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The Alan Turing Institute

Digital Twin based decision support: the Climate Resilience Demonstrator project

Newton Gateway to Mathematics, 7 June 2023

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(Support from NDTp and CPC under Innovate UK; Ofgem, Alan Turing Institute)

All views/interpretations expressed are mine!

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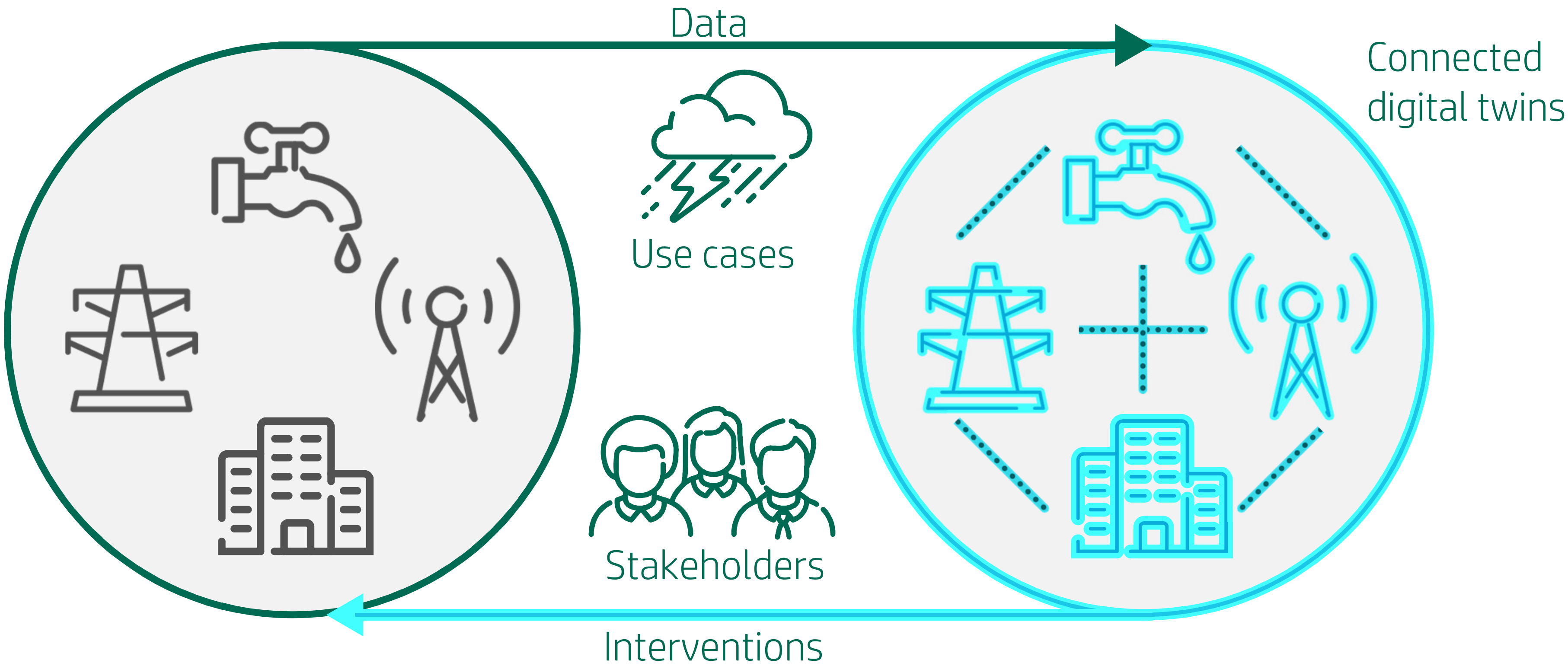
What is a digital twin?



What is a digital twin?

- This workshop!
  - *A digital twin is a computer model that simulates an object or process in the physical world… insights into the behaviour of the physical system… improve its design and/or functioning.*
- The National DT programme (broad church)
  - Importance on data interoperability (technical work)
  - Emphasises that aim is to improve operations / decision making
- Twin, model and shadow
  - Emphasis on two way flow of data (hard-linking) for DTs
  - Not universally accepted terminology
- Sometimes emphasis on high fidelity etc
  - Need to be careful to have right fidelity, right time (not real time) updating, be driven by needs of applications
- Tech development – e.g. platforms vs decision science
- CReDO - Demonstrates the two aims of NDTp

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The Climate Resilience Demonstrator project (CReDo)

Why climate?

House of Commons
House of Lords
Joint Committee on the National Security Strategy

Readiness for storms ahead? Critical national infrastructure in an age of climate change

First Report of Session 2022–23

Report, together with formal minutes relating to the report

Ordered by the House of Commons to be printed 17 October 2022

Ordered by the House of Lords to be printed 17 October 2022

HC 132
HL 74
Published on 27 October 2022
by authority of the House of Commons and the House of Lords

Why climate?

Committee on Climate Change

"There is a continuing lack of data on the vulnerability of infrastructure to extreme weather and the steps being taken to manage interdependencies between sectors."

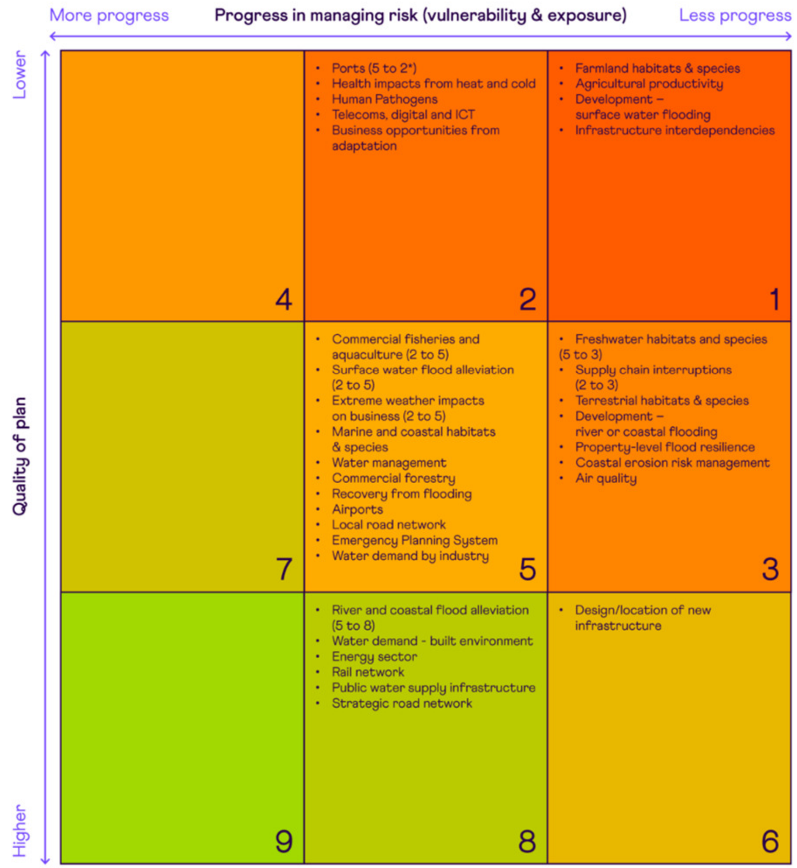

Figure ES.1 The Adaptation Committee's scoring of adaptation priorities (2021)

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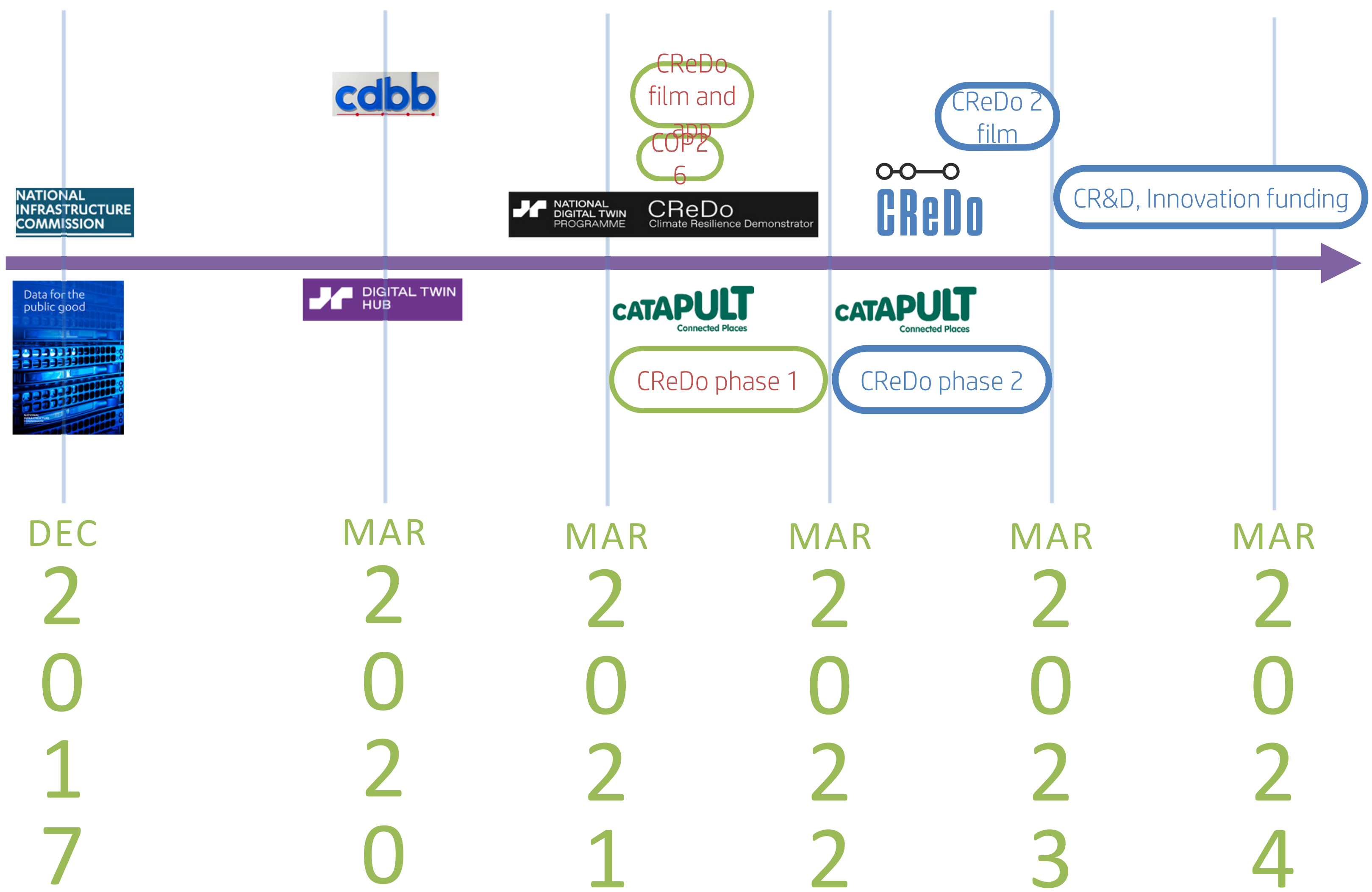
Timeline of CReDo project



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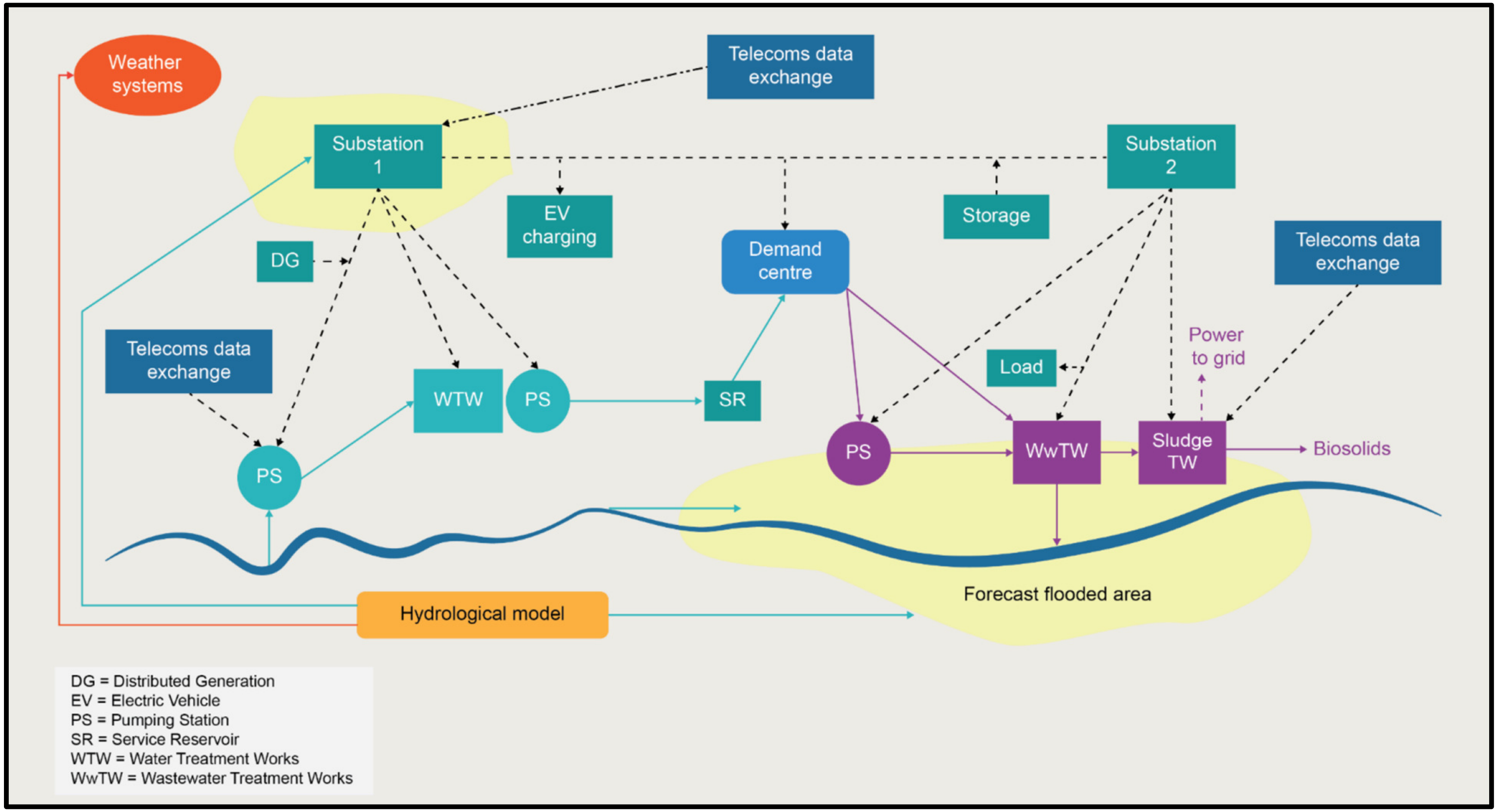
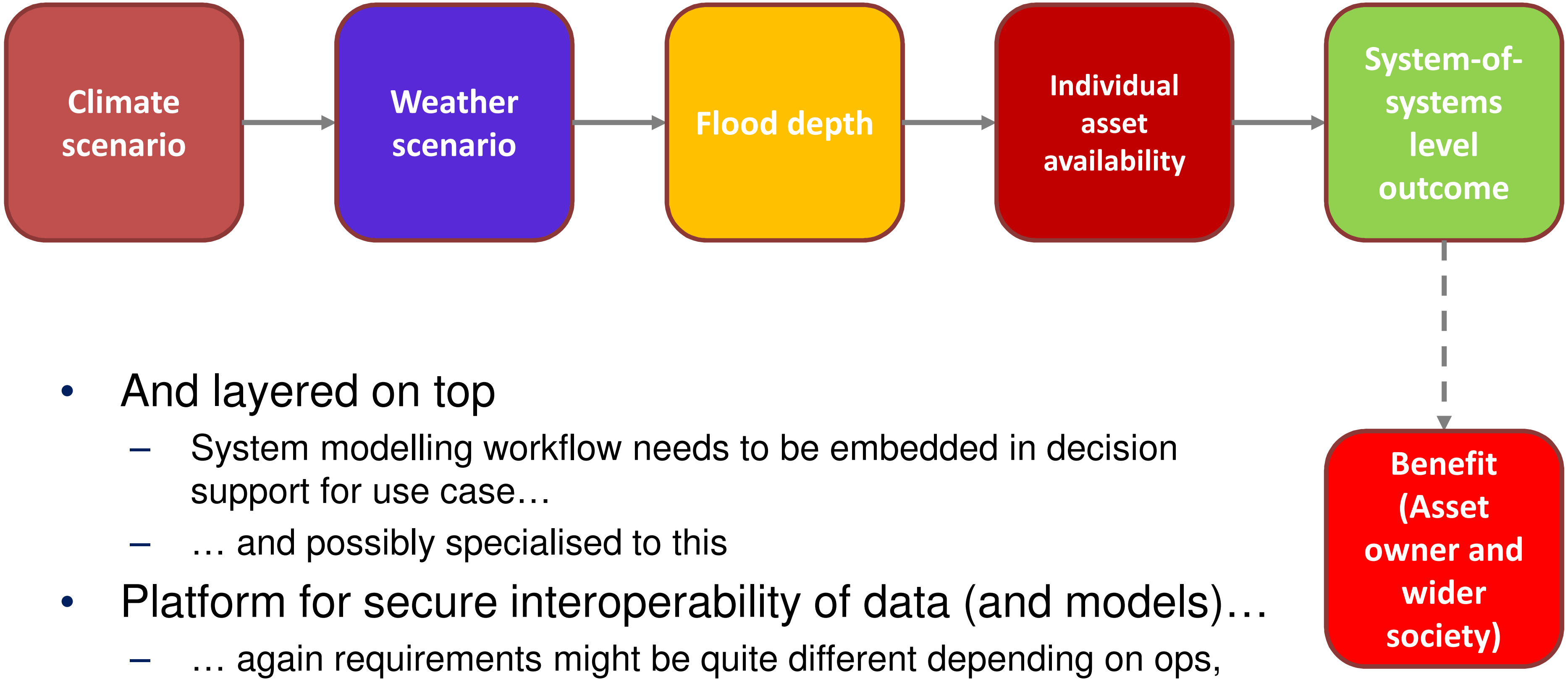
CReDo application



- National DT programme: data/model interoperability to add value
  - CReDo: demonstrate technology developed and value added by interoperability
  - Schematic demonstrates consequences for other networks
  - Everything relies on electricity, coordination relies on comms

CReDo architecture (flooding)

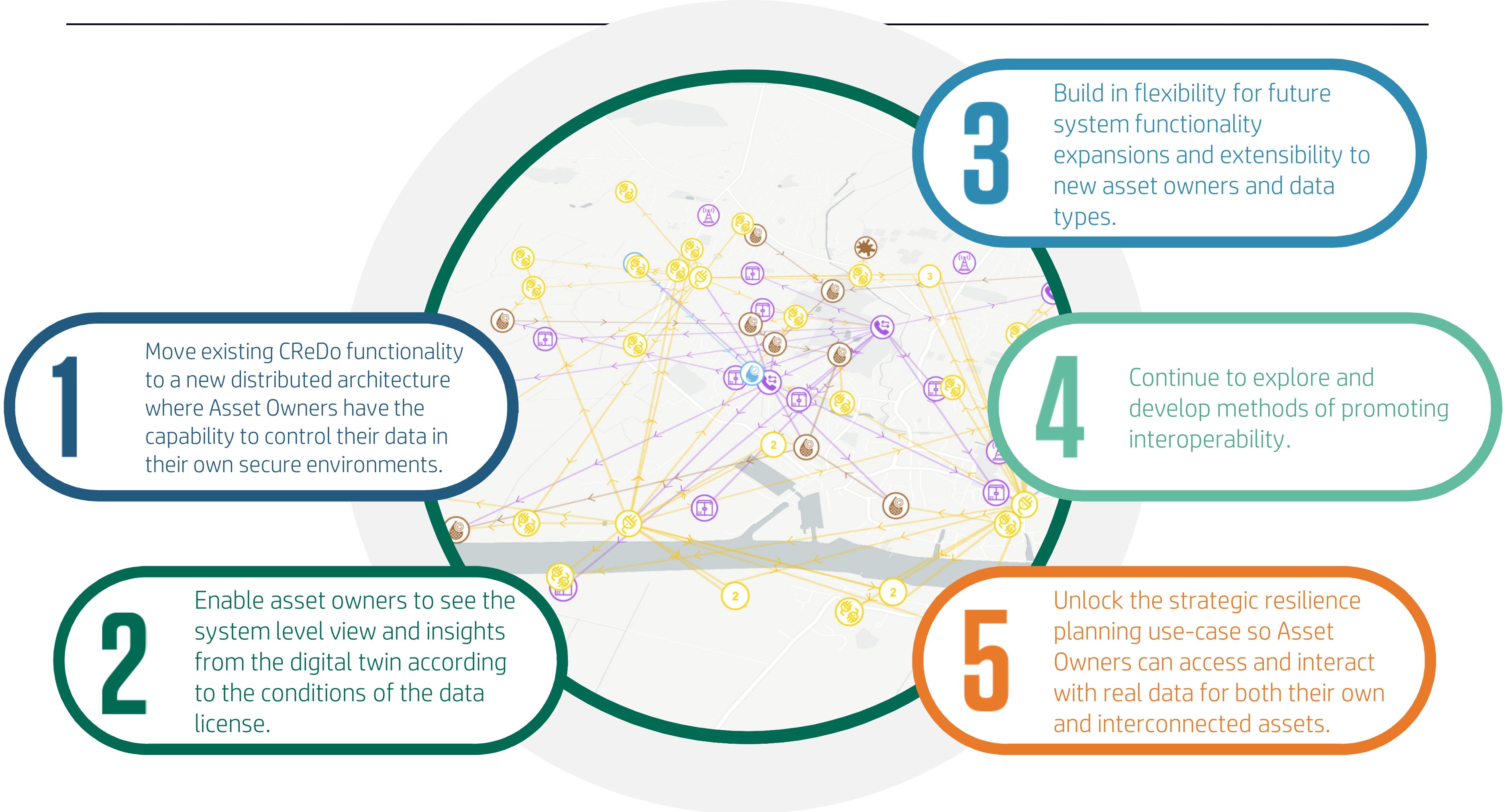


- And layered on top
  - System modelling workflow needs to be embedded in decision support for use case…
  - … and possibly specialised to this
- Platform for secure interoperability of data (and models)…
  - … again requirements might be quite different depending on ops, planning, etc

Limited direct data

- CReDo as DT
  - Representation of possible future systems and context on which to experiment, and which can be embedded in decision analysis
  - Automated / low friction data ingestion
  - Feedback to real system in form of planning decisions
  - Data interoperability between organisations vital
- Limited direct data
  - The future has not yet happened
  - Extremes relevant
  - Data do not include events that matter (eg failure modes)
  - Data are model-generated (e.g. climate, surveys)
- Consequences
  - Introduces uncertainty in modelling
  - Role of explicit expert judgment (or interpretation of data)

Data architecture

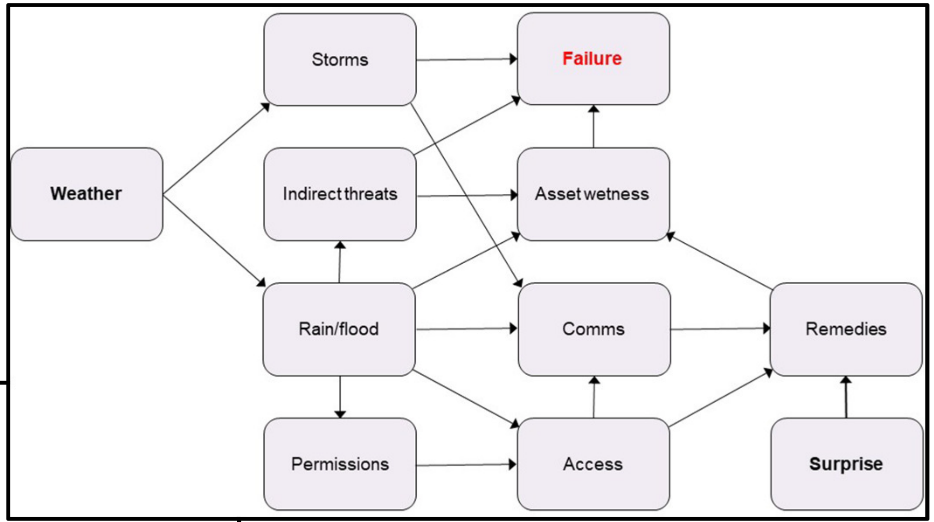


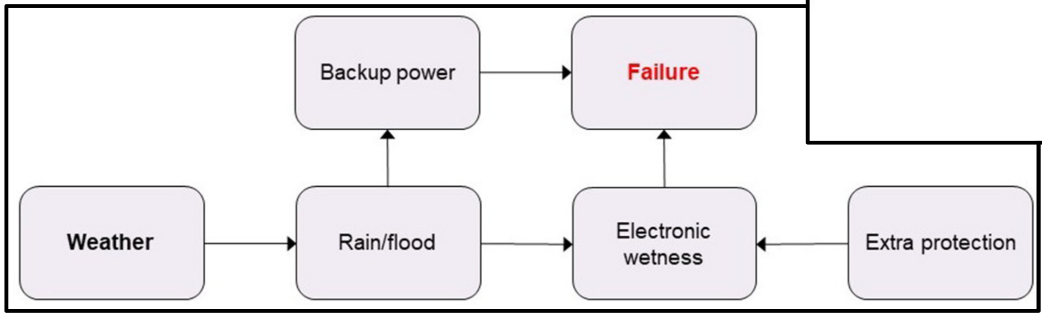
- I am a model-based decision support person
  - CMCL are represented here!
  - Interoperability and individual companies’ security needs

Limited data – asset failure modes

Asset availability (Smith/Wilson/CD)

Flood depth





- No direct data on [relevant] failure modes (common issue)
  - Elicit cause/effect (Smith) *and* quantification (K Wilson) from expert field operatives
- Generic cause-effect diagram
  - Arrows: ‘if this happens at tail then probability of event at head is…” (Bayes net)
  - Note ‘Permissions’ and ‘Access’
- Diagram for specific asset
  - Note ‘Electronic wetness’ and ‘Backup power’

Elicitation of probabilities

Top panel: Probabilities elicited directly					
Probability	Expert 1	Expert 2	Expert 3	Expert 4	Consensus
$p_o(o)$	0.9	0.99	0.99	0.7	0.95
$p_f(f \mid h = 900, d \leq 900)$	0.5	0.35	0.1	0.5	0.425
$p_f(f \mid h = 900, d \geq 900)$					≈ 1
$p_g(g)$	0.8	0.8	0.85	0.85	0.8
$p_e(e)$	0.7	0.25	0.05	0.2	0.7
$p_s(s)$					0.02
$p_v(v)$					0.05
Middle panel: Probabilities calculated from those elicited					
$p_c(c)$					0.26
$p_1^*(h = 900, d)$					0.66
$p_2^*(h = 900, d \leq 900)$					0.10
$p_2^*(h = 900, d \geq 900)$					0.27
Bottom panel: Probability of pumping station failure					
$p^*(h = 900, d \leq 900)$					0.76
$p^*(h = 900, d \geq 900)$					0.92

p_o: pumps overwhelmed

p_f: pumps fail given defences and depth

p_g: backup gen unavailable

p_e: electrics fried if flooded

p_s: backup batteries stolen

p_s: backup diesel stolen

- Probabilities elicited from field operatives (K Wilson)
  - Modified SHELF method
  - Each expert gives view first, then achieve consensus
  - Systematic way of mapping expert judgment to system properties
- How to scale this to whole enterprise
  - Limited resource for each individual asset (particularly local infrastructure)
  - Expertise within organisation (currently methods designed for specialists)

Complexity of climate resilience model

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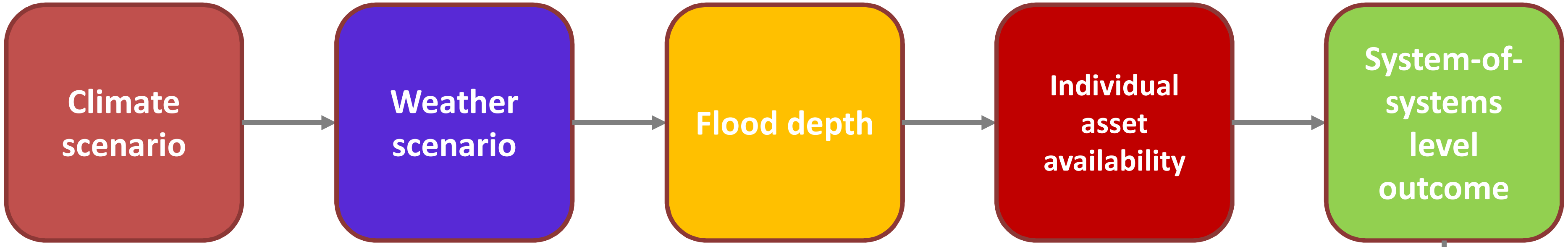
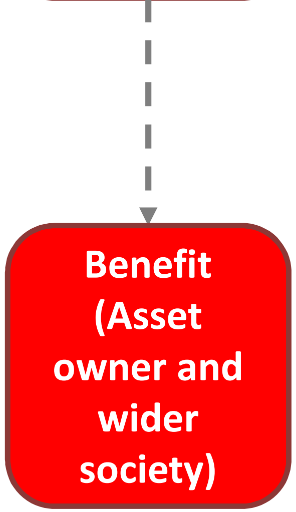
CReDo architecture (flooding)





- Infrastructure networks are not simple
  - Climate and wide-area hydrology may be more complex…
  - … at least in the way modelling is typically done…
  - … usually how climate science enters into decision support!
- Decision analysis usually assumes bespoke runs
  - If not bespoke model building!
  - Climate/hydrology runs may be done by someone else for different or general purpose
  - (Should be a purpose, and guidance on how they should be used!)
  - (And users should be asking for this, not "throw data over the wall")
- Preview – we have not solved this!

UK Climate Projections (UKCP18)

	Probabilistic projections	Global (60km) projections	Regional (12km) and Local (2.2km) projections	Derived projections
Description	Probabilistic changes in future climate based on a assessment of model uncertainties	A set of 28 climate futures with detailed data on how it may evolve in the 21st century ■ 15 x Hadley Centre Model variants HadGEM3-GC3.05 (PPE-15)‡ ■ 13 x Other climate models (CMIP5-13)‡	Two sets of 12 climate futures at high resolution: ■ 12km over Europe, downscaled from the global projections (PPE-15) using Hadley Centre model HadREM3-GA705 ■ 2.2km for the UK, providing further downscaling from the 12km simulations using HadREM3-RA11M	A set of climate futures derived from the global projections for a lower emissions scenario and global warming levels
Period	1961-2100	1900-2100	1981-2080 for 12km 1981-2000, 2021-2040, 2061-2080 for 2.2km	1900-2100
Temporal resolution	Monthly Seasonal Annual	Daily Monthly Seasonal Annual	Subdaily for 2.2km Daily Monthly Seasonal Annual	Daily Monthly Seasonal Annual

- Model generated data – not ground truth, need for calibration
  - Limited exploration of possible futures in high res data
  - May be aspects of weather/climate which *no* climate models treat well

Derived hydrology (UKCEH)

UK CEH Environmental Information Data Centre

EIDC | Find data | Deposit data | Support | About | Contact us | Help | Login

Hannaford, J. *et al*

Hydrological projections for the UK, based on UK Climate Projections 2018 (UKCP18) data, from the Enhanced Future Flows and Groundwater (eFLaG) project

https://doi.org/10.5285/1bb90673-ad37-4679-90b9-0126109639a9

“” Cite this dataset

Enhanced Future Flows and Groundwater (eFLaG) is an 12-member ensemble projection of river flow, groundwater level, and groundwater recharge time series for 200 catchments, 54 boreholes and 558 groundwater bodies in Great Britain and Northern Ireland. It is derived from the UKCP18 dataset, specifically the 'Regional' 12km projections, to which a bias correction is applied. River flows, groundwater level and groundwater recharge data are at a daily time step.

To be consistent with the driving meteorological dataset, eFLaG data use a simplified 360-day year, consisting of twelve 30-day months. eFLaG data span from 1981 to 2080.

The development of eFLaG was made during the partnership project funded by the Met Office-led component of the Strategic Priorities Fund Climate Resilience programme under contract P107493 (CR19_4 UK Climate Resilience).

Publication date: 2022-01-26

- Based on UKCP regional datasets (12 runs, perturbed initial conds)
  - For hydrology, calibration but no uncertainty treatment

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Sources of uncertainty (MG)

- Parametric uncertainty (each model requires a, typically high dimensional, parametric specification)
- Condition uncertainty (uncertainty as to boundary conditions, initial conditions, and forcing functions)
- **Functional uncertainty (model evaluations take a long time, so the function is unknown almost everywhere)**
- Stochastic uncertainty (either the model is stochastic, or it should be)
- **Solution uncertainty (as the system equations can only be solved to some necessary level of approximation)**
- **Structural uncertainty (the model only approximates the physical system)**
- Measurement uncertainty (as the model is calibrated against system data all of which is measured with error)
- **Multi-model uncertainty (usually we have not one but many models related to the physical system)**
- **Decision uncertainty** (to use the model to influence real world outcomes, we need to relate things in the world that we can influence to inputs to the simulator and through outputs to actual impacts. These links are uncertain.)
- **Uncertainty about what is meant by *uncertainty* and *probability***

Decision support in practice

HM Treasury

The Aqua Book:

guidance on producing quality analysis for government

- Aqua Book
  - V good on what one should aim for
  - Scope does not include detail of technical approaches
- How to design decision support for v complex systems
  - Co-design of system modelling, uncertainty treatment, and decision support
  - Linking of models and datasets between subsystems
  - May not be able to do own model runs…
  - … so use available model-generated data…
  - … and need expert interpretation in context
- Data driven approach will underestimate range of futures
  - May well also underestimate possible adverse extremes
- Need approaches to building logically well founded decision support systems
  - Context of current skills and practices

Summary

- Described CReDo project
- Challenges of climate (flood) resilience – heat next
- Expert elicitation in circumstance of limited direct data
- Need approaches to end-to-end decision support systems which can be used widely
  - Coordinate system modelling, uncertainty, decision support
  - Particular challenge for v complex systems

https://digitaltwinhub.co.uk/credo/technical/

https://www.ofgem.gov.uk/publications/decision-making-future-energy-systems

https://www.researchgate.net/publication/275645691_Bayesian_decision_AnalysisPrinciples_and_Practice