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Risk-driven MMV Plans

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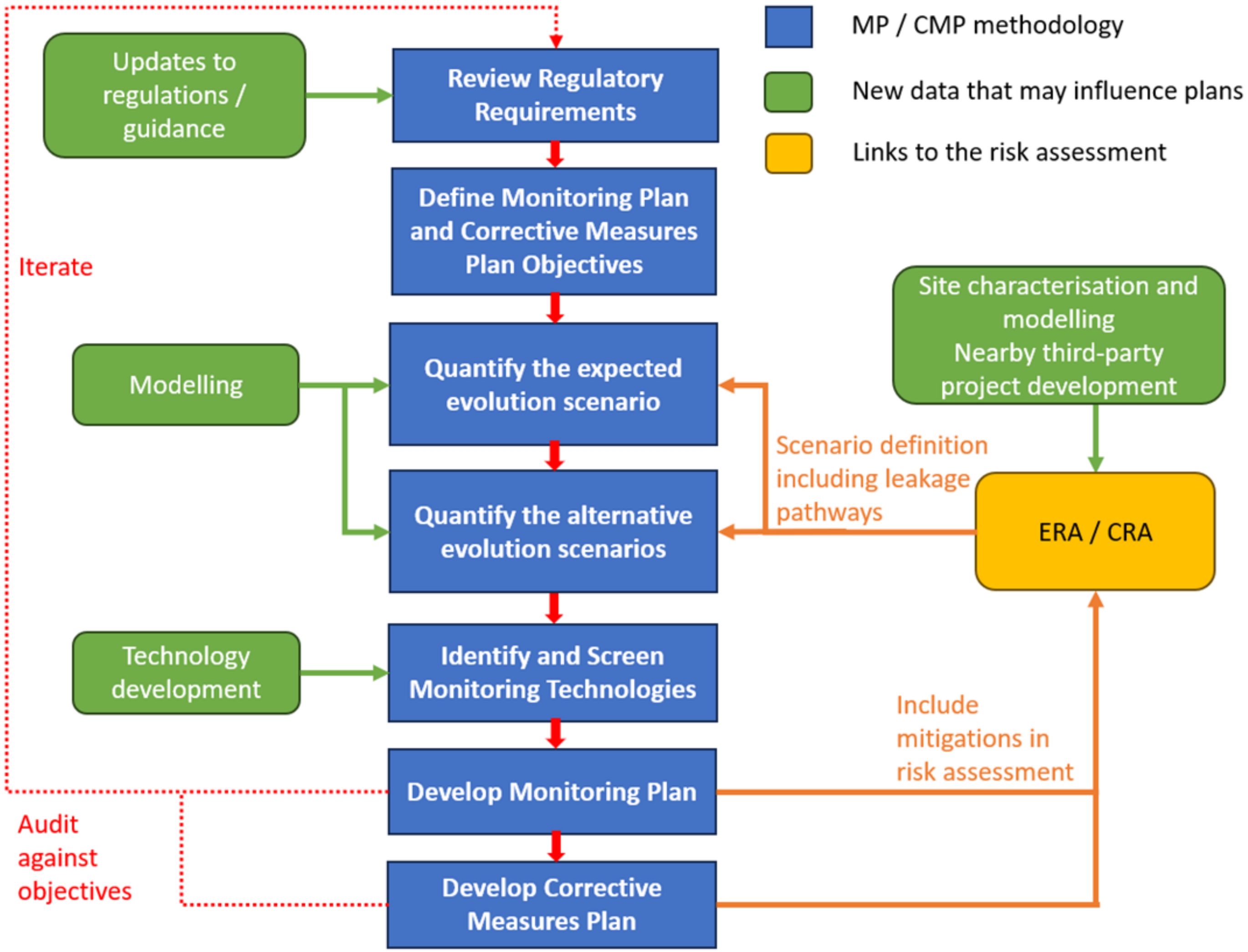
So where did we start?

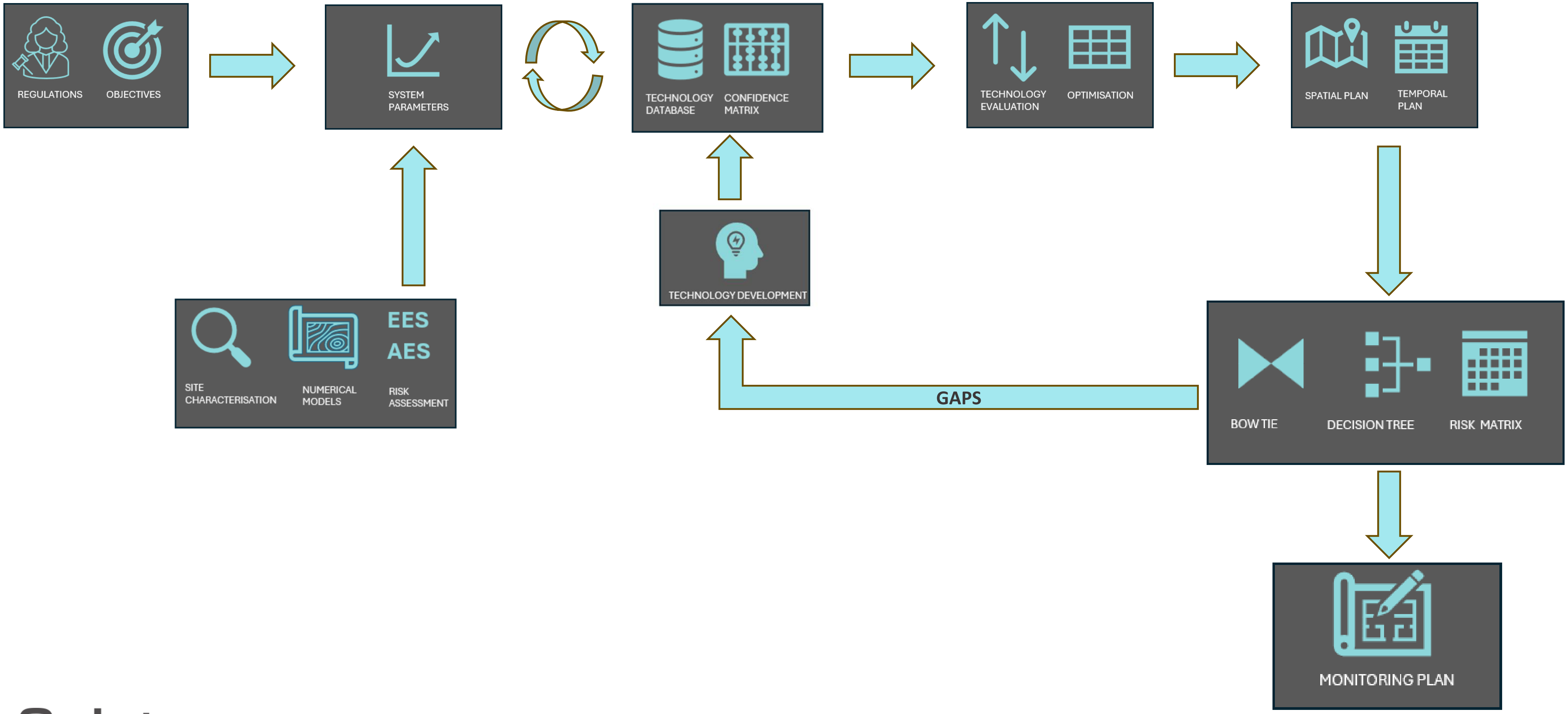
Workflow Development

- An iterative process - technical understanding increases through licence stages.
- Detail and definition develops to meet the requirements of each licence term / period (concept vs final plan).
- Recording how and why decisions have been made is an important part of the workflow - supports effective iteration.
- Early thinking related to the display and communication of outputs minimises re-working.
- Clear connection and feedback between technical components is critical to a robust MMV plan.

Workflow Cycle

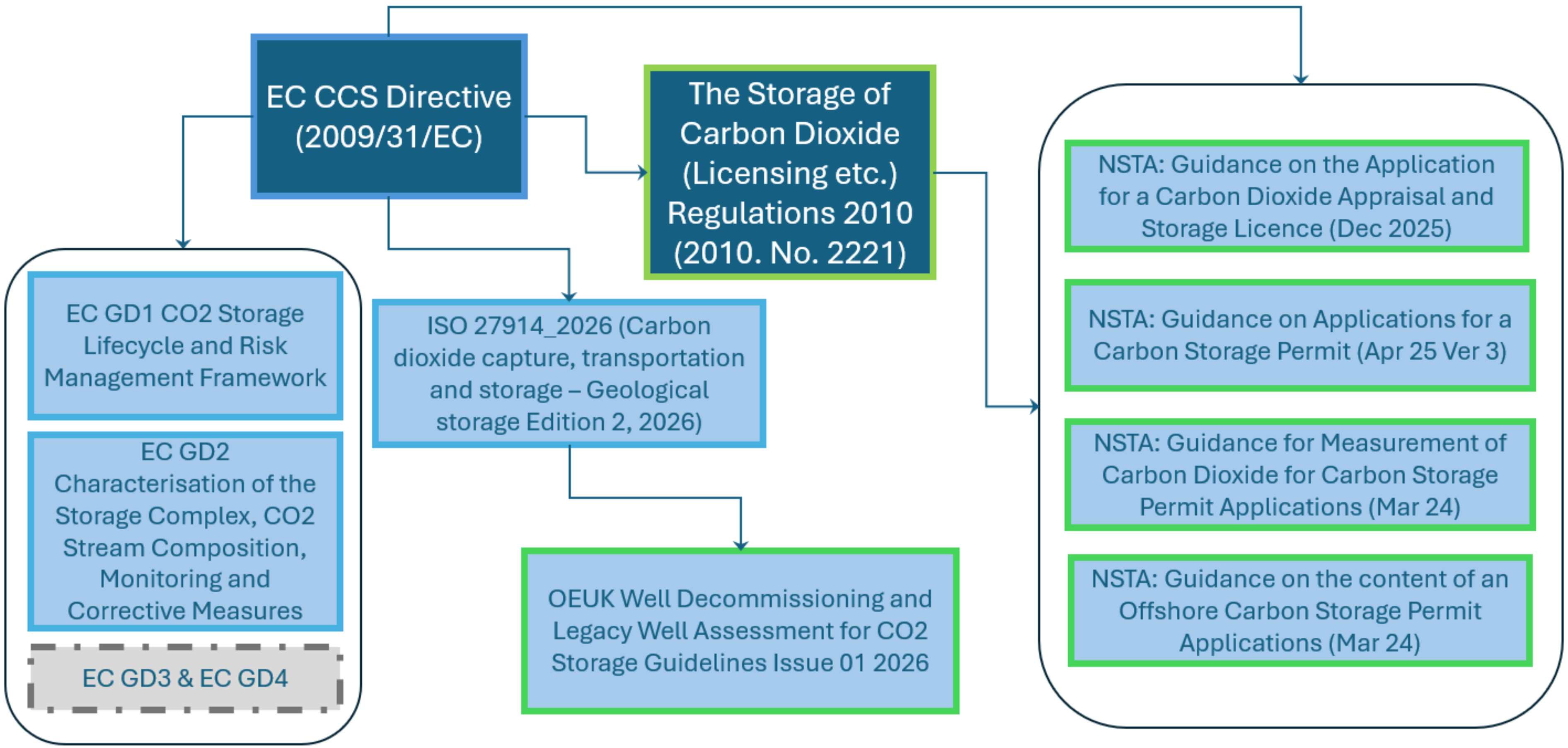


Monitoring Plan Concept Development



Review Regulatory Requirements

REGULATIONS



*Draft Detailed Guidance on the Carbon Storage Permit Application Process (March 2026) is currently being road tested with Licensees.

Structure Regulatory Requirements

OBJECTIVES

- Requirements re-structured into Objectives - provides a framework to measure the suitability / capabilities of monitoring technologies.
- Example from work undertaken prior to issue of updated guidance:

NSTA (2024) Guidance on the content of an Offshore Carbon Storage Permit Applications [p21]
NSTA (2023) v2 Guidance on Applications for a Carbon Storage Permit [134]
EC (2009) Directive 2009/31/EC - Annex II + Article 13
EC GD2 (2024) (p46/47)

  - Objective: To provide mandatory data to monitor the injection facilities and CO2 supply
  - Sub-requirement – CO2P and T at the wellhead
    - Relevant Parameters – Wellhead Temperature and Wellhead Pressure

Risk Assessment

- The Early and Containment Risk Assessments define Expected Evolution Scenarios (EES) and Alternative Evolution Scenarios (AES).
- The EES and AES identify specific risks (and associated pathways) which could arise throughout lifecycle.
- MP and CMP must mitigate risks which are significant.
- Developments in the ERA / CRA will require iteration of the MP and CMP.

How did we decide what to monitor?

System Parameters

NUMERICAL MODELS

SYSTEM PARAMETERS

- Anticipated ranges of parameters need to be defined (for EES and AES), examples are;
  - seabed uplift, storage site gas pressure, bottom hole temperature and wellhead pressure.
- Demonstrates understanding of the system in an EES or AES scenario.
- Supported through modelling.
- Helps to define when measurements indicate an irregularity (numerical or spatial pattern changes).
- Clearly shows how the system will change and the magnitude and location of that change - greater confidence that selected technologies will perform adequately.

Links to Risks

- Degree of change in a system parameter could be an early warning of activation of a risk(s).
- All significant unmitigated risks, and their associated system parameters, drive the requirements for MP and CMP.
- The most significant unmitigated risks will require the greatest focus on provision of MP and CMP lines of evidence and redundancy to reach the threshold of no significant risk of leakage.

How did we approach technology selection?

Technology Selection (1)

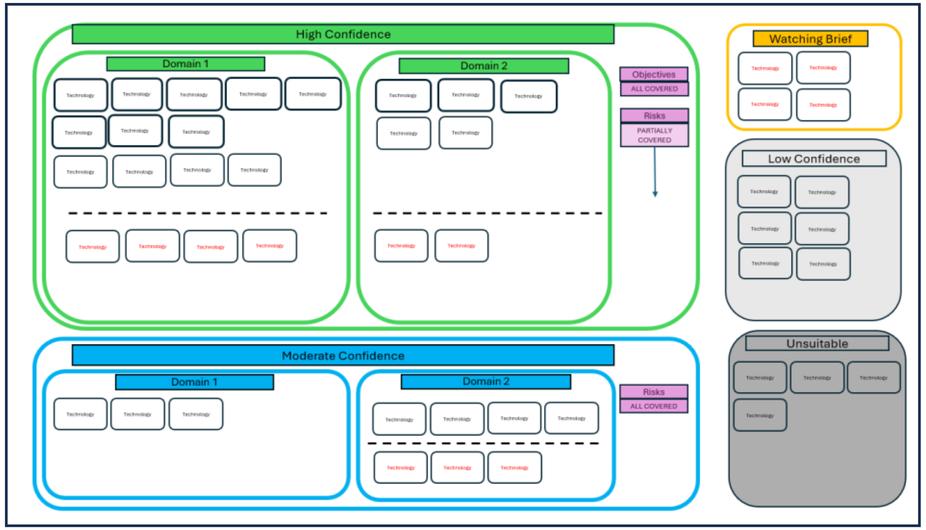
TECHNOLOGY DATABASE

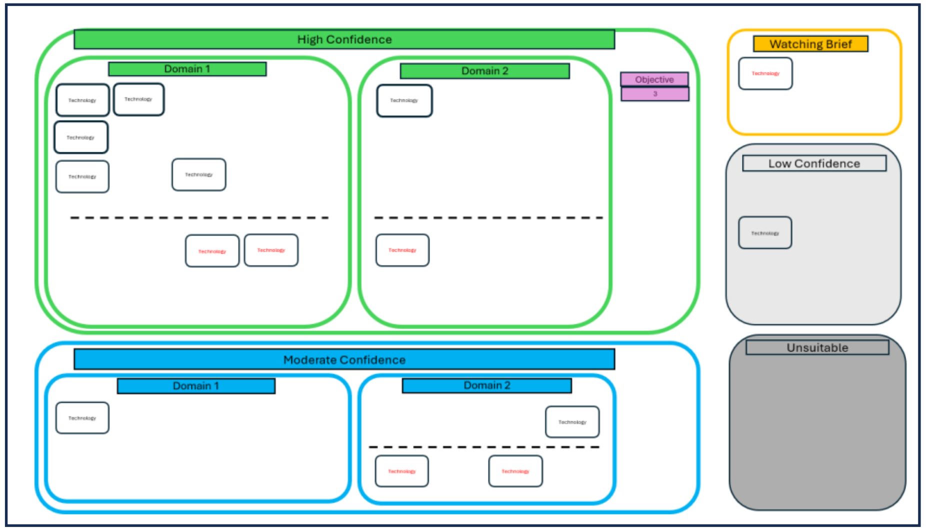
- Guidance expects operators to demonstrate a wide range of technology options have been evaluated before the preferred portfolio is selected for the MP and CMP.
- Early thinking around how technology information can be stored and presented for ease of performance comparison is important.
- We used a database structure for technologies which shows how each technology links to project data, project phases, objectives and specific risks.
- Database also records data acquisition fields to enable performance comparison.

Technology Selection (2)

TECHNOLOGY DATABASE
CONFIDENCE MATRIX

- Matrix structure supports review of technology available to provide data on individual risks or groups of risks.
- Structure also allows a review of objectives in the same way.
- If a technology does not meet any objectives or support the assessment of store-specific risks, it is unsuitable.
- A technology which provides data to support multiple objectives and risks is high value.
- Providing this hierarchy helps move towards technology selection.
- Knowledgeable stakeholders are needed to populate the technology entries.





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How did we assess technologies with limited data?

Performance Capability

TECHNOLOGY DATABASE CONFIDENCE MATRIX

- Several technologies could provide parameter data relevant to multiple objectives and risks.
- Performance capability fields in the database used to support down-selection.
- Data on aspects such as limit of detection, accuracy, precision, repeatability, measurement uncertainty, background interference etc. are required.
- Technology providers may not be in a position to provide this data in a store specific context in early stages of MP and CMP development.
- Stakeholder consensus can initially be used to give confidence levels against capability fields e.g. high confidence that the technology will be precise enough.

Key Performance Criteria

TECHNOLOGY DATABASE CONFIDENCE MATRIX

- Understanding the limit of detection is most important high-level performance criteria.
- If the technology has low confidence that it can measure the degree of change for a specific system parameter, it can be screened out from portfolio selection.
- Other performance criteria e.g. background interference or repeatability can then be used to order the performance for those remaining.
- As the project and technology development progress, stakeholder consensus confidence categories can be replaced by numerical data for comparison against system parameter change data.

How did we record decisions on technology selection?

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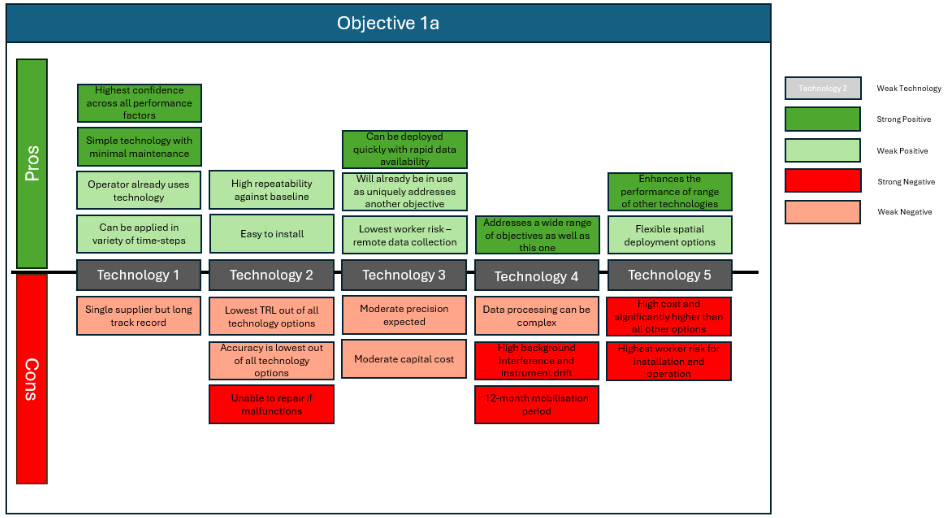
Down Selection

TECHNOLOGY EVALUATION

- Recording arguments in a structured and flexible way gives transparency and confidence in the outcome.
- Comparative pros and cons can be used to determine a preferred option.
- Graphical output from this process gives a clear overview of technologies which perform strongly across a range of objectives and risks.
- Also shows if there are gaps in technology capability or if a single technology is critical for assessing a particular risk.



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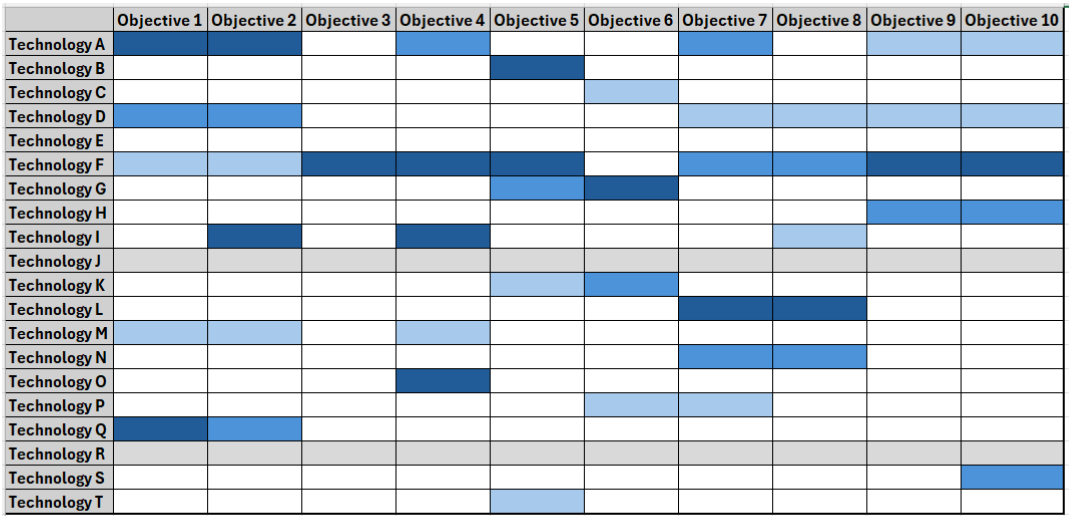
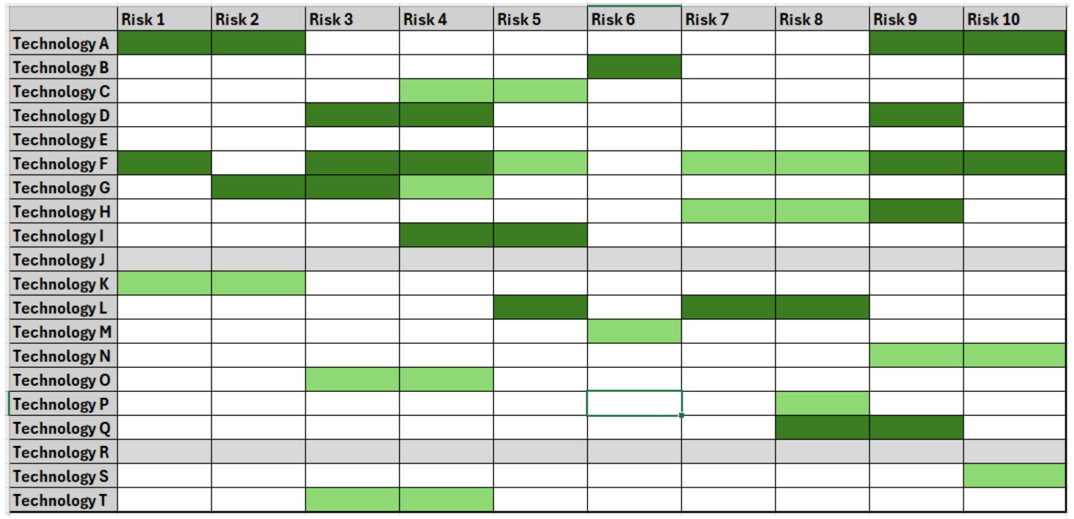
Optimisation

OPTIMISATION

- The strongest performing group of technologies which cover all objectives and associated risks are brought together as the lead technology group, with redundancy added as required.



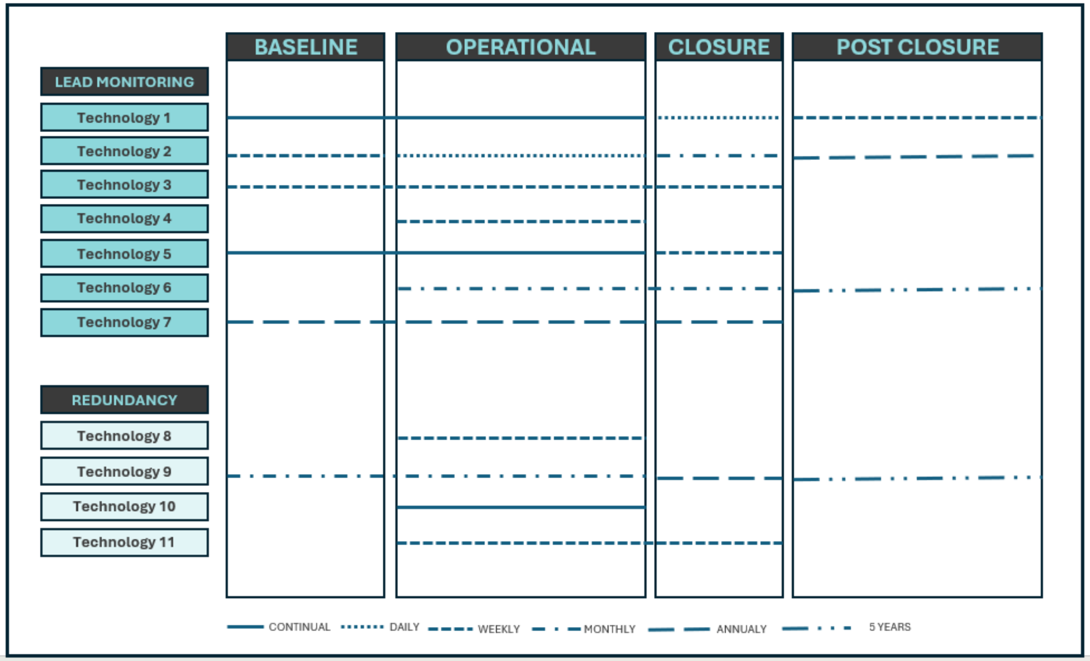


How did we approach where and when to monitor?

Temporal Optimisation

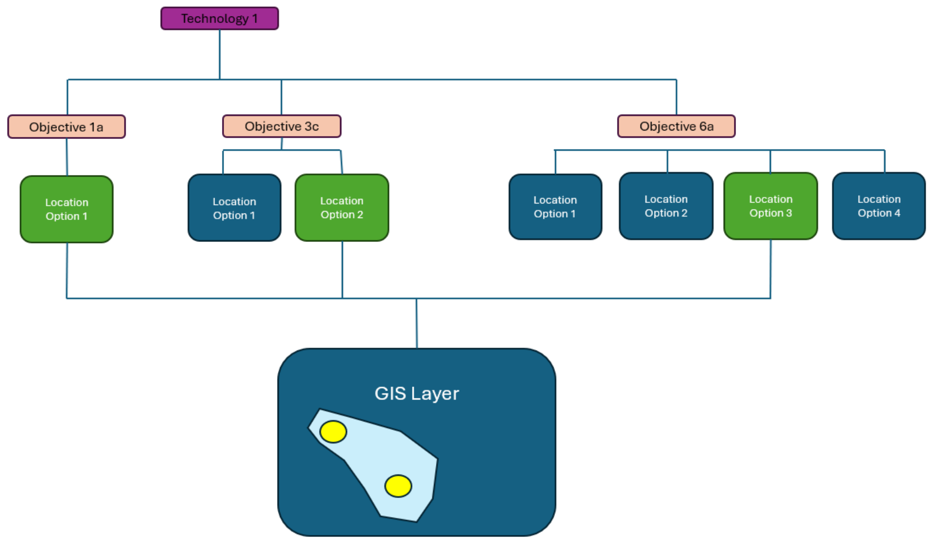
TEMPORAL PLAN

- Deployment frequency will change through project stages.
  - Baseline, Operational, Closure, Post Closure.
- Speed and magnitude of potential parameter change (supported by modelling) drives frequency requirements.
- System monitoring must be reviewed as a whole to ensure efficiencies in timing of monitoring and use of resources.



Spatial Optimisation

- Alternative spatial configurations for a technology can be set out for each objective or risk of relevance and the most effective selected to combine into a spatial deployment plan.
- Locations linked to risks, e.g. legacy well or injection well.

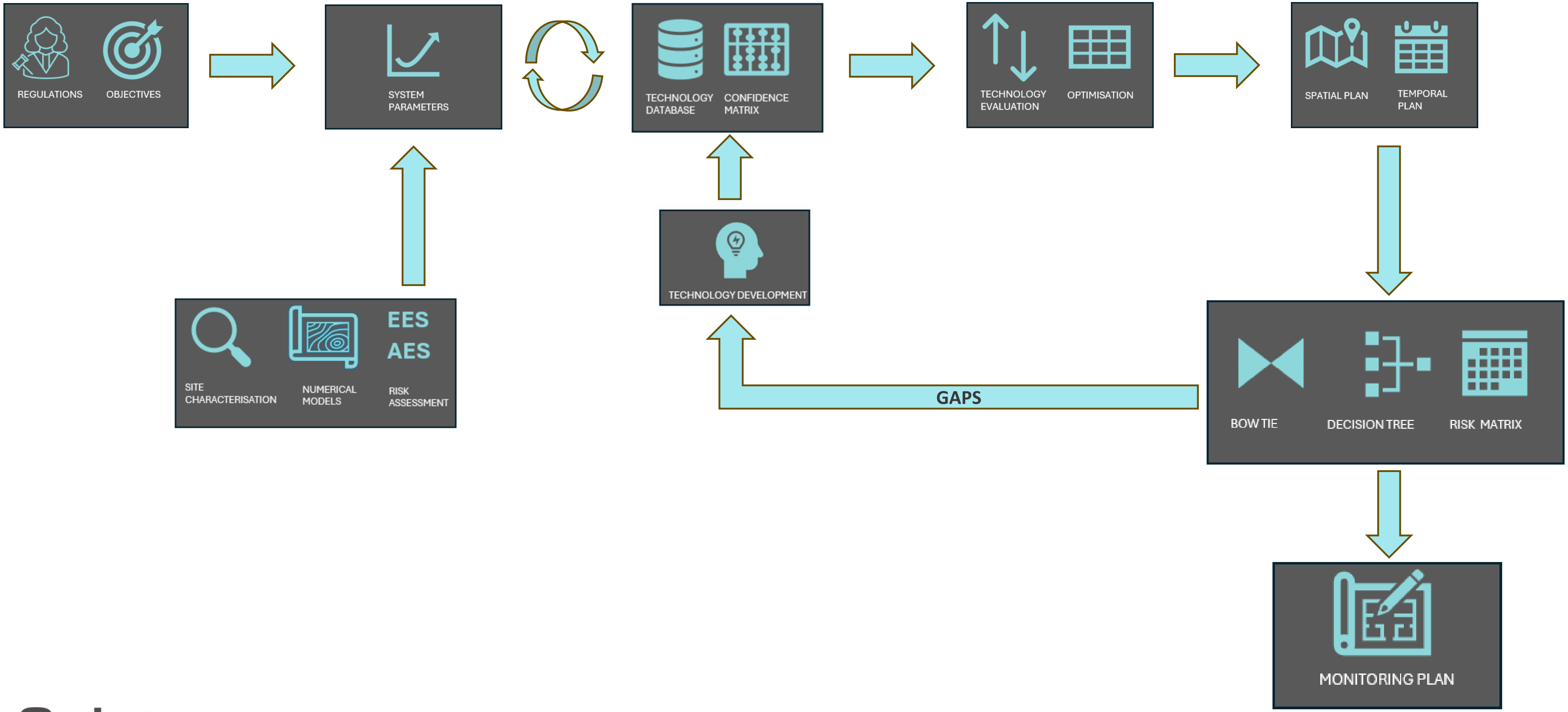


How did we maintain the link with risk assessment?

Links to Risk Assessment

- Rationalised approaches to monitoring now defined but the risk assessment might identify weaknesses in the monitoring programme.
- Tested by BowTie analysis and Decision Trees.
- Feedback and further iteration of the monitoring plan will resolve any weaknesses/identify mitigation gaps.

Monitoring Plan Concept Summary



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Corrective Measures (1)

- Concept development followed a similar logical process.
- Uses knowledge of technology developed from MP.
- Driven by understanding and categorisation of data observations linked to system parameters:
  - Regular Range
  - Significant Deviation
  - Significant Irregularity
  - Leak/Harm
- Escalation of action as category increases.

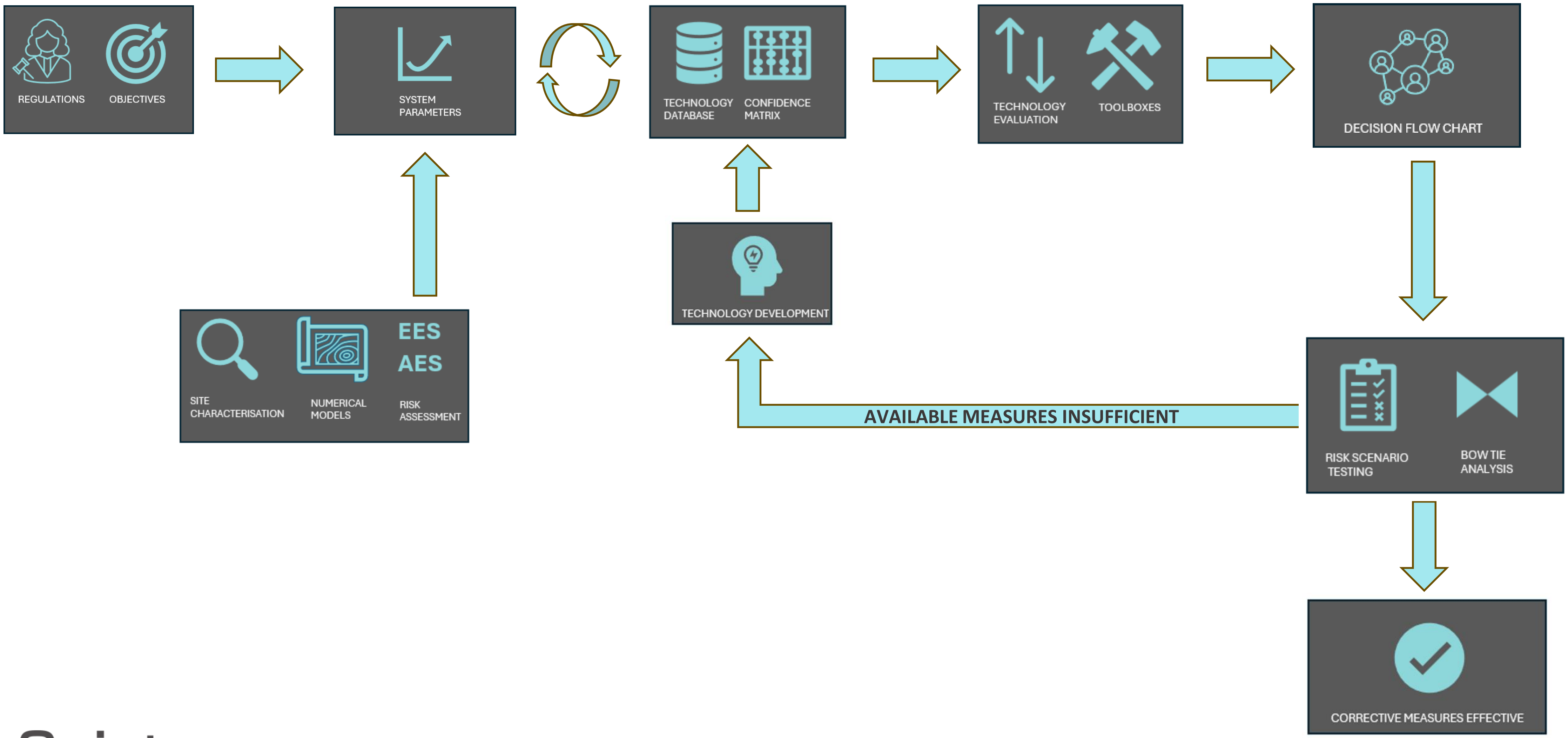
Corrective Measures (2)

- Actions set out in a decision flow, so pathways of escalation and de-escalation are available depending upon outcomes.
- No monitoring technology down-selection applied but viable technologies organised into toolboxes applicable to investigation and correction.
- Management actions also included in toolboxes, such as check instrument calibration or reduce injection pressure.
- Risk scenarios run through decision flow and toolboxes to ensure effective corrective measures are available.

Corrective Measures (3)

- Outcomes to the corrective measures process can vary, depending upon the scenario:
  - Revert to standard monitoring
  - Adjustments to Regular Range(s) of specific parameters
  - Updated monitoring plan
  - Additional long term corrective measures
  - Regulatory consultation
  - A combination of the above
- Outcomes integrated onto Bow Ties to test and underpin CMP.

Corrective Measures Concept Summary



Any Questions?