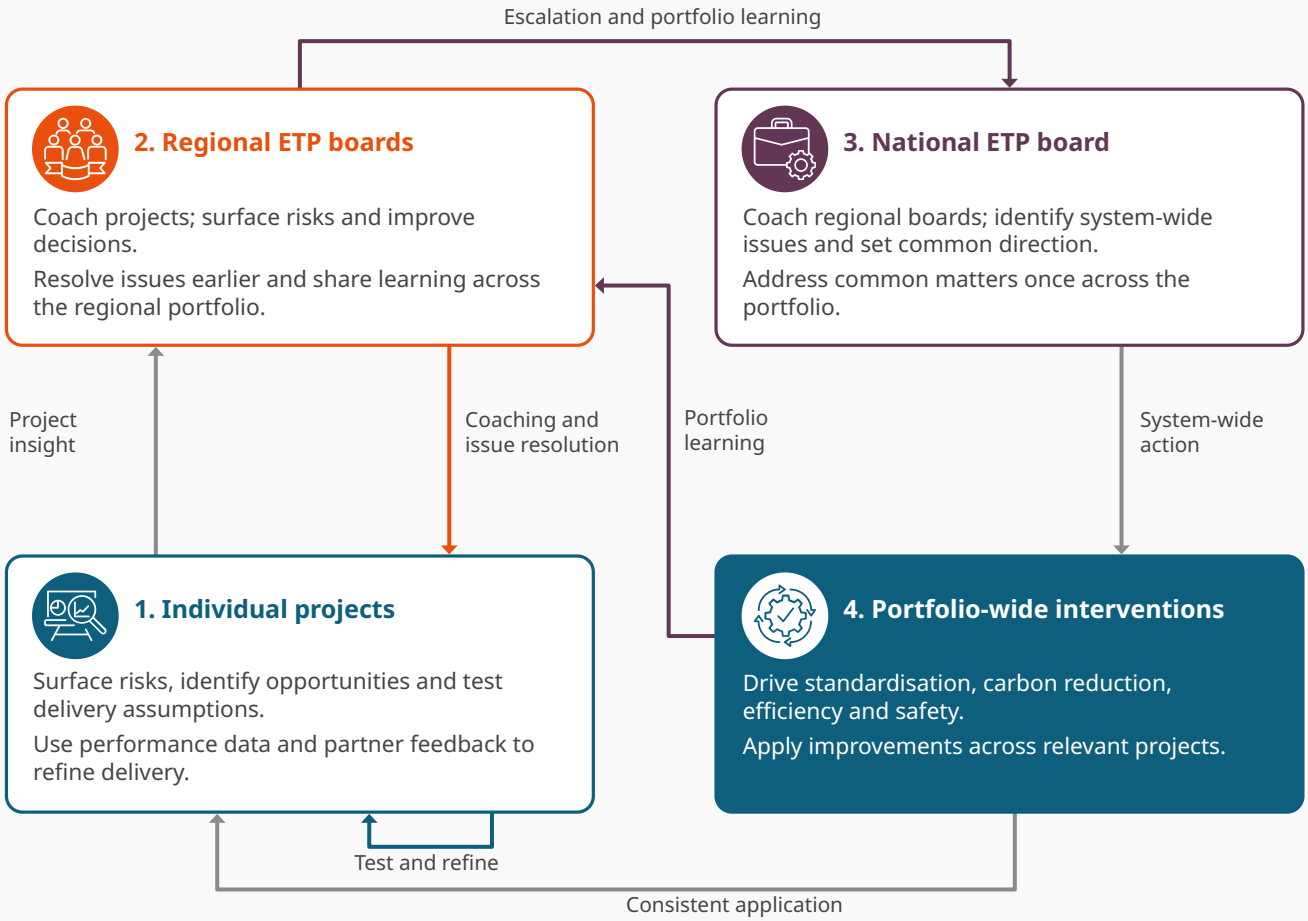
Delivery ecosystem conditions

Pipeline certainty | Delivery partner and supply-chain confidence | Workforce investment
Regional capability | Portfolio learning | Collaborative behaviours

Intended enabling logic; final outturn evidence is still developing.

ETP governance, assurance and portfolio learning

Coaching and learning connect project, regional and national decisions



Learning informs plans, decisions and interventions as the model matures.

Economic assessment

The economic baseline is a constrained delivery environment. The UK needs to expand electricity transmission capacity at a scale and pace that traditional, project-by-project delivery models were not designed to support. The economic question is therefore not only whether the ETP delivers individual projects more efficiently. It is whether the required infrastructure can be delivered at all without a more systemic approach to capacity, sequencing, supply chain confidence and workforce investment.

The value case should be read at two levels.

Project level: The ETP is expected to improve efficiency by reducing repeated procurement effort, remobilisation, duplication, sequencing problems and reactive procurement of long-lead items or scarce commissioning capability. Expected benefits include better supplier productivity, stronger workforce planning, improved use of regional delivery capacity, reduced interface friction and lower risk of delays across related projects. These benefits should be tracked through cost, schedule, quality, safety, productivity, carbon, workforce, supplier-performance and change-control measures.

System level: The more important question is whether the ETP improves the transmission system's ability to deliver the outcomes for which investment is being made. These include greater transfer capacity, faster connection of generation, storage and demand, maintained reliability, reduced constraint costs, resilience, clean power and long-term consumer value.

This distinction matters because a delivery model could improve project efficiency without materially improving system outcomes. Conversely, a delivery-system intervention may create high system value by reducing the risk that the wider RIIO-T3 programme becomes undeliverable, even before all benefits are visible in individual project outturn data.

This is the ETP's main enabled system value. It strengthens the delivery ecosystem needed to build the physical electricity system. That value is seen in improved deliverability, reduced risk of bottlenecks, better supply chain readiness and greater confidence that the wider investment programme can be delivered.

The avoided-cost logic is also important. Where transmission capacity is delayed, costs can arise elsewhere through

The economic question is not only whether the ETP delivers individual projects more efficiently. It is whether the required infrastructure can be delivered at all without a more systemic approach to capacity, sequencing, supply chain confidence and workforce investment.

constraint costs, delayed connections, inefficient system operation and weaker conditions for growth sectors that depend on reliable electricity capacity.

The ETP may also improve long-term value by changing supplier investment behaviour. A clearer pipeline and more stable relationship model should make it easier for partners to invest in people, skills, equipment, regional capability and innovation. It may also reduce social and environmental costs associated with unstable delivery patterns, including excessive travel, workforce disruption and inefficient mobilisation.

At this stage, there is not yet public outturn evidence showing quantified cost savings directly attributable to the ETP. The current evidence base supports a strong forward-looking economic logic, but final value-for-money evidence will depend on tracking cost, time, productivity, quality, safety, workforce, carbon, wellbeing, service performance, connection outcomes and constraint-cost impacts as the programme matures.

Systemic assessment

The ETP demonstrates that infrastructure delivery capacity can itself become a national system constraint. Clean power is not limited only by technology, finance or policy. It also depends on whether the market has the skills, supply chain confidence, governance, incentives and delivery capacity to build complex infrastructure at pace.

The main systemic inefficiencies addressed by the ETP are short-term procurement horizons, fragmented project pipelines, limited delivery-partner confidence to invest ahead of demand, competition for scarce technical skills, weak visibility across interdependent projects, and the risk that each substation is treated as a separate transaction rather than part of a connected programme.

The model appears strongest where outcomes, authority and incentives are aligned. National Grid has used its role as infrastructure client to give the supply chain clearer long-term demand signals, link future work to performance, and create governance arrangements that encourage collaboration rather than repeated transactional procurement. If incentives reward local optimisation, the wider system suffers. If they reward capacity growth, collaboration, delivery certainty and whole-system value, they can change system behaviour.

The main evidence gap is whether that logic will translate into measured performance over time. The ETP is still in its infancy. The key test will be whether learning mechanisms, behavioural insights, performance data and partner feedback lead to changes in plans, decisions and interventions as the programme matures. The immediate transferable lesson is that major infrastructure clients can use commercial design, governance and sustained pipeline visibility as levers for changing delivery-system behaviour and encouraging long-term investment across the delivery ecosystem.

Recommendations

Major infrastructure programmes should treat delivery capacity as a strategic system constraint, not simply as a procurement issue. Where the market needs confidence to invest in people, skills, equipment and regional capability, government, regulators and infrastructure clients should consider long-term portfolio partnerships rather than relying only on project-by-project contracting.

Procurement and commercial models should be designed as system levers. They should align incentives with whole-system outcomes, not only individual project cost and schedule. Performance-linked access to future work can support quality, safety, productivity, collaboration, innovation and capacity growth, provided that measures are transparent and linked to public value.

Benefits should be measured at both project and system level. For the ETP, project-level measures should include cost, schedule, quality, safety, productivity, carbon, workforce stability and supplier performance. System-level measures should include transmission capacity enabled, connection outcomes, avoided constraint costs, delivery bottlenecks reduced, supply chain investment, regional capability, integration with adjacent delivery routes, customer outcomes and consumer value.

National Grid should publish lessons from the ETP as delivery progresses, including what works and what does not. Particular attention should be given to regionalisation, growth and investment plans, partner incentives, behavioural governance, portfolio learning and alignment with other delivery strategies within its strategic procurement approach.

Other sectors should test whether fragmented procurement is limiting their ability to deliver system-level outcomes, particularly where long-term delivery capacity is a binding constraint. This is likely to be relevant to other network-based infrastructure sectors, including water, rail, flood resilience, heat networks and large-scale retrofit.

07



Hastings Landslide

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Coupled cliff stability, property and risk-financing.

Systems contribution and value: Reframed risk in terms of the cliff system, rather than individual properties, integrating geotechnics, monitoring, planning, finance and community action. Developed lower-cost intervention options with the potential to restore property value and insurability.

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Summary

This case study focuses on HASTE (Hydraulic Activity Stabilisation Template), which applies systems approaches to inland landslide risk in Hastings.

HASTE shows how a systems approach to inland landslide risk delivers better outcomes per pound than fragmented, reactive responses, and how its method is repeatable. In St Leonards-on-Sea, 1km of unstable cliff affects 540 homes: first the safety of the people who live on and below it, then their wellbeing, property values, insurability and mortgageability. What needs to change is the response – from property-by-property remediation that displaces risk, to coordinated intervention across the cliff as one system.

A community interest company (CIC) convenes parties, holds the evidence and coordinates the response, procuring design and construction from chartered firms carrying professional indemnity.

The cliff and its community form a system of four tightly coupled systems – physical, organisational, financial and informational – in which failure in one propagates rapidly to the others. The case shows three things. Estimates indicate that fragmentation is expensive: continuing as we are costs £32.3 million in present value over 30 years, against £8.6 million for an evidence-led response, and the affected homes have become progressively harder to insure, mortgage and sell. Delivering the same works at the scale of the engineering system, rather than the property boundary, cuts cost through economies of scale. And a financing architecture matched to the cliff's long life can fund stabilisation while restoring functioning insurance and mortgage markets.

HASTE's core innovation is organisational: a community-led body convening a whole-system response where no single actor could. As a template, what transfers to other places is its method, independent of Hastings' geology.

Scope

The system of interest is 1km of cliff frontage in St Leonards-on-Sea and the 540 properties, infrastructure and public realm it supports – the physical cliff and its hydrology and drainage; the built environment at risk; and the organisational and financial arrangements that determine whether risk can be managed over time.

The constraints are structural. Before HASTE, the response was reactive and case-by-case. No homeowner could stabilise ground beyond their boundary; no council or agency held a clear mandate or budget for inland cliff instability; and the evidence needed to act was scattered across planning files and privatised utilities. The pre-existing institutions were not resilient to a shared hazard but vulnerable to it. In the absence of any body positioned to act for the whole, locally-led coordination was the only route forward.



£43,990

HASTE reduction in whole-life cost per property from £59,840 to £15,850

HASTE's core innovation is organisational: a community-led body convening a whole-system response where no single actor could. As a template, what transfers to other places is its method, independent of Hastings' geology.

In scope are the system-level activities that shape outcomes: integrated evidence-gathering and modelling; identification of engineering zones; coordination of infrastructure works; planning controls to prevent further deterioration; and financing and governance aligned to long-term value. Stakeholders span residents; Hastings Borough Council; insurers, lenders and valuers; highways authorities and utilities; technical partners; central government and national agencies; the LGA Coastal SIG and peer councils; and developers where land-use change affects stability.

Out of scope are detailed engineering designs and property-specific decisions, which depend on later technical and governance stages. Government is a stakeholder throughout; what is out of scope is HASTE performing the functions only government can perform, set out in 'Systemic assessment', below.

Outcomes

The intended outcomes are clear: people should be safe in their homes, properties should remain insurable and mortgageable, communities should remain stable, and public bodies should avoid escalating emergency costs. These outcomes are experienced by people – and by the natural coastal-edge system – as benefits or disbenefits, which is why those most affected, including residents with no other voice in the process, must help define them. Pursuing them means explicit trade-offs – prioritising system-scale coordination over faster property-by-property fixes, and sequencing the most active zones first – held steady against the cliff's long timeline rather than annual funding cycles.

In practice, outcomes have diverged sharply. Residents experience anxiety and uncertainty as instability worsens. Insurance withdrawal and crude risk screening have rendered some properties uninsurable, triggering tighter mortgage conditions and reduced liquidity. Local authorities

Figure 1. HASTE has been conceived in terms of desired outcomes, the systems responsible for the outcomes, and the interventions necessary to change the performance of those systems.



SYSTEMS	INTERVENTIONS	OUTCOMES
Physical system Engineered coastal edge across several geological zones, with the water, power and highways infrastructure within it.	**Stabilisation works** System-scale engineering across the three zones, coordinated with statutory infrastructure works.	**Stabilised cliff** Maintained for the long term; the design horizon matched to the system, not the property boundary.
Informational system Planning records, geotechnical documents and borehole logs, consolidated into one picture.	**Shared evidence** One integrated ground model and a live monitoring network, replacing scattered private records.	**Shared decision-support** Evidence that planning, insurance, lending and delivery all draw on; held as community-owned data.
Financial system Mortgages, insurance, FloodRe and pension capital, against substantial housing value and mortgage exposure.	**Three-layer financing** Capital, recovery and endurance layers, matched to the cliff's long time horizon.	**Functioning markets** Insurable and mortgageable; value retained by residents; a route into the FloodRe transition.
Organisational system Households, council, parish, undertakers, government and partners; the community and its social capital.	**Stakeholder coordination** HASTE convenes the partners; named accountabilities; a trained resident workforce.	**Resilient community** Clear responsibilities; a durable, replicable governance model.

Organisational 'connective tissue' links systems, interventions and outcomes horizontally and vertically. It convenes the actors, holds the evidence in common, and sustains maintenance once the works are done.

face significant pressure to act but lack clear mandates, funding routes and national frameworks. On the HASTE cliff, six landslides since November 2023 – with around 20 more across the town – occurred in unmaintained ground during prolonged extreme rainfall, with estimated property-value falls of around 20% across the affected area, indicated by transaction analysis and resident accounts.

These outcomes arose from many organisations each behaving rationally within its own constraints and time horizons: insurers withdrew full cover; lenders tightened lending; councils avoided legal precedent; operators followed statutory regimes. Collectively, these rational actions created systemic lock-in. This is a collective-action failure: 540 homes are affected by an integrated failure surface and morphology, yet decisions are taken plot by plot. Actions by one change the risk carried by neighbours through externalities each is powerless to resolve alone, while responsibility for the cliff as a whole is fragmented across hundreds of titles and several statutory bodies. The result is a market that has stopped functioning.

Intensifying rainfall under climate change makes such events more frequent and severe, so a response that merely reinstates past conditions will be overtaken by the next. HASTE is therefore designed to be preventative and adaptive:

- monitoring the system continuously
- an early-warning network that gives residents time to act
- stabilising ahead of failure rather than repairing after it.

The systems are tightly coupled: how land is managed sets physical stability; the informational system makes that stability legible as shared evidence; and only against that evidence can the financial system price risk and fund the works.

Monitoring also serves as a learning mechanism: it tests assumptions and adapts interventions as ground behaviour is observed, with phased, reversible works allowing learning without disproportionate risk on a live cliff.

A systems approach also changes what each actor does. Insurers can price risk rather than withdraw from it. Authorities can share data and contribute to a solution rather than only manage failure. Developers can coordinate around shared ground evidence rather than externalise risk.

Benefits then accrue across the system. Homeowners gain safety, clarity and – through community-led delivery with professional oversight – opportunities for trained employment. Insurers and lenders gain better information. Councils gain defensible pathways. National bodies gain a replicable model that can inform the FloodRe 2039 transition.

Building this local capability – skills in monitoring, sensing, geology and stewardship – is itself a resilience outcome, and community agency both enables and outlasts the response.

Systems

The HASTE case is a system of four systems – physical, organisational, financial and informational.

The physical system spans 1km of engineered coastal edge across three geological zones, with ground, groundwater and slope behaviour that ignores property boundaries, plus the water, power and highways infrastructure within it.

The organisational system encompasses 540 households across hundreds of titles, Hastings Borough Council, statutory undertakers, national government and 60+ technical and policy partners.

The financial system represents around £148.5 million of housing-stock value, with mortgage security impaired across a frontage where every property still stands, coupled to insurers and pension capital.

The informational system provides the evidence the other three depend on. Relevant knowledge was fragmented across 6,171 planning records, 97 geotechnical documents and 17 prior investigations by eight consultancies, with community knowledge lost each time a property changed hands. HASTE consolidates this into an integrated ground model and live monitoring network, turning private records into shared decision-support that technical partners can scrutinise. Treated this way, data becomes a community asset rather than a private one pointing toward community-owned data stewardship and cooperative business models.

These systems are tightly coupled: how land is managed sets physical stability; the informational system makes that stability legible as shared evidence; and only against that evidence can the financial system price risk and fund the works. Running through all three is the organisational system – the community and the social capital it holds. It is the connective tissue the others depend on: it builds trust, inspires belief and leverages community skills – convening the actors, holding the evidence in common, and sustaining the maintenance once the works are done.

A systems approach reframes the problem from ‘who should fix the cliff?’ to ‘why does the system fail to deliver safe, insurable and mortgageable homes?’ Treating the cliff as a system avoids property-by-property fixes that displace risk. Shared evidence – a single representation that different parties reason from together (Figure 1) – supports consistent decision-making across markets and authorities.

Systems thinking makes trade-offs explicit and manageable, allowing decisions to be taken coherently across organisations and timescales. The binding constraint is as much governance as engineering, which is why HASTE’s innovation is organisational and informational as well as technical.

Interventions

Interventions in HASTE focus on enabling coordinated system action in place of isolated construction works. The approach is structured through a five-phase methodology – Understand > Plan > Finance > Stabilise > Monitor – applied once across the cliff, with each intervention assessed to support the wider slope system. The framing is deliberately about managing cliff risk: measures are selected by risk, mechanism and evidence and will differ along the frontage, combining engineering, drainage, monitoring and planning controls.

The key innovation is organisational rather than technical. HASTE creates the space in which system-scale intervention can be delivered by holding shared evidence, aligning incentives, and assembling patient finance matched to the life of the asset. The innovation is a new organisational model creating a repeatable way for a community to convene the whole system around a shared hazard.

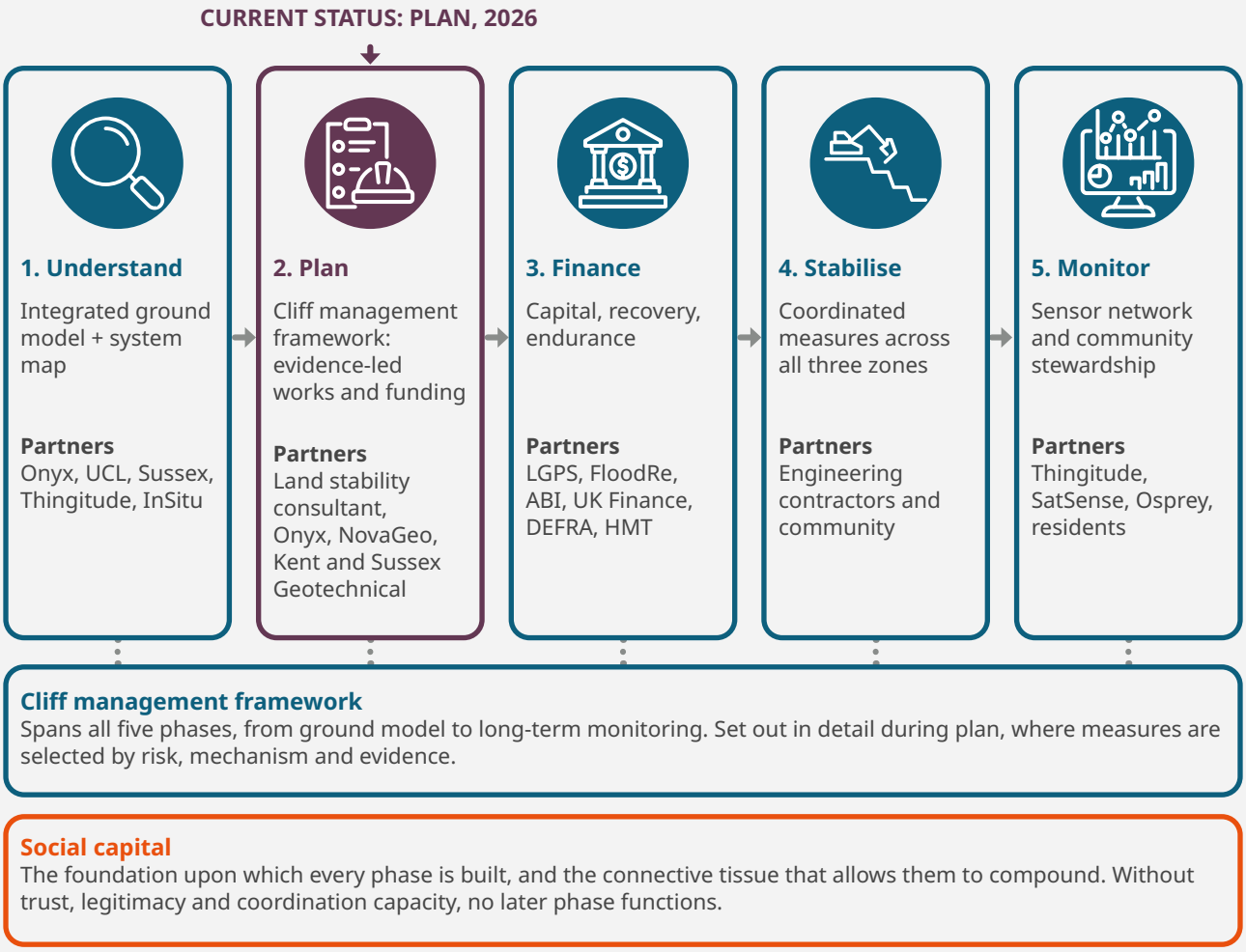
Conventional approaches commission independent investigations across the same ground, producing duplications and inconsistencies. HASTE treats the cliff as one system.

Evidence is generated once and shared with delivery coordinated and financed through one programme, and governance considered alongside engineering design.

Outputs to date include an integrated desk study across

Figure 2. HASTE's five-phase methodology

The cliff management framework spans all five phases and is set out in detail during plan.



Stabilisation delivery: 2027
Each phase produces durable assets that compound into the next, not a sequence to be completed and forgotten.

three engineering zones, installation of monitoring infrastructure, development of costed intervention options, and planning controls to prevent further deterioration. Designed to be replicable, these create templates for evidence, delivery, financing and governance that can be applied elsewhere.

Economic assessment

The economic case begins with a market failure. The cliff is one interacting coastal slope system, so stabilising one plot can push instability onto the next: each party, acting rationally but alone, worsens the position of the whole. Responsibility is fragmented across hundreds of titles and several statutory bodies, none with an enforceable duty.

Fragmentation costs in two distinct ways. First, money is being spent: continuing as we are costs £32.3m in present value over 30 years. Second, value is being lost: the market has repriced this stock since November 2023, while every property still stands. Land Registry repeat-sales analysis gives a discount of 17.3%. Homes are becoming uninsurable, making them unmortgageable. HASTE's intervention is therefore timely.

Four approaches are compared against a do-nothing baseline over 30 years:

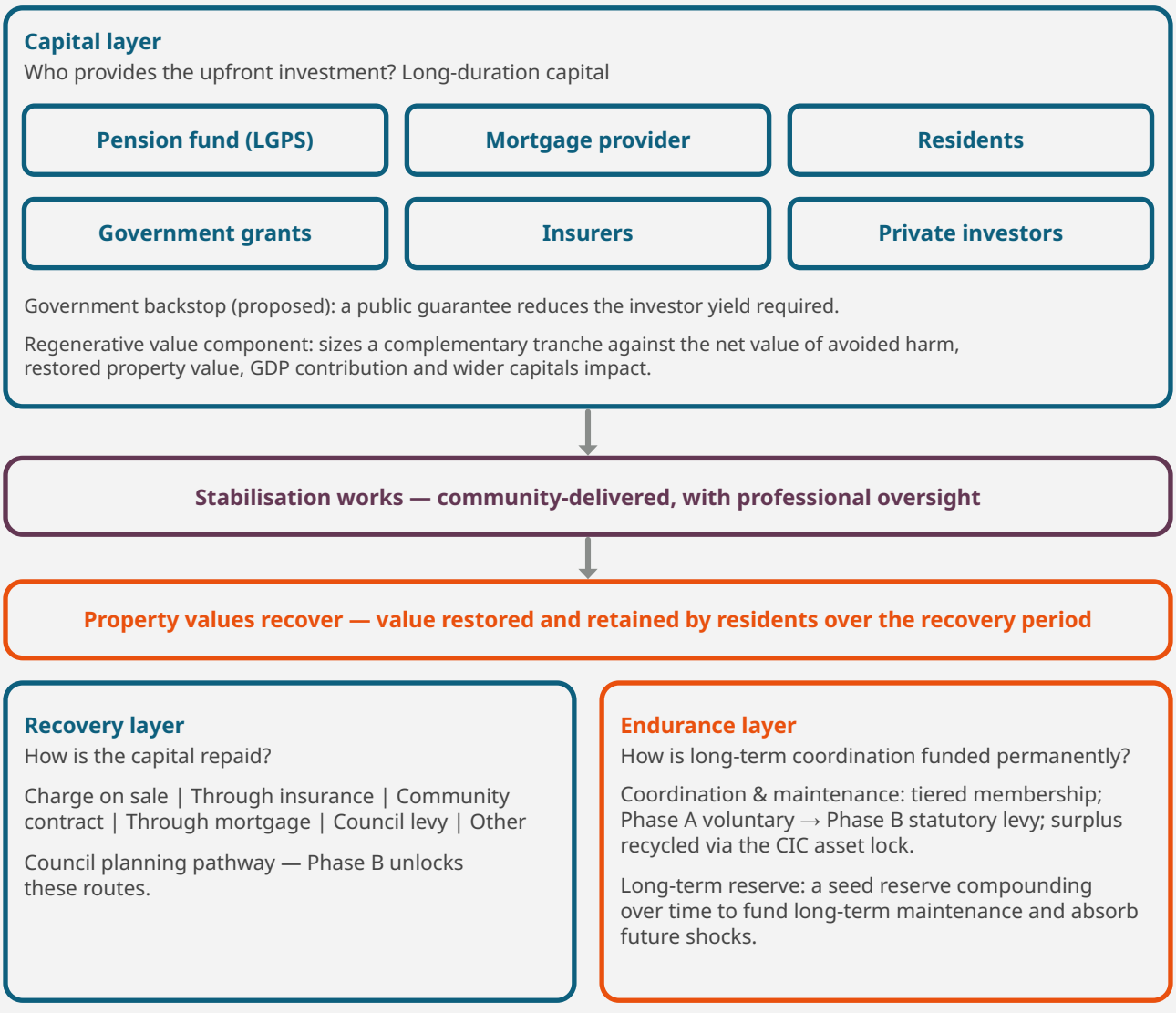
- no coordinated intervention
- reactive site-by-site management
- coordinated conventional stabilisation committed before a ground model exists
- building the ground model first, then selecting measures from it.

Continuing as we are returns a benefit-cost ratio of 0.49; coordinated delivery returns 1.95; understanding first

Table 1. Who bears the cost and who benefits, by scenario.

Party	Under business as usual	Under HASTE
Homeowners and residents	Falling value, uninsurable, unsellable homes; anxiety of unmanaged risk.	Pay a lower, shared cost; reduce risk to assets, wellbeing and life; gain local jobs.
Local council	Emergency costs, legal exposure; no funding route.	Administers a defensible levy; lower long-run cost.
Mortgage lenders	Rising exposure against impaired security.	Security improves as value and insurability recover, though outcomes vary by provider.
Insurers	Withdraw cover – cost avoided and shifted onto others.	Risk priceable again as it is reduced and shared
Infrastructure operators and developers	Separate regimes; risk displaced onto the cliff, cost externalised.	Coordinated via shared ground data; contribute to the solution.
Government	No mandate exercised; residual risk left with residents.	Underwrite uninsurable risk, set a national pathway, clarify ownership.

Figure 3: HASTE financing architecture



returns 3.77, with net present social value of £23.7 million and £23.8 million of cash released. It still clears at 1.43 if no further loss occurs. The coordinating body costs £2.5 million and returns 9.6 to 1. The 30-year appraisal period is deliberately shorter than the 60-year design life of the measures.[1]

Removing these inefficiencies reshuffles who bears the cost (Table 1, left).

HASTE reduces cost substantially, from £59,840 per property to £15,850 in whole-life-cost across all parties. The saving is cash-releasing and lowers real expenditure, as distinct from accruing as welfare value.

This is where government becomes decisive. HASTE can convene the system and coordinate finance, but only government can enable coordination at scale, underwrite risk no market will insure, and regulate insurers.

The financing connects the integrated systems into one framework: a capital layer sized against avoided harm; a recovery layer repaid through a council levy, subject to statutory basis and resident consent; and an endurance layer funding coordination.

Systemic assessment

HASTE frames inland landslide risk as four tightly coupled systems: physical, organisational, financial and informational. Integrated intervention depends on all four, and the current fragmented model creates avoidable cost, delay and risk.

Four structural findings emerge:

- **System-scale understanding is structurally cheaper and changes what must be built:** property-scale commissioning duplicates investigation and consent, and commits to a solution before the mechanism driving instability is understood. Coordination alone reduces whole-life cost while understanding the mechanism first changes which measures are needed. Together they release £23.8m against the current trajectory.
- **Finance must match physical time horizons:** Victorian retaining structures built as part of an integrated system still stand, but are now fragmented across hundreds of properties. Funding their renewal requires 60-year design lives, against the 20-30-year cycles that currently apply.
- **Integrated ground evidence is a public good:** scattered private investigations have limited system value until consolidated into a shared model. No national funding route exists to consolidate them: flood and coastal erosion risk management (FCERM) does not cover groundwater-driven landslides.
- **Community-led delivery works here, and its transferability is largely untested:** membership funding depends on a resident base with value to recover, and works differently where there is substantial social housing, absentee landlords or lower values. Establishing what transfers is work still to do.

The organisational system is implicated in every finding. HASTE provides boundary-spanning leadership across 60+ organisations, disciplines and lifecycle stages. But replicable intervention relies on the government, which alone can resolve cross-boundary trade-offs, fund long-term coordination, underwrite uninsurable risk and clarify ownership.

Recommendations

- **Deliver at system scale:** commission evidence, design and works around the geology, hydrology and infrastructure system, in place of ownership lines.
- **Treat ground evidence as public-good infrastructure:** consolidate surveys, borehole logs, historic reports and monitoring into shared ground models held as community-owned data – a community-scale demonstrator of what the Geotechnical Data Bill (Ground Data for Growth Bill) proposes nationally via NUAR and the BGS.
- **Recognise land stabilisation as critical infrastructure:** beginning in the Hastings Town Plan and scaling to national legislation.
- **Give landslide risk a departmental home:** name a lead department; create a duty to investigate and log ground-instability incidents; extend the FCERM definition to groundwater-driven instability and establish a remediation and search regime.[2] [3] [4]
- **Align incentives to long-term value:** reward value preservation and risk reduction across homeowners, insurers, lenders, councils and investors, with financing matched to the cliff's physical time horizon rather than short funding cycles.
- **Underwrite what the market will not:** extend FloodRe-style collective, preventative cover to geological hazards – which, unlike flooding, currently have no insurance or backstop – with government as insurer of last resort.
- **Build adaptive, learning-based governance:** let resilience policy learn from local innovation rather than foreclose it, feeding community monitoring into the local-tier risk assessment the Resilience Action Plan envisages, with clear institutional accountability.
- **Scale from a testbed:** support HASTE to extend the model across the wider Hastings catchment first, where the geology, institutions and community are known, and codify what transfers before claiming national applicability. A legal framework for collective action across property boundaries is the enabling step.

1 Appraised on the HM Treasury Green Book, February 2026 edition: 2026 prices, 3.5% discount rate, 25% optimism bias applied equally to all four scenarios. Scenario 1 is derived from the logged record of expenditure; the Scenario 2 and 3 cost stacks are scenario-modelled pending the ground model.

2 Groundwater is already a lead local flood authority responsibility under the Flood and Water Management Act 2010, so the driver of instability is within statutory scope; only the consequence falls outside it.

3 Mirroring the Section 19 duty to investigate and publish flood incidents. No equivalent exists for ground instability, which is why 25 events on this frontage went unrecorded until a community group compiled them.

4 On the Mining Remediation Authority model - statutory duty, public search data, an insurance market built on it - applied to geological instability, and correcting its exclusion of blight.

08



Catchment systems planning

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Integrated river catchments.

Systems contribution and value: Participatory mapping, integrated modelling and shared data improved understanding of boundaries, stakeholders, cause-effect relationships and trade-offs. Identified opportunities for coordination and co-funding.

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Summary

The 2026 government white paper 'A new vision for water'[1] calls for water to be planned as a whole system. By framing river catchments as systems, portfolios of interventions can be co-created by catchment stakeholders to address a set of outcomes that realises synergies across different planning frameworks and reflects a balance of different interest groups.

We review a combined approach to applied systems thinking including the use of:

- participatory systems mapping to synthesise stakeholder perspectives of the whole system
- integrated modelling to provide a quantitative analysis
- cost benefit analysis of potential interventions for an economic perspective.

These three steps are designed to give the systemic planning validity with respect to people (co-creation with stakeholders), science (data and modelling) and economics.

We draw on projects from River Lea in London, the Blackwater and Colne in Essex, the River Wye straddling Wales and England, and the River Frome in Bristol. Feedback from participants was positive, noting the importance of developing a shared understanding among participants.

Drawing on the Frome, we show how different interventions become cost effective when the assessment is made under planning frameworks in which a wider set of benefits is considered. This indicates that planning frameworks need to be set up to reflect system-wide benefits, to create cost-effective place-based outcomes over and above a narrow focus on sector-specific objectives.

Scope

This review considers four projects conducted within different river catchments. In each, a portfolio of multi-benefit interventions was co-created by a group of participants to achieve a range of results.

- East London's Subregional Integrated Water Management Strategy (SIWMS)[2] [3] which integrated planning across flood risk, water environment and water resources.
- Source to Sea System Mapping for the Blackwater and Colne in Essex.[4]
- Systems planning in the River Wye.[5]

Different interventions become cost effective when the assessment is made under planning frameworks in which a wider set of benefits is considered.

- Bristol: The Resilient Frome catchment – application of catchment systems thinking principles for flood risk appraisals. This project demonstrates the economic case for integrated investments.[6]

Both the Wye and Blackwater/Colne projects pioneer a new method for the Environment Agency's (EA) river basin management planning (RBMPs).

Project context

- In London, there was limited awareness among stakeholders of the wider systemic nature of the water issues. The project therefore ran a process that enabled participants to explore this wider perspective together as a platform for collaborative planning.
- In Essex and the Wye, the EA sought a robust process for river basin planning. The principle of 'fair share' in selection of measures was important here. Therefore, with participants, we investigated trade-offs that different options would bring.
- In Bristol, the client's selection criteria emphasised the need for cost-beneficial delivery of flood risk, water quality and other social and economic outcomes

Outcomes

A practical systems approach enhanced the ability to create impactful plans and account for benefits and trade-offs when viewing the system as a whole. Figure 1 shows how outcomes derive from the actions taken in these projects.

Outcomes include improved identification of externalities.

In London, reductions in domestic per capita consumption (PCC) are advantageous to water resource planning. However, this can have a potentially negative feedback loop affecting water quality. This is because lower PCC reduces the volume of wastewater produced, which in turn reduces

1 Department for Environment, Food and Rural Affairs (Defra) (2026) A new vision for water: White paper. London. Available at: https://www.gov.uk/government/publications/a-new-vision-for-water-white-paper
2 Greater London Authority (2023) Sub-regional integrated water management strategy East London. London: Greater London Authority. Available at: 100108845-5.1-F Sub-regional integrated water management strategy East London
3 Whaley, M. E., Benton, L., Bromwich, B., Mijic, A., Rousseau, E., Whaley, M. P., & Dobson, B. (2024). Implementing a systemic approach to water management: piloting a novel multi-level collaborative integrated water management framework in east London. AQUA—Water Infrastructure, Ecosystems and Society, 73(6), 1113-1134.
4 Environment Agency (2025) Natural capital approaches at the land-sea interface: mNCEA project NC74 WP8.1 Source to Sea System Mapping for Blackwater and Colne. Available at: Blackwater and Colne – Natural Capital at the Land Sea interface.
5 Mott MacDonald and Environment Agency (2024) Understanding the Wye catchment: Project update August 2024. Available at: Understanding-the-Wye-Catchment-Project-Summary-August-2024-1.pdf (Accessed: 6 August 2026).
6 Bristol City Council Newsroom (2022) £6 million funding for Resilient Frome project. 20 December. Available at: https://news.bristol.gov.uk/press-releases/fb3845b0-2581-423c-aa2d-1e6332c4e8c1/6-million-funding-for-resilient-frome-project.

Figure 1: From project actions to catchment outcomes

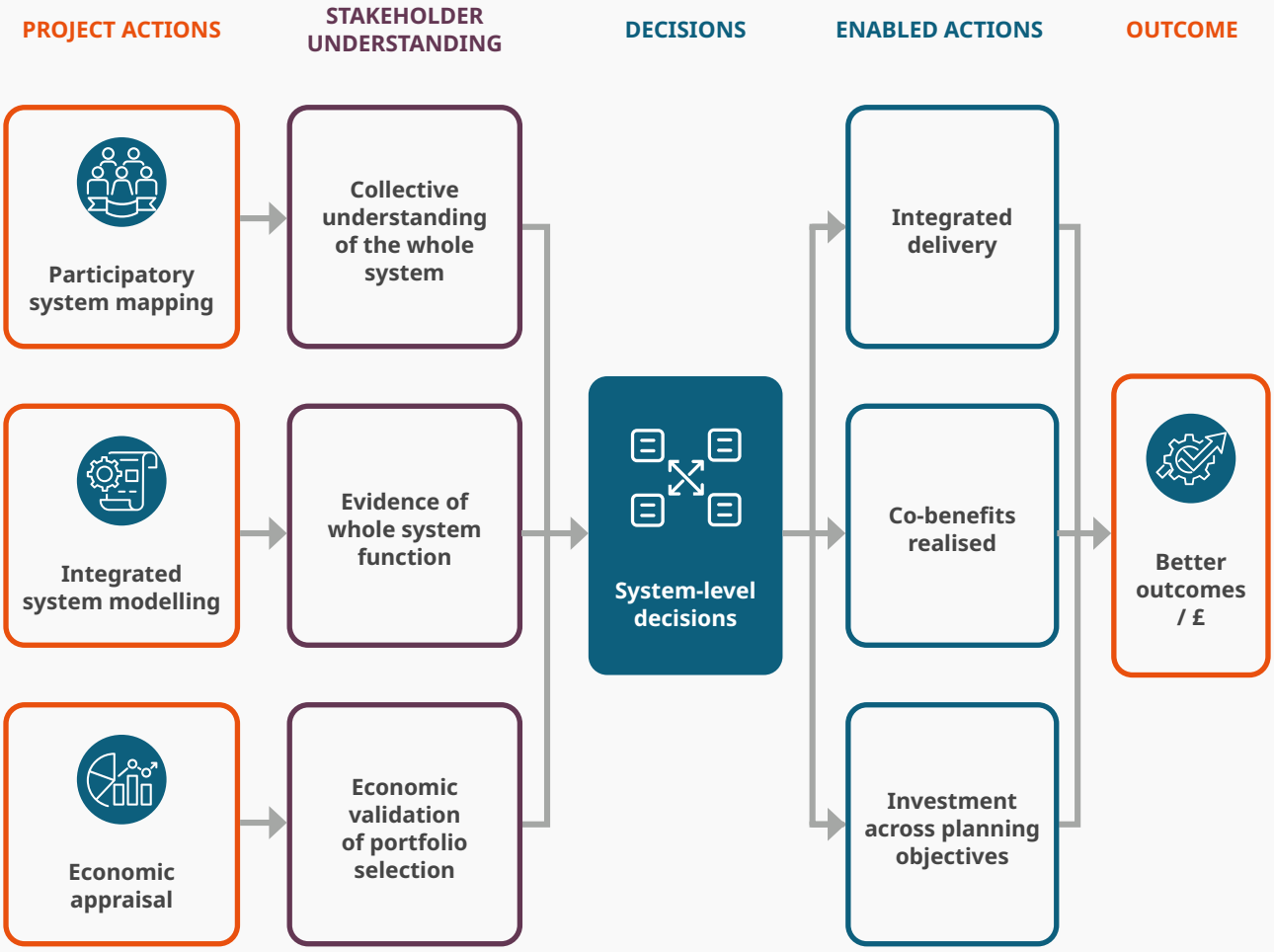
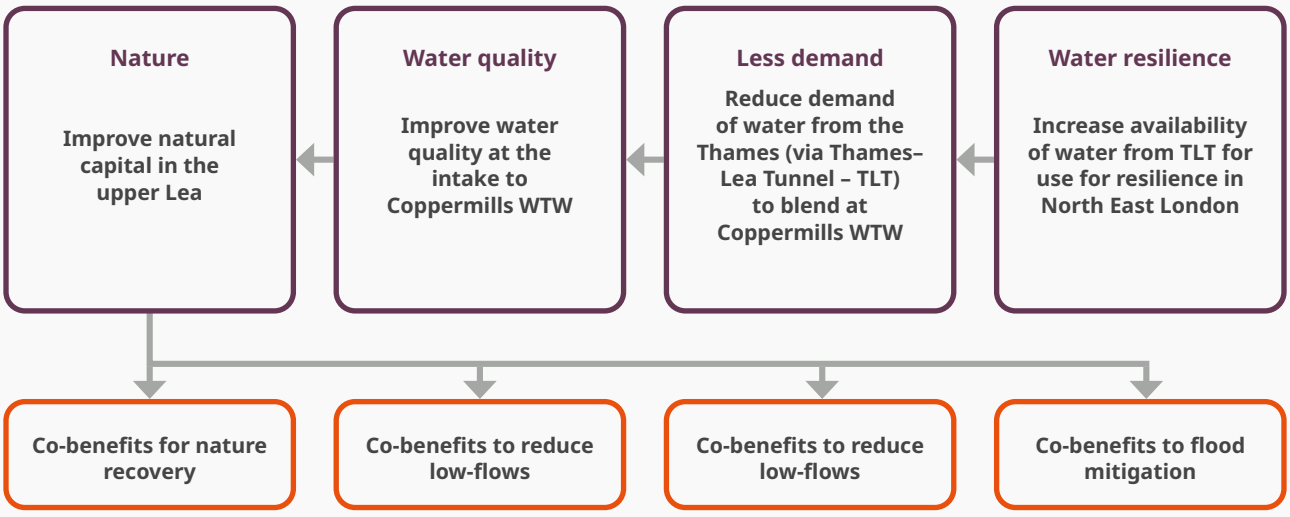


Figure 2: Cascading benefits and co-benefits



The system map was recast as a theory of change to show how interventions produce outcomes.

the discharge of treated back into the aquatic environment. Treated effluent discharges can contribute significantly to river flow in summer. Less flow would result in less dilution of pollutants from, for example, road runoff or sewer overflows resulting from in summer storms. Lower PCC could thereby heighten the risk to summer river ecology. Once identified, this externality can be managed and mitigated.

The approach also identified co-benefits and aided the resolution of market failures.

The work in London put forward a practical method of including interventions in more than one planning framework, thereby resolving the market failure inherent in siloed working. This is significant in rivers and landscapes where interventions have multiple benefits. For example, implementing sustainable drainage solutions (SuDS) has benefits to flood management, water quality and potentially water resource management.

In London, a market failure was mitigated by identifying potentially more cost effective interventions outside of the GLA area in the upstream catchment.

Also in London, cascading benefits were identified across other parts of the capital's water infrastructure, including more effective use of water abstracted from the Thames.

In Bristol, additional benefits were identified to match local ambitions to improve amenity and place value. These were included within the economic appraisal to justify the selection of options such as SuDS and natural flood management.

In each catchment, the process employed engaged diverse stakeholders and bridged their interests; it created plans addressing multiple objectives. Clients and stakeholders reported that it enabled progress on issues that had previously been considered intractable due to complex stakeholder landscapes.



£774k

cost of implementing SuDS at three demonstration sites

In London, referring to the qualitative outputs from the integrated modelling, the GLA described the work as "game-changing – in providing the evidence base for more collaborative working". In addition to the evidence base it also created patterns of collaborative behaviour that led directly into new collective actions being taken.

The EA described the progress made in the Wye and the Blackwater and Colne has as having created "enormous value" stating that the approach "helps us see the bigger picture and act in ways that influence the whole system".

The chair of the Wye Catchment Partnership stated that "the project has taken us from the storming phase to the norming phase", indicating that the level of contest in the partnership had diminished.

Systems

All four examples relate to river catchments comprising landscapes, natural capital and infrastructure. These systems lie within broader economic and social systems.

In the **London** case study, system management is provided by the boroughs, water companies, EA and the GLA (with a focus on economic development in London). However, the upper catchment, which has important opportunities for intervention, is outside the boroughs' and GLA's jurisdiction.

Poor water quality in the River Lea means that an additional water source must be blended to maintain satisfactory outcomes at Coppermills water treatment works. Implementing nature-based solutions (NbS) in the Chilterns, where the Lea originates, is a means of improving water quality and security: NbS reduces the sediment and nutrient loads in rainwater run-off, and slows the rate of flow, strengthening the resilience of water supply (Figure 2).

In the **Wye**, the system was represented[7] to stakeholders as a collection of sub-systems including agriculture, development and water utilities, which all interacted with each other around the central sub-system of river health. This overall framing gained traction with catchment stakeholders, helping them to articulate catchment trade-offs and challenges. This high-level representation was annotated with indicators under consideration for inclusion in the catchment plan as metrics. The system map was recast as a theory of change[8] to show how interventions produce outcomes.

A similar approach was taken in **Essex**. The system map was recast as a theory of change for the Blackwater and Colne[9] and can be filtered to show the overlapping place-based plans (drainage and wastewater, river basin, local nature recovery strategy, Essex highways), and annotated to show institutional responsibilities and hence identify partnership opportunities.

7 Understanding the Wye – catchment system map https://kumu.io/EDI14/wpdmmpsmkmv3#high-level-systems-map
8 River Wye theory of change https://kumu.io/EDI14/wpdmmpsmkmv3#planning-diagram
9 Blackwater and Colne theory of change https://kumu.io/SystemsECP/bwctocmmpsmjbv1

In **Bristol**, the local authorities, water company, and the EA coordinate catchment management across flood risk management, planning, economic growth, and environmental regulation. Optioneering and stakeholder consultation identified SuDS and natural flood management (NFM) as providing the greatest benefits to amenity and environment, in addition to reducing flood risk.

Interventions

All four examples enhanced the ability of catchment stakeholders to understand the river in whole-system terms. This new shared understanding informed decision-making by improving awareness of the impact of intervening. This understanding improves catchment governance and allows more strategic deployment of the following types of intervention:

- Engineering interventions such as wastewater improvements
- Behavioural interventions such as reduced PCC
- NbS such as buffer strips, NFM and SuDS
- Agricultural interventions relating to issues such as feed ingredients and management of manure.

NbS form a significant part of catchment portfolios due to the multiple benefits they deliver across different planning objectives. However, it can be difficult to define attribution of benefits to NbS precisely. This can make it challenging to justify the inclusion of NbS in intervention portfolios. Systems mapping and integrated modelling enable visualisation of benefit attribution to interventions.

Using participatory stakeholder management, all stakeholders contribute to the selection of a system wide set of metrics which represent their own place-based priorities.

Notwithstanding the difficulty of precisely predicting benefits of NbS, it is advantageous to show the breadth of benefits and the interconnected nature impacts, which thereby enhances the case for selecting NbS interventions.

On the Frome, SuDS and natural flood management provide greatest benefits



Table 1. Economic assessment of SuDS benefits in the Resilient Frome project.

Planning domain	Benefit type	Beneficiary	Method	Present value £000 over 40 years	Sum by domain £000
Environmental	Amenity – at SuDS sites	Site owner	CIRIA B£ST	640.6	648.51
	Air pollution	Site owner	CIRIA B£ST	0.51	
	Water environment improvement	RBMP	Environmental and Historic Outcomes Valuation (EHOV) data book	7.4	
Water resources	Water treatment	Water company	CIRIA B£ST	0.154	0.154
Flood risk	Reduction in surface water flood risk at site	FCERM - site owner	Modelling & Multi-Coloured Handbook (MCH)	584.4	726.9
	Reduction in regional surface water flood risk	FCERM – lead local flood authority	Modelling & MCH	112.2	
	Reduction in catchment fluvial flood risk	FCERM – Environment Agency	Modelling & MCH	30.3	
Social	Skills, knowledge and education	Department for Education	CIRIA B£ST	184.8	184.8
				Total	£1,560.4

Table 2: Projects and methods applied

Project	Participatory system mapping	Integrated modelling	Economic appraisal
East London's Subregional Integrated Water Management Strategy	Yes	Yes	
Blackwater and Colne in Essex	Yes		Partial
River Wye	Yes	Yes	Partial
The Resilient Frome catchment - Bristol			Yes

Economic assessment

Currently, different planning domains within water and environment have their own approach to economic appraisal. Our catchment systems planning method improves on this in the following ways:

- Using participatory stakeholder management, all stakeholders contribute to the selection of a system wide set of metrics which represent their own place-based priorities. The PSM provides a rationale and audit trail for these metrics – and therefore legitimacy for the metrics with stakeholders.
- Considering a wider set of benefits and metrics enables the co-benefits of interventions to be included in their valuation. This enhances the benefit-cost ratio of interventions.
- Where a wider set of benefits are considered, multi-benefit interventions may be eligible for inclusion under more than one planning framework. Therefore, costs could be shared across funding streams for both frameworks. These co-benefit interventions may displace more costly interventions that contribute to only one planning objective. In the London project, the GLA identified a governance mechanism that could realise these synergies across different planning domains in a cost-effective manner.

In the Frome catchment, affecting Bristol, SuDS had originally been rejected when the project was appraised against flood benefits alone, under the Flood and Coastal Erosion Management policy. However, when the project was reconsidered under the Department for Environment, Food and Rural Affairs' Flood and Coastal Resilience Innovation Programme, additional co-benefits beyond flood risk were admissible for inclusion in the business case. The additional benefits considered were environmental, water resources and social.

Inclusion of additional benefits beyond flood risk, moved the benefit-cost ratio from 0.94 to 2.02 – making the scheme cost-beneficial and eligible for progression.

The cost of implementing SuDS at the three demonstration sites was given as £774,000**.** This meant that the inclusion of additional benefits beyond flood risk, moved the benefit-cost ratio (BCR) from 0.94 to 2.02 – making the scheme cost-beneficial and eligible for progression.

Modelling in the Frome catchment showed that different interventions become cost effective when the assessment is made under planning frameworks in which a wider set of benefits is considered. This can create cost-effective place-based outcomes over and above a narrow focus on sector-specific objectives.

An economic case was made for implementation of NFM in the upper Frome catchment. It showed that for interventions that addressed only flood risk, a benefit to cost ration of 1.1 only just met value for money requirements. The inclusion of additional benefits improved the BCR to 4.0 which strengthened the business case.

Systemic assessment

The following systems thinking methods were used:

- A stepped approach to PSM[10] in which diverse stakeholders explore and illustrate how the catchment works as a whole system.
- Integrated modelling with Water Systems Integrated Modelling framework, to provide a numerical assessment of the system.[11]
- Theory of change based on the PSM so participants understand the attribution of outcomes and benefits to the portfolio of interventions they propose.[12]
- Cultural theory – to guide how system representation is informed by a diverse set of insights rather than reflecting a single perspective. Cultural theory underpins the significance of decision-making being valid when seen through the lens of people (an egalitarian worldview) science (a bureaucratic worldview) and economy (an individualist worldview).[13] [14]

This case study combines outputs from multiple projects (Table 2) to inform our systemic assessment of the quantified benefits of taking a systems approach to catchment planning.

The quantitative focus of this case is broadly aligned with Defra's Flood and Coastal Resilience Innovation Programme methodology. This is a satisfactory 'proxy' for systems thinking, as it includes holistic benefits. However, the authors are aware it is not an ideal methodology. Best practice would establish the relative benefits and costs of two approaches: one applying systems thinking, and one not. This will be considered in any future recommendations.

Recommendations

Participatory stakeholder management, mapping, modelling and appraisal (PSM) should be applied to river catchments to:

- enable co-creation of a coherent portfolio of interventions with relevant place-based benefits
- demonstrate legitimacy with participants in collaborative planning, with all relevant voices having been heard and recorded through the PSM
- enable resolution of complex multi-party and multi-sector trade-offs
- enable cost sharing across multiple funding streams, thereby enabling more cost-effective, multi-benefit options to be selected for implementation.

To realise these advantages, planning frameworks need to be set up to reflect system-wide benefits over and above a narrow focus on sector-specific objectives.

To ensure a proportionate approach, this method should be implemented in catchments with complex trade-offs or multi-faceted challenges for which multiple funding sources are relevant. It may not be needed in its full form in catchments with less complex challenges.

A key learning from this work is to recognise that applied systems thinking is about working with groups of people as well as doing more joined-up analysis. This is because people live and work in the infrastructure and environmental systems that we manage, seeking a variety of different objectives and understanding the catchment in a variety of ways. The stepped approach to PSM used in this case study reflects the fact that applied systems thinking may need to start by creating a collective understanding of the system across the stakeholders, from which they can negotiate shared objectives and work together to create an effective system-wide plan that benefits all actors.

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09



London's Thames Crossings

This is one of 15 case studies informing the Infrastructure Systems Review. It forms part of the evidence base for systems change in the built environment.

System: Cross-river transport.

Systems contribution and value: Proposes development from existing investment approaches, in which repairs and maintenance are coordinated between numerous custodians, to a fuller system approach that supports them in protecting cross-river connectivity, efficiency and resilience.

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Summary

London's Thames crossings are a critical part of the capital's transport, economic and social infrastructure. They connect communities, support public transport, enable freight and servicing, provide walking and cycling links, and help London's road and public transport networks operate as a whole. This case study considers the crossings within Greater London as a connected system, rather than a set of separate bridges, tunnels, ferries and rail links.

Ownership and maintenance responsibility for non-rail river crossings is split between TfL, the City Bridge Foundation and the London boroughs. Each owner assesses crossing investment alongside its wider infrastructure and organisational needs.

This is a reasonable approach, but priorities set separately may not fully reflect dependencies and benefits across the crossings system. Incorporating a wider system view into each owner's assessment could inform its investment priorities.

Many of the crossings are ageing assets requiring significant investment to maintain safe operation. Several, including Vauxhall bridge, Rotherhithe tunnel and Blackwall tunnel, are already closed or restricted, with further restrictions possible. However, for some owners, the cost of works can be substantially greater than the funding available through existing budgets and funding programmes. The amount of national funding available for London is expected to be insufficient for the scale of the maintenance and repair backlog.

Building on the longstanding pan-London bridge prioritisation approach developed by the boroughs and TfL through the London Bridges Engineering Group (LoBEG), a whole-system view would connect asset condition, usage, bus routes, active travel, freight, accessibility, resilience, ownership and funding. It would help owners assess how individual crossings contribute to connectivity across the portfolio.

A systems approach can help prioritise investment, reduce disruption, manage restrictions transparently, and strengthen the case for long-term funding.

The wider lesson is that system-wide outcomes can depend on assets owned and managed by different organisations, so realising system value depends on owners working together.



There are 58 river crossings, 28 for rail (plus one proposed) and 30 non-rail.

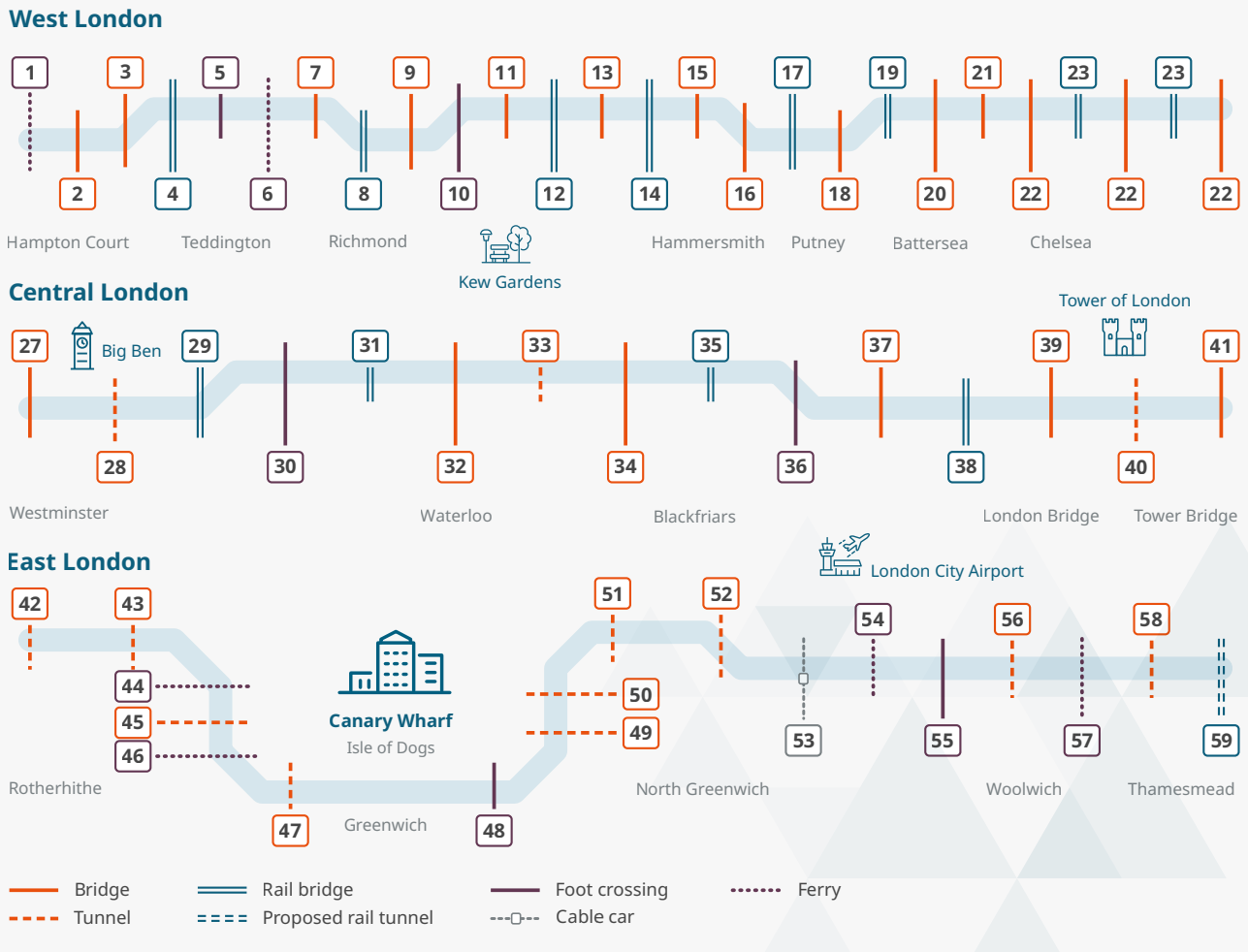
A systems approach can help prioritise investment, reduce disruption, manage restrictions transparently, and strengthen the case for long-term funding.

Disclaimer. It should be noted that this case study is a thought piece exploring how systems thinking could be applied to London's Thames crossings to support investment cases and improve overall benefits. It reflects the author's views and is not a policy position of TfL, the London boroughs, the City Bridge Foundation or LoBEG. The author thanks TfL for providing insights and background on the management of Thames crossings. The London boroughs, LoBEG and the City Bridge Foundation were not consulted in developing this paper.

Scope

This study covers London's Thames crossings as a connected system within Greater London. It includes road bridges and tunnels, pedestrian and cycling crossings, ferries, and relevant public transport crossings where these affect cross-river connectivity. The primary focus is on non-rail structures, reflecting TfL's traffic authority role, but the wider modal context is included because road, bus, rail, ferry, walking and cycling operate as one mobility system.

Figure 1: London's Thames crossings — spatial and modal portfolio





Hammersmith Bridge is one of several currently closed or restricted crossings.

The geographical scope covers west, central and east London. There is substantial variation in crossing density, modal choice, charging, accessibility and restrictions. West London has 23 crossings, central London has 18 and east London has 17. However, the mix and usability of those crossings differ markedly by mode (road, bus, rail, ferry, walking and cycling) and user group.

This case study is exploratory. It considers how systems thinking could help inform cross-boundary infrastructure challenges in a city like London, building on existing collaboration between crossing owners. It examines how the system is governed, funded, maintained and prioritised, and how a fuller portfolio view could improve outcomes.

The key stakeholders include TfL, London boroughs, the City Bridge Foundation, LoBEG, DfT, transport users, public transport operators, freight and servicing operators, local communities and businesses.

The systemic challenge is that a strategic London-wide network depends on assets owned, funded and maintained by many different organisations. The case study therefore focuses on how owners can steward the portfolio, rather than on the engineering design of individual assets.

Outcomes

London's Thames crossings are intended to support safe, reliable and inclusive movement across the river. They enable people, goods and services to move between communities, employment centres and strategic destinations. The desired outcomes are wider than transport connectivity alone. They include economic productivity, enabled by efficient freight, logistics and mobility, active travel, access to jobs, education, leisure and services, reduced severance, resilience to asset failure, and good value from existing infrastructure.

Actual outcomes vary significantly across the system. Central and west London have relatively dense crossing provision, with multiple bridges, rail links, walking and cycling routes, and many cross-river bus routes. East London has fewer practical choices, particularly for buses and active travel. There are approximately 52 cross-river bus routes in west London and 58 in central London, but only three in east London, despite continuing growth and development pressures. There are also constraints on cross-river movement in east London, including limited operating hours, lift availability at foot tunnels and restrictions affecting pedestrians, cyclists, vans and HGVs.

The condition and availability of existing crossings are major determinants of system outcomes. Several crossings are already closed or restricted, including Vauxhall Bridge, Hammersmith Bridge, Albert Bridge, Rotherhithe Tunnel and Woolwich Foot Tunnel. These limitations affect the wider movement system, not only the individual structures concerned. A closure or restriction displaces traffic, bus operations, walking, cycling and freight onto alternative crossings, increasing pressure elsewhere and reducing network resilience.

Access to cross-river movement is uneven. Where crossings are unavailable, restricted or have limited operating hours, some users face longer journeys or fewer practical choices.

The central systems insight is that cross-river connectivity is an emergent property of the portfolio. It cannot be understood by assessing each structure in isolation.

This particularly affects pedestrians, cyclists, bus users, disabled users and people without access to a private car. These constraints are particularly important in east London, where there are fewer practical choices and some crossings have constraints on access or use.

The economic outcomes are affected by funding constraints and by how fully decisions reflect impacts across the network. When crossings become restricted or unreliable, the costs appear as delay, diversion, reduced network capacity, increased operating costs, lost productivity and increased risk of emergency interventions.

The outcome gap is therefore not simply a shortage of crossings or poor condition in individual assets. It is the difference between the safe, reliable, accessible and resilient connectivity that London needs and the connectivity that the whole system delivers in practice. Closing that gap requires owners to work together to understand system performance and the distribution of benefits across London; and to use that understanding to inform their own investment and operational decisions.

Systems

London's crossings are parts of a wider movement system of physical, organisational and digital elements. The physical system includes walking and cycling links, connecting roads, transport interchanges, and bus and rail services. Assets differ in capacity, condition, accessibility, charging, opening hours and modal use. Their performance affects local streets, freight and public transport reliability, emergency access and the resilience of surrounding networks.

Organisational responsibilities are distributed. Responsibility for ownership, maintenance, funding and operation is split between TfL, boroughs, the City Bridge Foundation and other bodies. These arrangements reflect the history and particular circumstances of individual crossings, but do not necessarily take a joined-up view of the system as a whole, and organisations may have competing priorities. Each owner makes decisions within its own duties and budgets, while the consequences of closure or restriction are felt across London's wider transport and economic system.

In several cases, the scale and cost of maintaining and renewing river crossings can exceed funding available to asset owners, creating challenges in bringing forward timely interventions and increasing the risk of unplanned restrictions or closures. Any crossing, whoever owns it, can become a London-wide resilience issue if its closure displaces buses, freight and general traffic onto other crossings.

The digital and information system is well established and continuing to develop. TfL and the boroughs share data on condition, usage, restrictions and traffic volumes, and work together through LoBEG, while the Thames River Crossings Group coordinates works and shares knowledge across crossing owners. The value of this information can be maximised by using it more fully as part of a portfolio view, connecting condition data with service performance, accessibility, modal capacity, economic impact, development need and network resilience.

The main leverage point is therefore not a single crossing. It is how each owner's investment priorities reflect the wider crossings system alongside its other infrastructure needs. A systems approach makes visible the interdependencies between asset condition, modal choice, growth, equity and resilience. It helps identify where a relatively modest intervention could prevent wider disruption, where maintenance should be prioritised because of network criticality, and where new or improved crossings could unlock wider benefits.

The central systems insight is that cross-river connectivity is an emergent property of the portfolio. It cannot be understood by assessing each structure in isolation. Better outcomes can come from further developing existing approaches, including LoBEG's pan-London prioritisation of borough bridge investment, so that each crossing is assessed by its contribution to wider network performance, while ownership responsibilities remain distributed.

Economic assessment

The economic case for applying a systems approach to London's Thames crossings is not simply that more funding is needed. Consistent with Green Book principles, the rationale for intervention rests on the coordination challenge created by distributed responsibilities, namely that asset-level decisions may not fully reflect costs and benefits across the wider transport network. A systems approach could improve investment decisions by making these impacts visible and directing funding towards interventions that deliver the greatest overall public value.

Crossings are owned and funded by TfL, boroughs and the City Bridge Foundation. Each makes reasonable decisions within its own responsibilities and funding constraints, but those decisions may not fully reflect wider network impacts. Costs borne by transport users, operators, businesses, communities and other parts of the network may therefore not be fully reflected in decisions about individual assets.

The baseline of continuing current arrangements includes constrained funding and increasing risk to service performance. Several crossings are already closed or restricted, reducing the capacity and resilience of the cross-river movement system. The consequences include longer journeys, traffic diversions, bus disruption, reduced freight reliability, poorer access to jobs and services, lost productivity, pressure on neighbouring crossings and increased risk of emergency intervention. The economic value of a portfolio view lies in considering these wider effects alongside structural condition when setting priorities.



The Thames cable car was constructed to improve cross-river connectivity for pedestrians in east London.

The scale of the funding challenge is already evident across London's Thames crossings and makes better prioritisation especially important. Vauxhall Bridge, which is currently subject to an 18t weight restriction, illustrates the growing investment pressures associated with ageing assets. The national £1 billion Structures Fund may help, but it is open to highway authorities across the country and is expected to be heavily oversubscribed.

A systems approach could enable investment to be prioritised according to whole-network criticality and the consequences of closure. Its primary value lies in improving decision-making by bringing together evidence on asset condition, network performance, accessibility, resilience, economic activity and user impacts. This enables decisionmakers to compare investment scenarios and direct scarce resources towards the highest value interventions.

The available evidence identifies the relevant types of cost and benefit but does not yet quantify the economic value of a portfolio view. It therefore provides a clear qualitative case for a systems approach, while further work is required to establish the magnitude of potential benefits. This requires estimating the avoided costs of closure and restriction, including journey-time losses, bus operating impacts, freight delays, emergency works, carbon impacts, accessibility losses and effects on local economies. It should also compare planned preventative investment with reactive intervention after failure. This would turn the qualitative case for stewardship into a quantified investment case.

In summary, the economic proposition is that a systems approach can improve the allocation of scarce funding by reflecting costs and benefits that asset-level decisions may overlook, and by helping each owner weigh crossing investment against its wider infrastructure needs with a fuller understanding of network-wide outcomes.

The outcome gap is not simply a shortage of crossings or poor condition in individual assets. It is the difference between the safe, reliable, accessible and resilient connectivity that London needs and the connectivity that the whole system delivers in practice.

Systemic assessment

London's crossings show that system value can depend on assets owned by many different bodies. Crossings are owned, funded and maintained separately, but their performance affects movement, economic activity and resilience across the capital. The body responsible for a structure may not have the resources or remit to account fully for the wider consequences of closure or restriction.

The resulting challenge is not simply the level of investment in individual assets. It is how fully each owner's investment assessment reflects network-wide consequences alongside its wider infrastructure needs when funding is constrained. Existing pan-London prioritisation of borough bridges

provides a foundation. A fuller system view can help owners identify crossings whose closure would impose substantial costs beyond the owner's boundary or whose benefits are widely distributed.

There is also an equity and place issue. Crossing provision and accessibility vary across London. East London has fewer practical bus and active travel options, while some existing crossings are constrained by operating hours, lift availability or user restrictions. The number of crossings does not always reflect the connectivity the system provides.

The transferable lesson is that distributed ownership requires system stewardship across organisational boundaries. For nationally significant urban systems, shared evidence and common prioritisation criteria are needed to assess system-wide value. Owners need to work together, with appropriate funding, to address risks and investment needs that none can resolve alone. Better outcomes per pound depend not only on engineering, but on decisionmaking that connects asset condition and investment to service outcomes, user impacts and network resilience.

Interventions

The interventions suggested in this case study are primarily governance, coordination, data and investment-planning interventions. TfL supports the Thames River Crossings Group, which coordinates works, reduces disruption, shares knowledge and supports crossing owners. TfL and the boroughs work closely through LoBEG and share bridge data, including information on condition, usage, restrictions, traffic volumes and related metrics. Since 1999, LoBEG has also used a pan-London framework to prioritise TfL funding for major strengthening and refurbishment of borough bridges, using agreed criteria. These arrangements already take a road system view of bridge investment and coordinate works across crossings. Their value could be extended by drawing on a wider range of system evidence.

Further interventions could include developing a stronger case to government for long-term investment, using the planned 'State of the City' focus on river crossings; testing investment scenarios ranging from timely intervention to continuing restrictions; and developing existing prioritisation further to reflect criticality, modal function, accessibility and resilience alongside condition and usage.

Building on existing arrangements, crossing owners could use shared evidence and agreed criteria to identify collective priorities, inform their own investment decisions, coordinate interventions, monitor outcomes and address risks that no single owner can resolve, while each retains responsibility for its own assets.

The potential output is a clearer, shared, evidence-led view of investment priorities across London's river crossings. The potential system impact is to reduce the risk of unplanned closures, improve transparency about trade-offs, inform investment priorities, and protect cross-river connectivity for buses, freight, walking, cycling and general traffic.

Recommendations

London's Thames crossings could benefit from being considered as a connected infrastructure portfolio. The following actions are suggested:

- **Build on the existing pan-London prioritisation framework developed by LoBEG**, extending it to reflect system performance, modal function, accessibility, resilience, economic impact and consequences of closure.
- **Develop a Thames Crossings portfolio plan owned jointly by crossing owners**. It should cover condition, restrictions, usage, bus impacts, freight impacts, constraints on active travel, growth pressures, investment scenarios and quantified costs of closure and restriction, to inform each owner's priorities alongside its wider infrastructure needs.
- **Reflect system-wide value in investment cases**. Government should recognise that some locally owned crossings have London-wide and nationally significant value. Future investment cases should compare planned preventative maintenance with the costs of delay, diversion, emergency intervention and reduced service performance.
- **Strengthen collaboration between crossing owners**, building on the Thames River Crossings Group, LoBEG and the State of the City report, so that owners share evidence, identify collective priorities, inform their own investment decisions, coordinate interventions, monitor outcomes and address risks that no single owner can resolve.
- **Prioritise equity and place outcomes**, especially in east London, where practical cross-river choices for buses and active travel are more limited, and where reliable and accessible connectivity is needed to support growth.
- **Provide sustainable funding for strategically important crossings**, recognising that they support economic activity, housing growth and connectivity across London.

The wider national lesson is that ageing infrastructure portfolios need system stewardship. Asset condition data is necessary but not sufficient. Decisionmakers need to understand how individual assets contribute to service outcomes, network resilience and long-term public value.

References

London Assembly Transport Committee (2021) – London's river crossings: **bridging the Thames** – used for evidence on ownership and distributed responsibility of Thames crossings, variations in connectivity and access across London, the impacts of crossing closures and restrictions on network resilience.

National Engineering Policy Centre, Reviving our ageing infrastructure (2025) – used for wider evidence on infrastructure stewardship, the distinction between asset condition and system health, long-term financing, shared data, and coordination across organisational boundaries.

London Bridges Engineering Group: pan-London bridge prioritisation process – used for evidence on existing collaborative prioritisation of bridge investment.

10



Oxford to Cambridge Growth Corridor

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Cross-sector regional development.

Systems contribution and value: Outcome-led framing and systems mapping made cross-sector dependencies, sequencing needs, gaps and trade-offs visible before major choices. Identified opportunities to reduce coordination failure and de-risk cross-sector investment.

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Summary

The Oxford to Cambridge Growth Corridor is a designated economic and innovation region and network of high-tech industries, world-leading universities, science parks, and research-intensive businesses.

Government has already identified a valuable long-term investment opportunity for growth across the corridor. Much detailed work has been done to define the components of the corridor, by Supercluster (a consortium of institutions and businesses set up to shape and develop the corridor) and by HM Treasury.

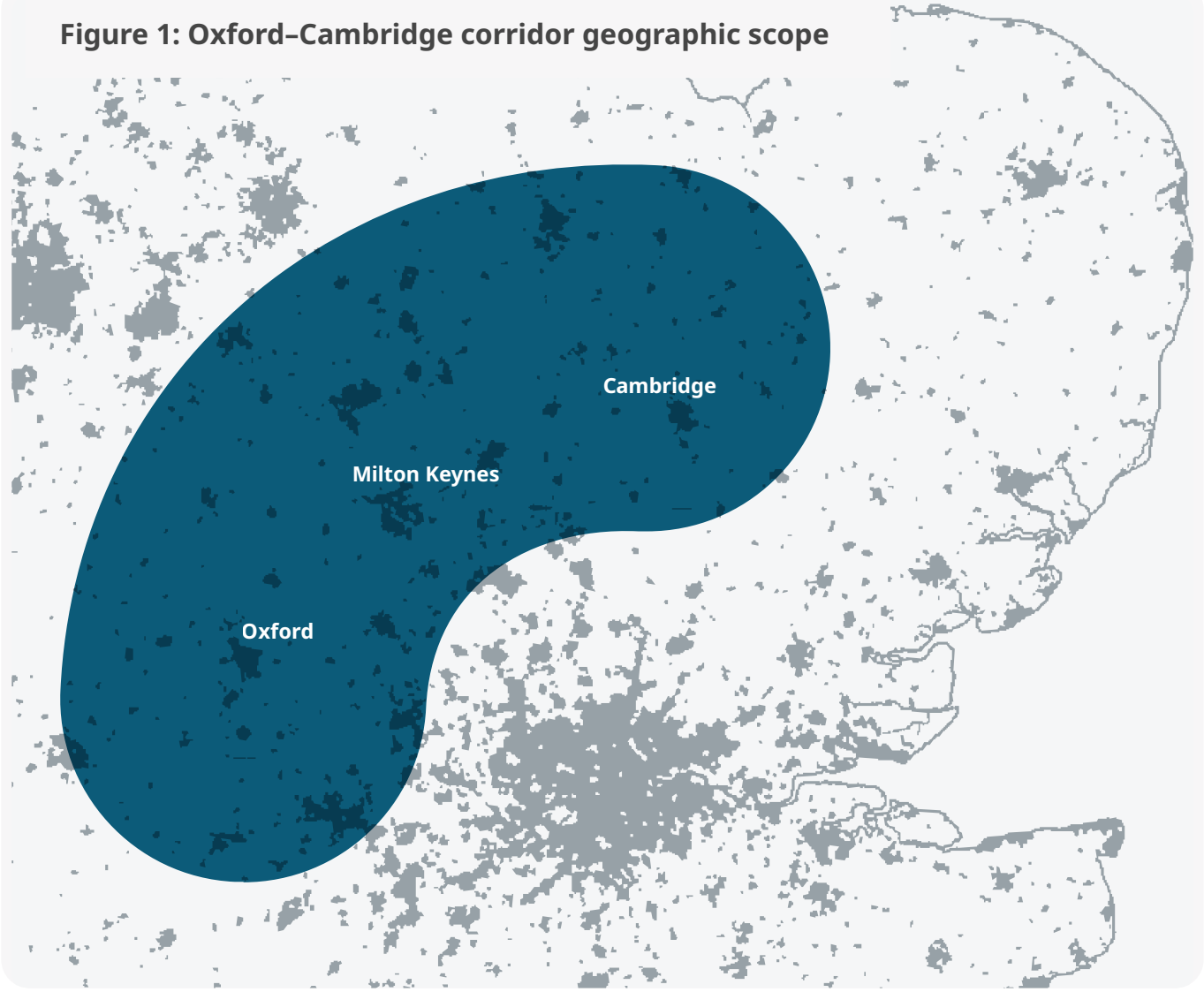
The Built Environment Connective's 'Connect to change' logic model[1] complements this by bringing focus on system-wide outcomes rather than the management of individual programmes. It identifies the interdependence of contributing systems; tipping points where there is a threshold of effectiveness; risks, bottlenecks and unintended consequences; and the sequence in which interventions should be executed. It also highlights the need for governance that brings together all interested parties to identify and agree trade-offs for competing resources, focusing on coordination and collaboration while leaving the management of individual programmes to their owners.

Through a series of workshops, transport, housing, skills, utilities and social infrastructure were identified as in particular need of coordinated action to deliver the best possible value for money. This case study recommends:

- A structured breakdown of requirements should be used to define a project or programme.
- The corridor should create a comprehensive systems map, both because of its value to programme management and because it will engage all of the actors.
- It should develop and agree a model for governance.

1 https://be-connective.com/wp-content/uploads/2025/07/Connect-to-change.pdf

Figure 1: Oxford–Cambridge corridor geographic scope



Scope

Extensive work has already defined many of the issues that have to be addressed to bring about Oxford to Cambridge Growth Corridor. This case study explores what value would be added by applying the approach set out in 'Connect to Change' (C2C) to accelerate the development, maximise its cost-effectiveness and minimise risk. This approach follows logical steps, starting with outcomes:

- Focusing and clarifying the outcomes sought for people and nature, understanding the gap between current and desired performance, and using those outcomes to compare options, make trade-offs and guide decisions.
- Understanding how outcomes depend on physical, organisational and digital systems, including the interdependencies and external influences that shape their performance.
- Driving effective interventions – those most likely to improve outcomes, including physical, operational, digital, behavioural, governance and nature-based interventions. Effort is focused where it can make the greatest difference.
- Observation, learning and adaptation, as conditions and evidence change.

The whole logic model is framed within a clear definition of scope – the system that is to be influenced, the boundaries that matter and the stakeholders who need to be involved.

To understand outcomes for the corridor, a guiding vision was required. This was developed through stakeholder discussions and workshops, and captured as: **"A region of world-leading innovation enabling inclusive and sustainable growth that benefits the whole economy and improves quality of life."**

Within the vision, "innovation" means the process of converting fundamental research into new technologies and "the whole economy" refers to benefits across the UK as well as within the corridor.

The corridor was defined in terms of geography (represented in Figure 1), and function – primarily economic growth. Secondary objectives, such as the creation of additional high quality housing, a good quality of life for a growing regional population, and environmental sustainability affect how the primary function is to be achieved.



'Meta-outcomes' were defined to federate disparate systems and then link them to requirements. This vast array of systems, and the way that they are implemented, impact the viability of the corridor.

Outcome

The vision alone does not define the outcome; it needs to be converted into a set of requirements. In turn, requirement must be supported by:

- metrics that measure progress against the requirements
- specifications which state quantitively what must be achieved for it to be considered that the vision has been achieved. Specifications are emphatically not targets. Targets are something to strive towards. Specifications are what is needed.

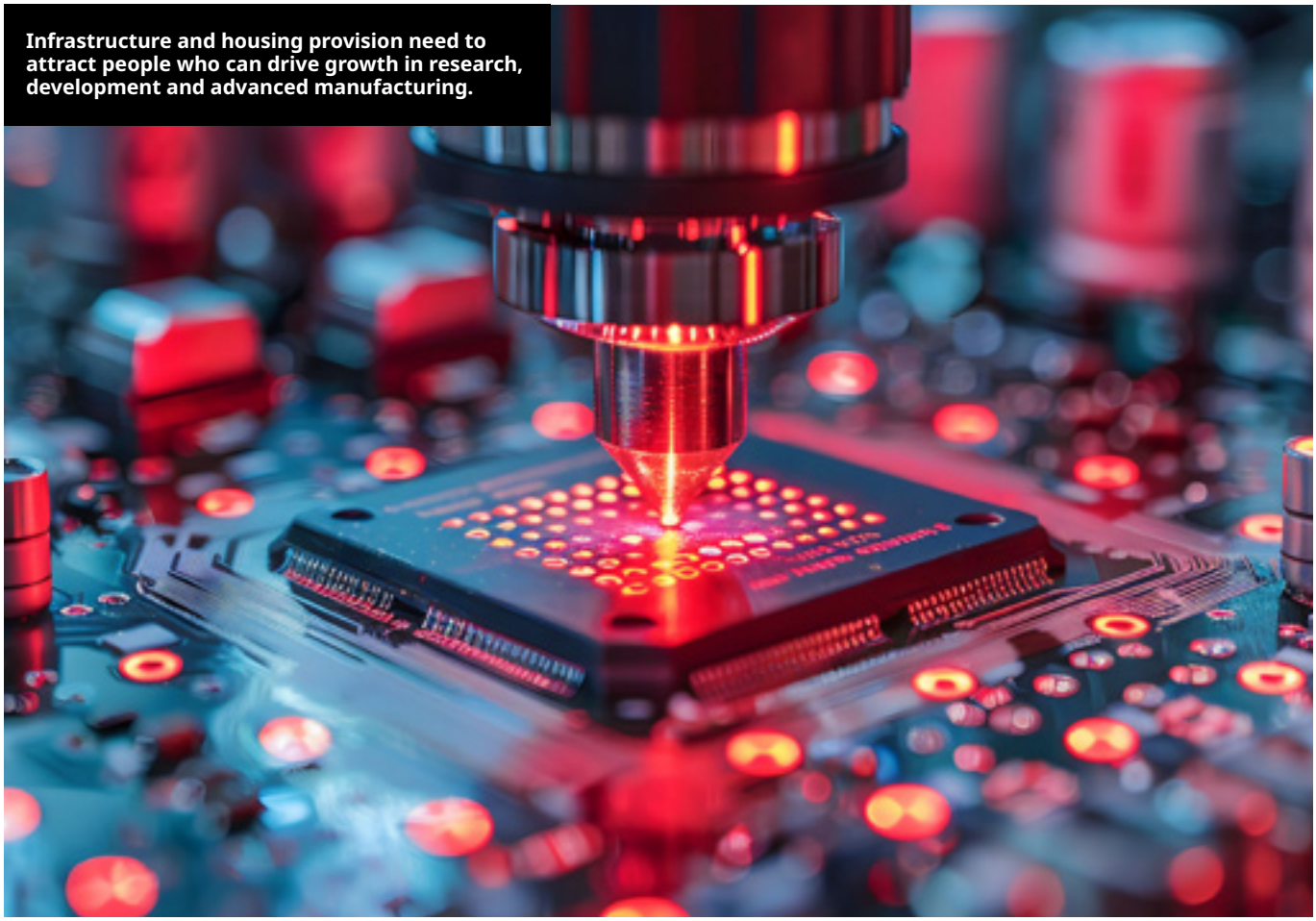
Systems

The Corridor consists of hundreds of systems with widely distributed ownership:

- Economic infrastructure: water, energy, transport, flood defence, waste
- Digital infrastructure: internet, data centres, models, digital twins
- Social infrastructure: health, education, culture, community
- Urban infrastructure: housing, industrial and retail buildings, public facilities
- Natural systems: biodiversity, water catchments, environmental quality
- Organisational systems: governance, institutions, regulation

In preparation for this case study an initial systems map was developed showing around 200 systems with around 20 interventions, all of which were linked to the requirements and hence the outcomes. A snapshot of an incomplete map is shown in Figure 2; the full map is too detailed to be readable on page but would emerge from a larger and more inclusive study of the corridor.

For clarity 'meta-outcomes' were defined to federate disparate systems and then link them to the requirements.



Infrastructure and housing provision need to attract people who can drive growth in research, development and advanced manufacturing.

Like solving a wicked problem, planning should not seek a complete solution but should identify key drivers (enablers and blockers) where leverage and coordination would best help.

This vast array of systems, and the way that they are implemented, impact the viability of the corridor. Some of the themes that were raised in workshops were:

- **Education and skills**: At labs, R&D facilities and campuses – not just near Oxford and Cambridge, but throughout the corridor – employers are struggling to recruit the skills they need at the scale needed for growth.
- **Transport:** Local and regional connectivity; avoiding car dependency; agglomeration benefits near stations.
- **Energy and water:** Utilities capacity, environmental constraints, innovation in provision.
- **Governance and long-term leadership**: Alignment of incentives; continuity of institutional memory.
- **People and labour market**: Diversity beyond PhDs, including nurses, bus drivers, bricklayers; also attracting international talent.
- **Community, place, and quality of life:** Personal sense of safety, housing that feels 'lovely', sense of place; learning from Silicon Valley's challenges, eg. housing affordability.
- **Digital infrastructure and data:** Federated digital twins, data sharing ecosystems, low-cost connectivity.
- **Alignment of actions** between the many different authorities, for example by aligning disparate local plans.

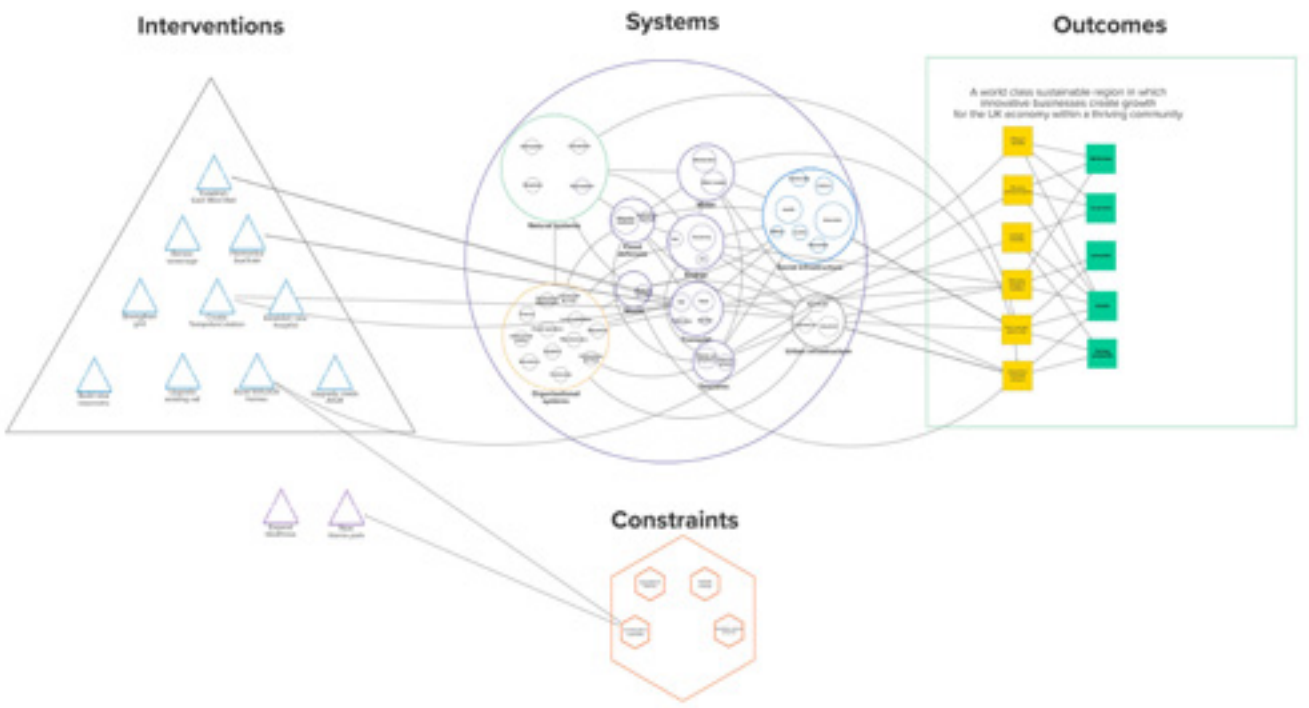
Economic assessment

Economic messages emerged from the workshops:

- A clear, stable, long-term vision, even if imperfect, enables better investment than constant change. Scenario analysis and adaptive policies can handle uncertainty.
- Interventions should be planned for the long term to optimise through-life costs, around principles of stewardship.
- Closely related to this, private investment needs adequate returns and acceptable risks.
- Many of the critical systems are administrative and organisational and must also be planned and managed.
- Success hinges on people; the corridor must be an attractive place to live and work for the entire community.

Government intervention is justified because of market failures: the benefits accrue across the economy but the costs and risks of action are borne by individual organisations, local authorities or investors. Intervention

Figure 2: Systems, interventions, outcomes and constraints



promotes positive externalities and shares information, for example to avoid two projects competing for labour that raises costs and causes delays.

HM Treasury already plays an important role, providing a 'helicopter view' while allowing departments to optimise delivery within their remits. However, more governance will optimise systems that span policy areas.

Many risks and opportunities sit between organisations rather than within them and require trade-offs to span those boundaries, for example to apportion a limited supply of a critical resource (eg. bricks or bricklayers, available land). East West Rail, housing and planning initiatives, development corporation proposals, and the work of HM Treasury, NISTA, the Supercluster and delivery partners have started to coordinate the corridor.

The C2C approach makes this coordination more systematic and hence improves the stakeholders' collective ability to avoid delayed growth, infrastructure bottlenecks, under-utilised assets, duplicated effort, low investor confidence, and missed opportunities.

The Supercluster estimates that the Corridor could contribute £78 billion to UK GVA by 2035. C2C reduces the risk of failure and increases the likelihood that the benefits will be realised through:

- **Avoiding the costs of failure**. Many costs arise when dependencies between systems are identified too late.
- **Improving sequencing**. The order in which interventions are delivered matters.
- **Accelerating benefits**. Coordination can bring forward benefits that are already planned rather than creating entirely new ones.
- **Enabling transformational change**. Opportunities emerge from interactions between systems, not just individual projects.

Trade-offs need transparent and adaptive governance to identify cross-system risks and align incentives. This is not centralised planning. Governance should:

- reflect the needs and contributions of each of the actors
- respect the authority of each actor within its silo
- have the authority to create alignment and trade-offs between competing demands.

The strongly emergent message is that an undertaking as complex as the corridor will at best be an expensive success and at worst an expensive failure unless a long-lived governance body exists that:

- has the requisite expertise and authority
- understands the systems, their contributions and interactions
- dynamically aligns all actions to the required outcome
- identifies tipping points, where a small change to timing or content has a big impact
- defines interventions so all necessary systems are available when needed, but leaves management of the programme and interventions to others.

Table 1. Requirements and some representative possible metrics and specifications

Requirement	Meaning	Examples of possible metrics	Examples of possible specifications
Growth	Value of economy in corridor	Rate of increase of GVA per head	2% per year
		Rate of increase of GVA in region	3% per year
	Whole economy	Income in other regions due to work done in corridor	>£5B per year after 10 years
Region	Geographic area with strong ecosystem	Fraction of collaborations with other actors in the region	>50%
World-leading	In top ten of innovation regions	Companies recognised as innovative	>25% of companies in region
		Startups and tech SMEs	>25 % of companies in region
		Square metres of lab space opened per year	10,000
Innovation	Employers in priority sectors	Life science, sustainable aviation, space, future mobility, zero-carbon energy	At least 10% of companies in the Corridor from each sector
	Innovative products and services	Patent applications per head of population	0.1
		VC investment per head of population	£100k
Inclusive	Wide range of demographics	% of population with PhD	<5
	Employment for skills, professions and trades	Number of apprenticeships	10% of workforce
Sustainable	Economic – short term	Ratio of private to public investment	2:1
	Economic – long term		5:1
	Environmental	Land actively managed for nature	double by 2050
Quality of life	Places where people want to live	Sense of place - flourishing communities, improved public services	90% of public services < 15 mins walk
			500,000 new homes: >25% for rent, >25% social, >50% affordable
		Valued jobs with low unemployment and fair distribution of rewards	Media earnings > 2x national avg
			(variance)/median earnings < 2
			Unemployment < 3%
			Poverty (all measures) < 30% national avg
		Strong and effective communications	E-W rail at 4 trains/hr
			E-W road 80% dualled
			1 Gb fibre-optic to 95% of buildings
		Settlements of the future, green, modern construction	Energy use per home <50% of national avg
			>50% of homes built offsite

Systemic assessment

The logic of C2C is: first, define the outcome and quantify it; second, identify the systems, including human and natural systems, needed to deliver it; and third, plan interventions to ensure that all systems will be ready when needed.

These steps reduce wasted effort, reduce cost creep and facilitate on-time delivery.

Some systems are already adequate; others will need an intervention. Some interventions are already planned and might affect the outcome positively or negatively. For example, the Universal Studios Theme Park, a keystone development in the corridor, might improve quality of life but compete for resources. Interventions must take account of the interaction between systems, which can be positive or negative. The NISTA paper 'Ox-Cambs high level interdependency mapping' highlights some important interactions; others would emerge from a systems map.

The corridor is a complex opportunity because of interdependencies and uncertainties of the systems and interventions. Like solving a wicked problem, planning should not seek a complete solution but should identify key drivers (enablers and blockers) where leverage and coordination would best help. They should address the situation as seen now, and concentrate efforts on these. Over time, the key drivers and the focus of action will change.

The programme should look far enough ahead to allow the interventions to be delivered in time. For example, a reservoir might need 10 years whereas a bus service could be delivered in six months, and resolving incompatible local plans might take two years. The programme should identify thresholds, for example a railway might need a minimum number of services per day to be effective.



Site of the planned Universal Studios theme park and resort, near Bedford, with Kempston Hardwick railway station in the foreground.

Recommendations

This case study had the dual purpose of using the corridor to test C2C and using C2C to help plan the corridor.

Recommendation for evolution of C2C

- Break the outcome into vision, requirements, metrics and specifications.
- Use 'meta-outcomes' to federate contributions by several systems.

Recommendations for the corridor
Build a comprehensive systems map. The specification and elements of the map should be linked to the existing work on individual systems, preferably by URLs to documents.

- All actors can contribute to the vision, requirements, metrics and specifications, seeking a shared view endorsed as widely as possible.
- The need for and impact of interventions may be assessed before committing to them.
- Consequences of trade-offs must be visible.
- Building the map will align the thinking of everyone involved.
- It could form the basis of a management tool, such as a digital twin, that shows the wider impact of decisions.

Work with all actors to define a governance body as a collaborative hub that provides stewardship to:

- Engage everyone involved, including local communities.
- Maintain the shared outcome.
- Track metrics and course correct as the corridor evolves.
- Agree priorities, sequence of actions and trade-offs.
- Align incentives across sectors and organisations.
- Preserve institutional knowledge.
- Promote the corridor as a 'brand' with a clear identity.

A small change in the estimated £78 billion benefits of the corridor will greatly repay the cost of these two recommendations.

11



River Intervention and Systems Model

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Great Ouse catchment and water resource.

Systems contribution and value: Modelled interventions considering water, land and ecology, to find balance between different user needs. Illustrated potential impacts on water security, water quality, reservoir and treatment costs, carbon, flood risk and biodiversity.

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Summary

People value the services infrastructure provides, not the infrastructure itself. Large water schemes deliver several services at once – water supply or wastewater disposal, but also environments enjoyed by people for leisure and recreation, habitats for wildlife, flood risk mitigation, carbon sequestration, and more. Different organisations are involved in delivering and managing the infrastructure. Others are impacted by the way it is delivered and operated. Every organisation has its own budget, its own rules and its own way of measuring what matters.

The Fens Reservoir is a joint venture between Cambridge Water and Anglian Water to increase deployable output in East Anglia while relieving pressure on chalk aquifers. The reservoir will be filled principally by drawing water from the region's land drainage and river network. Its operation will significantly influence operation of the drainage system, which will in turn influence land use and soil systems.

This case study examines an aspect of this interaction.

Both companies' water resources management plans (WRMP) were prepared following systems approaches under the Best Value Planning framework, which weighs environmental, social, resilience and carbon value alongside cost. Both WRMPs are accompanied by a strategic environmental assessment examining the wider benefits and impacts of delivering them.

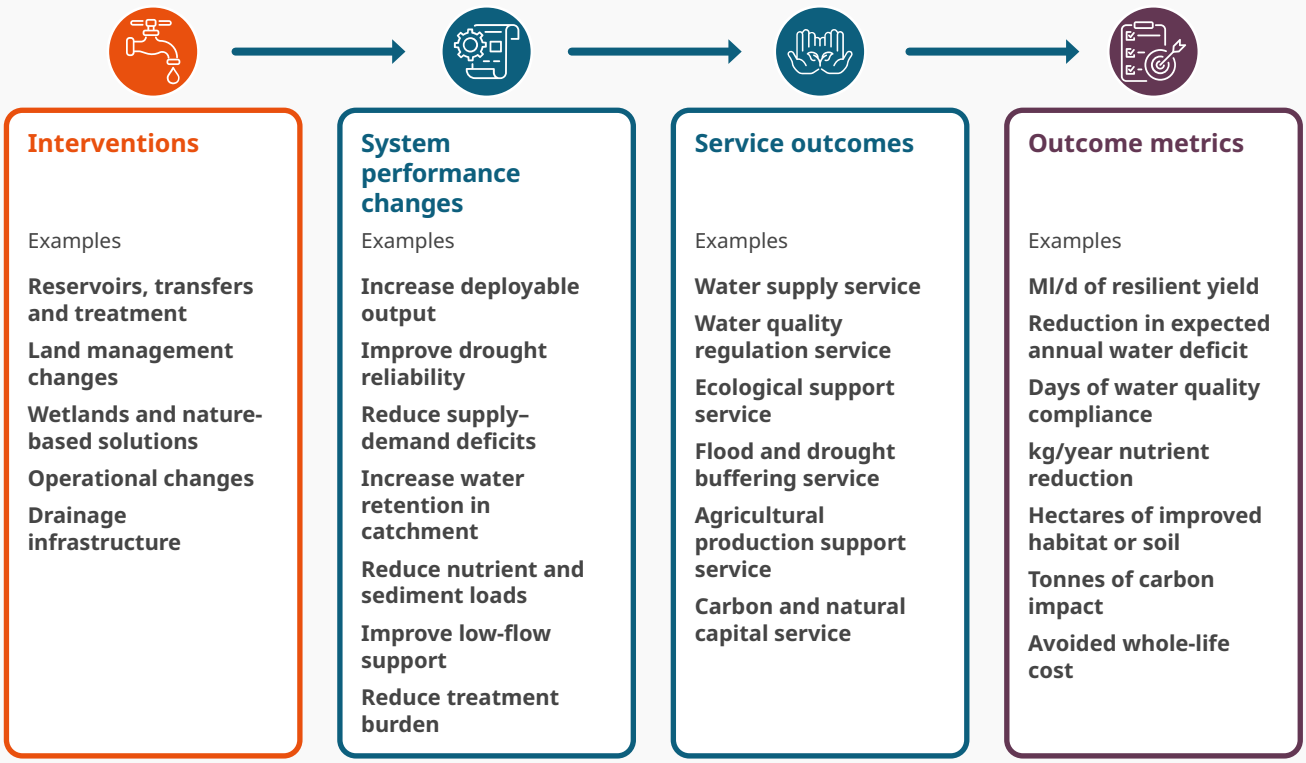
However, it remains challenging to consider the Fens Reservoir system, and systems more broadly, in a fully quantitative manner, and to set out exactly what each intervention means for every level of stakeholder.

To support and facilitate quantitative systems approaches, we have developed PRISM (Practical River Interventions and Systems Model). It is a tool for weighing catchment measures alongside major water infrastructure. PRISM draws out the benefits that arise across the system and how they interact, puts numbers behind them, and reports incremental changes in outcomes in terms that every level of stakeholder can understand and act on.

This case study introduces PRISM and illustrates it with aspects drawn from the Fens Reservoir scheme. It focuses, for brevity, on a peat rewetting intervention, though many other interventions are considered in the full version. The analysis is based on publicly available information and is

Figure 1: Principles of PRISM – from interventions to outcomes

PRISM links interventions to system performance, services and measurable outcomes.



PRISM quantifies the link from interventions → performance → services → outcomes for people, nature and the economy.

Quantitative outcomes allow comparison of alternative portfolios to identify the best combination of interventions.

independent of Cambridge Water and Anglian Water's actual project planning process.

PRISM is a systems model aiming to quantify outcomes as the sum of services that a system provides, and the benefits of interventions in terms of incremental outcome changes. Figure 1 illustrates the principles, figures 2 and 3 show screenshots from the model system itself.

PRISM models the river, the engineered infrastructure and the catchment as one connected system, so that a change in one place carries through to everything it touches, and it reports the same result three ways:

1. for those who plan, fund and regulate
2. for those who design, build and facilitate
3. for those whose land and property is affected.

Scenarios can be assessed in seconds allowing PRISM's use as an interactive tool amongst stakeholders.

Using the planned Fens Reservoir system as a worked example, we modelled what a coordinated set of catchment measures can add alongside it, what the co-benefits are, and how those can be communicated at every level. Modelling a whole catchment also exposes effects falling between the remits of the organisations involved (figure 4), several of which are set out in 'Outcomes', below.

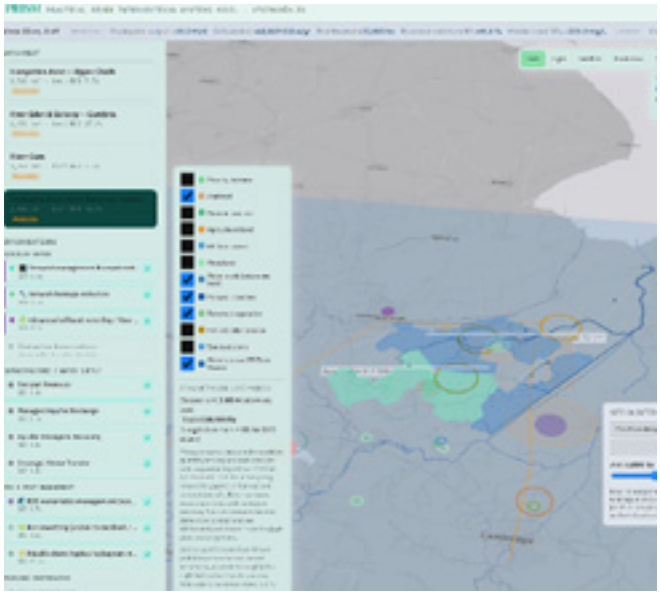


Figure 2. PRISM model interface for Fens case. Example values from a test configuration.



Figure 3: PRISM report for a demonstration portfolio.

Scope

Eastern England faces projected water shortages of around 800 million litres a day by 2050, equivalent to about a third of current use in the region (Water Resources East, Regional Water Resources Plan for Eastern England, 2023). The Fens Reservoir is included in both Anglian Water's and Cambridge Water's water resources management plans and will provide around 88 million litres a day, shared between the two companies' customers, to help address that shortfall (Ofwat, Case study: Anglian Water and Cambridge Water: Fens Reservoir, 2024). The reservoir is planned to be in supply by 2036 at the earliest, and is one of nine new reservoirs to which the government has committed (Department for Environment, Food and Rural Affairs (Defra), A New Vision for Water, CP 1490, 2026).

It is proposed that the reservoir will sit near Chatteris, Cambridgeshire. The area is historically waterlogged. To make it farmable, over centuries, a network of drainage channels has been dug, allowing water to be pumped out to dry the land and make it farmable. The level at which the water level is held is set by internal drainage boards and, on the main watercourses, by the Middle Level Commissioners.

The managed water level governs peat behaviour: wet peat stores water and breaks down slowly; dry peat breaks down rapidly, releasing carbon to the atmosphere and sulphur compounds that enter the water system when it rains – but peat's high absorbency provides buffering against flooding.

Responsibility for governing resources around the Fens Reservoir system is split several ways (figure 5). Drinking water supply sits with the water companies and their regulator; land drainage with the drainage boards and the Middle Level Commissioners; and peat and carbon largely with Defra and the Department for Energy Security and Net Zero. The land belongs to farmers, whose agreement is required in order to make any changes.

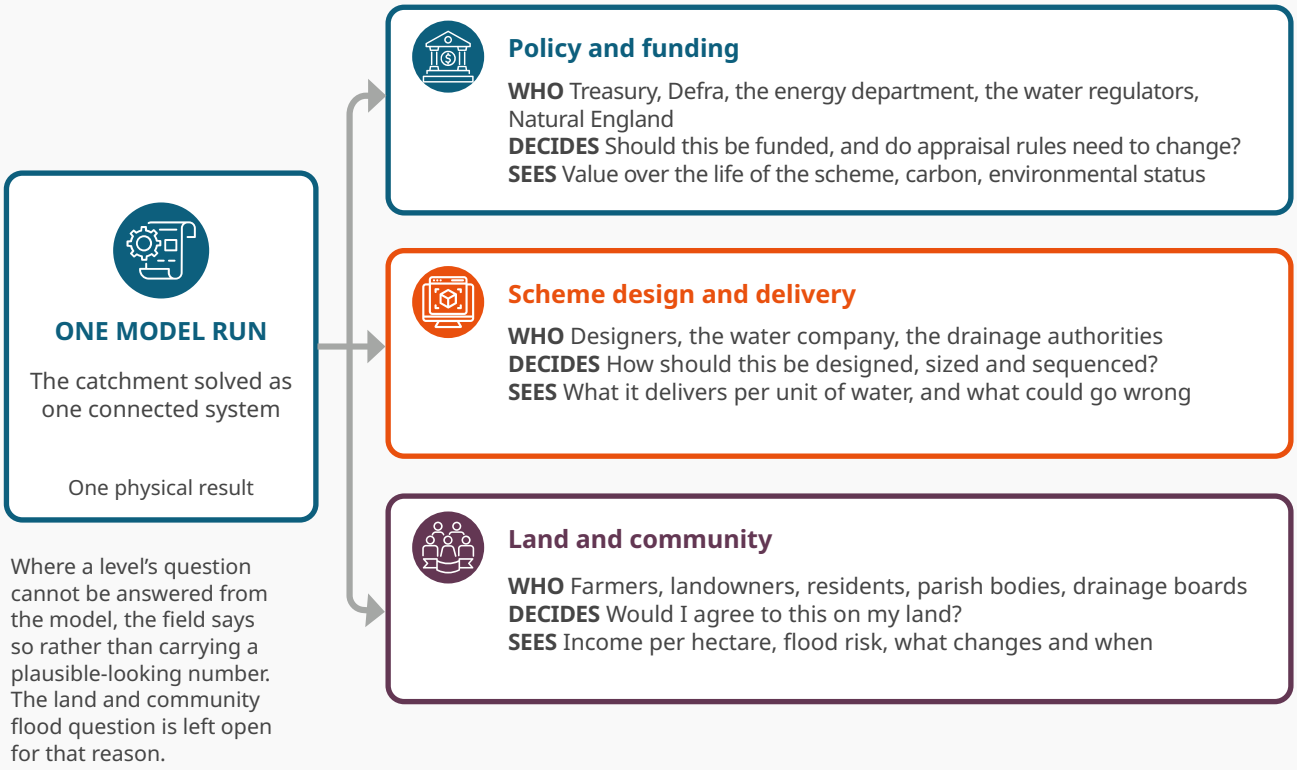
Bringing the water regulators into one body, as the government has committed to do, addresses part of this complexity. However, this change does not extend to the drainage boards, the carbon account or the landowner, and those parties between them set the water level.

These organisations already apply best value planning, strategic environmental assessment and integrated water management across the layers of the Fens Reservoir system. But it is challenging to capture every way that interventions interact with one another, and how each will alter outcomes overall: a measure taken for one purpose produces co-benefits that surface in another body's accounts, responsibilities intersect, and the parties at each tier (figure 4) depend on decisions taken at the others.

By setting out interventions and their interactions quantitatively then communicating them at the tier where each one lands, we can demonstrate the benefits of systems thinking in the system of the Fens Reservoir and beyond.

Figure 4: One model run, three sets of readers

The same physical result, reported in the units each group actually decides in. Nothing is recomputed between them.



Where a level's question cannot be answered from the model, the field says so rather than carrying a plausible-looking number. The land and community flood question is left open for that reason.

Outcomes

PRISM was applied to the catchment around the Fens Reservoir, drawing on 20 published national datasets listed at the end of the case study – climate, river flow, groundwater, soils and peat extent, protected sites, land classification, geology, flood risk and population – together with published research on the behaviour of drained peat.

PRISM can model many different scenarios depending on the interventions selected. As an example, choosing to raise the level at which water is held wets the peat beneath it, slowing decomposition and resulting in less carbon reaching the atmosphere; the same change alters the chemistry of the water leaving the drains, and creates wetland habitats. One operating decision therefore reaches carbon, water quality and biodiversity at once, and PRISM quantifies each of those consequences from the same run (figure 6).

Many organisational actions will have impacts beyond their own tier. For example, a drainage board setting a water level is, in practice, also affecting the national carbon account, resilience to drought and flood, the quality of nearby water and the habitat that land can support.

PRISM can be used to identify and model gains and trade-offs within a system. Focusing on water quality: wetting peat releases ammonium into the surrounding water, against a drinking water standard of 0.5 milligrams a litre; wetting peat can also reduce the release of sulphates to the water.

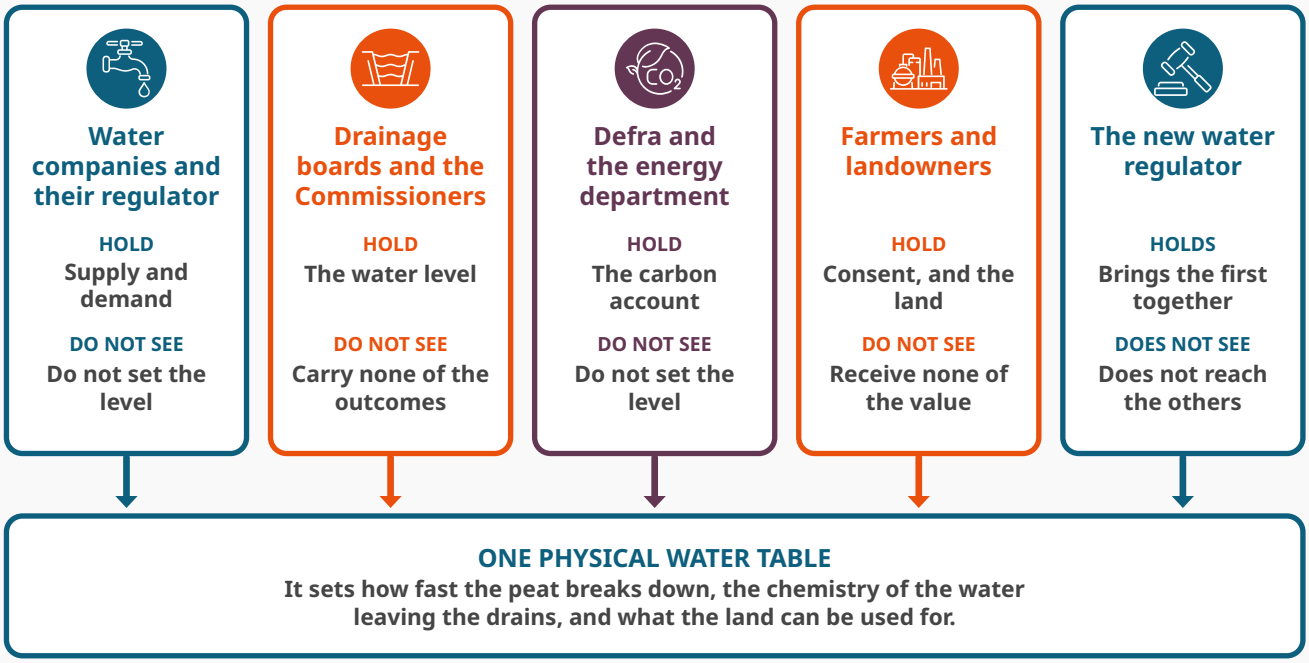
It remains challenging to consider the Fens Reservoir system, and systems more broadly, in a fully quantitative manner, and to set out exactly what each intervention means for every level of stakeholder.

The Fens programme considers these water quality changes and the resulting constraints on abstractions, blending and treatment requirements. PRISM can support this plan by running the hydrology and quantifying the changes in water quality to establish compliance with standards, in combination with reservoir fill and empty rate scenarios.

Similarly on flood risk, holding water at a higher level leaves less room in the system to buffer a winter storm but stores more water that can provide greater resilience in dry periods. PRISM can identify and facilitate planning even when issues fall between organisations' responsibilities.

Figure 5: One water table, five parties, no single holder

Each organisation controls part of the system and sees part of the result. None of them sees all of it, and none can act alone.



Bringing the water regulators into one body addresses the first column. It does not reach the drainage boards, the carbon account or the landowner, and those are the parties who between them determine the level. Every connector runs one way: no party receives back the consequences of the level it helps set.

Catchment measures are not only environmental in their effects. Several of those in PRISM's library add to the water available or ease the constraints that limit how much of a source can be drawn on, and PRISM reports those alongside the carbon, habitat and flood consequences so that all can be weighed together.

The same example reaches the landowner as well. Drained arable land on lowland peat earns roughly £450 to £1,100 a hectare a year, while wet farming earns roughly £150 to £600 (Defra Lowland Agricultural Peat Task Force, Final Report, 2023); carbon is valued for appraisal at £273 a tonne (DESNZ carbon values), and biodiversity units trade at around £45,000 each (Natural England, 2025). PRISM holds all three in the same ledger, so the value created by wetting the peat can be set directly against the farm income it displaces.

Systems

Modelling what happens in the fens means representing how the landscape is drained, and not only how much rain falls on it. The fen is pumped rather than drained by gravity. Water is removed from the drain system only when pumps start. The operation of pumps is determined by target levels, which are set as an operating decision rather than by the weather. Therefore, a model of rainfall and rivers alone cannot see that mechanism.

The raw water sources for the reservoir are not yet settled, with proposals identifying the Middle Level system (exiting at St Germans or to Ouse Washes), the Bedford Ouse at Earith or the Ouse Washes, and the River Nene and its Counter Drain as candidate sources, with abstraction only at higher flows and subject to licensing.

It is unlikely that all displayed in figure 9 would be used, and unlikely that they would be used in the proportions any single model configuration shows.

But this demonstrates an example of how PRISM can be used to facilitate building the systems picture. When a target level is changed, the water table moves with it; the carbon released and the chemistry of the water leaving the drains follow from that; and the quality of a filling route changes in turn. This is the physical system model component that underlies the benefits quantification and decision support facilitation of the whole systems model approach.

PRISM's hydrology was tested against the measured river flow record published by the National River Flow Archive (NRFA), being calibrated on one half, and verified against the other previously unseen half.

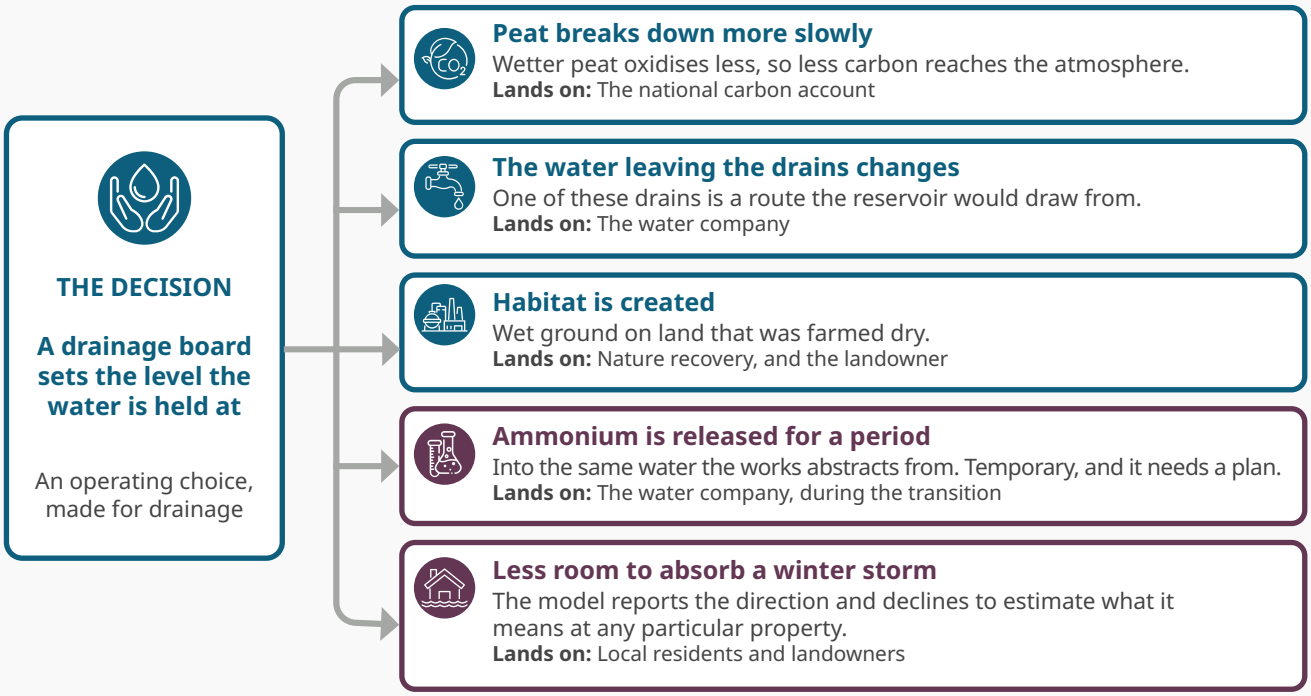
The gauge used is the Ely Ouse at Denver Complex[1]. It is the gauged outlet of this catchment (Figure 11) and it has the longest continuous river flow record of any gauge in the

1 NRFA station 33035

Figure 6: One decision, five consequences

A drainage board sets the level water is held at. Everything below follows from that single choice, and none of it belongs to the board.

BLUE: A GAIN | PURPLE: A TRADE-OFF



The board receives none of these outcomes and has no reason to see any of them.

region. For these reasons, it was used as a reference point for testing the model against measured flows, but it is not a proposed source for the reservoir.

Every result is accompanied by a record of how it was produced: which measures acted through which pathway, the assumptions in force, and anything the model stands in for rather than calculates.

Interventions

PRISM currently holds a library of 31 intervention measures, organised into nine groups. They range from changes to land and water levels through to demand-side and reuse schemes. Each one is described in the same service terms:

- what it does to the quantity of water available
- what it does to the quality of a source and to the land and the biodiversity it supports
- what it costs
- how it interacts with the other measures in a portfolio – whether it reinforces, competes, or produces co-benefits that none of them delivers on its own.

Those declarations travel with every result, so a reader can see what each measure is contributing and on what basis.

Each intervention has metrics of service provided, which drive the gains and trade-offs calculated. PRISM searches the whole library rather than scoring a few combinations.

Because the model records which measures affect each other, the search of more than 2 billion combinations is solved exactly rather than sampled, providing an optimised combination of interventions. Which measures are appropriate in any particular catchment remains a decision for the people who would deliver and consent to them. But parameters, including specific scheme budgets, can be set to produce sensible long- and shortlists for consultation and decision-making. PRISM presents viable measures and indicates how they will meet objectives. Some measures have associated financial quantification and some as yet do not. Ultimate selection and optimisation of interventions lies with users and their stakeholders.

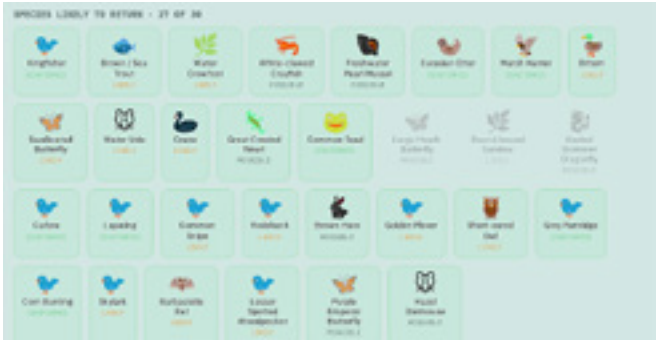
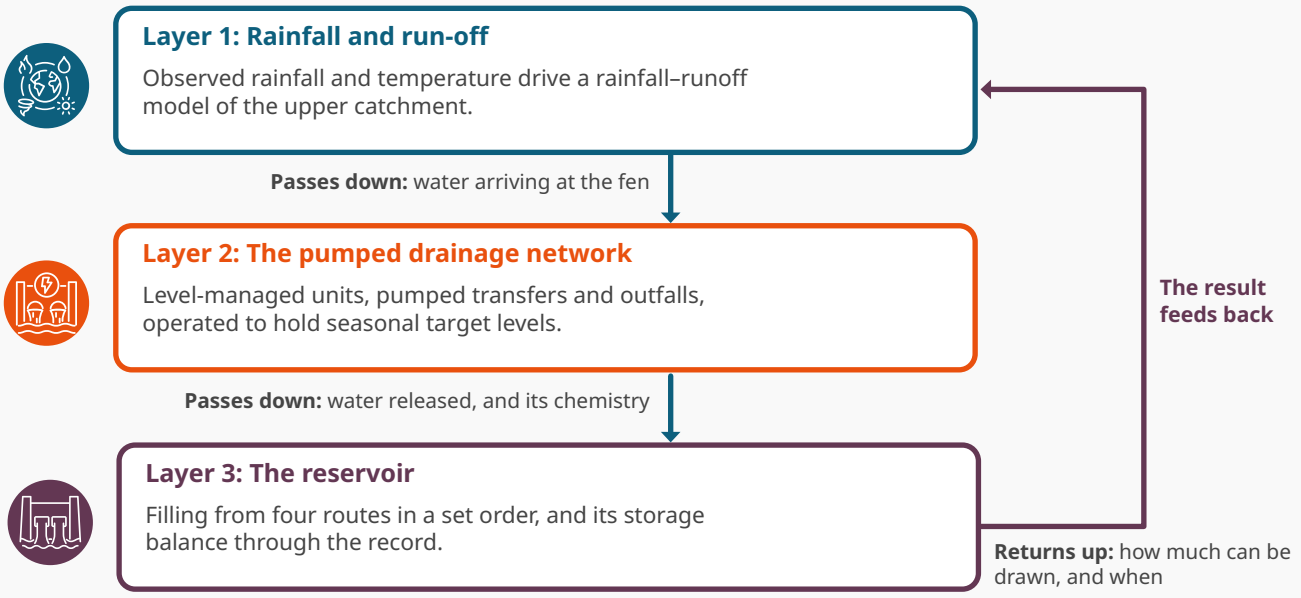


Figure 7. Habitat consequences, species by species, indicating confirmed, likely or possible.

Figure 8: Fens hydrology – why the layers had to be solved together

The fen is pumped, not drained by gravity. Water leaves when a pump starts, and pumps start against a target level, so a model of rainfall and rivers alone cannot see it.



Change a target level and the water table moves, the carbon and the chemistry follow, and the quality of a filling route changes with them. Every step is calculated rather than assumed, and a full run of 24 years of daily records completes in seconds.

Economic assessment

Underlying the appraisal is a single organising idea: the outcome increment. For any intervention, or any combination of interventions, PRISM computes the change it produces in each outcome the system delivers – water available, water quality, carbon, habitat, flood risk. These are assessed against outcomes delivered by the system without intervention. The increment, rather than the absolute level of any outcome, establishes the relative value of one intervention against another, and allows measures acting through different mechanisms to be compared.

PRISM carries a full appraisal of those increments, based on the quantification of services provided by the system. It is expressed in £, based on Green Book conventions, over 25 or 60 years at a 3.5% discount rate for a given strategic water price (HM Treasury, Green Book, 2022, Annex A6). An example of this in figure 12 shows the benefit as overall increment in outcome value (£4,657 million over 60 years) allocated by the measure that creates it, to the organisation that receives it and the framework that would count it.

Cost estimates for the scheme are still being developed, so no actual appraisal result for the Fens Reservoir is reproduced here. The values shown in the screens throughout this report are examples, not settled results.

A scenario is created, run, inspected and locked, and a locked record cannot be re-run or quietly edited. Each carries the model version, a fingerprint of every input and a count of warnings raised.

Outcome value can be distributed to the tier 1 stakeholders, both as an indication of the value they are creating, and as a guide in determining compensation or payments to them. This can be a major advance in facilitating catchment and nature-based solutions that are economically optimal but currently lack mechanisms for implementation.

There are additional qualitative and quantitative benefits in the identified outcomes: greater resilience, adaptability, decision quality, governance, coordination, risk reduction, learning and long-term stewardship.

Systemic assessment

PRISM reports the same run at three tiers, because the parties at each tier decide different things and decide them in different units. One physical result becomes three answers, without recalculating or double counting:

- carbon and resilience on a national account
- deployable output and water quality compliance to those running the supply
- farm income to the person whose field it is

We illustrate this in Figure 14, though as yet without all co-benefits included as financial expressions of service value.

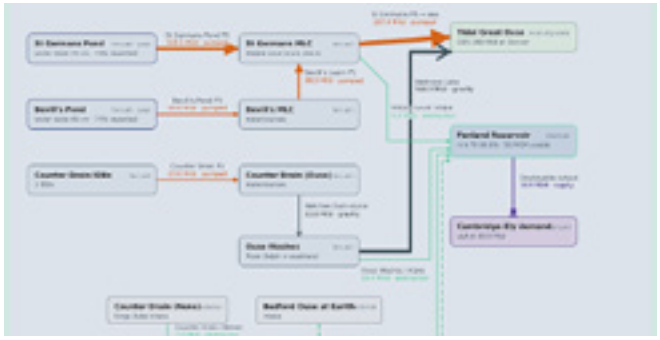


Figure 9. The coupling as PRISM draws it, with the run's values on every link. The sources and proportions shown are one possible configuration, not a proposed operating pattern.



Figure 10. Measures sited by drainage district on the map, beside the system they act on.

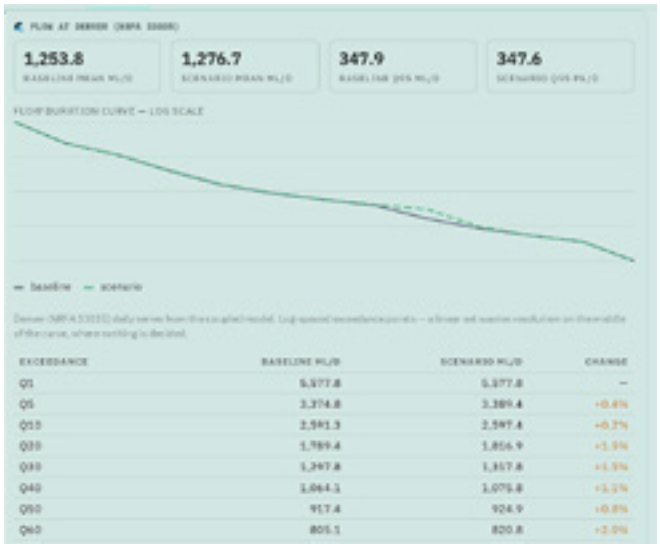


Figure 11. Flow at the catchment outlet gauge, baseline against scenario. Example values from a test configuration.

One physical result becomes three answers, without recalculating or double counting.

Reporting the same run at every tier is what makes the co-benefits of an intervention visible to the body that receives them, rather than only to the body that funds it. For every benefit, PRISM records who receives it and who pays, and in this catchment those are frequently different parties, with the one whose consent is needed often being neither.

Recommendations

A systems approach is already taken by Cambridge Water and Anglian Water, through best value planning, strategic environmental assessment and their catchment and integrated water management work. What a coupled model adds is arithmetic: the same judgement, with the interactions between measures calculated rather than assumed, each effect traced to the record it came from, and the whole thing quick enough to re-run while people are still in the room.

In the case presented the additional benefits of peat rewetting are demonstrated and could be taken further together with other catchment measures.

Reporting one result at each stakeholder tier is worth adopting wherever consent is needed. A single run expressed in the decision currencies of each tier lets the same analysis speak to the bodies that plan, fund and regulate; the teams that design, build and facilitate; and the people whose land it happens on.

A clearer route for lowland peat carbon would help a great deal. The Peatland Code has covered lowland fen since Version 2.0 in 2023, with fens of at least 45 centimetres peat depth eligible, but activity remains far more established for upland bog. Making that route easier to use in the fens would let carbon value on lowland peat reach the landowner who changes practice to create it, which is a policy matter rather than a modelling one, and shapes what is deliverable.

The same treatment applies well beyond this catchment. Wherever the benefits of a scheme, its costs and the consent for it sit with different organisations measuring different things, the approach transfers. This is true across the water sector, and equally in transport, energy networks and coastal management. We recommend that the PRISM approach be trialled on case studies in these different sectors.

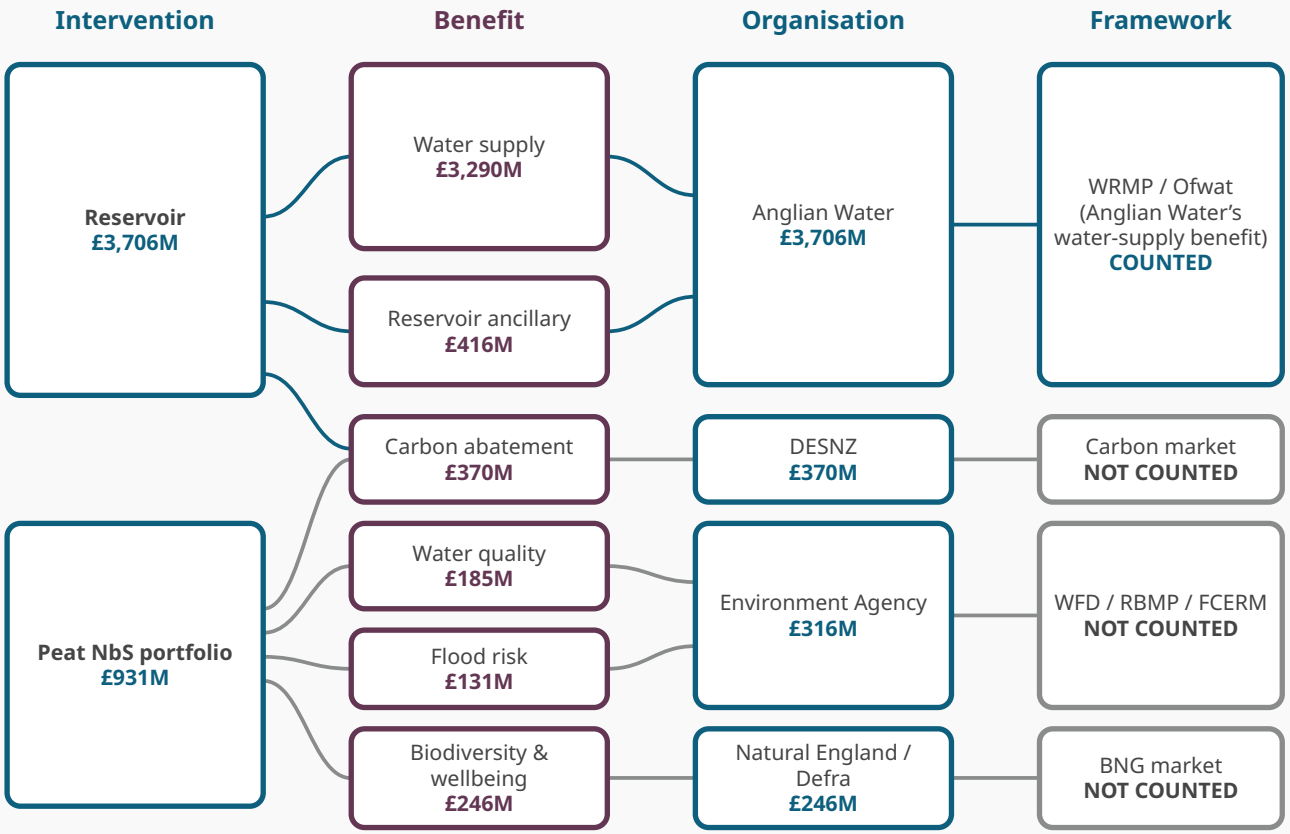
Where else this applies

Nineteen of the 20 national datasets PRISM draws on cover the whole of England, and 15 are openly licensed. Only operating records held by the drainage authority are specific to this Fens catchment. The hydrology, appraisal ledger, three-tier reporting and assurance machinery are not Fens-specific; a new catchment would supply its own drainage layout and candidate measures.

Although this case study has focused on peat rewetting, PRISM can consider many possible measures together, just as Cambridge and Anglian Water's catchment management programme does. Defra's white paper 'A new vision for water' advocates taking a systems approach to the planning of

Figure 12: Governance – who owns each benefit

Illustrative example based on £4.00/m³ strategic water value green book reference case.
NbS – nature-based solutions | WFD – Water Framework Directive | RBMP – river basin management plan | FCERM – flood and coastal erosion risk management | BNG – biodiversity net gain.



water infrastructure and meeting climate change challenges in coming decades. Systems approaches as set out here can be the mechanism to deliver this.

PRISM can also be adapted for non-water sector challenges where the multiple tiers of stakeholders need to coordinate to deliver transition to sustainable infrastructure for example in energy, building services, transport, agriculture and wider circular economy areas.

Because the model records which measures affect each other, the search of more than 2 billion combinations is solved exactly rather than sampled, providing an optimised combination of interventions.

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Published sources
– Defra (2026). A New Vision for Water, CP 1490.
– Defra Lowland Agricultural Peat Task Force (2023). Final Report.
– Department for Energy Security and Net Zero (2025). Carbon Valuation in UK Policy Appraisal.
– Environment Agency, Natural Resources Wales and Ofwat (2023). Water Resources Planning Guideline.
– Evans, C.D. et al. (2021). Overriding water table control on managed peatland greenhouse gas emissions. Nature 593, 548–552.
– HM Treasury (2022). The Green Book, Annex A6.
– IUCN UK Peatland Programme (2023). Peatland Code Version 2.0.

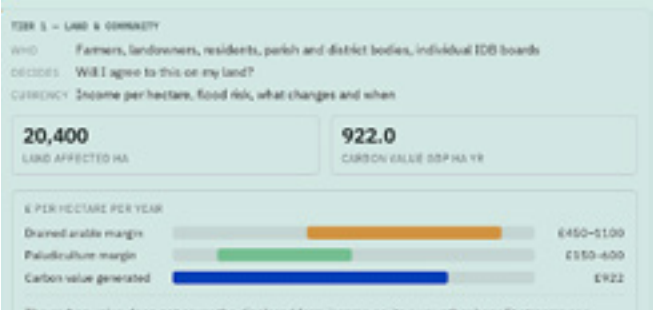


Figure 14. The Tier 1 land and community view in full: what changes on the ground, what it costs the person whose land it is, and the flood question PRISM does not answer at property level. Example values from a test configuration.

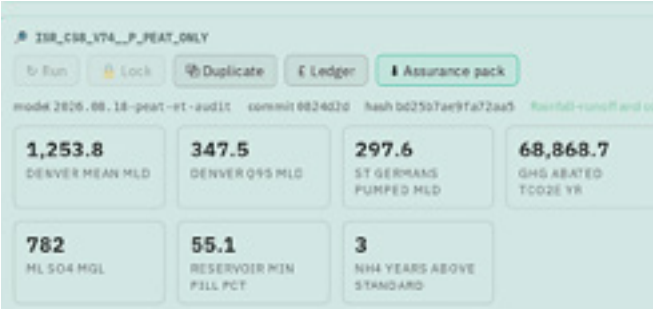


Figure 13. Every result traced to a stored record with its version, its commit, a fingerprint of its inputs and its calibration state.

– Met Office (2025). HadUK-Grid Gridded Climate Observations, 1 km. Centre for Environmental Data Analysis. Open Government Licence v3.
– Mott MacDonald for Anglian Water (2024). Water Resources Management Plan 2024: Environmental Report (Strategic Environmental Assessment, with Habitats Regulations Assessment, Water Framework Directive assessment, Biodiversity Net Gain and Natural Capital assessments).
– National River Flow Archive. Station 33035, Ely Ouse at Denver Complex. UK Centre for Ecology and Hydrology. Open Government Licence v3.
– Natural England (2025). Biodiversity Net Gain market data.
– Ofwat (2024). Case study: Anglian Water and Cambridge Water: Fens Reservoir.
– Water Supply (Water Quality) Regulations 2016, SI 2016/614, Schedule 1.
– Water Resources East (2023). Regional Water Resources Plan for Eastern England.

National datasets

The 20 national datasets PRISM draws on, as recorded in its own dataset register.

– Environment Agency. WFD waterbody classification (Cycle 3). Open Government Licence v3.0.
– Environment Agency. Water Quality Archive (WIMS) determinand series. Open Government Licence v3.0.
– Environment Agency / water companies. Event Duration Monitoring, storm overflow spills. Open Government Licence v3.0.
– Environment Agency / Defra. Designated bathing waters and classifications. Open Government Licence v3.0.
– Environment Agency. Water discharge permits and consented quality limits. Open Government Licence v3.0.
– Environment Agency. Abstraction licences and returns. Open Government Licence v3.0.
– UK Centre for Ecology & Hydrology (NRFA). Gauged daily flow and catchment descriptors. Open Government Licence v3.0.
– Environment Agency / British Geological Survey. Groundwater level and quality monitoring. Open Government Licence v3.0.
– Met Office. UKCP18 regional climate projections. Open Government Licence v3.0 (registration required).
– Met Office. HadUK-Grid 1 km observed climate. Open Government Licence v3.0 (CEDA registration).
– Natural England. England peat and peaty soils extent. Open Government Licence v3.0.
– Natural England. SSSI, SAC, SPA and Ramsar boundaries. Open Government Licence v3.0.
– Natural England. Agricultural Land Classification grades. Open Government Licence v3.0.
– British Geological Survey. BGS 1:50,000 bedrock and superficial geology. BGS Open Data / commercial for derived products.
– Environment Agency. WFD operational catchments and management catchments. Open Government Licence v3.0.
– Environment Agency. Flood Map for Planning and Risk of Flooding from Rivers and Sea. Open Government Licence v3.0.
– Environment Agency. Recorded flood outlines and historic events. Open Government Licence v3.0.
– Office for National Statistics. ONS population, household and IMD statistics. Open Government Licence v3.0.
– Ordnance Survey. AddressBase Premium property points. PSGA / commercial licence.
– Client (water company, IDB, navigation authority). Operator telemetry: pumping records, STW flows, DO, levels. Client-owned, per engagement.

Disclaimer: All values shown in this report are generated solely for illustrative purposes and do not represent published scheme results. The data and evidence used in this case study are drawn from publicly available sources and are cited in the report.

A single run expressed in the decision currencies of each tier lets the same analysis speak to the bodies that plan, fund and regulate; the teams that design, build and facilitate; and the people whose land it happens on.

Table 1. PRISM holds a library of 31 intervention measures, organised into nine groups.

WS water supply, **WQ** water quality, **FR** flood risk, **C** carbon, **B** biodiversity and habitat, **A** soil and agriculture, **H** amenity and health

Group	Intervention	Services
Water supply and transfer	Fens Reservoir	WS · B · H
	Managed aquifer recharge	WS
	Aquifer storage and recovery	WS
	Strategic water transfer	WS
Circular water	Demand management and smart metering	WS · C
	Network leakage reduction	WS · C
	Advanced effluent recycling and flow reversal	WS · WQ · C
	Abstraction licence reform †	WS · WQ
Fen and peat management	IDB water table management, raise 10 cm	C · WQ · B · A · FR
	Fen rewetting, arable to reedbed or wet grassland	C · WQ · B · A · FR
	Paludiculture, typha or sphagnum wet crop	C · B · A · WQ
Peatland restoration	Grip and drain blocking †	C · FR · WQ · B
	Sphagnum reintroduction †	C · B
	Bare peat revegetation †	C · WQ · B
In-stream natural flood management	Offline flood storage ponds	FR · WQ · B
	Leaky woody debris dams	FR · WQ · B
	Large woody material introduction	FR · B · WQ
Riparian management	Riparian grass buffer strip	WQ · B · A
	Wildflower riparian buffer	WQ · B · H
Woodland creation	Floodplain wet woodland, carr	FR · C · B · WQ
	Riparian alder and willow corridor	WQ · B · C · FR
	Native broadleaf woodland	C · B · H · WQ
	Ancient woodland restoration, PAWS	B · C · H
	Upland birch-oak woodland †	C · B · FR
Agricultural management	Winter cover crops	WQ · C · A
	No-till and min-till cultivation	C · A · WQ
	Precision nutrient management	WQ · A · C
Highway management	Permeable highway verge restoration	FR · WQ · B
	Highway attenuation pond	FR · WQ · B
	Highway SuDS swale network	FR · WQ · B
	Green bridge and culvert naturalisation	B · H

Table 2. Stakeholder tiers

Tier	Who	What they decide	What they need to see
Tier 3 Policy and funding – answerable for the provision of service	Treasury, Defra, DESNZ, the water regulators, Natural England	Should this be funded, and do the appraisal rules need to change?	Value over the scheme's life, carbon, environmental status
Tier 2 Scheme design and delivery – responsible for delivery	Designers, the water companies, the drainage authorities	How should this be designed, sized and sequenced?	Cost for each unit of water, what it delivers, what could go wrong
Tier 1 Land and community – delivering the service	Farmers, landowners, residents, parish bodies, drainage boards	Would I agree to this on my land?	Income for each hectare, flood risk, what changes and when

12



Strategic Nature Network

This is one of 15 case studies informing the Infrastructure Systems Review.

System: UK natural infrastructure.

Systems contribution and value: Reframes nature as critical national infrastructure, strategically connected and managed to improve ecological resilience, reduce climate and environmental risks, and increase value from existing public and private investment.

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Summary

The primary challenge facing nature and biodiversity in the UK is not a lack of activity, investment or ecological knowledge, but the absence of a system that aligns them towards a shared national outcome.

This understanding led to the launch in June 2026 of the Strategic Nature Network (SNN) Version 1.

SNN establishes the vision and methodology for creating, for the first time, a functioning system of natural infrastructure capable of delivering the ecological services upon which the UK's economy, communities and public services depend.

The intended future state is one in which nature is planned, financed and stewarded with the same strategic intent as other forms of critical national infrastructure: supporting productivity, increasing resilience and sustaining prosperity over the long term, in addition to safeguarding our natural wealth for future generations.

Significant public and private investments are directed towards nature through agricultural support schemes, environmental programmes, flood and water management, infrastructure investment, planning requirements and emerging nature markets. However, these interventions are frequently designed and delivered independently. Policies and incentives owned by different parts of government can inadvertently pull in different directions, resulting in duplication, inefficiency and missed opportunities.

The SNN sets a shared national outcome around which existing expenditure can be aligned, increasing the value generated from every pound already invested. It is an example amongst many others of where systems thinking based on what we want to achieve could deliver substantially better value for money – in this case mitigating an issue that the Joint Intelligence Committee classified as a threat to national security: the intertwined climate and nature crises.

Coordinated, landscape scale restoration of nature achieves more than fragmented delivery of isolated projects. Natural systems and processes are more robust, and provide increased services where habitat is in good condition, connected and at scale.

The SNN identifies where investment has the greatest potential to extend and join up habitat and increase the ecosystem services provided.

This includes those areas where nature-based flood management would deliver the greatest protection for economic infrastructure.

Building the SNN improves outcomes per unit of investment and shifts expenditure from reactive responses towards preventative resilience. It enables a more strategic approach to environmental regulation, framed around development proposals demonstrating how they deliver a net gain to the SNN. This would move the debate beyond a perceived trade-off between nature and development towards a model in which economic growth actively contributes to the resilience of the natural systems on which it depends.

A functioning full scale SNN offers the prospect of lower long-term public liabilities, reduced expenditure associated with climate-related disruption and environmental decline, improved returns on existing investment, and greater confidence for private capital to participate in nature recovery. The result is not simply an environmental recovery programme, but a national infrastructure strategy that strengthens resilience, improves productivity and leaves the UK's natural assets in a more robust condition.

Scope

This case study considers the development of a UK-wide Strategic Nature Network (SNN): a coherent ecological system designed, managed and financed as critical national infrastructure. Spanning England, Scotland, Wales and Northern Ireland, it recognises devolved responsibilities while providing the strategic coordination necessary to ensure that the UK's natural assets function as an integrated national network.

The SNN is both an outcome – a vision to be built into something real that provides resilience for UK plc – and a framework on which to hang changes in governance, planning and investment to achieve this goal. It is also an advocacy tool to get us to the point where decisionmakers and the public view nature as an enabler of economic growth, better health, and greater security.

The SNN would not replace existing conservation, restoration or land management initiatives. Rather, it would provide the infrastructure framework through which they can be aligned and optimised. It would coordinate the diverse policies, incentives and investment mechanisms that influence land use – including environmental land management schemes, planning policy, flood risk management, water investment, biodiversity net gain, private nature markets and infrastructure delivery – to realise a shared national outcome.

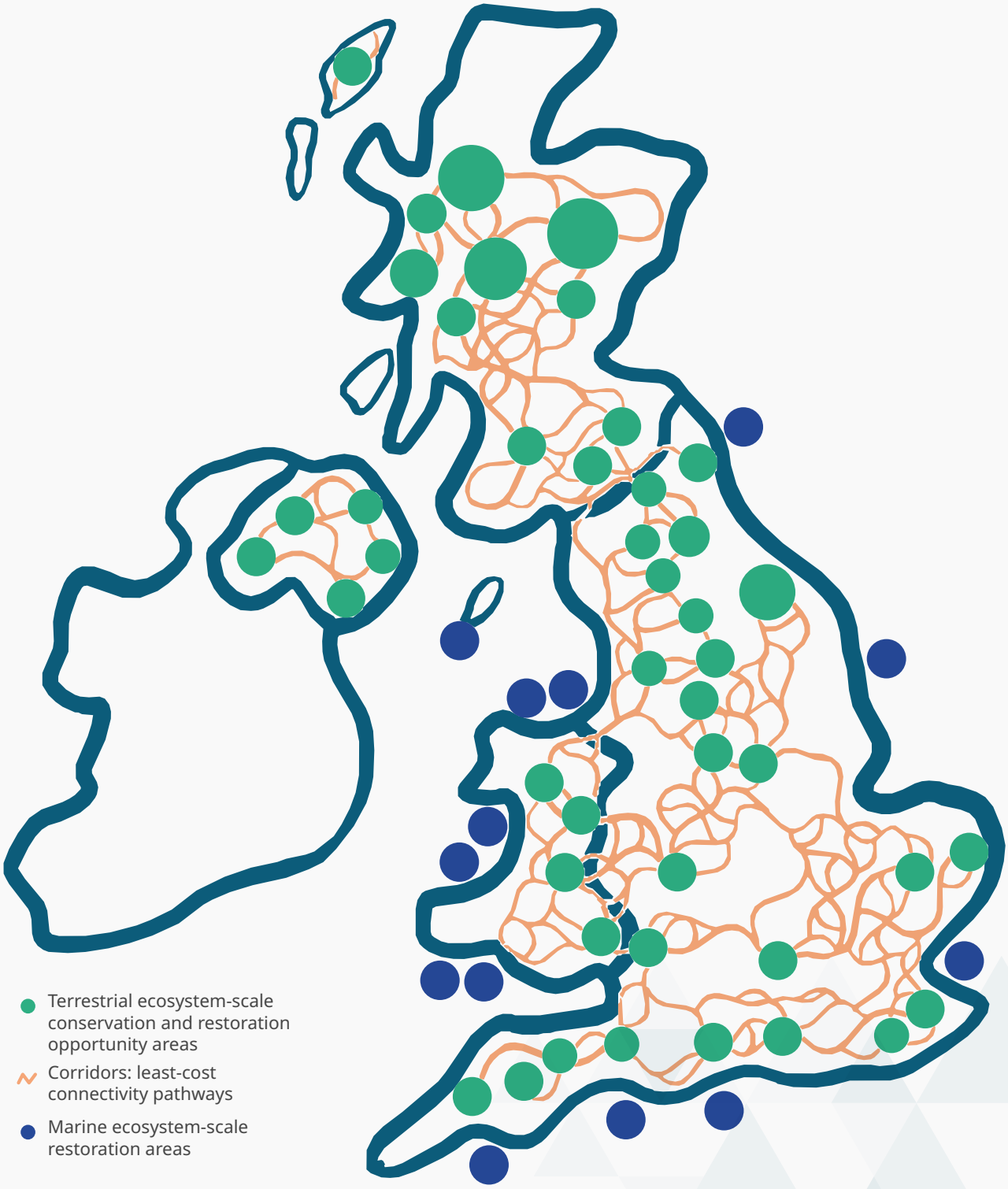
The terrestrial Strategic Nature Network v1 identifies approximately 7.4 million hectares of interconnected ecological assets across the UK, equivalent to around 30% of the UK's land area. Around 3.5 million hectares of this network is already protected through existing designations. A further 3.9 million hectares of strategically targeted restoration corridors would create a fully connected system capable of supporting ecological resilience and delivering long-term economic benefits.

Other forms of critical infrastructure rely on institutions that oversee the functioning of the whole network, ensuring

The SNN identifies where investment has the greatest potential to extend and join up habitat and increase the ecosystem services provided.

Figure 1. Strategic Nature Network Version 1.

The SNN is an essential counterpart to national energy transmission, road and rail networks, requiring equivalent strategy, investment and management.





A coherent ecological network will strengthen the UK's resilience to future shocks.

that individual investments contribute to overall system performance. The UK's natural infrastructure currently lacks an equivalent mechanism. The SNN provides the opportunity for a similar approach with coordinated planning, investment alignment and adaptive stewardship across national, regional, catchment and local scales.

Current barriers – including fragmented funding, siloed governance, short policy cycles and inconsistent incentives – make incremental reform insufficient. A systems-based infrastructure approach is required given the scale of the challenge we now face.

Outcomes

The full-scale SNN would establish, for the first time, a functioning system of natural infrastructure capable of delivering the ecological services upon which the UK's economy, communities and public services depend. The intended future state is one in which nature is planned, financed and stewarded with the same strategic intent as other forms of critical national infrastructure: providing resilience, supporting productivity and sustaining prosperity over the long term.

The outcome is not simply the restoration of habitats, but the creation of a coherent ecological network that strengthens the UK's capacity to withstand and adapt to shocks. The SNN would enhance resilience to flooding, drought, overheating and climate change; improve food and water security; support healthier communities; restore biodiversity and ecological function; and provide the environmental stability required for sustainable economic growth.

Importantly, this need not rely solely on new funding. Significant public and private investment are already directed towards nature through agricultural support schemes,

The SNN offers the prospect of lower long-term public liabilities, reduced expenditure associated with climate-related disruption and environmental decline, improved returns on existing investment, and greater confidence for private capital to participate in nature recovery.

environmental programmes, flood and water management, infrastructure investment, biodiversity requirements and emerging nature markets. However, these interventions are frequently designed and delivered independently of one another. In some cases, policies and incentives owned by different parts of government pull in different directions, resulting in duplication, inefficiency and missed opportunities. The SNN provides a shared national outcome around which existing expenditure can be aligned, increasing the value generated from every pound already invested.

This systems approach enables interventions to deliver multiple benefits simultaneously. Investments targeted through the SNN can improve biodiversity outcomes while also enhancing agricultural productivity, reducing flood risk, improving water quality, sequestering carbon, protecting

infrastructure assets and supporting public health and wellbeing. By coordinating action spatially and institutionally, the network improves outcomes per unit of investment and shifts expenditure from reactive responses towards preventative resilience.

The SNN would also provide greater certainty for planning, regulation and investment. By establishing a nationally recognised ecological framework, it would enable a more strategic approach to environmental regulation, allowing development and infrastructure proposals to demonstrate how they contribute to the functioning of the wider network. This would move the debate beyond a perceived trade-off between nature and development towards a model in which economic growth actively contributes to the resilience of the natural systems on which it depends.

For HM Treasury, the outcomes are particularly significant. The SNN offers the prospect of lower long-term public liabilities, reduced expenditure associated with climate-related disruption and environmental decline, improved returns on existing investment, and greater confidence for private capital to participate in nature recovery. The result is not simply an environmental recovery programme, but a national infrastructure strategy that strengthens resilience, improves productivity and leaves the UK's natural assets in a more robust condition for future generations.

Systems

The SNN is fundamentally a systems intervention. Its purpose is not simply to create additional habitat or expand existing conservation programmes, but to enable the UK's natural infrastructure to function as a coherent national system whose performance can be planned, coordinated and improved over time.

Nature already operates as an interconnected system. Rivers influence flood risk far downstream; soils affect water quality and agricultural productivity; wetlands regulate water flows; urban green infrastructure moderates temperatures and supports public health; and ecological connectivity allows species and ecosystems to adapt to changing conditions. Yet the institutions responsible for influencing these outcomes frequently operate within sectoral boundaries, with different objectives, funding mechanisms and regulatory frameworks. The result is that interventions are often designed to optimise individual programmes rather than the performance of the wider system.

In the UK we have historically focused on optimizing individual 'conservation' programmes for assemblages of species. We need to shift to optimizing overall system performance at regional ecosystem level to benefit people. We need to distinguish local value and community, regional and national benefits. Outside the UK regional-scale natural parks protect multiple watersheds and influence rainfall that adds resilience to agriculture.

The central systems challenge is therefore not ecological capability, but shared institutional values and coordination. Decisions affecting the natural environment are currently distributed across multiple departments, regulators, infrastructure providers, land managers and investors. Without a shared framework and common outcomes, opportunities to generate multiple benefits are lost and, in some cases, incentives can work against one another.

The SNN provides the mechanism through which these interactions can be managed deliberately. Through shared spatial priorities, common evidence and coordinated investment, it enables public and private actors to direct activity towards outcomes that strengthen the functioning of the overall network. This allows interventions to be targeted where they generate the greatest system-wide value – for example, reducing downstream flood risk through upstream land management, improving infrastructure resilience through nature-based solutions, or aligning development with ecological recovery and adaptation priorities.

As with other forms of critical national infrastructure, effective stewardship depends upon reliable information and adaptive management. Monitoring, spatial data and performance assessment will enable the network to evolve in response to changing conditions and emerging evidence, ensuring that it remains effective over the long term.

The institutional fragmentation that holds back nature's contribution to national resilience requires new governance arrangements that promote ownership, accountability, coordination and trade-off resolution. These must be developed with input from multiple stakeholders across multiple sectors. They are going to have to consider factors like the local devolution agenda and learn from international thinking on bioregional development.

A cross-departmental body akin to National Highways is needed to coordinate this multi-decadal critical natural infrastructure programme. This body should build on locally-formulated strategies – for example, local nature recovery strategies. It needs to achieve both local buy-in and national political support, whilst enabling scaled financing, again potentially harnessing the existing structure of built infrastructure programmes.

This type of coordination is complicated but it is what has led to Version 1 of the SNN. We now need to move from concept to build. Its governance system has been guided by the vision of a shared national product, whilst being inclusive. It is designed to embrace parallel thinking about data collection, roles, responsibilities, and investment – aligned with shared outcomes, clearly defined benefits and transparent management of risk and reward.

The SNN shifts nature from being treated by siloed organisations as a collection of individual sites and projects, to being managed as a strategic national asset: a living infrastructure system that underpins the resilience and performance of the UK's economy, communities and other critical infrastructure networks.

Economic assessment

Consistent with HM Treasury's Green Book approach, the economic case for the SNN is based on comparing the expected outcomes of intervention against a business-as-usual counterfactual.

Under a 'do minimum' scenario, the UK would continue to invest significant public and private resources in nature-related outcomes through agricultural support, flood and

coastal management, environmental regulation, planning obligations, infrastructure mitigation, water company investment and emerging environmental markets. However, these investments would remain largely fragmented across sectors, institutions and geographies.

Environmental pressures associated with climate change, biodiversity decline and land-use change would continue to intensify. These are estimated to cost between 4.7% and 12% of GDP per annum by the 2030s, while opportunities to maximise the benefits arising from existing expenditure would be missed. In some cases, policies and incentives owned by different parts of government would operate in tension with one another, limiting the overall value generated from public investment and disincentivising private financing.

Creating the SNN would establish a national infrastructure framework through which activities are coordinated around shared system-level outcomes.

Rather than replacing existing programmes, the SNN provides the strategic architecture that enables them to work together more effectively, aligning investment, incentives and regulation towards the creation and stewardship of a functioning ecological network that supports long-term prosperity and resilience.

Compared with the counterfactual, delivery of the SNN would increase carbon sequestration and storage, improve ecological connectivity and biodiversity outcomes, strengthen flood and drought resilience, enhance water quality and availability, support healthier and more productive agricultural systems, and improve the resilience of communities and critical infrastructure to climate-related shocks. It would also provide greater certainty for investors, developers and infrastructure operators by establishing a clear strategic framework within which public and private investment decisions can be made.

Initial analysis also illustrates the scale of the opportunity. The restoration zones identified within the SNN delivered to a high ecological condition could generate around 30 million biodiversity units, demonstrating the substantial uplift in ecological functionality, connectivity and resilience that could be achieved through a coordinated national approach. Delivery of the English terrestrial restoration zones is estimated to remove an additional 300MtCO_2 over a 50-year period.

Beyond carbon and biodiversity, a nationally connected ecological network would also strengthen the delivery of a wide range of critical ecosystem services. Restored woodlands, wetlands, floodplains and peatlands slow the movement of water through catchments, helping to reduce downstream flood risk while improving water quality and increasing resilience to drought. The Environment Agency's Natural Flood Management Programme demonstrated that relatively modest investments in nature-based interventions slowed and stored 1.6Mm3 of floodwater upstream of 15,000 homes, while simultaneously improving over 610km of rivers and 4,000 hectares of habitat.

Healthy, connected ecosystems also underpin food security through pollination and healthy soils. Natural England estimates that insect pollination provides around £500 million of value to UK agriculture each year, illustrating

A connected ecological network would enhance flood regulation, improve water quality, support pollination and agricultural productivity, increase drought resilience, strengthen climate adaptation, and deliver significant benefits for public health and wellbeing.

that investment in ecological recovery delivers substantial economic as well as environmental returns.

A connected ecological network would enhance flood regulation, improve water quality, support pollination and agricultural productivity, increase drought resilience, strengthen climate adaptation, and deliver significant benefits for public health and wellbeing.

While these ecosystem services are often considered separately, the SNN provides the spatial framework through which they can be optimised simultaneously, maximising the return on both public and private investment in nature. This would help sustain and enhance the stock of natural capital that in England the ONS values at £1.4 trillion with annual benefits of service flows at over £35 billion.

The economic benefits arise from additional investment and improved coordination of existing activity. By taking a systems view of the outcomes required, the SNN enables interventions undertaken by different departments, regulators and market participants to become mutually reinforcing rather than operating in isolation. This increases the effectiveness of current expenditure, improves the return generated from public and private investment, and creates the conditions for more strategic regulation and planning.

The economic assessment suggests that the relevant question is not whether the UK can afford to invest in the SNN, but whether it can afford not to. Viewed through the lens of the Green Book, the SNN represents an option capable of improving value for money, supporting sustainable growth and enhancing the resilience of the national assets upon which future prosperity depends.

Systemic assessment

The SNN highlights that the UK's principal challenge is not an absence of ecological knowledge, local delivery capability or even investment in nature. Significant activity is already underway across government, regulators, infrastructure providers, environmental markets and civil society. However, these interventions are often shaped by institutional

boundaries, short-term objectives and sector-specific mandates, rather than by a shared understanding of the system-level outcomes they collectively seek to achieve.

The consequence is that funding, regulation, planning and delivery mechanisms can operate in parallel, and occasionally in tension with one another. Opportunities to generate multiple benefits from a single intervention are missed, while investment is not consistently directed towards those places where returns are likely to be greatest, whether in terms of biodiversity recovery, flood resilience, carbon sequestration, water security or wider ecosystem services.

The value of the SNN is in beginning with a clear shared national outcome that enables alignment of the wider system of organisations, initiatives, projects and investments. It would support:

- integration of nature into infrastructure planning and growth strategies from the outset
- coordination of incentives, such as higher level agri-payments
- regulation and investment across departmental boundaries, for example by viewing regional adopted chunks of the SNN as nature investment zones; these would operate as sandboxes for trialling multi-sectoral collaborations outside national policy constraints, funded by specific public private partnerships and delivering scaled incomes, such as from re-naturalisation of major river systems to prevent flooding of cities
- national strategic direction with locally led delivery
- long-term stewardship through adaptive management and evidence-led decision-making.

These lessons extend beyond nature recovery. They suggest a broader model for public policy in which government focuses less on optimising individual programmes in isolation and more on improving the performance of the systems upon which national resilience and prosperity depend. In this respect, the SNN is both a proposal for natural infrastructure and a practical demonstration of systems-led national planning.

Recommendations

The analysis presented in this case study suggests that the UK's challenge is not simply to increase investment in nature, but to ensure that existing and future activity is organised around the delivery of a shared national outcome: a functioning Strategic Nature Network that strengthens resilience, supports prosperity and sustains the natural systems upon which society depends. The following actions would provide a practical route towards implementation:

- **Recognise nature as critical national infrastructure within appraisal, resilience and investment frameworks.** This would establish thriving natural systems as productive national assets essential to economic performance, public wellbeing and long-term prosperity.
- **Establish the Strategic Nature Network as a UK-wide programme**, working in partnership with devolved governments and regional delivery bodies to provide strategic direction while enabling locally led implementation.
- **Develop nature investment zones (NIZs) as multi-decadal masterplans for nature investment at scale.** Focused on places of strategic importance to the health and functioning of the SNN, NIZs would align public and private investment, aggregate projects into investable pipelines and provide confidence for long-term stewardship and blended finance. NIZs should be treated as financial, physical, and policy sandboxes, with Treasury backing to evolve policy and enable innovation, via guarantees to investors, with successes and emerging best practices shared and scaled.
- **Integrate the SNN into planning, infrastructure and economic development frameworks.** A nationally recognised ecological framework would enable a more strategic approach to regulation, whereby development proposals could demonstrate how they deliver a measurable net gain to the Strategic Nature Network. This would provide greater certainty for developers and regulators alike, enabling sustainable growth while strengthening natural infrastructure.
- **Establish cross-government governance arrangements**, supported by Cabinet-level ownership, to align policy, regulation and investment across departments responsible for environment, transport, housing, health, energy, infrastructure and regional growth.
- **Invest in the evidence base required for adaptive management**, including national spatial datasets, common outcome metrics and monitoring systems capable of tracking resilience, biodiversity, carbon, water, health and productivity outcomes over time.
- **Ensure that the benefits of the SNN are widely shared.** Delivery should support farmers and land managers through clear incentives and diversified income opportunities, create skilled employment in restoration and land stewardship, improve access to nature for communities, and contribute to better physical and mental health outcomes across the population.

The SNN provides a credible route through which the UK can strengthen national resilience, improve the value generated from existing public and private investment, support sustainable growth and restore the natural systems upon which future prosperity depends. In doing so, it offers not only a vision for nature recovery, but a practical model for systems-led infrastructure planning in an era increasingly defined by climate risk, ecological change and growing demands on public resources.

The overarching recommendation is to create a roadmap for development of the SNN, with an iteratively improved suite of NIZs. Targets should be set for before and after 2030: perhaps 10 officially recognised, financed, and in implementation by 2030, with a further 35 before 2040, together covering 75% of the Strategic Nature Network.

The political opportunity for adoption is huge, given regional devolution. The SNN and NIZs provide an opportunity to simplify a complex overlay of policies, and to realise synergies between them under one multi-decadal masterplan. Examples include biodiversity net gain, environmental delivery plans, and nature recovery plans.

The SNN creates the collective mechanism for implementing a critical system change – the treatment of nature as critical national infrastructure.

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Thames Estuary 2100

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Thames Estuary tidal flood-risk management system.

Systems contribution and value: Shift to adaptive pathways, estuary-wide management and system-level intervention timing. Deferred high-cost interventions, improved maintenance timing, reduced whole-life flood-risk cost and supported co-funding.

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Summary

TEAM2100 (Thames Estuary Asset Management 2100) was a 10-year (2015-25) capital investment and flood-risk management programme run by the Environment Agency. It covered some 350km of flood walls and embankments, and 3,229 fixed-defence assets, most owned by third parties.

This case study shows that, by taking a long-term, whole estuary approach to flood risk and defensive performance, TEAM2100 enabled better investment decisions, resulting in better value for money.

- At estuary-wide level, understanding hydraulic interactions improved strategic choices about the timing and scale of major interventions.
- At asset-system level, whole-life modelling improved decisions about capital intervention, inspection and maintenance.
- Across both levels, moving beyond fragmented asset appraisal delivered measurable whole-life value.

It illustrates these benefits with examples.

The outer estuary is naturally constricted by the Lower Hope Point and North Kent Marshes, influencing mean water levels across the estuary. Their loss would increase defence requirements across multiple asset systems and bring forward extensive defence raising. Sustaining and strengthening the marshes – thereby deferring the defence raising works – was shown to deliver an annualised whole life cost saving of approximately £135 million.

Higher up the estuary, proactive refurbishment was carried out at Ocean Wharf, where an existing gravity wall defence was retained at a cost of approximately £1 million. This contrasts with the £11 million cost of replacing a similar defence at Duke Shore Wharf, where the asset management strategy was to respond on failure. System-wide modelling estimated that each year of deferred maintenance increased whole-life costs by approximately £45 million.

The central lesson is that an approved long-term strategy, sustained delivery capability and integrated leadership enabled TEAM2100 to move beyond fragmented asset decisions, improve system understanding and make better investments. Continued progress depends on using evidence of system contribution and whole-life value to support decisions with third-party asset owners. Opportunities for additional value through integration with environmental, economic and societal systems should be investigated.

350km²
land area protected against flood risk

500,000
properties and nationally significant infrastructure protected

£135M
annualised whole life cost saving

Scope

This case study examines how the TE2100 Plan and TEAM2100 programme applied a systems approach to manage tidal flood risk across the Thames Estuary over the long term. The TE2100 Plan was developed from 2005 and published in 2012. TEAM2100 subsequently ran from 2014 to 2025, translating the strategy into coordinated delivery (figure 1).

The challenge set within the plan was to maintain the required standard of protection under uncertain future conditions while coordinating decisions across a large, diverse and partly third party-owned asset base.

The Thames Estuary tidal flood risk management system extends from Teddington Weir to the outer estuary at Southend and Sheerness. It covers approximately 350km² of floodplain and includes the Thames Barrier, other tidal barriers, raised defences, outfalls and pumping stations. Together, these assets protect more than one million people, over 500,000 properties and nationally significant infrastructure. The system is organised into 23 asset systems, each representing a hydraulically independent flood cell and referred to as a policy unit within the TE2100 Plan (figure 2). These asset systems provide a practical basis for planning and managing risk.[1] [2]

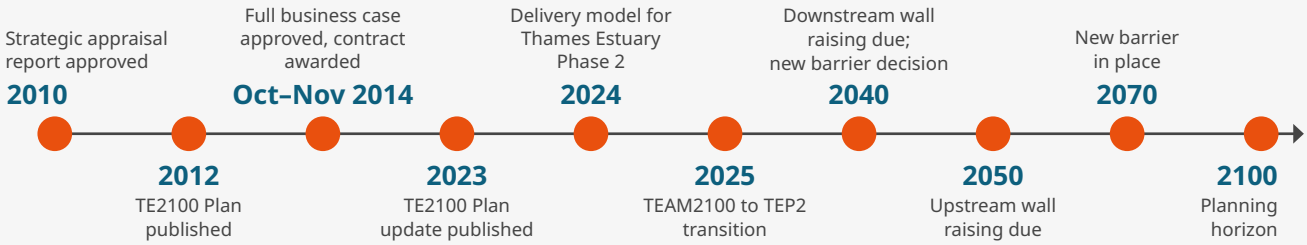
This study examines decision-making at connected levels:

- estuary-wide – understanding hydraulic behaviour and the system-wide role of major assets supports strategic choices about interventions and their timing.
- asset-system level – understanding whole-life performance and condition supports decisions about inspection, operation, maintenance and refurbishment.

It assesses how this two-level approach improved the timing and targeting of investment, operations and maintenance, and the resulting whole-life value. It also considers the constraint created by fragmented ownership, as the Environment Agency owns only around 5% of the raised tidal defences.

1 Environment Agency, Thames Estuary 2100 Flood Risk Management Strategy Appraisal Report, Version 1.4, Scheme Reference RETH000060, Mar. 2010.
2 Environment Agency, Thames Estuary Asset Management 2100 Programme: Asset Management Strategy, Issue 6, Document No. TEA-00-00.00-SG-AM-00-000001, Oct. 2023.

Figure 1. TEAM2100 within the long-term TE2100 delivery and adaptation timeline.



Phase 1: 2010–2034
Maintain defences, create habitats and safeguard space for future flood management.

Phase 2: 2035–2049
Renew and raise walls, embankments and barriers. Work with partners to reshape the riverside.

Phase 3: From 2050
Choose the long-term option at the start of the phase. Prepare for new arrangements by 2070.

Figure 2. The 23 TE2100 policy units, referred to as asset systems in this case study. Each was originally treated as a hydraulically independent flood cell for planning and appraisal.

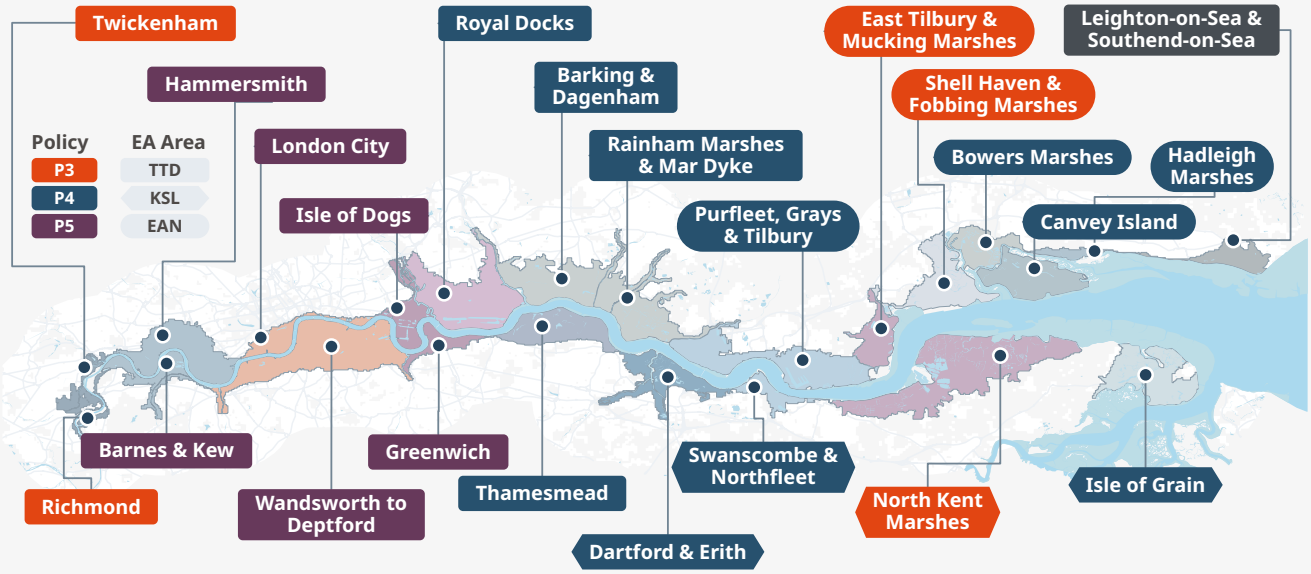
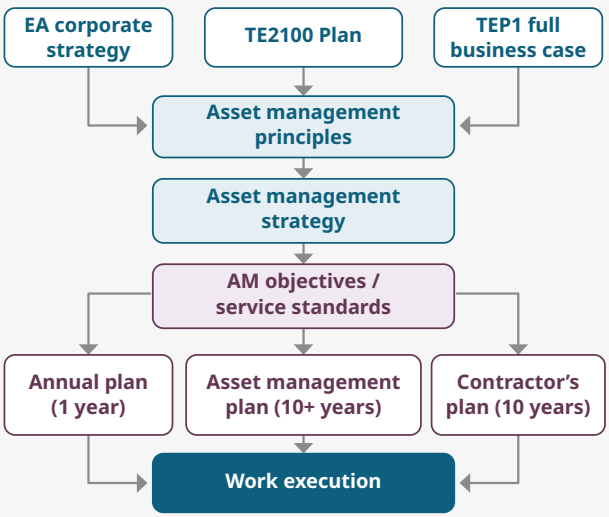


Figure 3. TEAM2100 decision-making process connecting estuary-wide strategy, asset-system evidence and scheme-level delivery.



Key outputs

Estuary-wide system

- Strategic objectives
- Preferred investment approach
- Preferred standard of protection
- Preferred flood risk management policy
- Preferred delivery approach
- Preferred value-adding opportunities

Asset-system level

- Short- and medium-term programme
- Identified local opportunities to add value
- Funding opportunities and constraints
- Design water levels
- Target condition

Asset level

- Asset condition
- Preferred asset intervention option
- Detailed design
- Asset-level opportunities to add value
- Scheme delivery approach

Outcomes

The systems approach improved decision-making at two connected levels within the Thames Estuary tidal flood risk management system: strategic choices affecting the estuary as a whole; and operational and maintenance decisions within asset systems.

At estuary-wide level, the principal change was moving beyond the local value of individual assets to understand how assets and physical processes influence overall system performance. Under a conventional asset-led approach, an intervention may be assessed mainly against the people, property and infrastructure it protects locally. System-level analysis also considers whether an asset affects water levels, barrier operations, defence requirements or the timing of interventions elsewhere in the estuary.

The North Kent Marshes demonstrate the value of this broader perspective. Although they provide relatively limited local benefits, the marshes influence mean water levels across the estuary. Understanding this function showed that their loss would increase defence requirements across multiple asset systems and bring forward extensive defence raising. This changed the basis for decision-making because the assets could be valued according to their contribution to estuary-wide performance, rather than their local benefits alone. The economic assessment quantifies the resulting whole-life value.[3]

At asset-system level, the systems approach improved understanding of asset condition, function, reliability, redundancy and interdependencies. Asset systems provided a practical basis for considering how groups of assets collectively maintain the required standard of protection. Whole-life modelling then enabled decisions about inspection, operation, maintenance and refurbishment to reflect both asset condition and the consequences of deterioration for the wider asset system.

This changed the timing of interventions. Rather than maintaining every asset to the same regime or extending its life until replacement became unavoidable, decisions could be based on the point at which intervention provided the best whole-life outcome. The comparison between Ocean Wharf and Duke Shore Wharf illustrates the consequences. Timely refurbishment at Ocean Wharf retained the existing asset at substantially lower cost, whereas delayed intervention at Duke Shore Wharf resulted in emergency works and major reinstatement. The approach therefore supports earlier intervention where deterioration would create disproportionate future cost. But it also enables deferral of major capital works where systems will continue to perform without increasing unacceptable risk.

Considering asset cohorts within their system context enabled more targeted inspection and maintenance. For example, mapping Victorian masonry defences with shallow foundations against locations vulnerable to erosion can identify where that cohort faces greater deterioration risk. Inspection frequencies can then reflect both asset characteristics and system exposure, strengthening the connection between day-to-day asset management and the long-term strategy.

The flood risk management system operates at two connected levels. Understanding both provides a view of how the system behaves and how changes in one part can affect performance elsewhere.

The principal outcome examined by this case study is improved management of tidal flood risk and whole-life value through better strategic, operational and maintenance decisions, at both estuary-wide and asset-system levels.

Additional benefits were observed where the flood risk management system interacts with wider environmental, economic and societal systems to create further value. These interactions are beyond the scope of this case study and merit further study.

Systems

The Thames Estuary tidal flood risk management system operates at two connected levels. At estuary-wide level, assets and hydraulic processes interact across geographical boundaries. At asset-system level, groups of defences work collectively to provide the required standard of protection. Understanding both levels provides a structured view of how the system behaves and how changes in one part can affect performance elsewhere.

At estuary-wide level, interactions between assets and environmental processes shape hydraulic performance across multiple locations. Operation of the Thames Barrier influences downstream water levels, while features in the outer estuary, including Lower Hope Point and the North Kent Marshes, exert hydraulic control over wider system behaviour. Changes in these locations can affect defence requirements and the timing and scale of interventions elsewhere. These relationships demonstrate that the role of an asset cannot always be understood from its location or local benefits alone.[4]

At asset system level, the approach represented an important progression from appraising individual assets. Each of the 23 asset systems was treated as a hydraulically independent flood cell, within which barriers, walls, embankments and operational assets collectively provide the required standard of protection. With limited exceptions, assets were assumed to contribute only to the protection

3 E. Morris, J. Clarke, D. Matthews and C. Zegers, Rethinking Estuary Appraisal, Document No. TEA-00-00.00-RP-AM-00-000006, unpublished internal TEAM2100 project report, Oct. 2017.
4 Environment Agency, TE2100 High Level Options Pilot Portfolios, Volume 2, Appendices D and E, internal TE2100 technical study, n.d.

Figure 4. Location of North Kent Marshes within the estuary and their impact in reducing tidal water levels

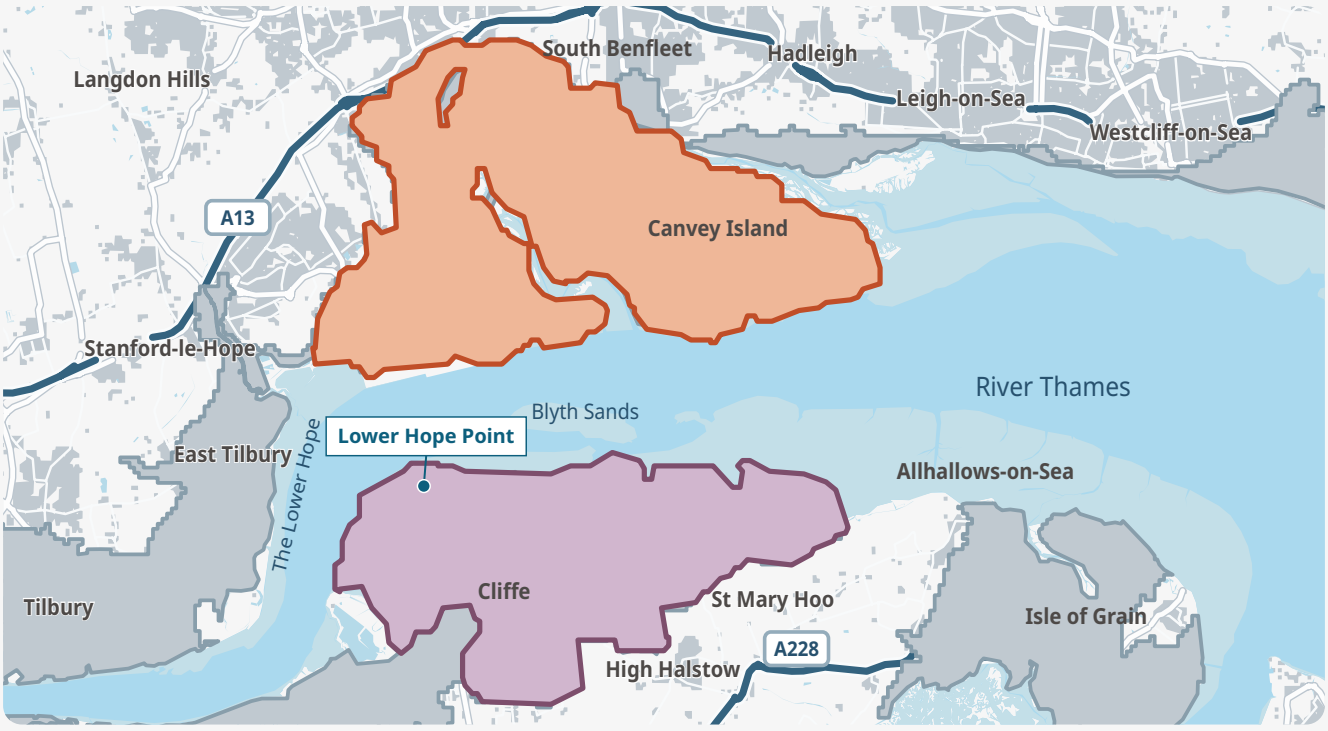
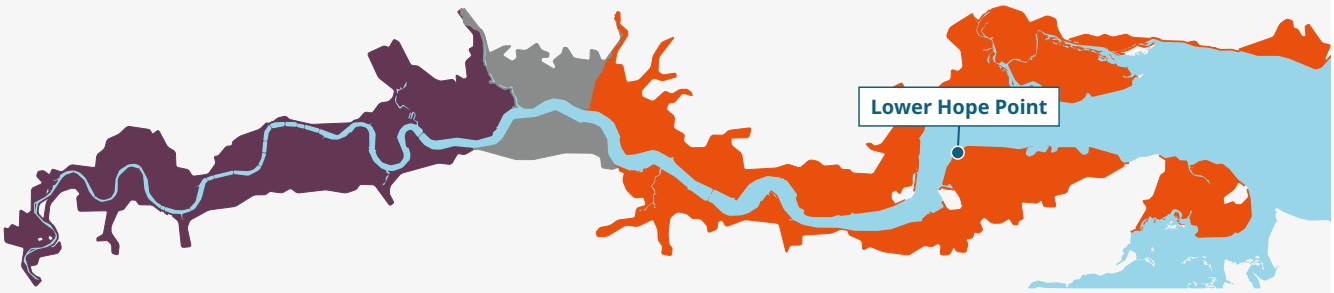


Figure 5. How loss of the Lower Hope Point would accelerate major interventions in the Thames Estuary



Accelerated bank raising		No effect	Increased defence level	
Twickenham	London City	Thamesmead	Rainham Marshes	Shellhaven & Fobbing
Richmond	Isle of Dogs & Lea Valley	Barking & Dagenham	Dartford & Erith	Bowers Marshes
Barnes & Kew	Greenwich		Swanscombe & Northfleet	Canvey Island
Hammersmith	Royal Docks		Purfleet, Grays & Tilbury	Hadleigh Marshes
Bermondsey			East Tilbury	Isle of Grain
			North Kent Marshes	Leigh & Southend

Decision level	System insight	Decision improved	Evidence of value
Estuary-wide	Lower Hope Point and the North Kent Marshes influence water levels and intervention requirements across the estuary	Whether maintaining the hydraulic constriction avoids bringing forward major defence raising and the long-term estuary option	Up to 190km of earlier defence raising avoided; approximately £135 million present-value impact
Asset-system	Whole-life modelling links asset condition and deterioration to the performance required from the asset system	When to inspect, maintain, refurbish or replace assets	Ocean Wharf refurbishment approximately £1 million versus approximately £11 million at Duke Shore Wharf; deferred maintenance approximately £45 million present value per year

of their own asset system. This allowed the function and performance of each asset to be understood in relation to the asset system as a whole, rather than in isolation.

The two levels are connected through an exchange of information. Estuary-wide analysis identifies the influence of major assets, hydraulic processes and alternative intervention pathways across asset-system boundaries. Evidence from asset systems provides a more detailed understanding of asset function, condition and performance. As TEAM2100 moved into delivery, understanding of both the individual asset systems and the estuary-wide system became progressively more developed.

Together, these two levels provide an increasingly refined model of the flood risk management system. This connects the behaviour and performance of assets within individual asset systems to the strategic choices required across the estuary, providing the system understanding that underpins subsequent decisions about capital investment, inspection and maintenance. In addition to the tidal flood risk management benefits evaluated in this case study, opportunities for additional value were identified by integrating flood risk decisions with wider environmental, economic and societal systems (figure 3).

Economic assessment

The systems approach improved whole-life value by changing when, where and at what scale investment was required across the Thames Estuary. At estuary-wide level, value is driven principally by the timing of major interventions. Sea level rise will increase water levels in the estuary and require further investment over time, but understanding how assets and hydraulic processes influence overall system performance allows high cost works to be deferred where the required standard of protection can be maintained without increasing unacceptable risk (Table 1).

Lower Hope Point demonstrates this mechanism because it forms a natural constriction that restricts tidal flow and water levels upstream. Long-term erosion of this feature, followed by tidal inundation of the freshwater North Kent Marshes, would increase the volume of tidal water entering the estuary upstream of this point (figure 4). Although Lower Hope Point provides relatively limited local flood risk benefit, its hydraulic function creates value across the estuary.

TEAM2100 estimated that the loss of this function would increase whole-life costs by approximately £135 million present value, through earlier implementation of up to 190km of defence raising and acceleration of the long-term estuary option (figure 5). An asset-led appraisal based principally on local benefits would not fully recognise this value. The systems approach demonstrates how maintaining a critical hydraulic function can safely defer substantially greater expenditure elsewhere.

At asset-system level, value comes from identifying the optimum point for capital intervention. Strategic deferral is beneficial when performance allows works to be postponed safely. Delay is costly when deterioration increases the scale, complexity or urgency of the eventual intervention. Whole-life modelling distinguishes between these circumstances, relating asset condition and deterioration to the performance required from the system.

Ocean Wharf and Duke Shore Wharf illustrate this distinction. Timely refurbishment at Ocean Wharf retained the existing gravity-wall defence for approximately £1 million. Delayed intervention at Duke Shore Wharf resulted in emergency works and major reinstatement costing approximately £11 million. The comparison demonstrates that extending an asset towards failure is not necessarily economically efficient, particularly where deterioration removes the option for lower-cost refurbishment.

System-based inspection and maintenance planning provides the evidence needed to identify intervention points. Modelling of different regimes across the system indicated that the annualised whole life cost of deferring maintenance came to approximately £45 million (present value) – or £450 million over 10 years.

Understanding asset cohorts within their system context also enables inspection and maintenance to be targeted according to deterioration, exposure and contribution to flood-cell performance.

Long-term visibility of the investment pipeline supported coordinated funding. At the Port of Tilbury, partnership working enabled delivery of a dual-function lock gate and secured £6 million from third-party and local sources, releasing Grant in Aid for investment elsewhere. Across the strategy, aligning whole-life carbon and investment planning is also forecast to reduce carbon emissions by up to 45%, demonstrating the potential to optimise cost and carbon through the same system-level decisions.

The cost associated with collecting the information required to implement this level of systems thinking is particularly interesting. Before TEAM2100, separate engineering inspections and appraisals cost approximately £93,700

per asset in 2026 prices. The business case for TEAM2100 showed that system efficiencies achieved by inspecting assets as cohorts would reduce the cost to approximately £13,390 per assessed asset.

Costs were cut further by bringing together the Environment Agency's then ongoing T98 inspections with georeferenced photography, LiDAR, 3D scanning, GIS and targeted professional input. This enabled consistent and more informed monitoring and analysis across all 3,229 fixed-defence assets. The initial pilot of advanced monitoring for the Isle of Dogs asset system assessed approximately 400 assets for £297,000, equivalent to approximately £363,000 or £910 per asset in 2026 prices.

Applying the Isle of Dogs unit cost across all 3,229 fixed-defence assets gives an indicative cost of approximately £2.9 million. This is slightly below, the £3.1 million estimated for the full business case's targeted programme of 439 engineering inspections and 173 appraisals. The comparison therefore suggests that TEAM2100 could extend analysis across the whole asset base without increasing the direct cost of assessment.

Systemic assessment

The principal lesson from TEAM2100 is that effective systems working required sufficient strategic authority, time and investment certainty to move beyond fragmented asset-level decisions. The TE2100 plan provided the long-term vision and approved strategic direction. TEAM2100 gave a 10 year mandate to deliver that strategy, creating the space to develop system understanding and improve our investment decision making.

This long-term authorising environment was a critical success factor. It enabled TEAM2100 to examine how assets and hydraulic processes contributed to estuary-wide and asset-system performance, improve whole-life modelling and use emerging evidence to refine investment, inspection and maintenance decisions. A piecemeal asset-led approach would have constrained this learning by focusing resources on immediate interventions and local benefits, limiting the programme's ability to identify opportunities for better investment across the system.

Integrated leadership and alignment between strategy, delivery and asset management were also important. The development of a 'one system' delivery model provided a shared basis for decision-making, while progressively improved asset information supported consistent assessment of system contribution, condition and performance.

The principal constraint was fragmented asset ownership. The Environment Agency is responsible for managing flood risk across the estuary but does not own most raised tidal defences. Acting on system-level evidence therefore requires engagement with owners whose responsibilities and priorities may differ, particularly where an intervention creates benefits beyond its immediate location.

The transferable lesson is that technical understanding alone is insufficient. Systems approaches require long-term authorisation, sustained delivery capability and organisational arrangements that allow decisionmakers to learn about the system and act on that evidence. Without these conditions, investment is likely to remain fragmented and opportunities to improve whole-life value may be lost.

Recommendations

1. Enable system-level strategies to guide adaptive delivery
Long-term strategies should define outcomes, performance requirements and adaptive pathways, enabling delivery to refine decisions as system understanding improves. Sustained programme authorisation is essential to provide the time and investment certainty needed to develop this understanding and avoid reverting to fragmented asset-level decisions.

2. Embed adaptive, system-wide decision-making
Value is created through decisions made over time across the system. Decision making should connect estuary-wide strategic choices with asset-system evidence, enabling the timing and form of interventions to be refined as conditions, asset performance and system understanding develop.

3. Align delivery around shared system outcomes
A 'one system' approach should align strategy, delivery and asset management around common objectives. Integrated leadership and a shared evidence base improve coherence and enable decisions to be taken consistently in the interests of overall flood risk management system performance.

4. Enable coordinated investment across organisations
System performance depends partly on assets owned by third parties. Engagement with asset owners should use evidence of system contribution and whole life value to establish a shared basis for intervention decisions. Further work should examine how benefits extending beyond individual assets can support collective business cases and coordinated investment.

5. Build capability and tools for system management
System management requires sustained capability in whole-life modelling, asset information and hydraulic analysis. These tools should support decisions about capital intervention, inspection and maintenance, while allowing system understanding to improve through delivery. Opportunities to create additional value through integration with environmental, economic and societal systems should also be investigated further.

14



Transpennine Route Upgrade

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Transpennine rail delivery.

Systems contribution and value: Established enterprise governance, requirements architecture, and whole-railway integration for scope, interface and readiness decisions. Potential to reduce integration risk, late change and rework.

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Summary

The Transpennine Route Upgrade (TRU) is an £11 billion, 130km railway programme in the north of England. Three configuration stages, representing over 40% of the programme, have been completed to date, including new electrification on 25% of the route and the opening of three stations. This work has improved railway performance and passengers' travel experience.

Strong programme performance has been enabled by a systems approach:

- Creating an enterprise delivery organisation, with key stakeholders involved in governance and decision making from the outset, all equally committed to delivery, and with systems integration at its heart.
- Specifying and contracting focused on outputs and outcomes, with clearly defined business case benefits.
- Systems integration approaches used to identify and communicate scope, interfaces and dependencies.
- Systems thinking applied across all functions in the organisation, taking it beyond engineering into sponsorship, schedule, risk, cost and benefits delivery.
- Phased delivery linked to funding, with stakeholder confidence gained from early benefits delivery.

The operating model takes a whole railway approach, focused on delivering agreed outcomes for passengers and freight.

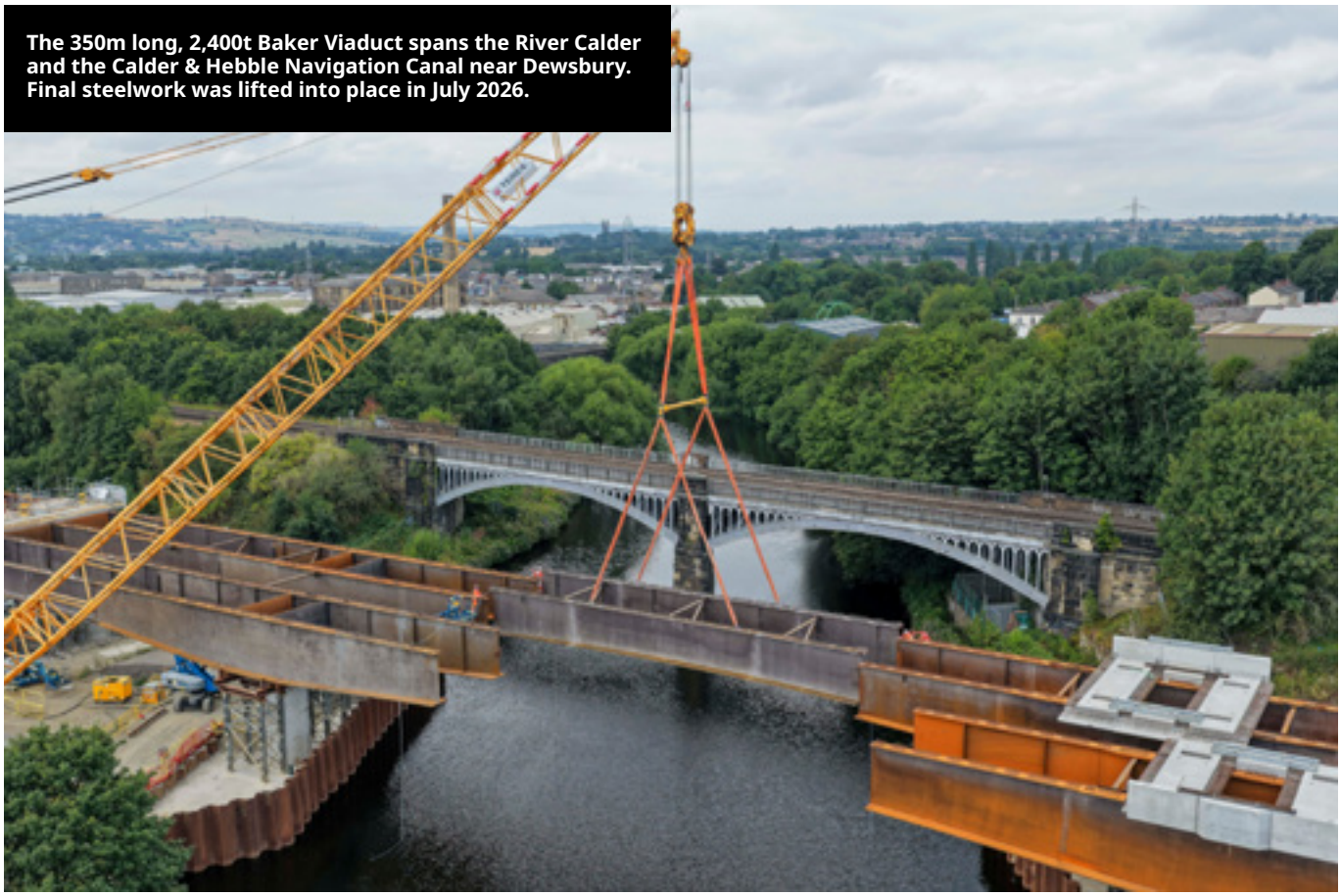
Scope

TRU is upgrading the existing east-west corridor between Manchester, Huddersfield, Leeds and York. It consists of more than 100 interventions, or projects, at various stages from development to in-delivery, completed and in-service. The programme's scope includes creating new assets, maximising the use of existing assets, improving reliability and enabling cost-effective future maintenance. Work will continue until the late 2030s.

While Manchester to York is the core 'system of interest' (figure 1), TRU's scope encompasses the origination and destination of services across the wider rail network. The 'system boundary' extends from first to last mile of each journey, for both passengers and freight; and it includes train operations, new and existing rolling stock, the timetable, railway infrastructure, train control and maintenance.

Outcomes

TRU will deliver significant environmental, social and economic benefits in the north of England by creating a faster, more reliable and lower-carbon railway. This is expected to support economic growth by improving access to employment and improving connectivity between regional economic hubs. Improved rail transport will make the region more competitive within the UK and internationally. TRU will enable the removal of up to 1,200 lorries per day from the M62, providing greater capacity and reduced journey times. The rail system itself will shift from diesel to electric trains.



The 350m long, 2,400t Baker Viaduct spans the River Calder and the Calder & Hebble Navigation Canal near Dewsbury. Final steelwork was lifted into place in July 2026.

Systems requiring integration

— 6 signalling systems
— 10 classes of civil structures
— 1 DNO connection
— 3 electrical control rooms
— 3 high voltage feeder stations
— 8 traction section cabins
— 2 communication systems
— 1 diversionary route
— 2 new stations
— 22 existing stations
— 6 stabling and maintenance depots
— 1 freight terminal
— Track
— Switches and crossings
— 4 connecting routes
— Trains
— Train operations and timetabling
— Lighting
— Security
— Passenger and customer information
— Revenue collection
— Local environment
— Adjacent routes

The TRU benefits map (figure 3) shows how government strategic missions and obligations (outcomes) translate into projects. Benefits include:

- A 50% improvement in train punctuality
- Reduced journey times between Manchester, Leeds and York from 74 to 64 mins
- More frequent trains and better connections
- 30% more seating capacity, to achieve 80,000 seats per day
- Additional hourly passenger services and a new container freight capacity
- Electrification of the route and introduction of electric and battery trains to reduce carbon emissions

The existing railway was characterised by ageing infrastructure, constrained capacity, poor performance, and fragmented delivery. Performance was poor, with only 38% of trains arriving within a minute of the scheduled time, compared to a national average of 65%. Delays, crowding and inconsistent quality blighted passenger services; freight and operational flexibility were limited. Carbon emissions were high due to the route's reliance on diesel traction.

TRU has set simple, clear target outcomes and used them to define interventions. Through a system integration and management plan (SIMP), TRU has strengthened requirements traceability, interface management and system assurance. This has improved decisionmaking, reduced rework and ensured that individual project outputs combine to deliver whole-system benefits. Service performance and operational needs are better aligned, enhancing reliability, safety and long-term asset performance.

Figure 1. TRU system of interest – core (shaded box) and extended.

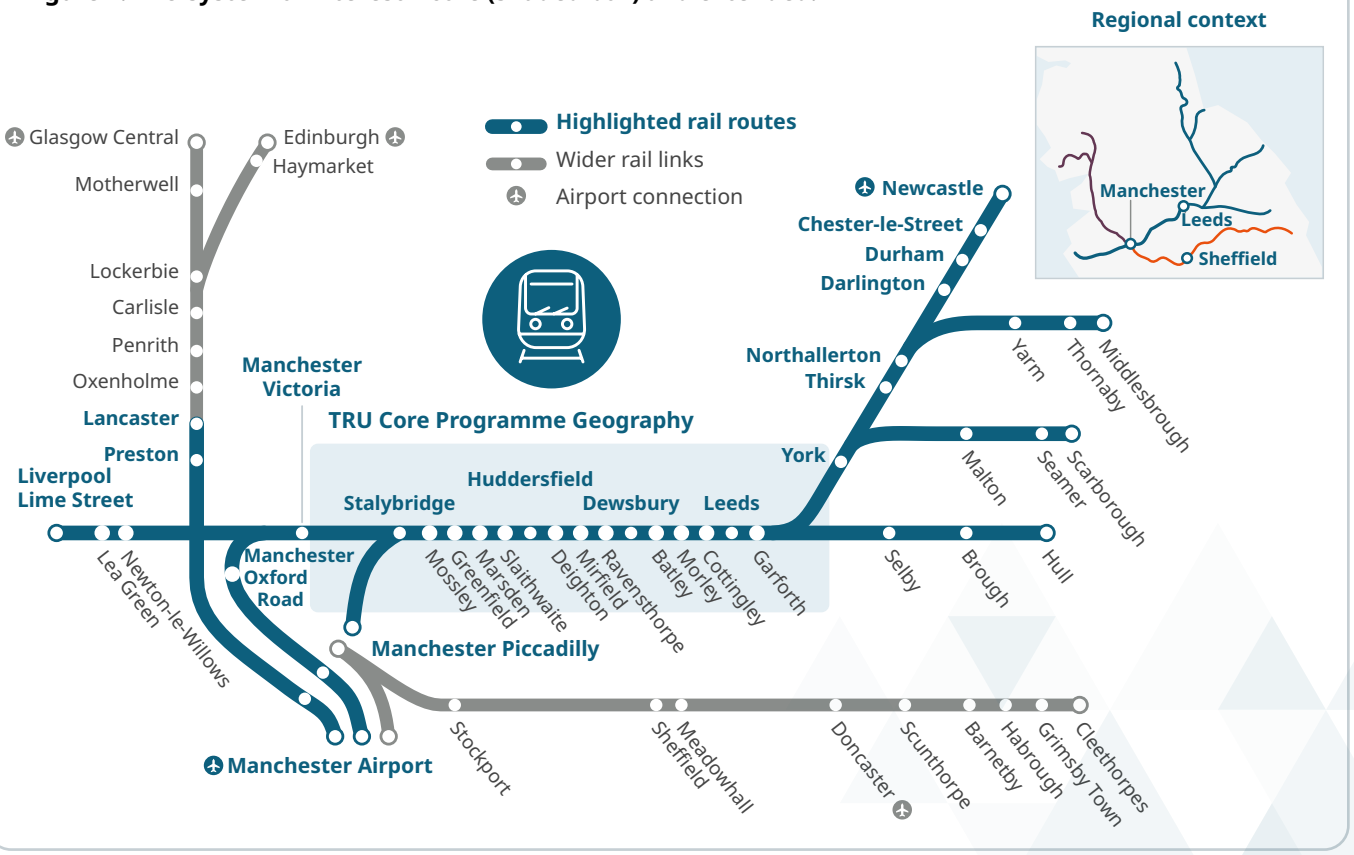
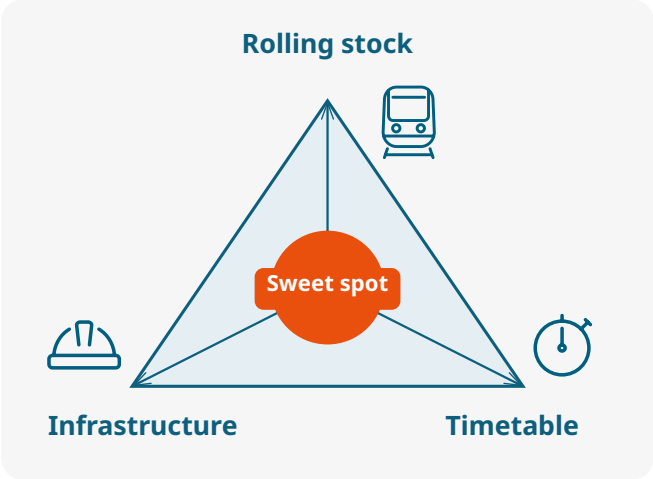


Figure 2. TRU investment sweet spot.



From a stakeholder perspective, passengers benefit from improved journey quality, while operators gain a more reliable and flexible railway. However, delivery partners have faced increased coordination requirements and governance complexity. Trade-offs have included balancing short-term disruption and revenue impact during construction against long-term gains, and managing cost, schedule, and scope within a live railway environment.

Developing outcome-led solutions that balance infrastructure, railway and train operational needs has required close working within the enterprise. It has 'scanned ahead' to determine risks and solve them early.

Systems

TRU can be understood as a complex system of systems, combining physical, organisational, operational and digital elements. Physically, it includes track, electrification, structures, stations, and rolling stock. Organisationally, it brings together Network Rail, the Department for Transport, the North of England Mayoral Authorities, train and freight operators, and a diverse supply chain. Digitally, it incorporates signalling systems, requirements databases, configuration tools, and assurance processes.

All these elements are highly interdependent, with performance outcomes emerging from their interactions rather than any single component.

At the outset of TRU, there was evidence of performance-related challenges stemming from fragmented delivery, discipline silos, a reliance on statutory rights to protect stakeholder perspectives, and limited visibility of cross-project dependencies. Further challenges were added by the condition of legacy infrastructure and poor operational performance, impacting customer experience. Together, they created the potential for weak alignment between design, delivery and operational performance.

Applying systems thinking enabled the development of a structured understanding of relationships and requirements. Tools such as requirements traceability, interface management frameworks, and configuration control enabled the programme to map and manage dependencies across physical and organisational boundaries. This established a baseline view of the railway as an integrated system, clarifying how infrastructure performance translates into service outcomes, such as reliability and capacity.

Key leverage points included improving interface definition between disciplines, aligning requirements to operational needs, and strengthening integration governance. These influenced investment sequencing, ensuring that interventions delivered cumulative, system-wide benefits rather than isolated gains. Governance structures were adapted to support cross-discipline decision making and whole system assurance.

Value of the integration approach was unlocked through reducing rework, improving coordination, and enabling best for programme decision-making across delivery partners. The approach also enhanced long-term service performance by ensuring that new and existing assets function cohesively. Overall, understanding the system holistically allowed TRU to move from fragmented upgrades to a coordinated transformation.

A useful tool for communicating the changes which TRU will deliver, and the dependencies it has on external factors, has been the enterprise project architecture. It defines the total system changes needed to deliver TRU outcomes, and has been commended for its ability to communicate scope, forming part of the TRU baseline delivery documentation. It proves that simplicity is essential to communicate systems thinking successfully.

Interventions

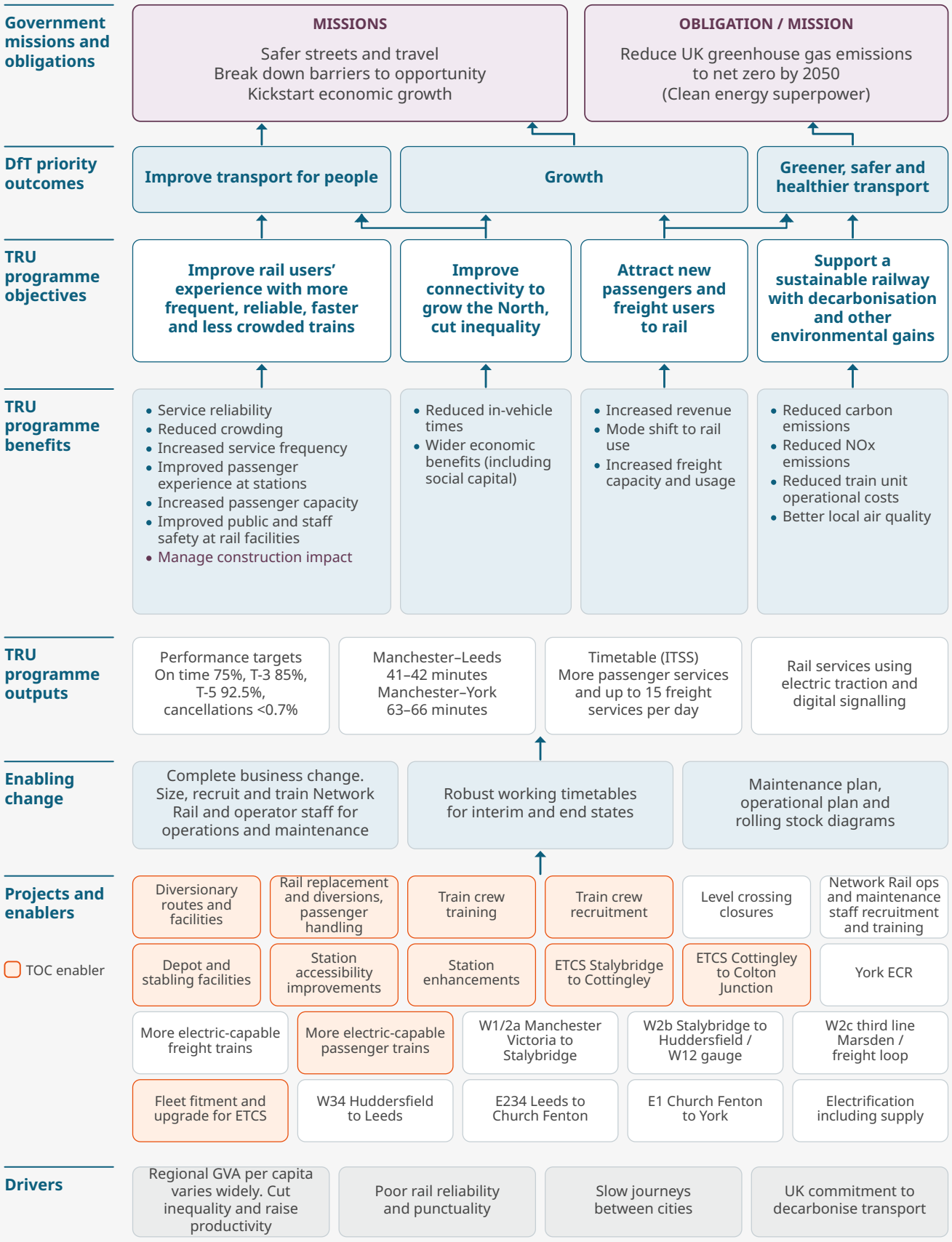
When TRU was initiated, Network Rail was focused on the delivery of infrastructure. The DfT was separately focused on integration, working with operators. The TRU enterprise model brought all the stakeholders together to ensure that joint 'best for programme' decisions would be made, consider how projects and assets would be integrated, and where best value for the investment can be achieved.

In practice, this has enabled the enterprise to find the TRU 'investment sweet spot', providing best system-wide value by finding the optimum trade-offs between rolling stock, timetable and infrastructure (figure 2).

Key interventions to close the gap between the railway's existing performance and expected outcomes include:

- **Timetable.** Alternative solutions were developed, testing the frequency of services, rolling stock needs, train lengths, freight gauges and infrastructure interventions. The railway service timetable has been restricted so that punctuality performance can be maintained during the programme; services will be increased post-completion to six fast and two local passenger trains, and one freight service per hour.
- **Rolling stock.** Aged diesel rolling stock will be replaced by electric trains with in-train digital signalling, delivering increased capacity. Battery technology will be used to overcome challenges with full route electrification – for example under low bridges and in tunnels. The train-platform interface will be improved to achieve better accessibility.
- **Infrastructure.** Capacity 'bottlenecks' will be removed by

Figure 3. TRU benefits map.



using digital signalling to allow reduced headway – trains will be able to operate at closer intervals. Electrification will allow the operation of new rolling stock. Infrastructure work has been planned and executed to minimise impacts on the operational railway and passenger service.
- **Maintenance.** Railway assets have been fitted with sensors to improve condition monitoring and fault detection, allowing proactive maintenance and rapid repairs. Maintenance scheduling has been amended to allow freight services to operation 24/6, aligning with customers' needs.
- **Stations.** New and upgraded stations improve accessibility and customer experience.

Investment trade-offs between interventions are aligned with their contribution to programme outcomes. The TRU enterprise developed a 'hot house' decisionmaking forum to reach decisions transparently and quickly.

One of the most significant physical interventions on TRU was the Baker Viaduct between Huddersfield and Dewsbury. It supports the operation of reliable fast train services between Leeds and Manchester by providing an 'overtaking' path for faster trains. Due to the strength and quality of the benefits case, giving confidence that the solution was the best whole enterprise system solution, it progressed smoothly through its Transport and Works Act Order consents process, which was a potential schedule risk.

Economic assessment

TRU was established against a backdrop of major rail enhancement programmes that offered significant lessons in the importance of integrating infrastructure delivery, train operations and passenger outcomes. Under traditional delivery models, infrastructure sponsors, infrastructure managers, train operators, freight operators and suppliers operate within separate organisational and contractual boundaries. While individual organisations can be incentivised to optimise their own objectives, there is often no equivalent mechanism to optimise the delivery and performance of the railway system as a whole.

This approach can create several failure modes.

Information can be fragmented across organisations, making it difficult to understand how decisions made in one part of the programme could affect performance elsewhere. The benefits arising from integration between infrastructure, operations, rolling stock and timetable changes may not be visible to all organisations, creating a risk that opportunities delivering wider system value get overlooked. Incentives can be misaligned, with projects capable of meeting their own objectives while still creating constraints on railway operations or limiting the benefits ultimately experienced by passengers and freight users.

Several reviews of significant rail programmes have illustrated how the complexity of rail systems delivery in a disaggregated environment can lead to undesired outcomes. The National Audit Office reported that the Great Western Electrification Project[1] and Intercity Express Programme[2] experienced cost increases of approximately £2.1 billion and delays of 18-36 months, leading to around £330 million of additional operating costs and a reduction in programme scope. Crossrail also made clear the importance of creating a dedicated, central team at the very start of a programme, with responsibility to actively manage system integration.

TRU's systems-informed enterprise approach to delivery has resulted in project costs that compare favourably with other large programmes.

The principal economic benefits realised to date arise through improved decisionmaking, risk reduction and sequencing of investment. The approach has reduced the risk of incompatible decisions, improved management of interfaces and dependencies, and enabled benefits to be realised progressively through phased delivery.

Key outcomes delivered to date include:

- Additional infrastructure and train capacity to provide up to three trains per hour on diversion routes, while construction on the core TRU route is under way, thereby minimising service disruption.
- Introduction of electric passenger services between Manchester and Stalybridge. Improved railway performance and reduced emissions in areas of high population.
- Introduction of electric passenger services between Church Fenton and York, including integration with East Coast Main Line power upgrades. Delivers faster train services by removing historic restrictions and reduces emissions in the York area.
- Further outcomes will be delivered through the remainder of the programme, reflecting the changing configuration of the railway as infrastructure and digital signalling is delivered, new rolling stock is introduced, and operation and maintenance approaches change.

Defined and agreed key outcomes hold the enterprise and programme to account and build confidence for future investment decisions.

There have so far been in excess of 100 commissioning stages. The TRU systems assurance case (TSAC), developed from a similar Crossrail tool, provides a structured approach to demonstrating readiness at each stage.

Additional value has been realised through systems thinking led efficiency focus. So far, some £900 million worth of efficiencies have been identified through integrated programme delivery and operator input.

While the programme is still in delivery, stronger integration has improved decision quality, reduced delivery risk and increased confidence that passenger, freight and decarbonisation outcomes will be delivered effectively.

1 Modernising the Great Western railway, NAO, Nov 2016
2 Procuring new trains, NAO, July 2014

Systemic assessment

This case study highlights several systemic inefficiencies and barriers that can constrain performance under traditional delivery approaches. These include fragmented governance structures, siloed funding and investment decisions, and misalignment between policy objectives and operational railway outcomes. Regulatory and assurance processes are often applied at project level rather than system level, limiting visibility of cross-interface risks and increasing the likelihood of late stage issues. Additionally, organisational silos across disciplines and supply chain partners can inhibit information sharing, reduce transparency, and drive duplication of effort and cost.

The industry transition to Great British Railways represents an opportunity to adopt the enterprise structure developed by TRU, setting a benchmark for rail programme delivery across the network.

The relative strength or weakness in any system approach for railway programmes arises from:

- where the programme or system boundaries are drawn
- the relative control the programme enterprise has over decision making and integration choices

For TRU this is illustrated by its interfaces in Manchester and with the East Coast Main Line, considering the activities and aspirations of other programmes. There may be benefits from a wider enterprise programme approach, which could be driven by Great British Railways.

TRU's focus on outcomes requires a clear decomposition and traceability to outputs, and allocation to the enterprise partners. It is not yet a standard approach to managing integration in rail projects, but offers great potential. It needs promotion or formalisation within future Great British Railways delivery models.

A successful enterprise approach has reduced TRU's dependencies on traditional regulatory processes to approve schemes. This has been notable for network change and station change schemes. Avoiding delay has allowed schedules to be maintained, and created confidence in the quality of delivered outputs.

Historically, silos between DfT, Network Rail and train operators have caused technical compatibility, cost and delay challenges in train procurement. Integration of train procurement and infrastructure has the potential to overcome these issues – again requiring Great British Railways intervention.

TRU has mitigated potential inefficiencies resulting from a complex standards landscape by developing application guidance documents in conjunction with government, the regulator and other stakeholder bodies. There is an opportunity to learn from these to create a more efficient, more integrated approach between rail stakeholders.

The planned investments in Northern Powerhouse Rail (NPR) and East West Rail (EWR) provide ideal opportunities for the implementation of the TRU integration approach, noting the scale of investment and the current maturity of development.

Investment trade-offs between interventions are aligned with their contribution to programme outcomes. The TRU enterprise developed a 'hot house' decision making forum to reach decisions transparently and quickly.

Recommendations

TRU demonstrates that an engaged enterprise organisation and the early and consistent application of systems thinking is critical to successfully managing complexity and delivering whole-system outcomes.

Key lessons from TRU include the need to establish clear requirements traceability, strong interface ownership, and integrated governance and assurance across organisational functions from the outset. Fragmented governance and siloed delivery has been proven to significantly increase cost and risk, while the TRU coordinated systems approach improves alignment, reduces rework, and enhances long-term performance. The programme also highlights that value is improved when investment decisions focus on service outcomes, and these are used to guide asset delivery.

Priority recommendations:

- **Government**. Align funding and requirements with whole-system outcomes. Ensure business cases prioritise service performance, resilience and net zero, rather than defining discrete project interventions which cannot be traced directly to benefits. Mandate systems integration strategies for major programmes.
- **Clients.** Support upfront investment in enterprise delivery models, including systems engineering capability, recognising that modest early costs deliver significant downstream savings and risk reduction. Support enterprise-wide decision making, early enough to avoid inefficiency.
- **Programme delivery teams.** Implement industry learning processes, standardise systems engineering practices, align incentives, and strengthen cross-organisational collaboration. Address trade-offs to find optimal solutions aligned with mutually agreed outcomes. Focus on how best to deliver outputs, finding a 'sweet spot' between stakeholders' competencies, capabilities and capacity. Link outputs to outcomes.

Together, these actions will improve investment effectiveness, enable scalable delivery models, and support more coherent, resilient infrastructure systems.

15



Wye-Usk Transition Lab

This is one of 15 case studies informing the Infrastructure Systems Review.

System: Wye-Usk – socio-ecological and economic.

Systems contribution and value: Shared diagnosis, convening and trust-building developed common priorities for project, finance and governance development. Strengthened collaboration and developed a pipeline of potentially investable landscape-scale interventions.

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Summary

Rural economies across England and Wales are chronically underperforming. In landscapes like the Welsh Marches, Gross Value Added (GVA) per head is 65-70% of the UK average.[1]

- Agricultural value is extracted rather than retained locally.
- Producers are confined to low-margin commodity markets.
- Natural capital is depreciating.
- Fragmented top-down governance prevents regionally coordinated management and investment needed to reverse these trends.

Isolated, sector-specific interventions repeatedly fail to address the structural causes of this underperformance.

Focus
Wye-Usk Transition Lab offers a replicable model for rural economic development. A transition lab builds strong relationships, which are foundational to economic wellbeing. It convenes farmers, businesses, communities, public bodies and investors around a shared, bottom-up understanding of systemic challenges. A coordinated programme of mutually reinforcing interventions is emerging across five priorities: profitable and resilient farming; landscape restoration; locally owned renewable energy; population health and wellbeing; and landscape finance and governance frameworks.

Value
The lab demonstrates that devolved, coordinated, place-based investment can simultaneously address market failures across multiple capital types (financial, natural, human, social, manufactured, intellectual). Siloed approaches leave such failures unresolved. Its aim is to produce a coherent, investible programme from fragmented initiatives.

Alignment with UK national priorities
The lab's approach directly supports the government's missions on clean energy, nature recovery and economic growth, alongside the Land Use Framework, the Environmental Improvement Plan 2025, Defra's £2.7 billion land management schemes, and the Seventh Carbon Budget's emphasis on nature-based solutions. It generates quantifiable economic returns.

Scope

The rivers Wye and Usk are special areas of conservation. Home to around 400,000 people, they drain catchments of 4,136km^2 and 1,160km^2 respectively. While the Usk passes through Newport's urban centre, the region is mostly rural, with the lower, flatter lands supporting mixed farming, and hill farms in the upper reaches.

The Wye and Usk landscapes face:

- ecological degradation: polluted rivers, degraded soil, and flood/drought pressures
- extraction of economic value and equity
- low farm incomes with high input costs
- inadequate infrastructure and transport

Many feel fatigued by repeated attempts to meet national and regional goals that do not align with their values and interests. They live with the poverty produced by multiple deprivations which maintain a malfunctioning system.

- weak market access
- rural isolation
- a food-energy-poverty-wellbeing nexus antithetical to good health.

People in the region have little fiscal decisionmaking power and operate in silos, locking in practices that embed and worsen negative outcomes. Mistrust between stakeholders supresses local development.

Treating these landscapes as a single socio-ecological and economic system, not a set of isolated sites, Wye-Usk Transition Lab is developing a new approach to rural economic development. It works across five interconnected themes defined by stakeholders: nature-based flood and water management; food, farming and local value chains; transport and renewable energy; health and wellbeing; finance and governance.

The lab uses a methodology co-developed with University College London's Climate Action Unit, and supports stakeholders to work collectively. Over three years, 200+ participants have taken part, including farmers, unions, environmental and health bodies, regulators, local and national government, community projects, and financial institutions.

Providing the coordination capacity the market cannot, the lab aligns stakeholders, governance and investors, aggregating fragmented local initiatives into a coherent programme to raise GVA and retain economic value.

Outcomes

Persistent rural poverty and economic underperformance in the Wye-Usk region follow a self-reinforcing cycle. Without a systemic approach to long-term outcomes that accounts for local conditions and fiscal realities, this underperformance cannot shift.

When stakeholders enter a transition lab to discuss ways to break this cycle, they often feel sceptical of further interventions and guarded towards outsiders claiming expertise on the challenges facing their landscape

1 C. Jones, 'Green and pleasant land', LPIP Hub Report 2026



The Wye (pictured) and Usk are polluted and face severe flood/drought pressures.

and community. Many feel fatigued by repeated attempts to meet national and regional goals that do not align with their values and interests. They live with the poverty produced by multiple deprivations which maintain a malfunctioning system.

Once in the lab, in a collective process, these stakeholders can begin to define the costs and cumulative, systemic harms they face. Their budget-setting and governance decisionmaking is limited. They express concern about not meeting resilience or net zero goals because of inadequate farming methods. Structural barriers to sustainable growth include housing, geographic isolation, high energy costs, and insufficient transport connectivity. They worry about restrictions being placed on current land use, adjustment costs, and uncertainty when new governance or finance models challenge existing practice.

The transition lab guides them to align multiple, interconnected outcomes and take better advantage of available financial support. For example, soil management that improves productivity, biodiversity, water retention and reduces flood risk; local renewables that support energy security, a modern local transport system, and rural income and wellbeing.

When guided to imagine opportunities from transitioning to regenerative approaches and pooling risk, the quantifiable outcomes stakeholders described included more effective and locally appropriate spending, better farm resilience, new income streams and local jobs, improved water quality, lower flood risk, and greater wellbeing for the community. They articulated how ecological health, economic viability and social wellbeing can be mutually reinforcing.

Stakeholders' input was synthesised by the team to generate five themes, capturing multiple potential intervention points: profitable and resilient farming; landscape restoration; distributed, locally owned renewable energy; effective transport; a healthy and well population; and appropriate, localised finance and governance.

By developing relationships, mental models and actions, the transition lab positions stakeholders for more effective local autonomy and ownership. Stakeholders overcome sectoral fragmentation and identify leverage points to foster greater local public control over essential services. They envisage how to aggregate small initiatives into larger programmes with devolved, distributed responsibilities and leadership. This creates stronger social legitimacy and opens new opportunity for investment.

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Participating in the lab makes trade-offs explicit for decisionmakers. For example, market mechanisms such as nature credits or nutrient trading seek particular outcomes but can miss the mark on related challenges. And high-return financial expectations can produce degenerative outcomes if the profits they produce are extracted from the area. The labs provide a means of understanding how and why.

Even in its early stages, the lab's systems approach is adding value beyond what individual initiatives can generate. The lab is actively mapping funding pathways to consolidate fragmented, small-scale projects into a coherent, investible programme, while building the cross-sector connections and shared purpose on which durable investment depends.

Systems

The Wye-Usk's structural and systems failures result from a lack of local autonomy and budgets, and from treating mutually dependent ecological, economic and social systems as separable. In the transition lab process, diverse stakeholders address these challenges, learning and sharing knowledge in iterative facilitated workshops, identifying interdependencies, causal relationships and common objectives.

With guidance, stakeholders reflected on the costs of artificially separating people, economy and environment, and the longitudinal impacts of reduced local autonomy to coordinate resources and responsibilities. Participants recognised the local economy and landscape health as interdependent: without healthy soils, clean water and biodiversity – and localised autonomy to prioritise and protect these – a durable agricultural or rural business base is impossible. Finance mechanisms and fragmented or misaligned policy and governance exacerbate the situation, such as when mechanisms for carbon, biodiversity or nutrient credits pay for single outcomes. By contrast, systems interventions produce multiple outcomes, such as wetlands restoration simultaneously reducing flooding, filtering nutrients, sequestering carbon and restoring habitat and amenity value.

The lab also surfaces structural disconnects between economic systems.

The transition lab enables stakeholders' attention to shift from improbable, 'silver bullet' solutions to those that are more achievable and locally responsive. Stakeholders identify leverage points that could change multiple outcomes at once.

- Although the Wye-Usk region produces substantial agricultural output, existing farming methods deplete soils and contaminate waters. Local equity and much of the economic value from agricultural production is extracted from the region, and opportunities for local horticulture, new entrants and nearby urban markets remain unrealised.
- Rural wellbeing is undermined by centralised fiscal and policy systems that entrench isolation, poor mobility, weak services and uneven health outcomes.
- The regenerative potential of the energy transition is reduced by overly centralised infrastructure decision-making. Investing in more locally owned and distributed energy encourages entrepreneurship, supports farm resilience, reduces emissions, and contributes to long-term renewal and wellbeing.

Participants are equipped in the transition lab to identify where governance and finance can become coherent and appropriate to local and regional needs. Significant topics that have emerged include:

- more adaptive and inclusive local governance and decision-making
- stronger farmer-to-farmer learning
- better cross-sector integration
- catalysing investment that bundles complementary actions into connected programmes with clear and measurable outcomes, and cross-outcome budgets.

The transition lab enables stakeholders' attention to shift from improbable, 'silver bullet' solutions to those that are more achievable and locally responsive. Stakeholders identify leverage points that could change multiple outcomes at once. Systemic approaches emerging from the lab offer decision-makers practical ways to move from triaging individual symptoms towards grounded, distributive systems design that can improve long-term economic and environmental performance across the landscape.

Interventions

Wye-Usk Transition Lab is supporting stakeholders to identify regional opportunities and design interconnected actions to drive the system-wide change necessary for landscape regeneration. Five such priority action areas have emerged, and North Star Transition is working with stakeholders to scale, align and find resources to carry out interventions within each area.

1. Profitable and resilient farming: a region-wide programme of farm transition plans, farm clustering for peer support and resource sharing, local supply chain development, agroecological horticulture, and soil health restoration – to improve nutrient cycling, increase water retention, reduce emissions, and cut costs and pollution.

2. Landscape restoration: deploying nature-based practices across the catchment – to restore wetlands and soil, improve flood management, sequester carbon, enhance biodiversity – and paying farmers for delivering on environmental goals.

3. Community-owned renewable energy: solar, wind and bio energy on farms and public buildings, electrified transport, local trading, storage, and distribution – delivering decarbonisation and new income streams.

Farmers in both catchments are economically trapped into reinforcing the conditions for increasingly severe drought-flood cycles.





Table 1. A multi-capital deficit in the Wye-Usk landscape.

Capital	Current trajectory	Key driver
Financial	Net loss and leakage; lack of autonomy	Centralised fiscal policy, siloed budgets, misaligned subsidies, commodity pricing
Natural	Depreciation	Intensive farming, unpriced externalities
Human	Erosion	Farm income compression and viability pressure, diet-related ill-health
Social	Fragmentation	Value extraction and social fragmentation; loss of trust
Manufactured	Underinvestment and leakage	Externally owned energy infrastructure
Intellectual	Loss of local and applied knowledge	Monoculture pressure

4. Finance and governance innovation to deliver multiple, localised outcomes: combining public, private, philanthropic, community and corporate capital, bridging and transition funds, co-operative models and governance structures.

5. Landscape-scale aggregation: linking farm clusters, nature restoration, energy schemes, food networks and improved health outcomes into larger programmes – to attract investment and generate systemic returns.

Outputs so far include over 100 identified intervention opportunities, early project development, stronger collaboration and momentum for coordinated action, early inputs into reformed finance, and governance design. These should catalyse coordinated, investible, locally owned and designed programmes to deliver durable, measurable outcomes.

Economic assessment

Long-term centralised fiscal decision-making has resulted in a fragmented and depleted infrastructure and economic system in the Wye-Usk region. Without an effective local reinvestment strategy, including local procurement, more value is extracted from the Wye-Usk landscape than is retained locally.

Farmers and other producers are confined to low-margin commodity markets and compete primarily on price, while many of the higher-value services, processing activities, supply chains and ownership structures that could add value and support the rural economy accrue outside the region.

Broad national and regional policy and investment objectives – including the energy transition – are often inappropriate and difficult to meet. Where policy objectives are pursued at a distance, and in isolation, implementation risks compounding an already weak local economic position.

The region experiences a self-reinforcing cycle of a lack of autonomy, underinvestment characterised by low business resilience, limited capacity for local investment, increasing pressure on public services, outmigration of labour, and degradation of the natural assets on which long-term prosperity depends.



Systemic barriers must be tackled, from fragmented governance to disconnected stakeholders, limited investment capacity, and incentive structures misaligned with long-term value creation. No single organisation has the mandate or capability to address these issues alone.

Addressing these interconnected challenges requires more devolution and local financial control, so that local drivers of economic renewal are activated. As that renewal occurs, the economic rewards need to be reinvested to rebuild and expand local equity and drive regeneration. Ground-level systemic barriers must also be tackled, from fragmented governance to disconnected stakeholders, limited investment capacity, and incentive structures misaligned with long-term value creation. No single organisation has the mandate or capability to address these issues alone.

The transition lab addresses the coordination failure that prevents local actors from achieving landscape-scale outcomes. It convenes farmers, businesses, communities, public bodies and investors around shared goals, producing mutually reinforcing interventions designed to attract investment while retaining economic value locally.

Taken together, the lab's priority action areas are designed to transform the Wye-Usk region from a low-value, externally dependent, extractive economic model characterised by degraded natural capital, to a more resilient, productive and locally rooted region – one with the capacity for autonomous and accountable public control over essential services, including food systems, water, energy and transport.

The transition lab's contribution is not only to enable individual projects, but to build the governance and coordination capacity to make devolution work effectively and visibly.

The lab builds the coordination infrastructure that fragmented actors cannot create alone: shared knowledge, governance capacity and accountable leadership across the landscape. It creates: the potential for reciprocal contracts between local governments and communities; space for private investors; and the planning of integrated, cross-outcome budgets to support holistic outcomes. This is the foundation for mobilising and devolving public and private resources at the scale landscape transition requires – and for ensuring the returns are retained and reinvested locally.

Systemic assessment

Table 1 reveals a multi-capital deficit in the Wye-Usk landscape. These are not six separate problems, but six angles of a single, systemic failure.

Farming systems are placed under acute strain by lack of localised budget control and capacity to make autonomous decisions, rising input costs, climate instability, debt pressures and market uncertainty.

Farmers struggle to balance profitability with environmental stewardship and are trapped into reinforcing the conditions for increasingly severe drought-flood cycles and wider ecological degradation.

Inappropriate agricultural practices and ageing sewage infrastructure add nutrient and pollutant loads to already stressed rivers.

Inadequate transport and energy systems create isolation.

The result is poorer health and economic outcomes, including youth outmigration. These challenges together erode the value base on which farming, local business and community wellbeing depend.

As part of a national devolution strategy, all six interconnected trajectories could be reversed simultaneously, revitalising the local economy and community wellbeing. In the Wye-Usk Transition Lab, stakeholders acquire the skills to begin this process. They apply a multi-capital deficit framework, then design an alternative, locally coherent and adapted system including subsidies suitable to regenerative farming conditions, local energy retention and cross-sectoral budgeting.

Recommendations

The programme is ongoing. These recommendations and systemic insights have emerged to date.

- For local and combined authorities, transition labs offer a proven method to coordinate fragmented local initiatives into investible, landscape-scale economic renewal programmes.
- For national government, adopt the transition lab model as a replicable instrument for place-based rural economic development, capable of advancing devolution, raising GVA and retaining value in underperforming landscapes.
- For regulators and investors, the lab creates the governance and coordination infrastructure needed to aggregate disconnected actors into accountable, multi-sector programmes – improving the risk-adjusted case for capital deployment.
- For all partners, sustained, place-based engagement is essential, supported by appropriate and predictable resourcing. The transition lab approach should be embedded in long-term governance frameworks.
- For regulators, the lab approach provides an enabling environment for regulatory alignment across sectors, reducing enforcement gaps that arise when actors operate in silos.
- Funders require consistent long-term engagement that builds trust, distributing responsibilities and supporting innovation – it is a precondition for landscape-scale investment.

Systemic insights:

- Systems level thinking can be learned and applied wherever stakeholders work collectively for change. A lab's place-based, inclusive approach – backed by appropriate resourcing and governance – is the delivery mechanism.
- Landscape-scale rural economic development is achievable and replicable in comparably underperforming regions. The model does not depend on exceptional local conditions.
- Building stakeholder trust requires sustained in-person engagement. This cannot be substituted by digital interaction and must be resourced accordingly.
- Regions function as systems. Ground-up actions, when aligned and adequately resourced, can scale to deliver economic and environmental outcomes.

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