WSX11 - Annexes - Maintaining our services

Business plan 2025-2030

Wessex Water
YTL GROUP

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WSX11 – Annexes - Maintaining our services

CONTENTS

This supporting document is part of Wessex Water's business plan for 2025-2030.

Please see 'WSX00 – Navigation document' for where this document sits within our business plan submission.

More information can be found at wessexwater.co.uk

A1 EDA System Implementation Document

EDA Implementation

System Implementation Documentation

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Contents

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Abbreviations

Term	Definition
EDA	Enterprise Decision Analytics
GIS	Geographical Information Systems
AIP	Asset Investment Planning
BAU	Business as Usual
IM	Investment Management
SMF	Service Measure Framework
VF	Value Framework
SIF	Site Info
API	Application Programming Interface
UAT	User Acceptance Testing
SIT	Systems Integration Testing

1 Executive Summary

Wessex Water procured Arcadis Gen's Enterprise Decision Analytics (EDA) as an off-the-shelf solution for their investment management (IM) tool requirement. This IM tool acts as a single repository for all investment needs and solutions together with recorded evidence. Furthermore, it allows for prioritisation and optimisation aligned to Wessex Water corporate objectives. The tool allows Wessex Water to plan and manage investments using a streamlined process that balances risk, cost and performance in the most optimal way. This alignment is supported by the Wessex Water Service Measure Framework (SMF) ensuring that all investments align to a core list of drivers which are then monetised accordingly such that it is no longer 'who shouts loudest'.

Initially to be used for PR24 planning, the tool will also be used in a business-as-usual (BAU) environment to ensure additional efficiencies and evidence to the range of business plans created by Wessex Water, for both internal and regulatory use.

An initial group of Wessex Water users were trained on its use based on user scripts aligned to Wessex Water's to-be business processes and key user scenarios. This included the ability to create and update investment needs and solutions, approve and review them, run optimisations and collate a centralised business plan. This has been followed by a number of user acceptance testing cycles to ensure the configuration meets Wessex Water requirements. Four environments have been deployed for Wessex Water use, providing sufficient areas for production, testing, training and development.

EDA is also integrated with core Wessex Water systems to ensure a sufficient feedback loop for investment planning. This includes inbound integration with the risk system, M7, to ensure new risks and issues, filtered based on business rules, are converted into investment needs and aligned to the Wessex Water SMF. Likewise, EDA is integrated with Agresso to ensure that investments are up to date in terms of costs and purposes. Outbound integration with Qlik enables dashboard views of the outputs for presentation to a wider audience.

In addition to portfolio modelling, above ground asset modelling also takes place in EDA informing more operational decisions on non-infrastructure replacements and refurbishments. This modelling also allows for users to run 'what-if' optimisation scenarios on the assets themselves. The outputs of which feed the values on existing investment needs and solutions in addition to creating new ones.

Together with additional documentation linked within this document, this document looks to summarise the key assumptions, inputs, and outputs from this implementation in addition to providing conclusions and recommendations for future use.

2 Enterprise Decision Analytics (EDA)

Since 2002, Arcadis Gen and our EDA solution have helped clients implement asset decision making and capital planning and Investment methodologies, across different sectors and asset types, and within best practices and regulatory contexts.

EDA enables:

- Capital Planning and asset/project decision analytics from raw data from source systems to optimised investment and delivery plans, with sophisticated predictive and prescriptive models forecasting cost, risk and performance for Assets and Projects.
- Multiple investment scenario comparisons (service/risk targets, cost projections) and presentation via graphical interfaces, dashboards and maps.
- Transparent audit trail from predicted investment requirements, through the supporting analysis, back to the original data.
- Customers to determine the least-cost plan to meet their objectives and outcomes through the deployment of powerful optimisation engines.
- Customer, Regulatory and Stakeholder confidence with a proven solution that is compliant with and facilitates ISO 55000 and other relevant standards.
- Employs recognised industry standards for databases, services and application, security and authentication for Microsoft Windows and web environments.

EDA is highly flexible and configurable, and empowers best practice Asset Management processes, encapsulates future change, and provides maximum value for all stakeholders – strategically and tactically. EDA consists of key modules EDA (EDAA) Asset and EDA Portfolio (EDAP). It includes functionality out of the box that supports:

EDA Asset

- Asset health – flexible configuration of asset health, considering the level of asset data available
- Asset deterioration modelling – any deterioration logic can be modelled within EDA
- Asset risk frameworks - global standards are available 'out of the box' or any framework can be easily configured.
- Asset bundling logic – by using either engineering logic or more sophisticated mathematical equations to determine the most cost / beneficial combinations of interventions, EDA can automatically bundle interventions into programs of work – that maximise budgets and resources
- Asset level optimisation – optimisation in EDA can be achieved at an asset level, ensuring the best mix of interventions are recommended to achieve the goals chosen – for each scenario

EDA Portfolio

- Project portfolio optimisation – as well as asset level optimisation, EDA also optimises projects and programs of work
- Diverse projects portfolio - able to bring in potential projects from different sources including – asset level modelling, risks (via EDA's risk module or an external risk solution), innovation ideas, new infrastructure options or any other source, including non-network assets.
- Value frameworks – EDA can utilise any Value Framework, with a clear line of sight and audit trail from the project portfolio level decisions back down to asset level interventions.
- Workflows and auditability – configurable approvals workflows allow users to track, review and approve investments through stage gates. Version control ensures users can review changes made through time.

Wessex Water have procured a full configuration of EDA Portfolio in addition to configuration of EDA Asset for non-infra asset modelling. Below ground asset modelling was out of scope of this implementation but could be implemented at a later date. Through EDA Asset Train-the-Trainer, Wessex Water users will be able to make model updates including building below ground asset level models in the future.

EDA is also supported by two other extensively used modules. EDA Data Hub is a central repository for all modelling data outside those formatted and found in the EDA Portfolio needs and solutions registry.; it is therefore used to collate data from inbound systems or data transformed from modelling and manipulation activities in EDA. EDA Data Labs is an analytics toolkit which is used for cost and deterioration modelling in addition to data transforms. For this implementation, it has been primarily used for Agresso, M7 and asset data transforms.

3 Implementation

The following section explores how EDA has been implemented and associated knowledge transferred to Wessex Water over the course of the project.

3.1 Project Plan

The project plan consisted of the following key phases and deliverables:

- Initiate
  - Kick-off
  - Project Planning and Management
  - EDA Platform Deployment (and Active Directory integration)
- Design
  - Design workshops
  - Design documentation
- Build
  - Integration with Agresso, M7, Hansen and Qlik (including associated data transforms)
  - EDA Portfolio configured and populated (Descriptive Data, Model, Service Measure Framework, Approvals Workflows, Investment Lines)
  - EDA Asset configured and populated (data manipulation, asset modelling including consequences, condition and failure data)
  - Test optimisation scenarios
  - Playback sessions
  - Testing
- Training
  - Train-the-Trainer workshops
  - System Implementation document
- User Acceptance Testing (UAT)
  - UAT script builds
  - UAT support and cadence
- Migration and Go-Live
  - Migration to SIT, UAT and Production environments
  - Go-Live

The following figure demonstrates the initial project plan. For EDA Portfolio, this has stayed on course until the user acceptance testing phase. The UAT phase was initially envisaged as a 6-week period (4 weeks of UAT with 2 weeks of fixes). However, this has been moved to the right during the project due to fixes required and associated further testing. The final test was completed on 14th April 2022 following a final update to the Agresso data transforms. The resulting Go-Live date was 25th April 2022. The resulting updates (as explained later in Section 3.3) ensured a fully functional system for Wessex Water, ready for business as usual.

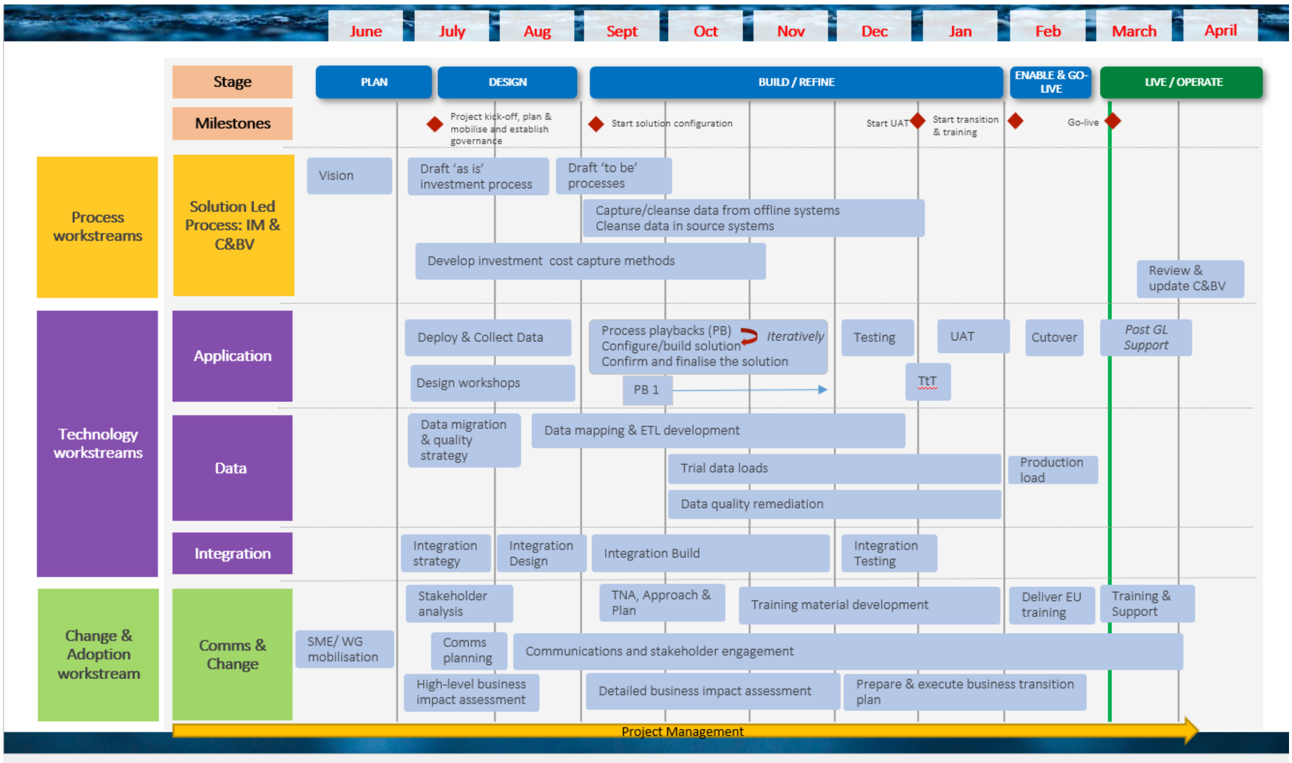


Figure 1 - Project Plan

3.2 Training

Transfer of knowledge has happened progressively over the course of the project through a number of playback sessions in addition to set of train-the-trainer (TtT) sessions.

The TtT sessions for EDA Portfolio covered the following areas:

- Introduction to EDA
- Data refresh (i.e. creating new investment needs and solutions)
- Modelling, scenarios and optimisation
- Results reporting
- Administrative training
  - Updating the SMF
  - Updating descriptive data
  - User access control
  - High level configuration (i.e. start years and modelled period length)
  - Value framework calibration

The TtT sessions for EDA Asset covered the following areas:

- Introduction to EDA
- Data Refresh

- Model Refresh
- Model Optimisation
- Results & Dashboard
- Asset Model Building

The training sessions made use of Wessex Water data and configuration. Additional training pertinent to specific user stories and challenges was also given during user acceptance testing. We often find that users learn better ‘on the job’ by using EDA and the user acceptance testing cycles helped to cement initial knowledge taken from the training sessions.

The training sessions were recorded and are available within https://wessexwater.sharepoint.com/sites/e00029/Correspondence/Forms/Default.aspx under Training and the playback sessions under Playback Sessions Recordings.

3.3 Testing

User acceptance testing (UAT) took place over three cycles with associated fixes in between. For EDA Portfolio, UAT encompassed a wide range of EDA Portfolio functionality in addition to ensuring transparency of Wessex Water processes within the system. The Wessex Water high-level business process is available at Investment Tool -high-level process.pdf.

A full template of each of the scripts given to users is available at User Acceptance Testing Scripts Workbook.xlsx. For Portfolio & User Acceptance Testing Scripts Workbook.xlsx. for Asset.

Associated issues from UAT Asset were collated in IM Asset Issues Log.xlsx
There were 2 areas of focus:

- Security groups & user profiles
- A single table, date ordering issue

Associated issues from UAT Portfolio were collated in IM Portfolio Issues Log.xlsx

A summary of fixes (and in certain cases, enhancements) completed during the user acceptance testing phase to ensure a fit for purpose system for Wessex Water includes:

- Cosmetic fix to descriptive data as guidance covered the entry
- Validation fix for mandatory fields such that users are told where the errors lie
- Ability to edit a solution (which was broken after an update above)
- Ability to create dashboard definitions for non-admin users
- Fixes for EDA to EDA Portfolio integration (Amalgamating data tables / import errors)
- Additional fixes to the Snapshot feature (based on testing by both Yorkshire and Wessex Water)
- Enhancement: Addition of weekly/monthly schedule types for integration

Additionally, the following configuration updates were made following more extensive use and feedback:

- Updates to the Agresso data transformation
- Timeout and email notifications
- Descriptive data attribute updates
- Additional user access granted
- Database updates to remove erroneous data

Arcadis Gen are thankful for the extensive user testing given that the testing performed by Wessex Water will not just support Wessex Water's implementation but also other clients.

Associated issues extending from UAT Asset were collated in IM Asset Issues Log.xlsx

4 EDA Portfolio Configuration

Wessex Water have procured EDA Portfolio as their investment management tool to firstly collate the investments against the associated SMF but also to understand the optimal investments for PR24 and beyond as part of BAU.

4.1 Investment Data and Integrations

Investment data arriving for digestion into EDA comes from four key areas:

- Agresso – Wessex Water's project management / finance system
- MetricStream M7 – Wessex Water's risk management system
- EDA Asset – above ground asset investment needs and solutions will be integrated from the other modelling stream
- Offline files and manually – Wessex Water users also upload investments that are currently handled in offline files such as Excel spreadsheets in addition to creating manually within the tool

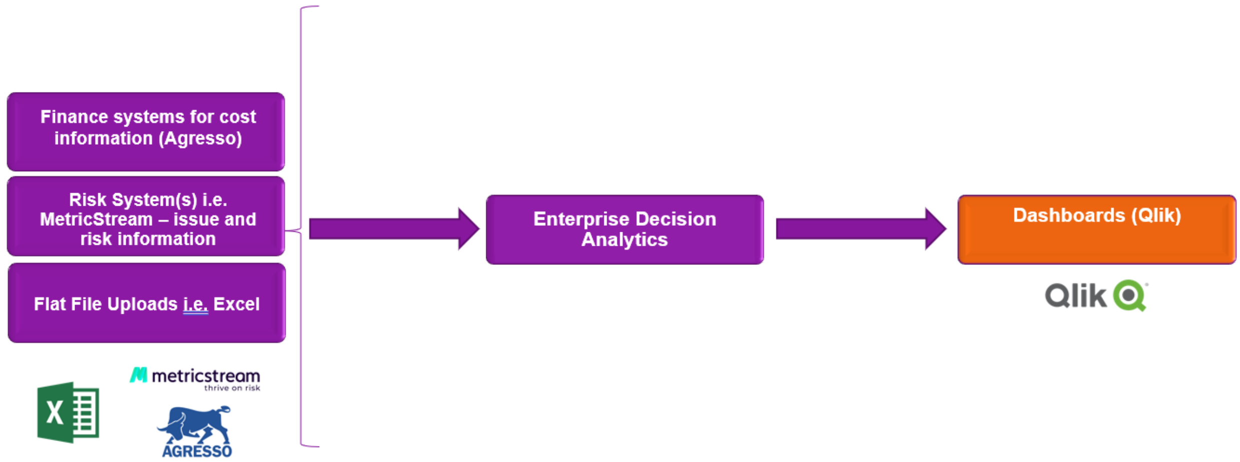


Figure 2 – Investment Data & Integrations

The full list of fields captured from these source systems in addition to those collated within EDA itself are available at Investment Management Data Fields - Master.xlsx.

4.1.1 Agresso

During the implementation, Agresso has been used for two types of integration:

- Add the currently active projects to EDA such that in-flight investments are aligned to the SMF and optimised around
- Update the costs and regulatory data on an investment such that they align with the most recent data from Agresso. This is completed by joining based on the Scheme ID.

Following the initial import of current projects, the Agresso data is now only used to update existing with the ability to create new 'turned off'.

The data from Agresso comes in two files; one providing the scheme regulatory purpose and programme data, and another to provide the costs per year. These files, together with an EDA Portfolio snapshot CSV (to obtain the current set of scheme IDs and costs in EDA Portfolio) in addition to relevant SMF and regulatory purpose mapping tables, are brought together in EDA Data Labs to create the relevant files for import into the EDA Portfolio repository. This manual data transform also produces a report such that users are able to understand the schemes which have been updated, understand why and the cost updates made. An example of the report is shown below.

Agresso Data Manipulation Report

The following details the updates that have been made by bringing together the data in the IM tool with the most recent dataset from Agresso, the finance system.

If the scheme does not exist within the IM Tool but does live within Agresso then the data used to be brought across as a new solution (together with a baseline need) with its CAPEX (from Agresso's forecast cost) and attributes prepopulated. However, this has been switched off such that this transform only updates and does not create new.

If the scheme already exists in the IM Tool (using the Scheme ID) then the Scheme ID is joined with the Agresso dataset to find the most up to date cost. It is then updated if this has changed.

If the scheme does not have a scheme ID within the IM tool (or has a scheme ID that is not within the Agresso dataset) then no changes are made.

Initially, 2209 rows have been extracted from Agresso, from 1142 schemes. Separate rows display different regulatory purposes or infra/non-infra splits.

In summary, the following updates have been made.

Summary	Total
New scheme from Agresso. Not in IM tool.	56
Scheme from IM tool. Not in Agresso extract.	17
Scheme has been updated.	5
Total Cost Difference	-304,559

Show 10 entries Search:

SchemeID	Scheme Title	Agresso Forecast	IM Tool Forecast	Years Changed	State	Cost Change
B17956	B17956 Mere AMP7 Investigation	125476	161040.09	4	Scheme has been updated.	-35564.09
B17960	B17960 AMP7 Catchment Biodiversity Delivery	648261	735290.57	4	Scheme has been updated.	-87029.5700000001
B18025	B18025 AMP7 Supply Network Modelling	900000			New scheme from Agresso. Not in IM tool.	
B18037	B18037 AMP7 Water Efficiency Digital Engagement Strategy	130900.63			New scheme from Agresso. Not in IM tool.	

Figure 3 - Agresso Data Manipulation Report

4.1.2 MetricStream M7

Data from MetricStream M7 comprises current risks and issues. Data from the risk system is initially in several exports which are amalgamated by Wessex Water before transfer into EDA. Similar to Agresso above, this data is transformed in EDA Data Labs into the format required for the EDA Portfolio investment repository, and also produces a report detailing the risks that have been created. The risks are filtered before import based on a series of rules detailed in the Risk Logic tab of Investment Management Data Fields - Master.xlsx.

Risks to be imported into EDA Portfolio are then created as an investment need alongside any risk data (such as hazards and residual risk). A placeholder investment solution is also created. Similarly, the risk data is joined with the SMF and a hazard mapping table to create placeholders for potential impact categories that should be filled in by a user based on the risk's hazards. Other entries into the transformation process include an issue owner mapping table to only include issues created by particular owners in addition to a table informing the process of any risks that have already been uploaded such that they are not duplicated. If this were not the case, a new version of the investment need would be created.

4.2 Service Measure Framework (SMF) and Value Framework (VF)

Portfolio optimisation looks to balance investments across disparate areas of an organisation. To facilitate this, it is necessary that a Value Framework (VF) is defined such that investments can be weighted fairly so it is no longer 'who shouts loudest'. Having a consistent set of performance measures (or KPIs) supports this such that portfolio/project managers know the data that needs to be collected or calculated. We call this list of measures, a Service Measure Framework (SMF).

EDA comes complete with the flexibility to incorporate any SMF and VF alongside an interface to make changes providing that the user has the associated permissions. The SMF and VF are version controlled. An example of the Wessex Water SMF is given below in Figure 4.

Type	Group	Measure	Units	Labels
Service	Avoidable costs 41	Annual avoidable costs 01	£000s per Year / **Nr**	per Year
	Bathing water 30	Shellfish water deterioration in classification 01	Nr of shellfish water per Year / **Nr**	per Year
		Bathing water deterioration in classification excellent to good 02	Nr of bathing water per Year / **Nr**	per Year
		Bathing water deterioration in classification good to less than good 03	Nr of bathing water per Year / **Nr**	per Year
		Blue Flag Beach 04	Nr of beaches per Year / **Nr**	per Year
	Blockages 22	Sewer blockages 01	Reporting only: Nr of blockages per Year / **Nr**	per Year
	Bursts 21	Water mains burst 01	Reporting only: Nr of bursts per Year / **Nr**	per Year
	Customer billing 02	Reduction in the nr of properties receiving services but not being billed 01	Nr of properties per Year / **Nr**	per Year
		Reduction in the nr of properties receiving services that we dont know about 02	Nr of properties per Year / **Nr**	per Year
	Customer financial support 01	Nr of successful applications to receive financial assistance 01	Nr of applications (per household) per Year / **Nr**	per Year
		Nr of additional households now receiving social tariffs 02	Nr of households per Year / **Nr**	per Year
	Customer satisfaction and brand reputation 03	Complaint CMEX related 01	Nr of complaints per Event / **Nr**	per Event
		Complaint CMEX related FoF 01	Frequency per Year / **Nr**	per Year
		Complaint DMEX related 02	Nr of complaints per Event / **Nr**	per Event
		Complaint DMEX related FoF 02	Frequency per Year / **Nr**	per Year
		Average contact resolution time residential 03	Nr of hours per Event / **Nr**	per Event

Figure 4 – Example of the Wessex Water Service Measure Framework

The VF configured within EDA for Wessex Water is very similar in format to those configured for other UK water companies. The value/risk associated with each service sub measure (impact category) against each value capital is given as a monetary weighting based on associated studies. An example of the Wessex VF is shown in Figure 5. The Wessex Water framework has differing service measures based on Wessex's own SMF and the sub measures are impact categories. Likewise, the Wessex VF has its own capitals and associated subtypes.

Sample of the data

Area	LookupName	Measure	Financial	Natural_Carbon	Natural_Other	Social	HumanAndIntellectual
Area	Capitals_VF	Sludgetreatmentanddisposal_Additionalsludgetransportrequired	7.245710364	0.197775714	0	0	0
Area	Capitals_VF	POST_Avoidablecosts_Annualavoidablecosts	0	0	0	0	0
Area	Capitals_VF	POST_Landuse_Areaofbaregroundimpermeable	0	0	-2744.589664	0	0
Area	Capitals_VF	POST_Landuse_Areaofbroadleavedwoodland	0	-383.5948895	-5178.997676	0	0
Area	Capitals_VF	POST_Landuse_Areaofcoastalmargins	0	-391.181544	-6713.345859	0	0
Area	Capitals_VF	POST_Landuse_Areaofconiferouswoodland	0	-383.5948895	-2973.71604	0	0
Area	Capitals_VF	POST_Landuse_Areaoffarmland	0	-78.85006062	-453.0148701	-1671.558074	0
Area	Capitals_VF	POST_Landuse_Areaofgreenspaceegurbanparks	0	-282.7236408	-7537.047696	0	0
Area	Capitals_VF	POST_Landuse_Areaofhedgerows	0	0	-139.0381243	0	0
Area	Capitals_VF	POST_Landuse_Areaofmountainsandmoorsandheaths	0	-49.72526346	-1369.788374	0	0

Figure 5 – Example of a Value Framework

For Wessex Water, the user defines an associated annual frequency of failure in addition to a quantity value for each service measure impact category. In certain cases, these are not available to a user since the category has a default value provided (i.e. 1 or 365 as provided) and as such just provide the quantity or frequency respectively.

In order to calculate the total value of completing an investment, the five capitals (Financial, Natural, Social and Human & Intellectual, with Natural split between Carbon and Other) are then calculated for each impact category by multiplying their associated monetary weighting with the product of the associated frequency of failure and quantity values. An example expression for an individual impact category and an individual capital (i.e. financial) is as follows:

$$Capital\ Value = FoF * Q * \pounds$$

Where:

- Capital Value is the total value associated with one of the capitals (i.e. financial) for the impact category
- FoF is the frequency of failure allocated to the investment
- Q is the quantity allocated to the investment
- £ is the monetary weighting applied to the capital for the impact category.

This calculation is replicated for each combination of impact category and capital.

In addition to the service measures forming part of the value framework, the following cost and Carbon metrics can also be captured on an investment need / solution. The above value framework calculations do not apply.

- Cost of Solution (capex)
- Cost of Solution (Total opex)
- Cost of Solution (opex- Labour)
- Cost of Solution (opex- Power)
- Cost of Solution (opex- Chemicals)
- Cost of Solution (opex- Sludge)
- Cost of Solution (opex- M&E maintenance)
- Cost of Solution (opex- Business rates)

- Operational Carbon(tCO2)
- Embedded Carbon(tCO2)

Capital costs are inflated based on the consumers price index (CPIH). The user inputs the cost index against the investment which are then updated within the modelling calculations. This is assumed to increase at 3% for future years.

4.3 Administrative Functionality

4.3.1 Descriptive Data

EDA's investment register holds all the investment needs and associated solutions. Within the register, to facilitate data formatting, EDA offers a concept of descriptive data which allows users to define their own data structures. Users can then either import, manually input or integrate with other systems to bring this data into the tool. This allows bespoke forms to be created for Wessex Water users to enter data attributes. It is then possible to create filters and views using these descriptive data fields, this approach allows EDA to display a data driven UI.

Fields can be made mandatory, made invisible, and these fields can also be configured for use when searching. Similarly, these fields can be used as part of a filter for data exports (inc. list views) and for creating filtered optimisations. These fields can be Boolean, dates, free text, drop downs or numeric alongside defined default values and guidance for users. Drop downs can be linked to other drop downs to restrict the available entries (i.e. by business area).

The data fields in the below spreadsheet have been configured, some of which as descriptive data in the portfolio registry. These are then imported from Agresso or M7 or from within EDA itself (i.e. manually). The full list of fields currently required by the Investment Management tool is defined in Investment Management Data Fields - Master.xlsx.

There are also fields which will are within the Asset Register, calculated in the models themselves or are collated as part of EDA's integral service measure framework (SMF) as described within the Excel spreadsheet above. A full list of those incorporated in the SMF are within the previous section.

4.3.2 Approvals Workflows

Approvals workflows are used in EDA to state approval states, transitions and project stages. A standard one can be used within EDA or modifications can be made during configuration. The Wessex Water desired workflow has been configured and is described at Workflow stage detail.xlsx

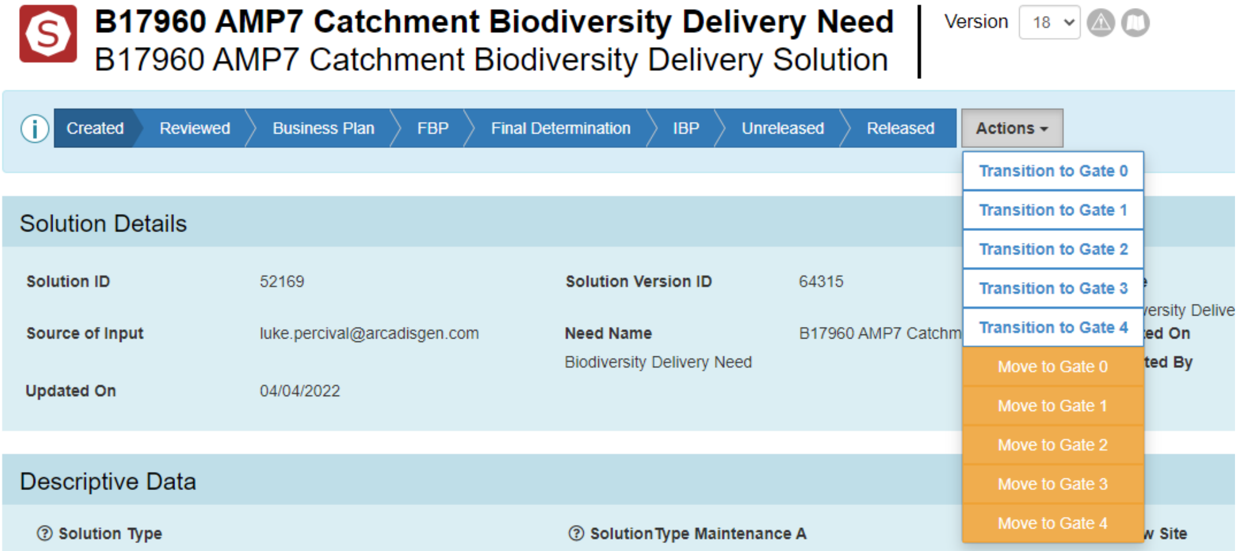


Figure 6 – Project Stages

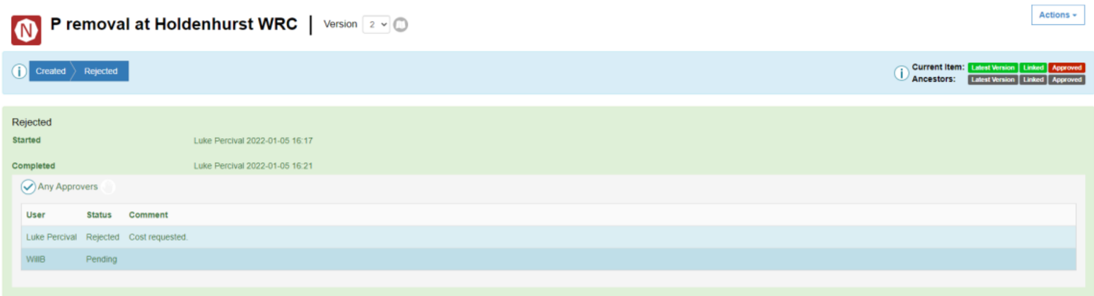


Figure 7 – Approvals Stage

4.3.3 Investment Lines / Purpose Codes

Investment lines (or purpose codes) are used to support economics calculations such as net present value (NPV). These are used to ensure that the time value for money is represented in optimisation and it reduces bias against expensive, but long life, capital investments.

As part of the NPV approach, Capex costs should be converted into annual costs using the company's weighted average cost of capital (WACC). In order to annualise the costs, the projected 'life' of the investment needs to be considered. This is represented as part of the purpose code for the investment. The following extract of investment lines, shown in Figure 8, have been used following input by Wessex Water.

Figure 8 – Sample of the Wessex Water Investment Lines

5 EDA Asset Configuration

5.1 Data Processing

There are a number of data sources used by the Non-Inf modelling framework, several of which are taken from the “Hansen” data warehouse at Wessex Water via and automated importing service called Data Links.

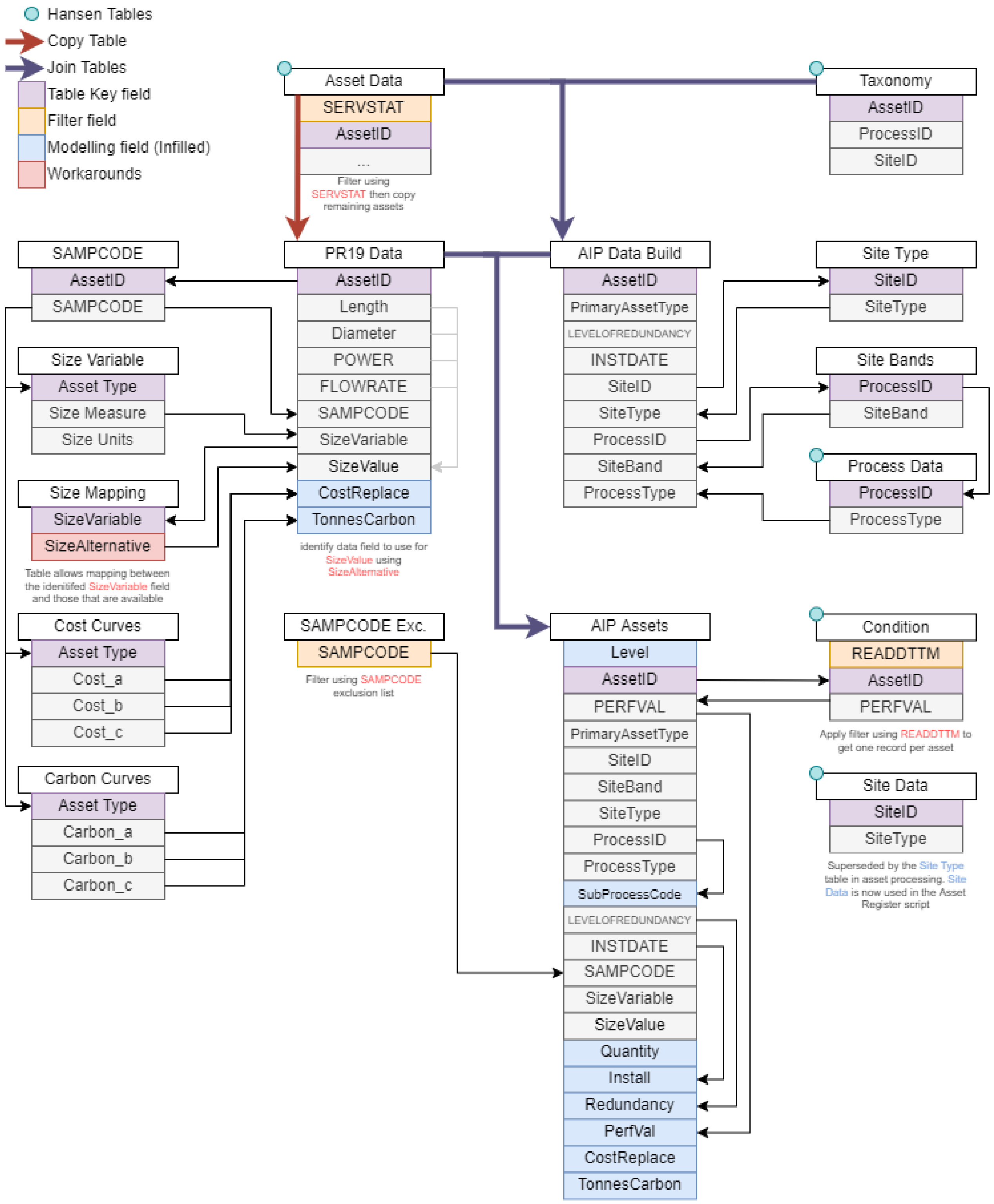


Figure 9 – Data table relationships

Other tables are manually uploaded to the EDA Data Hub from other sources, including extracts from the PR19 methodology document and user assembled tables derived from expert opinion. In order to support visualisation of the relationships between the various tables the diagram in Figure 9.

5.1.1 Data Clean

Data was removed from the asset base; either it was not intended for modelling, or it was not able to be used in modelling.

As only above ground assets were being modelled, assets with PrimaryAssetType “L” were removed from the asset data. As were assets with state (“CHECKED”, “DEMOLISHED”, “ABANDONED”, “UNKNOWN”, “CONSTRUCT”, “UNADOPTED”, “SOLD”).

Additionally, asset condition data considered too old was removed from analysis. This can be controlled by the user when running the processing script by using the variable ‘ConditionCutoff’. The number entered here is the number of years before a condition is considered too old.

The supplied list of SAMP codes (SAMPCODE Exclude List.csv) indicated a below ground asset, which was used during the creation of the asset data table to remove any assets below ground.

Data unable to be modelled was also removed, comprising of ProcessIDs, SiteIDs or AssetIDs being NULL or 0, duplicate records in asset condition data (most recent records were kept) or the condition date being NULL.

The following chart, taken from the Asset Processing Report, shows the number of rows that were initially removed from each of the Hansen inputs.

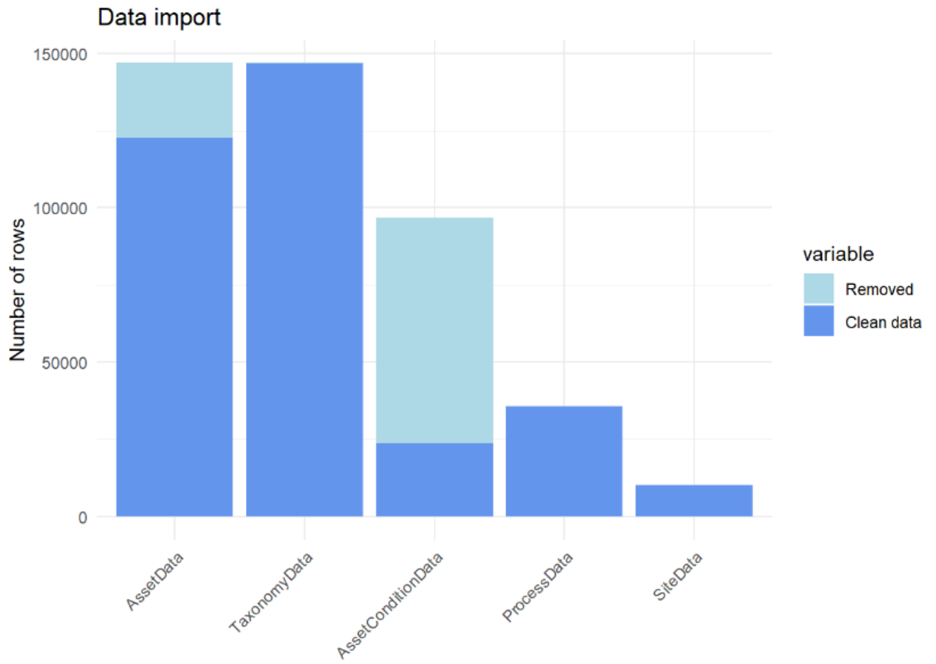


Figure 10 – Row Removal from Data Imports

5.1.2 Data Infill

Data required for modelling, yet incomplete, was infilled using one of two methods.

For the install year (Install), level of redundancy (Redundancy), cost of replacement (CostReplace) and amount of carbon (TonnesCarbon) variables, the following logic was applied to infill missing values:

- The mode (most common) average of each asset group, grouped by (SAMPCODE)
- If this did not exist, the mode average of each asset group, grouped by (PrimaryAssetType) was used
- If the above did not exist, the mode average of each asset group, grouped by (DISCIPLINE) was used
- If none of the above existed, the overall mode average for the variable was used

For ProcessType, SAMPCODE, SizeVariable, SizeValue, SiteType and Perval values were assigned to incomplete data. The following table displays which values were used:

Variable	Value assigned
ProcessType	Unknown
SAMPCODE	Unknown
SizeVariable	Unknown
SizeValue	-1
SiteBand	a*
SiteType	Unknown
Perfval	-1

** Under the assumption that if no SiteBand was defined, an arbitrary choice can be made*

Figure 11, taken from the Asset Processing Report, shows the proportion of each variable that was infilled.

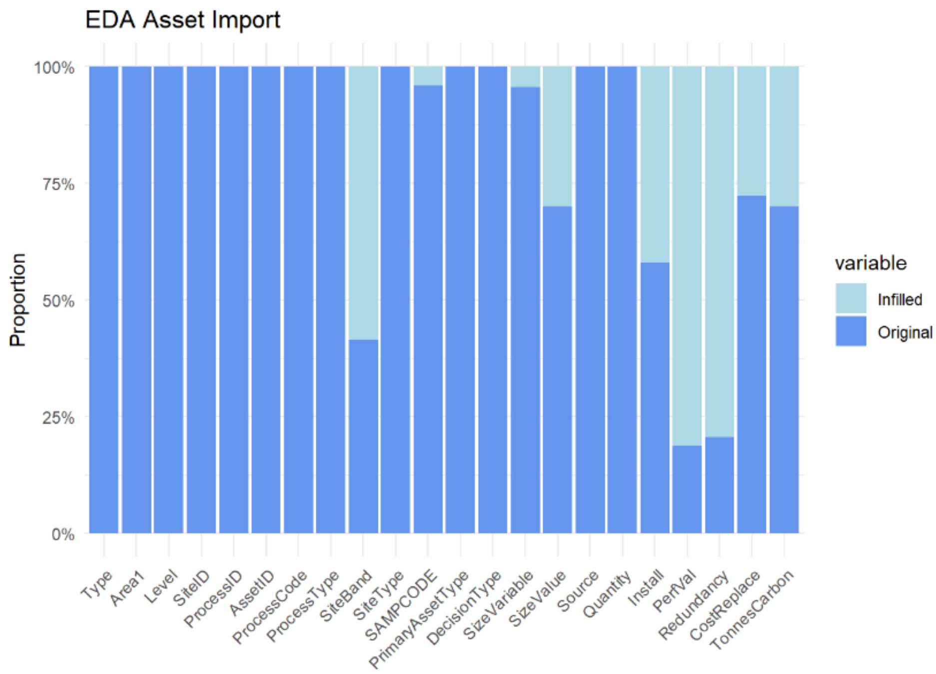


Figure 11 – Proportion of infilled variables on AIP import

5.2 Life Distribution Modelling

The AIP model is underpinned by the Life Distribution Modelling (LDM) methodology. The approach is centred around a set of Weibull relationships that govern the predicted reliability of an asset over time, with reliability decreasing as the assets age. Weibull relationships are widely used in LDM because they can be defined from historic failure data or through the use of expert opinion where data is not available. A well-researched and reliable way of modelling assets with a predictable end-of-life (EOL) failure mode.

5.2.1 Weibull Relationships

Weibull relationships are characterised by two or three parameters. The Scale, typically denoted by the µ (Eta) symbol, is a measure of the assets expected life. Life can be measured in any number of units; seconds, days, years, revolutions or on/off cycles. For example, in the AIP model the Weibull relationships are measured with Scale in years.

The second parameter is the Shape, typically denoted by the symbol b (Beta), governs the 'shape' of the probability curve. For Shape less than 1, reliability increases over time, presenting a 'burn in' relationship where a population of assets overall reliability increases over time because those units with manufacturing defects or poor installation have failed early, and the remaining assets are those that do not suffer from such issues. A Shape of exactly 1 produces a constant failure rate, in this state assets can fail randomly but their reliability is not affected by operating time. Finally, for Shape greater than 1, assets reliability will decrease with time. The latter option is used to model deterioration with age and predict an assets EOL.

There is an optional third Weibull parameter called the Location that is typically represented by the g (Gamma) symbol. This parameter provides a sort of 'failure free period' at the start of the reliability distribution during which assets are not expected to fail. Within Wessex Water AIP model, the Weibull relationships do not use Location.

5.2.2 AIP Implementation

For the AIP model the Weibull relationships are defined based on the `SAMPCODE` field in the data, which can be thought of as an assets 'type'. For example, the SAMPCODE "P-WWC1" is a "Wet Well Centrifugal (Submersible) Pump less than 7.5kW in Power". Each relationship is governed by two parameters, Scale and Shape, with Scale measured in years. Shape is in the 'greater than 1' regime indicating reliability will decrease as assets age.

There are up to three Weibull relationships per SAMPCODE defined for the assets, they represent the expected life of the asset measured against three different strategies, Replacement or Refurbishment of the asset, and cleaning the asset. Not all relationships apply to all SAMPCODE values, but it is expected that the Replace relationship will apply in all cases. The Weibull relationships are stored in the `WeibullModels` lookup table within the AIP model.

5.2.3 Asset end of Life

Within the AIP model assets, mathematics governing the consequences and risks are all derived from the probabilities within Weibull relationships. In order to define a point at which assets are *more than likely* to have failed and use this to help the optimiser make decisions on the timing of interventions, the AIP model includes an end of life (EoL) state for the assets. This is controlled by one of two possible parameters, the Median Life or the Weibull Scale parameter; the EoL discussion will use the term 'Scale Life' to provide context. Median Life can be derived from the Weibull relationship coefficients according to Equation A and represents the time by which 50% of a set of identical assets would have failed. The Scale Life is slightly longer than the Median Life, it is the time by which 63.2% of assets would have failed.

Equation A - Weibull Median Life

$$T = \gamma + \mu(\ln 2)^{\frac{1}{\beta}}$$

To visualise the concepts, imagine a set of 1,000 identical assets, all brand new and started running for the first time. The failure of these assets is governed by a Weibull relationship with a Scale parameter of 18 years, and therefore a Scale Life of 18 years, Shape in the >1 regime and a Median Life calculated as 15 years. It would be expected that after 15 years 500 of those assets will have failed and 500 would still be running, at 18 years it would be expected that 632 had failed while 368 were still running. For a single asset this can be thought of in terms of odds, at Median Life an asset is *as likely* to be failed as running, at Scale Life an asset is *more likely* to be failed than running.

For the AIP model, an asset is considered to be in a failed state once its age exceeds the life measure configured in the model. By default, the life measure in the Scale Life but it can be changed to the Median Life by the user in the dataflow at run-time--controlled by the `UseScaleAsLife` parameter. An illustration of the EoL state of assets is shown in Figure 12 for the Scale Life option.

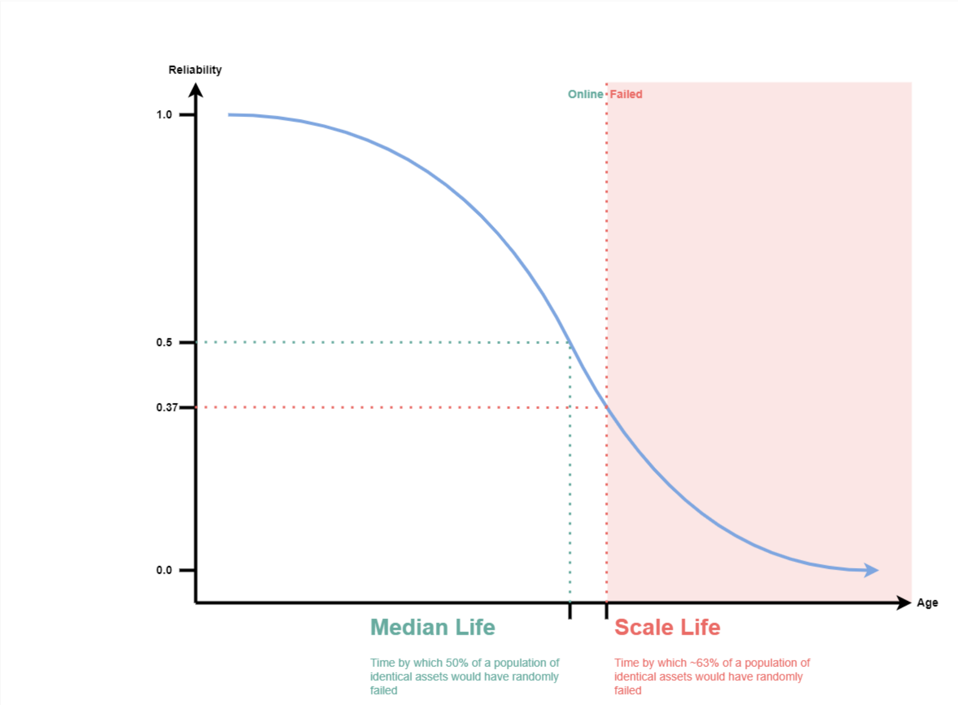


Figure 12 - Weibull measures of asset life and 'end of life' state in the AIP model

5.3 Asset Redundancy Methodology

It is expected that some above ground assets will have redundancy in place, to varying degrees, in order to help prevent service outages when equipment fails or needs maintenance. While it can be difficult to record the exact relationships between different assets it is usually possible to report an approximate degree of redundancy per asset. A similarity is available in the Wessex data based on the `LEVELOFREDUNDANCY` field on the assets, which provides a score from 1 to 5--where 1 indicates little to no redundancy on the asset and 5 means there is significant redundancy.

The AIP model uses this information to modify the Probability of Failure (PoF) of the assets. PoF is derived from the LDM methodology, the Weibull relationships, as the complement to reliability (i.e. `1 - R`) and is then modified by a scaling factor based on the assets reported level of redundancy. The methodology is described in Figure 13 below:

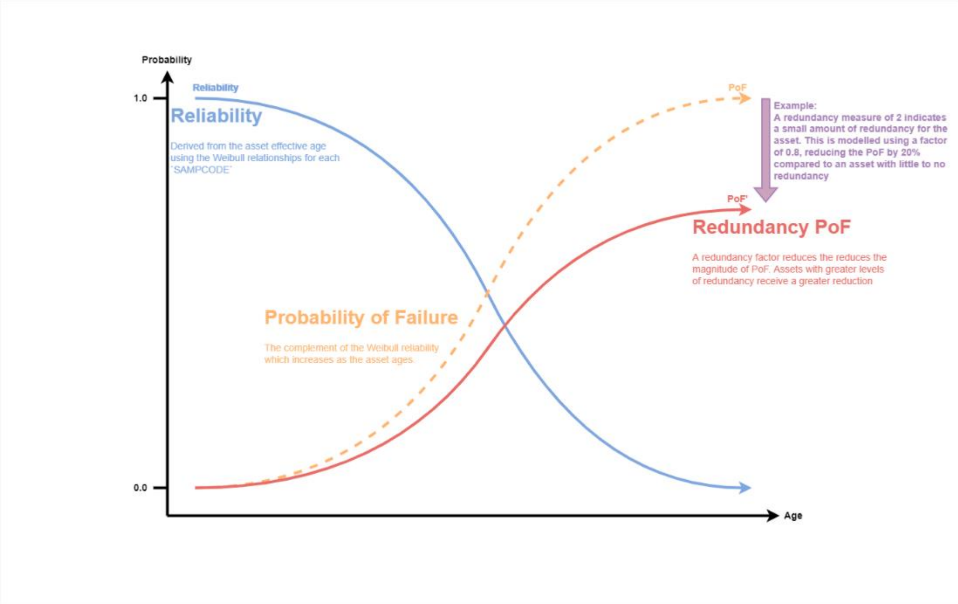


Figure 13 - Probability of Failure relationships to reliability and redundancy

The scaling factors are stored in the `RedundancyFactor` lookup table within the AIP model. The default values, used during the development and testing of the AIP model are seen in Figure 14 below for reference. These can be changed at run-time by the user by supplying alternative values to the dataflow:

Redundancy	Factor
1	1.0
2	0.8
3	0.5
4	0.2
5	0.0

Figure 14 - Default redundancy scaling factors used for development and testing of the AIP model

5.4 Condition Assessment Methodology

Combination of design document for background then translate the model calculations into this.
The condition of the assets is a factor in determining the asset age used in the Weibull relationships. For assets that have a condition assessment made recently, by default within the last 3 years, that condition is used to help define the starting point for the models measures of reliability, PoF and EoL states. This is expressed in the AIP model by defining an 'effective age' of the assets, which is then passed to the Weibull relationships instead of the 'physical age' of the assets.

In order to define the 'effective age' the methodology starts with a condition score, an integer value in the range 1 to 5 where 1 is good condition and 5 is bad. In the AIP model the measure is called `PerfVal` (performance value) and is evaluated during the asset processing steps that precede prescriptive modelling. Each level of the condition score is allocated to a range of probabilities on the reliability curve defined by the Weibull relationships. During AIP model development and testing these bands were configured according to the values in Figure 15 - Condition levels and reliability bands. In the AIP model the values are stored in the `ConditionFactor` lookup table and users can change the bands at run-time by providing an alternative set to the dataflow.

Condition	Reliability Band

1	0.8 <= R
2	0.6 <= R < 0.8
3	0.4 <= R < 0.6
4	0.2 <= R < 0.4
5	R < 0.2

Figure 15 - Condition levels and reliability bands

An assets `PerfVal` measure determines which band of reliability the asset is expected to be in given the observation of its condition, and this is compared to the reliability it is expected to have based on physical age. There are three scenarios an asset can be in:

1. The physical age of the asset predicts a reliability within the band defined by condition. This means the asset is roughly the expected condition given its age.
2. The physical age predicts reliability higher than the band defined by condition. This means the assets condition is worse than expected given its age.
3. The physical age predicts reliability lower than the band defined by condition. This means the assets condition is better than expected given its age.

The 'effective age' of the asset is determined based on which state the asset is in. For any instances where the physical age predicts a reliability within the condition band (state 1) the 'effective age' is simply the 'physical age'. In other words, the asset is in the expected condition given its age so there is no need to change anything. This is illustrated in Figure 16 below where an asset has a condition score of 3 and age that predicts reliability in the band 0.4 <= R < 0.6.

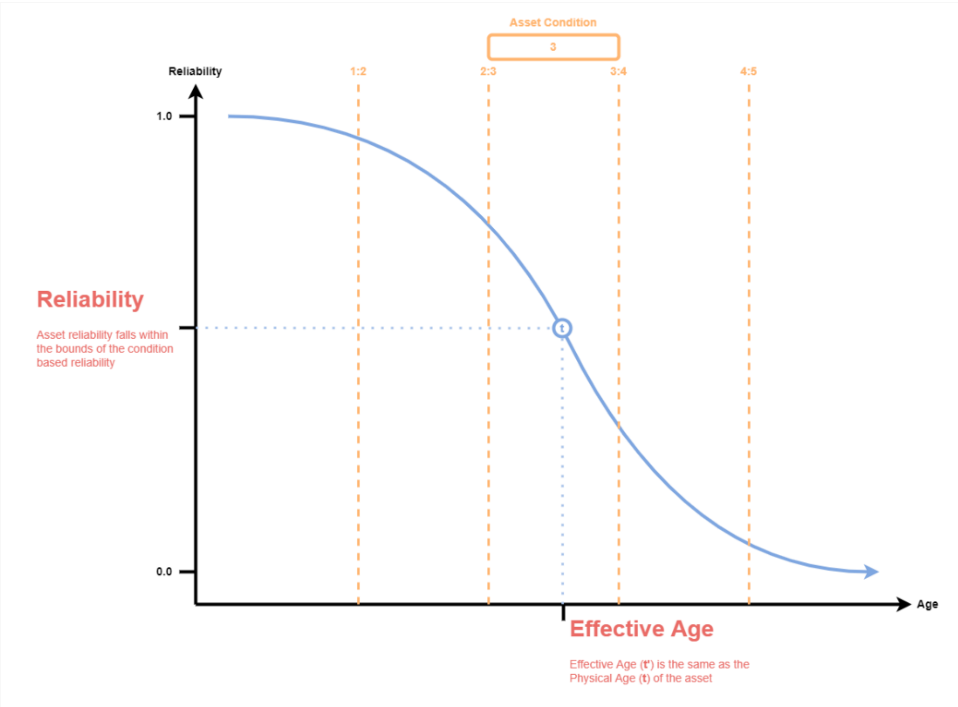


Figure 16 - Asset condition and physical age are in-sync

In the second state the assets physical age predicts a higher reliability than the condition band. meaning it is in worse condition than age suggests. In this case there is a need to define the 'effective age' of the asset to be different to the physical age--the asset is 'older' than its age. In this case the 'effective age' is set to correspond to the lower edge of the reliability band. This is illustrated in Figure 17, where the asset has a condition of 4. This corresponds to a reliability band between 0.4 and 0.2 so the effective age is determined by a reliability of 0.4--the closest edge of the band to the prediction based on age.

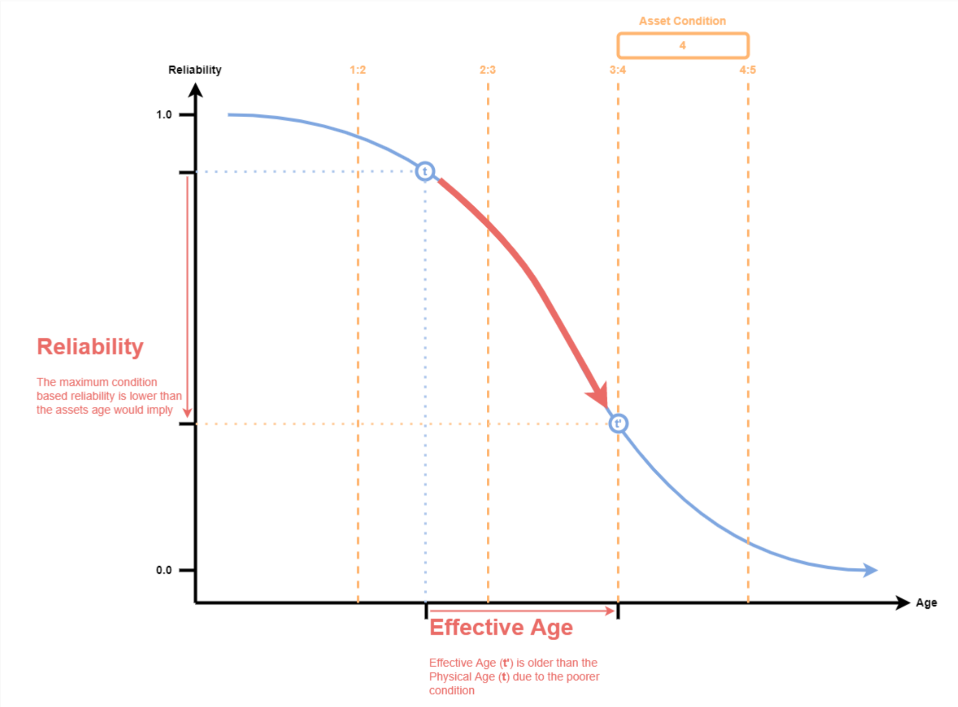


Figure 17 - Asset condition is worse than physical age suggests

The final situation, where the score suggests an asset is in better condition than age predicts, works the opposite to the previous example. Effective age is defined lower than physical age so that the initial reliability of the asset is higher and better reflects its observed condition. This is illustrated in Figure 18 where an asset has a condition score of 2 placing its expected reliability between 0.8 and 0.6, but the age predicts a lower value. Effective age is defined in this case by the lower edge of the reliability band, 0.6.

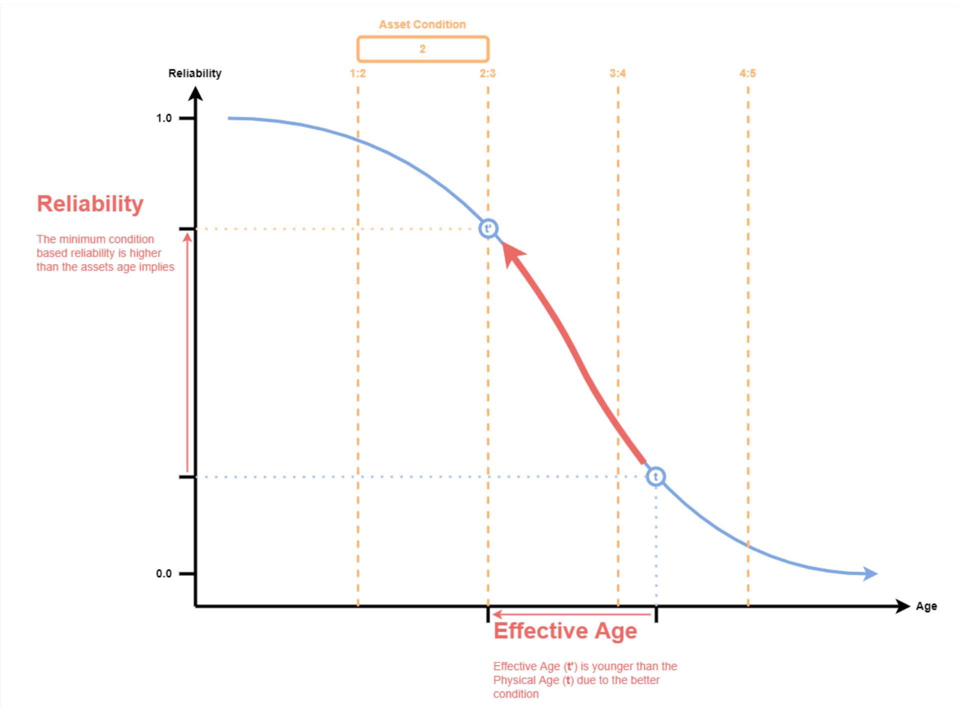


Figure 18 - Asset condition is better than physical age suggests

5.5 Capital and Operational Costs

Costs for the investment of the assets are defined in two locations. First, as part of the asset processing script, the cost of replacement is calculated using a power curve based on a measure of the assets size. This `SizeVariable` as it is called in the AIP model differs based on the assets `SAMPCODE` and could be a measure of the physical dimensions of the asset (its actual size) *or* some equivalent measure, like the volume, electricity power rating, length, any one of about a dozen options. The cost curve is given in *Equation B* for reference and the value appears in the AIP model as the `CostReplace` measure:

Equation B - Cost equation for the replacement cost (`y`) of an asset, where `x` is the assets 'size'

$$y = 1000 \times (a + bx^c)$$

The cost curves were defined in 2017 so the replacement costs they predict all reflect costs from that year. In the AIP model an uplift factor is applied based on the CPIH price index for the UK between 2017 and the model start year. This ensures that the model reports costs that are relevant to the current price review (PR) and are an accurate representation of like-for-like replacement of the assets. The replacement cost is subject to the asset processing scripts infilling methodology as described in Section 5.1.2 of this document.

The other costs the AIP model tracks, refurbishment and cleaning, are both defined as a percentage of the replacement cost. Typically, though there is a degree of variation in both cases, refurbishment costs are about 70% of the replacement cost and cleaning about 10%. These factors are defined for each `SAMPCODE` and are a component of the `WeibullModels` lookup table so the user can change them by supplying an alternative set of values in the lookup.

5.6 Carbon Consideration

As part of the investment in assets the AIP model captures a measure of the carbon the intervention incurs. This is defined in a similar manner to the replacement cost in that there is a three-parameter equation that governs the amount of carbon the asset represents, which is driven by the same `SizeVariable` that drives the cost curves. The carbon calculation, which predicts 'tonnes of carbon', is given in *Equation C* below for reference and appears in the AIP model as the `TonnesCarbon` measure on the assets.

Equation C - Tonnes of Carbon incurred when assets are replaced, where `x` is the assets 'size'

$$y = ax^2 + bx + c$$

As with the asset replacement cost, carbon is subject to the gap infilling methodology described in Section 5.1.2 of this document.

5.7 Intervention Configuration

The intervention in the AIP model is configured to apply to each individual asset and can apply a like-for-like replacement of that asset according to the decisions of an optimiser. If a refurbishment Weibull relationship is available for the asset, it is also possible for the optimiser to refurbish. All assets in the model can be replaced, Weibull relationship or not, but refurbishment can only be applied if a Weibull relationship is defined. Cleaning is **not** considered an intervention option in the AIP model. Cleaning, if it is applicable to the asset, has no impact on performance (consequences and risks) and is assumed to be a necessary part of the assets maintenance cycle not a decision for the optimiser to make.

Intervention timing is controlled by a linear optimiser based on two types of constraint, bounds and goals. Bounds are absolute constraints that must be met in order for a valid solution to be produced. In the event that no combination of interventions can meet the bounds then the optimisation fails--reporting an 'infeasible' problem. Goals are a measure of the quality of the solution and are not absolute, an optimiser does not 'meet' goals it simply tries to minimise (or maximise) their value. To define an optimisation scenario a goal must be set so the optimiser can measure how well it is doing, bounds are optional.

Where an asset has both the replacement and refurbishment Weibull relationships defined, **both** deterioration curves are applied to the asset and are tracked independently. A refurbishment intervention should be applied by the optimiser when the Scale Life for refurbishment is exceeded but doing so does **not** affect the replacement curve, this continues unchanged. However, when a replacement intervention is applied to the asset, it also resets the refurbishment deterioration curve--this is to model the concept of a new asset being installed. In both cases, the cleaning schedule is reset since it is assumed that refurbishment includes any necessary cleaning of the asset, and a replaced asset will already be clean.

5.8 Consequence Mapping

Consequences of failure, such as water discolouration or supply interruptions, are predicted based on the assets PoF, which is defined by the Weibull relationship and includes the scaling factor for redundancy. The failure of an asset does not necessarily mean there will be a failure of service (a consequence) so PoF is combined with a probability of failure leading to consequence (PFLC) to predict the number of consequence events. This is in turn scaled to the number of people or properties affected by the consequence, the 'quantity' measure. Thus, consequences are predicted based on *Equation D*:

Equation D - Consequence measures

$$C = PoF' \times PFLC \times Q \times S$$

There are a total of 17 consequence events tracked in the AIP model.

5.9 Risk Scores

Risks are split into four categories related to different critical measures such as financial, human resources (injury and death), natural (pollution and environmental damage) and social (Wessex's reputation). There are also two measures related to carbon, one for carbon incurred due to consequences of failure and the other incurred when investing in assets. The latter of these is unique among the six measures as it will increase with investment, unlike the others which all decrease.

A risk measure is calculated as the sum-product of consequences and a 'cost per incident'. For example, the financial risk would be, the number of discolouration events multiplied by the cost per discolouration event, plus the number of interruptions events multiplied by the cost of an interruptions, and so on for all 17 possible consequence events.

5.10 Sensitivity Analysis

There were two aspects to the sensitivity analysis (SA) methodology, one using alternative data for the various model lookup tables, and the other utilising the Monte-Carlo (M-C) module. Some updates were required to the model to accommodate the M-C module.

The M-C module injects random values, within a defined distribution, into the EDA model and calculates the effect. This is repeated over hundreds or thousands of iterations to build up the statistical variance those changes introduce in the output KPIs.

The M-C module can only be targeted at measures, whether on the assets or a driver, that exist in the model without it being calculated. In other words, those measures that have been imported or manually created—

and not measures created as a result of expressions in the PMs or Intervention Effects. To accommodate this requirement several asset measures were added to the data import to act as targets for the M-C.

These new measures are all set to 1 initially, and inserted as multiplication factors to the parameters in the model the M-C will target. This is done so that, in the absence of the M-C being applied, the factors do nothing—since multiplying by 1 does not change a value. The new measures all use a naming convention that clearly identifies them and their purpose, that being: "McFact[name of measure being targeted]"

As of completion of the first stage of SA there are five M-C factor measures configured in the model:

- McFactAssetLifeReplace
- McFactAssetLifeRefurbish
- McFactPerfVal
- McFactScaleReplace
- McFactScaleRefurbish

For the implementation in expressions as an example, the M-C will target Weibull Scale, via the appropriate measures in the list above. Scale is a measure of asset life and we want to be able to increase or decrease it by a percentage. The basic form of this expression is a `lookup` function that sets the value for each asset[1]. This is changed to include a multiplication with the new measure as shown in *Equation E*:

Equation E – Monte-Carlo factor measure implementation in Expressions

$$ScaleReplace = \text{lookup}(\text{"WeibullModels"}, \text{@SAMPCODE}, \text{@SiteType}, 1, \text{"Scale"})$$
$$ScaleReplace = \text{ScaleReplace} \times \text{McFactScaleReplace}$$

When the M-C is not in use the second equation does nothing because the default value of the M-C factor measures is 1. When the M-C is in use, the factor changes with each iteration and as a result will alter the Weibull Scale as well.

6 Outputs

6.1 EDA Portfolio Outputs

EDA is designed as a comprehensive asset investment planning suite with optimisation at the core of the software. Inclusivity, exclusivity or dependency constraints can also be applied. When setting up the optimisations the user has the ultimate choice regarding objective and constraint setting. Any value in the system (whether budgetary, resource, a performance threshold etc.) can be a constraint or part of the weighted objective function (goal). Multiple constraints can be applied, and the goal can be made up of one or more measures (such that users can quickly change whether more emphasis should be placed on the environment rather than safety for example). These constraints can be set by year (i.e. a glide path to a certain performance target by 2025 with targets set for 2022, 2023, 2024 and 2025) or single value targets can be applied (e.g. You must achieve a certain performance level set in 2025 but there is freedom in the years running up to that). Regional constraints can also be easily added. The duration of the optimisation can also be set.

Based on the above, Wessex Water have complete flexibility for plan balancing. Users are trained in running existing scenarios in addition to creating new configurations based on their own constraints and objectives, and Wessex Water models are currently running up to 30 years into the future. Example scenarios ran by the Wessex Water team include:

- What is the least investment we need to do based on our mandatory projects?

[1] This is a simplification, but the details do not matter for these purposes.

- What is the (unconstrained) most cost beneficial series of investments that we could do based on minimising our total (capitals) risk from our value framework?
- How about if we ask the same question as previously but we add extra weighting to a particular service measure or capital? (i.e. focus on the environment).
- What is the most cost beneficial series of investments that we could do if we had a total budget of £100m per year based on minimising our total (capitals) risk from our value framework?
- What is the minimum investment required if we would like to maintain the level of pollution events through time while reducing the leakage rate by 15% by 2030?
- Departmental or regional scenarios. What is the most cost beneficial investments for a subset of our portfolio (i.e. IT projects only) if we had a total budget of £10m per year based on minimising our total (capitals) risk from our value framework?

Wessex Water have currently tested out a number of these scenarios on a small sample of investment needs and solutions as part of user acceptance testing and will now move on to the production environment. Around 40 user acceptance testing scripts were created and then ran by Wessex Water users to test out system functionality in addition to applying skills learnt during Train-the-Trainer sessions.

In addition to running the optimisations, Wessex Water users have a range of visualisation features at their fingertips, especially given integrations with Qlik Sense, providing dashboard visualisations.

Example visualisations after running the optimisations above include the scenario comparisons, breakdowns by particular categories (i.e. Capitals, OPEX subtypes or by investment), a list (or Gantt chart) of the projects selected in addition to outcome delivery incentive (ODI) graphics.

After running any scenario, the user can simply click the View Result icon to have access to any metric within the result (including any service measure impact category, any OPEX subcategory, CAPEX, or risk based on the Capitals). This can be shown at an aggregate level or at an individual investment level. Likewise, users can quickly drag-and-drop additional scenarios or measures to compare them or create further charts. An example of a scenario comparison is shown in the below figure, showcasing major differences in CAPEX profiles between two scenarios.

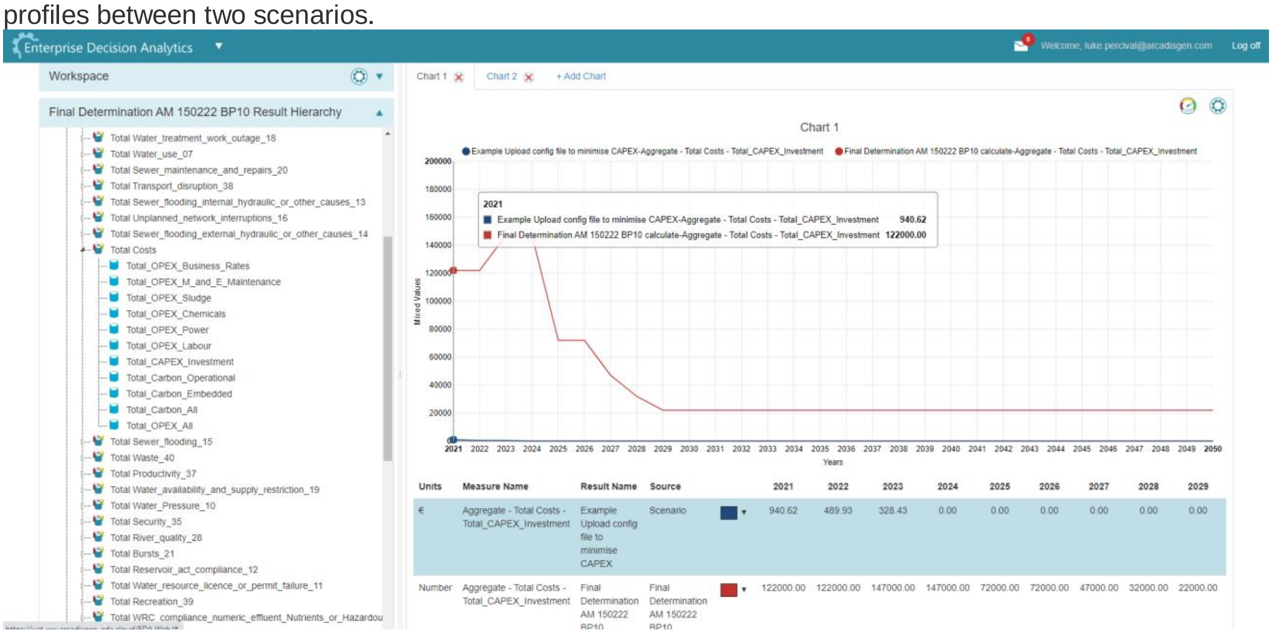


Figure 19 - Scenario Comparison

Outcome delivery incentives (ODIs) are also calculated in the portfolio model for visualisation by end users. These are calculated based on the aggregated values for the relevant service measure impact categories within the model. As such background levels of leakage/bursts/collapses etc. need to be captured within the investment needs as can be seen by the large incentive for pollution incidents in the below example (based on a small optimisation). The example below shows a subset of the ODIs showing penalties for hosepipe bans and, children and students engaged but a significant incentive on pollution incidents. Given the uncertainty in the actual penalties and incentives in addition to uncertainty in the service measure values entering these calculations, ODIs have brought into the models for visualisation purposes only. The parameters for which are editable by Wessex Water users.

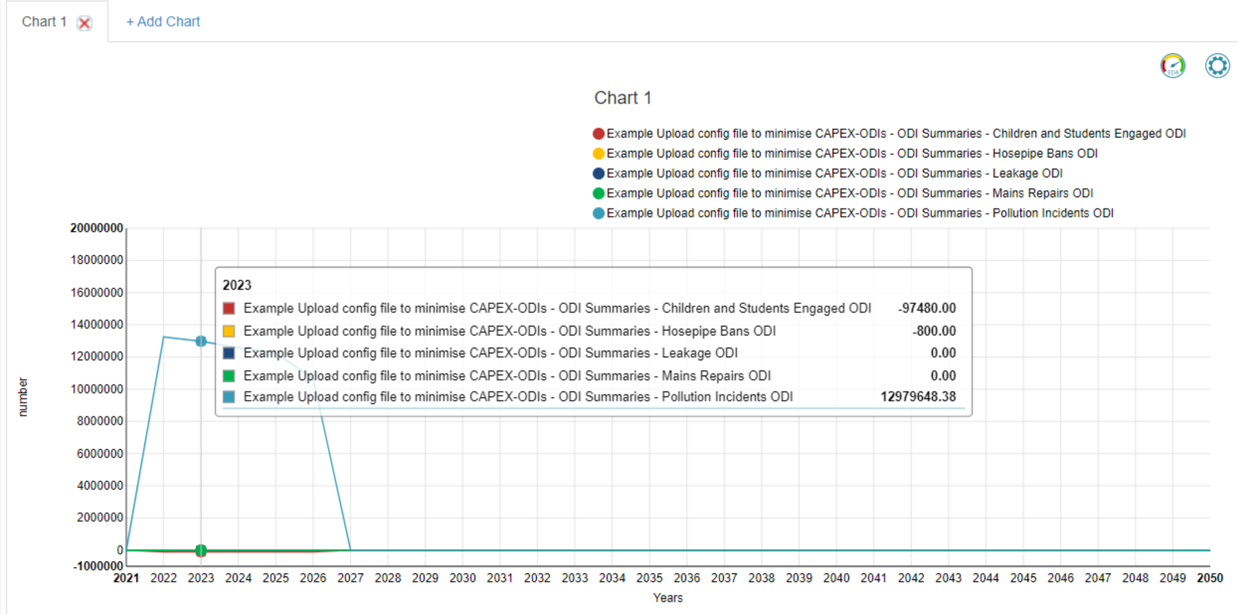


Figure 20 - ODI's

The scenario can also be used as the baseline plan within EDA by using the Baseline Programme Toolkit (BPT) module. This opens up a centralised view of the plan including the ability to view all the projects that have been selected in Gantt chart style views, comparisons between plans, in addition to further aggregated graphics. The examples below show a comparison where certain investments are selected in one scenario but not in another, followed by a view of aggregated bursts and CAPEX in a test baseline plan.

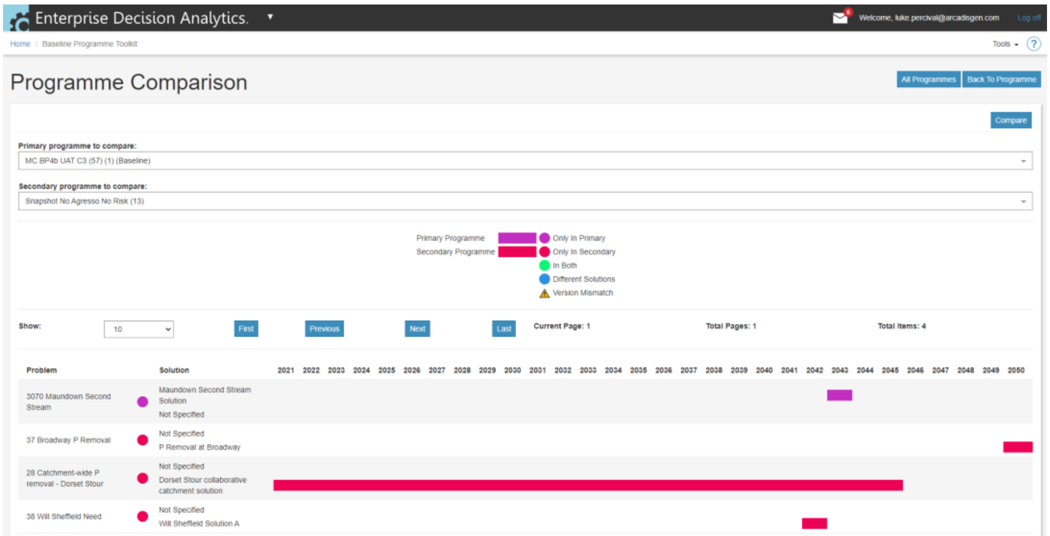


Figure 21 - Gantt style view

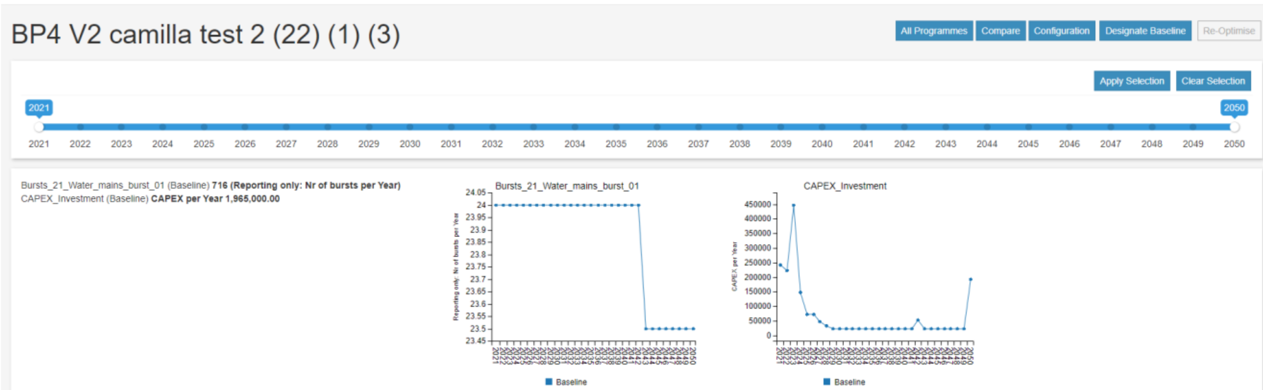


Figure 22 - Test baseline plan

Results can also be exported out to Excel using EDA's native Dashboard Definitions module (and the same module also creates endpoints which can be integrated with Qlik Sense, as mentioned later in this section). Users create queries on the data, selecting the attributes and metrics to export. The example below shows an export of OPEX, CAPEX and the net present value (NPV) of CAPEX.

	A	B	C	D	E	F	G	H	I	J	K
1	Result	AssetId	Division	Investmer	Investmer	Investmer	Timestep	CAPEX_In	NPV_Cape	Total_OPEX	
122	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	1	0	0	3000	
123	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	2	0	0	3000	
124	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	3	0	0	3000	
125	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	4	0	0	3000	
126	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	5	0	0	3000	
127	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	6	0	0	3000	
128	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	7	0	0	3000	
129	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	8	0	0	3000	
130	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	9	0	0	3000	
131	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	10	0	0	3000	
132	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	11	0	0	3000	
133	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	12	0	0	3000	
134	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	13	0	0	3000	
135	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	14	0	0	3000	
136	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	15	0	0	3000	
137	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	16	0	0	3000	
138	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	17	0	0	3000	
139	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	18	0	0	3000	
140	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	19	0	0	3000	
141	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	20	0	0	3000	
142	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	21	0	0	3000	
143	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	22	30000	934.9559	500	
144	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	23	0	890.4342	500	
145	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	24	0	848.0325	500	
146	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	25	0	807.65	500	
147	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	26	0	769.1905	500	
148	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	27	0	732.5624	500	
149	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	28	0	697.6785	500	
150	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	29	0	664.4557	500	
151	AMiles 15	4	Waste Re	Need38	38 Will Sh	3126	30	0	632.8149	500	
152	AMiles 15	5	Waste We	Need3074	3074 Creat	3192	1	0	0	0	
153	AMiles 15	5	Waste We	Need3074	3074 Creat	3192	2	0	0	0	
154	AMiles 15	5	Waste We	Need3074	3074 Creat	3192	3	200000	40178.03	0	
155	AMiles 15	5	Waste We	Need3074	3074 Creat	3192	4	0	38264.79	0	
156	AMiles 15	5	Waste We	Need3074	3074 Creat	3192	5	0	36442.65	0	
157	AMiles 15	5	Waste We	Need3074	3074 Creat	3192	6	0	34707.29	0	

Figure 23 – EDA results export to Excel

As previously mentioned, the results can be exported to Qlik Sense dashboards for further visualisations. Here is a similar scenario comparison view to that available out of the box in EDA, comparing CAPEX, OPEX and Risk in addition to giving the user the ability to select a service measure impact category. The following compares three scenarios at an aggregated level (but can be broken down i.e. by investment). These visualisations allow users to see spikes in CAPEX between scenarios and evidencing changes in investment strategies.

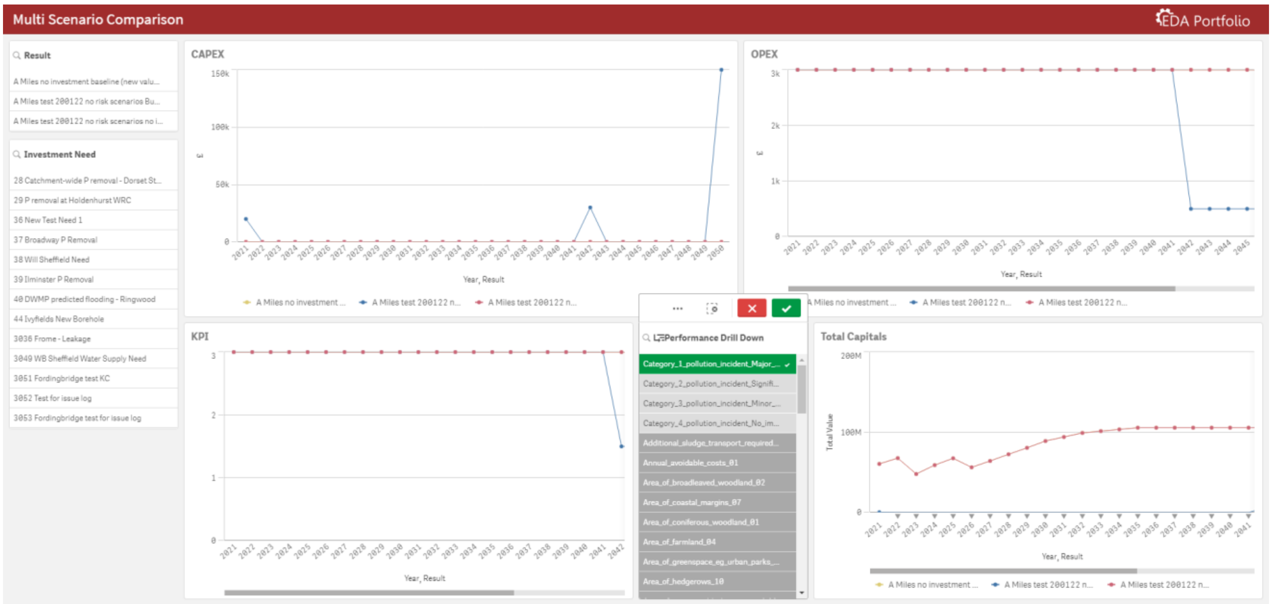


Figure 24 – 3 scenario comparison in Qlik

Similar to the BPT already mentioned, the dashboards also give Gantt chart views for comparison of investments selected in each scenario. In the visualisation below, we can see which investment option (solution) was selected for each need in addition to the time period selected for each scenario (although in the visual below only one scenario has been selected). As an example, we see that the *Dorset Stour Collaborative Catchment Solution* has been selected in 2020 to resolve the need of *Catchment Wide P-Removal – Dorset Stour*.

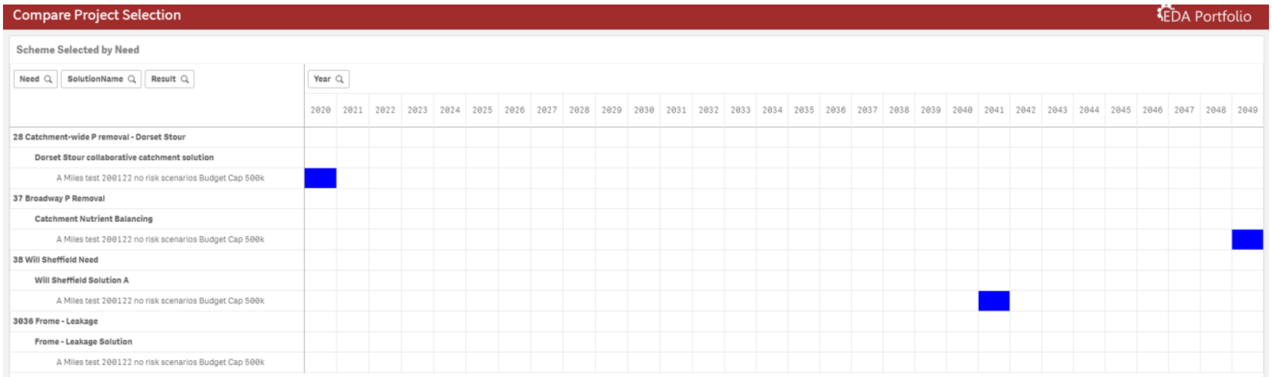


Figure 25 – Qlik Gantt chart view

Furthermore, as risk, broken down by each capital, is calculated in the models, it can also be viewed in EDA's results viewer or within dashboard visualisations. Here we show this in a stacked bar chart view, showcasing that within the result shown, there is greater social risk than any other capital, closely followed by financial risk.

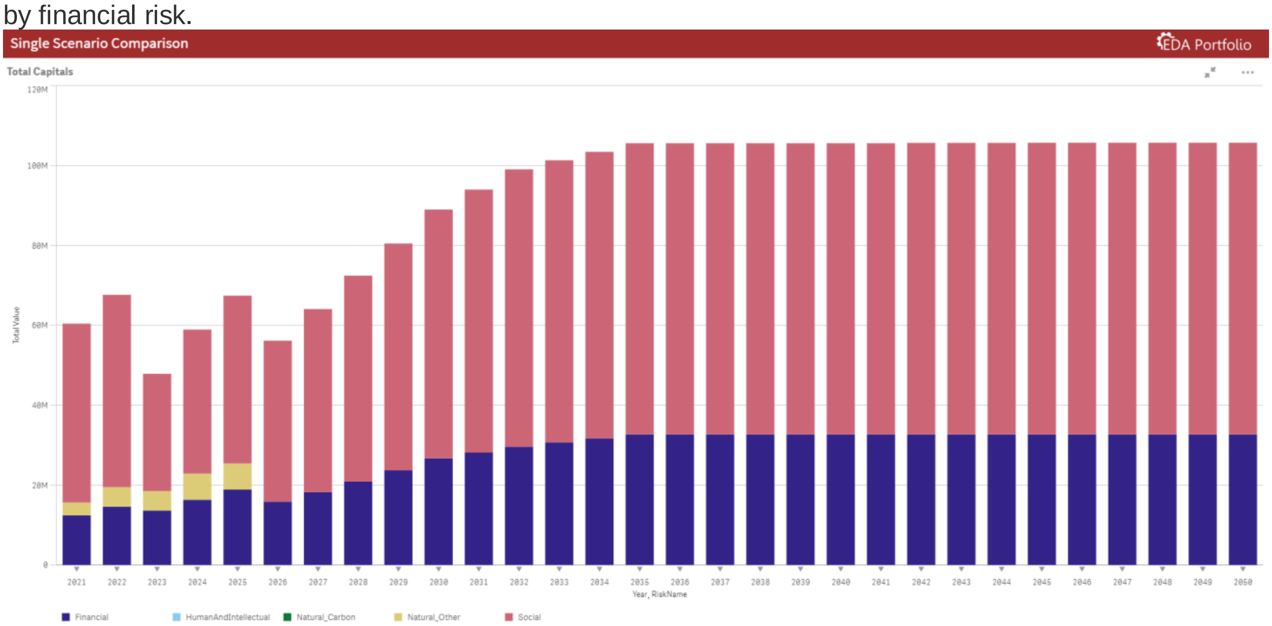


Figure 26 – Stacked bar chart view

6.2 EDA Asset Outputs

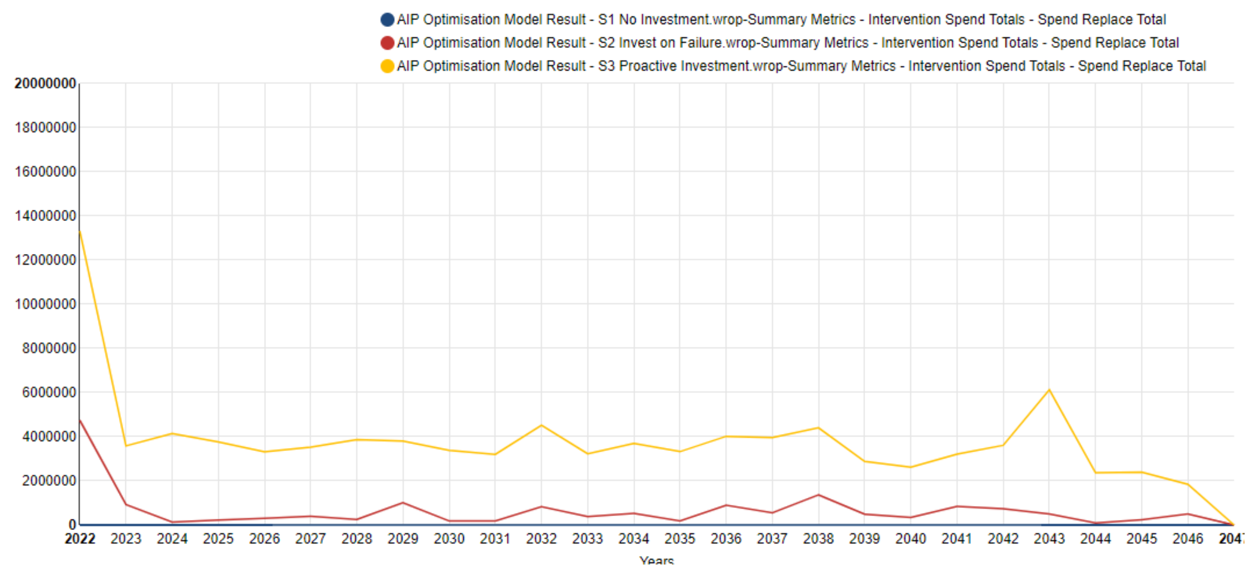
Three scenarios have been run as part of the workflow in EDA:

- No Investment
- Invest on Failure
- Proactive Investment

No investment shows what will happen if no investment is made to the assets even at the end of their life, it can be used as a baseline comparison but is not intended as a real-world option for Wessex. Both optimised scenarios use linear optimisation. The Invest on Failure scenario's objective is to invest in assets only at their point of failure. It therefore minimizes the cost of replacing or refurbishing the assets but does not consider the effect on service measure risks. The Proactive Investment scenario's objective is to invest in the assets when it is cost beneficial to do so (i.e. the capital spend to intervene is less than the risk of not intervening), or, when they fail. It minimizes the cost of failure and the assets net present value (NPV).

As previously described, the Results Viewer allows Wessex Water users to compare and contrast the different scenarios. The summary metrics are Service Totals (i.e. the social risk, human risk, natural risk, carbon risk and financial risk), Intervention Spend Totals (the amount spent on replacing, refurbishing or cleaning the assets), Consequence Totals (the total number of events) and End of Life State Counts (the number of failed assets).

Figure 27 – Total cost to replace assets in the three scenarios



For example, this chart shows how much would need to be spent on replacing assets each year for each of the three scenarios:

The following chart shows the total number of basic customer complaints in the three scenarios.

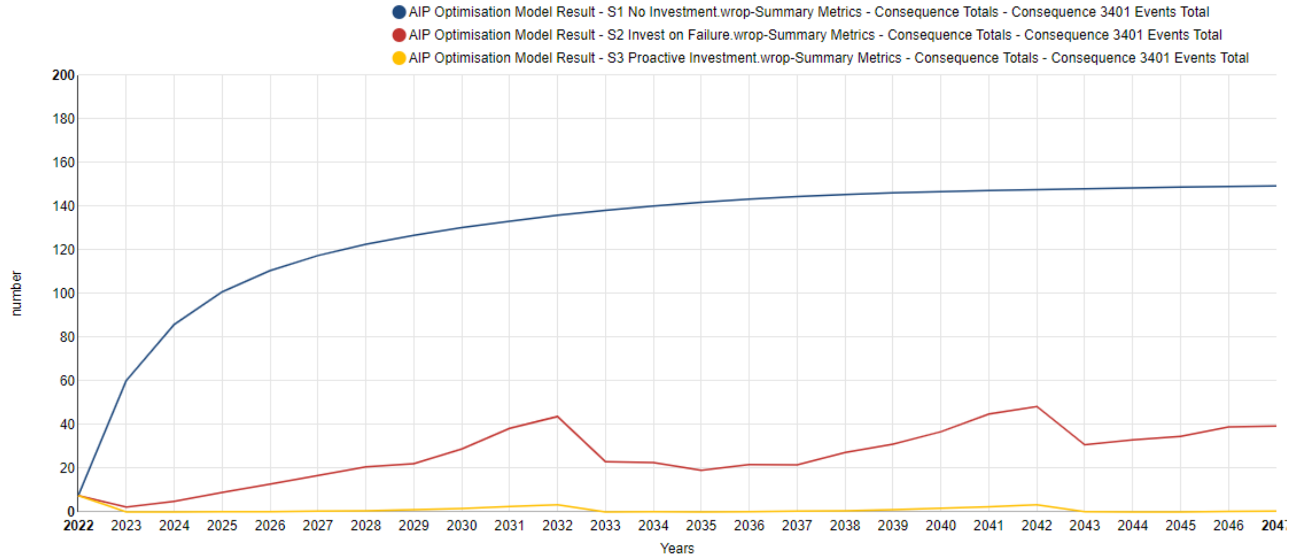


Figure 28 – Total number of basic customer complaints in the three scenarios

As with Portfolio, the results can also be exported via the Dashboard Definitions module to a Qlik dashboard. There are three pages within the dashboard; Asset Overview, Interventions Overview and Consequence View.

Asset Overview enables Wessex Water users to view the date the assets were installed, their age and their reliability and the amount to spend on either refurbishing or replacing the assets under the different scenarios. There are filters which allow the users to drill down to a certain group of assets. For example, the following graph shows the average age of the assets in Avonmouth in the Invest on Failure scenario.

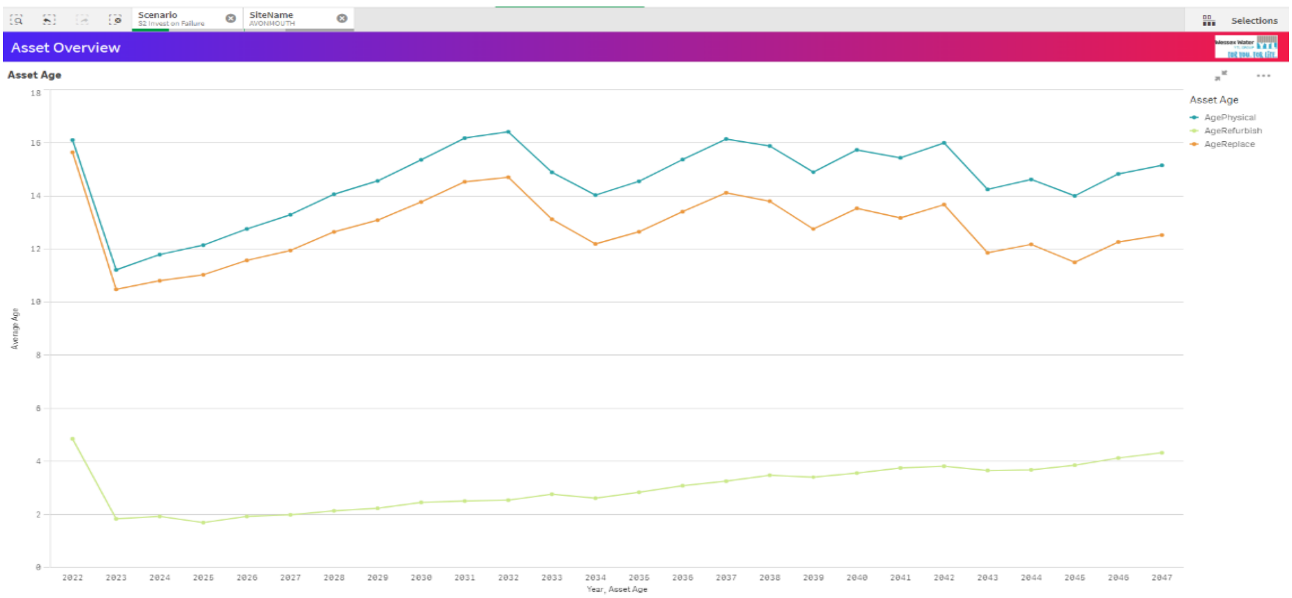


Figure 28 – Average age of assets in Avonmouth in the 'Invest of Failure' scenario

The following table shows which assets should be replaced and when, under this scenario.

Scenario: S2 Invest on Failure | SiteName: AVONMOUTH | Selections

Asset Overview

SiteID	ProcessID	AssetID	ProcessType	SizeVariable	Year	Spent Refurbish(£)	Spend Replace(£)	Total Cost Spent(£)
13013	13013-21	P-00039177	INLET - PUMPING (UNTREATED)	POWER	2025	0.00	929,216.39	929,216.39
13013	13013-21	P-00039178	INLET - PUMPING (UNTREATED)	POWER	2025	0.00	929,216.39	929,216.39
13013	13013-22	C-00901852	INLET - INLET	POWER	2026	0.00	813,006.24	813,006.24
13013	13013-22	C-00901853	INLET - INLET	POWER	2026	0.00	813,006.24	813,006.24
13013	13013-22	C-00901852	INLET - INLET	POWER	2044	0.00	813,006.24	813,006.24
13013	13013-22	C-00901853	INLET - INLET	POWER	2044	0.00	813,006.24	813,006.24
13013	13013-64	T-00038998	SLUDGE - DIGESTION	VOLUME	2022	0.00	649,021.97	649,021.97
13013	13013-64	T-00038999	SLUDGE - DIGESTION	VOLUME	2022	0.00	649,021.97	649,021.97
13013	13013-64	T-00039001	SLUDGE - DIGESTION	VOLUME	2022	0.00	649,021.97	649,021.97
13013	13013-64	T-00039004	SLUDGE - DIGESTION	VOLUME	2022	0.00	649,021.97	649,021.97
13013	13013-64	T-00038997	SLUDGE - DIGESTION	VOLUME	2022	0.00	643,313.01	643,313.01
13013	13013-64	T-00039000	SLUDGE - DIGESTION	VOLUME	2022	0.00	643,313.01	643,313.01
13013	13013-64	T-00039002	SLUDGE - DIGESTION	VOLUME	2022	0.00	643,313.01	643,313.01
13013	13013-64	T-00039003	SLUDGE - DIGESTION	VOLUME	2022	0.00	643,313.01	643,313.01
13013	13013-64	T-00039005	SLUDGE - DIGESTION	VOLUME	2022	0.00	643,313.01	643,313.01
13013	13013-64	T-00039007	SLUDGE - DIGESTION	VOLUME	2022	0.00	643,313.01	643,313.01
13013	13013-64	T-00039006	SLUDGE - DIGESTION	VOLUME	2022	0.00	581,867.26	581,867.26
13013	13013-64	T-00039008	SLUDGE - DIGESTION	VOLUME	2022	0.00	581,867.26	581,867.26
13013	13013-42	B-00065678	SECONDARY - BIOLOGICAL	POWER	2028	0.00	343,236.35	343,236.35
13013	13013-42	B-00065679	SECONDARY - BIOLOGICAL	POWER	2028	0.00	343,236.35	343,236.35
13013	13013-42	B-00065680	SECONDARY - BIOLOGICAL	POWER	2028	0.00	343,236.35	343,236.35
13013	13013-42	B-00069481	SECONDARY -	POWER	2030	0.00	343,236.35	343,236.35

Figure 29 – Table showing the cost of replacing the assets in each year in the 'Invest on Failure' scenario

Interventions Overview shows the number of assets to be replaced or refurbished for the different scenarios. The following table shows the number of assets required to be replaced and refurbished each year for each site in an Invest on Failure scenario.

Scenario: S2 Invest on Failure

Interventions Overview

Interventions Summary

Site Name	Year	Count of Replace	Count of Refurbish
Totals		**3301**	**3696**
POOLE	2022	82	88
BLASHFORD	2022	63	26
TAUNTON	2022	62	82
BERRY HILL	2022	62	53
AVONMOUTH	2022	58	94
DURLEIGH	2022	53	42
WESTON-SUPER-MARE	2022	52	58
YEOVIL	2022	52	54
AVONMOUTH STC	2022	50	51
SUTTON BINGHAM	2022	49	21
GLASTONBURY	2022	46	43
WEST HUNTSPILL	2022	45	44
BRIDGWATER	2022	45	42
CHRISTCHURCH	2022	44	52
WEYMOUTH	2022	43	42
MINEHEAD	2022	39	31
CHIPPENHAM	2022	38	36
CORFE MULLEN	2022	38	33
WELLINGTON	2022	38	25
DORCHESTER	2022	36	44
CHILTON TRINITY	2022	36	41

Figure 30 – Table showing the number of assets to be replaced and refurbished each year in each site in the 'Invest on Failure' scenario

And in a Proactive Investment scenario.

Scenario
S3 Proactive Investm...

Interventions Overview

Interventions Summary

Site Name	Year	Count of Replace	Count of Refurbish
Totals		**5000**	**4011**
YEOVIL	2022	112	26
DORCHESTER	2022	106	27
WESTON-SUPER-MARE	2022	98	45
SHEPTON MALLET	2022	92	21
PALMERSFORD	2022	85	20
CHILTON TRINITY	2022	85	17
CHRISTCHURCH	2022	84	41
WEST HUNTSPILL	2022	84	26
SALTFORD	2022	84	16
WEYMOUTH	2022	83	38
GLASTONBURY	2022	83	27
POOLE	2022	80	72
CHARD	2022	80	11
CALNE	2022	77	19
WIMBORNE	2022	77	15
MALMESBURY	2022	76	40
FROME	2022	76	12
SALISBURY	2022	73	22
WARMINSTER	2022	72	26
GILLINGHAM	2022	72	17
ROYAL WOOTTON BASSETT	2022	72	16
WIVELISCOMBE	2022	69	21

Figure 31 - Table showing the number of assets to be replaced and refurbished each year in each site in the 'Proactive Investment' scenario

The Consequence View page allows Wessex Water users to easily compare the outcomes of the different scenarios. It includes summaries of the modelled consequences, the risk values, the failure conditions and the amount spent. For example, comparing the Model Results for the three scenarios shows how the different interventions can reduce the number of different consequences occurring.

No Investment:

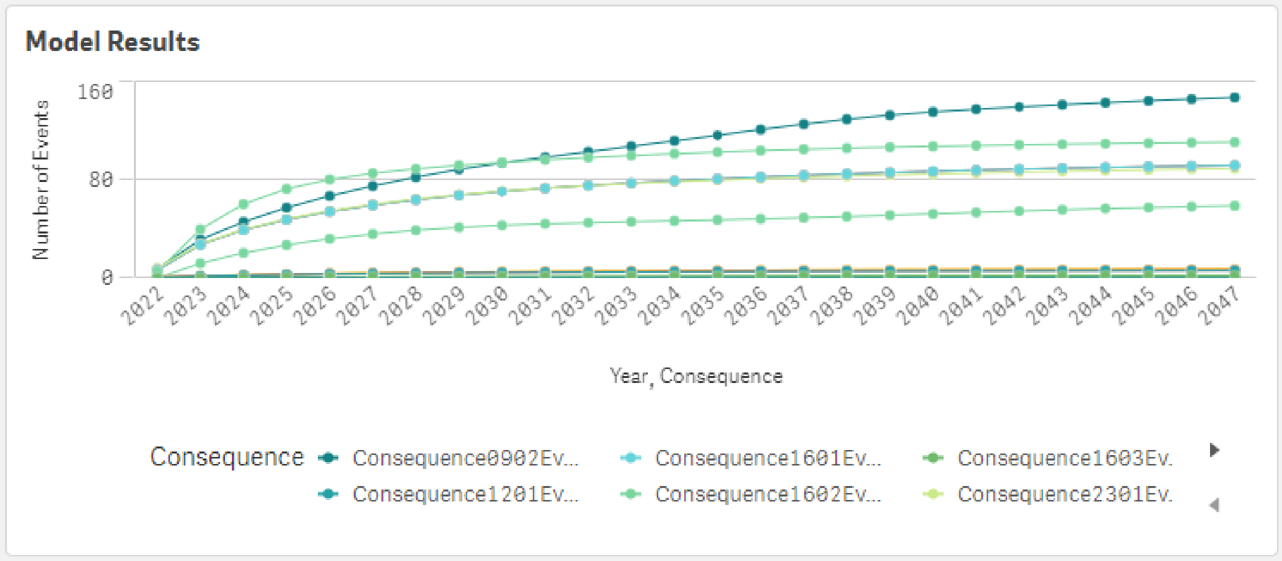


Figure 32 – Number of times each consequence occurs in the 'No Investment' scenario (for a sample of the asset base)

Invest on Failure:

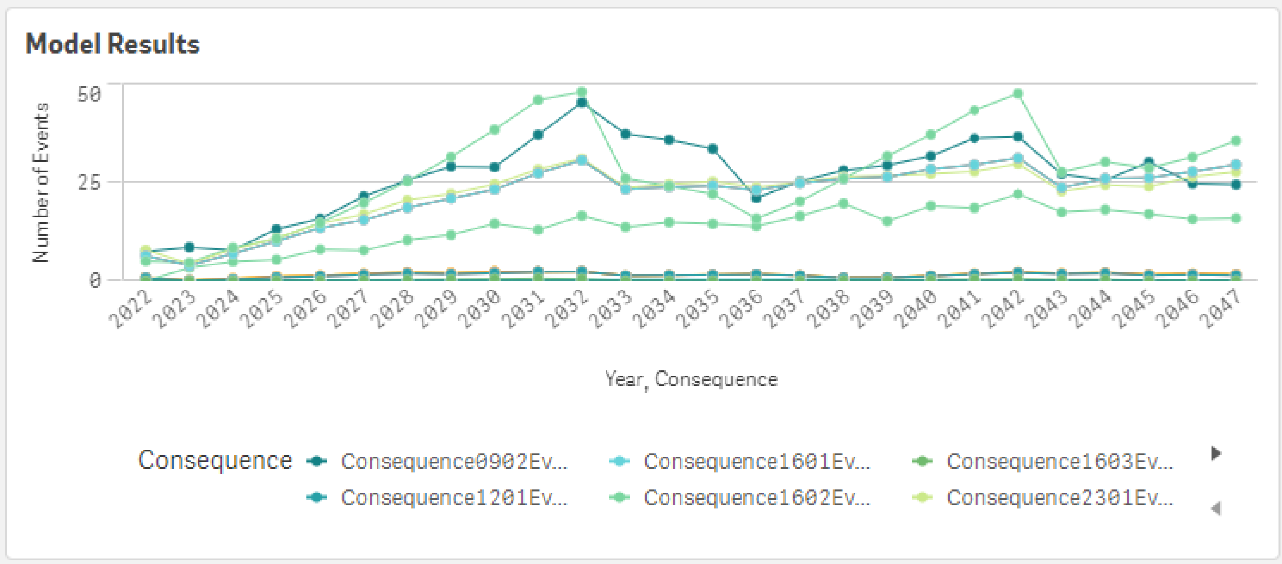


Figure 33 – Number of times each consequence occurs in the 'Invest on Failure' scenario (for a sample of the asset base)

Proactive Investment:

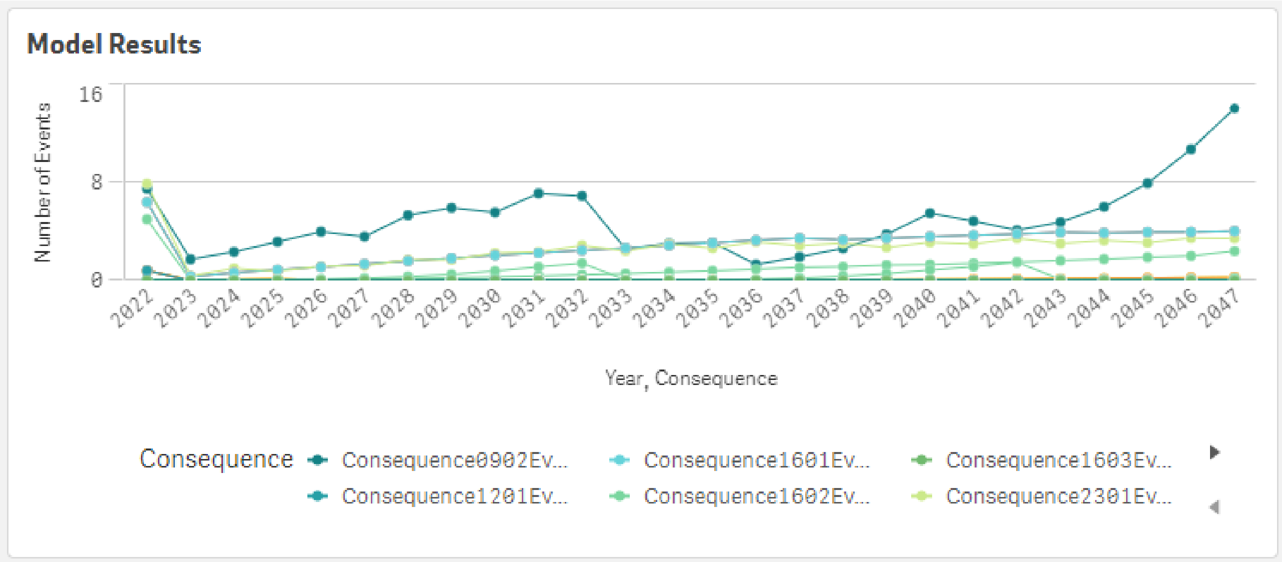


Figure 34 – Number of times each consequence occurs in the 'Proactive Investment' scenario (for a sample of the asset base)

6.3 EDA Developer Monte-Carlo Outputs

The Monte-Carlo module is accessed through EDA Developer and has its own type of chart that includes expressions of the variability the process creates. With a result file (.wrop) open in the EDA Developer Results Viewer module, there will be Monte-Carlo output measures available in the Area level Driver collection as seen in Figure 36. All M-C outputs measures are created in the result automatically and use the naming convention: "MC_[output measure name]", these are highlighted in the figure in the red box.

To open the M-C result chart, right click the measure name and select the bottom most option labelled "View Monte Carlo Results Chart" as see here:

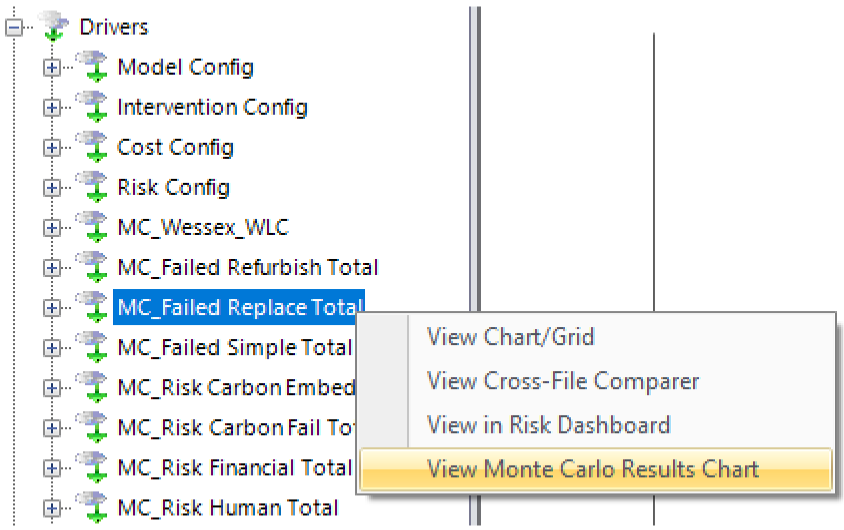


Figure 35 – Opening the M-C Results Chart

This will open a specialised charting tool that allows you to visualise the variations in the measure that were introduced by the M-C.

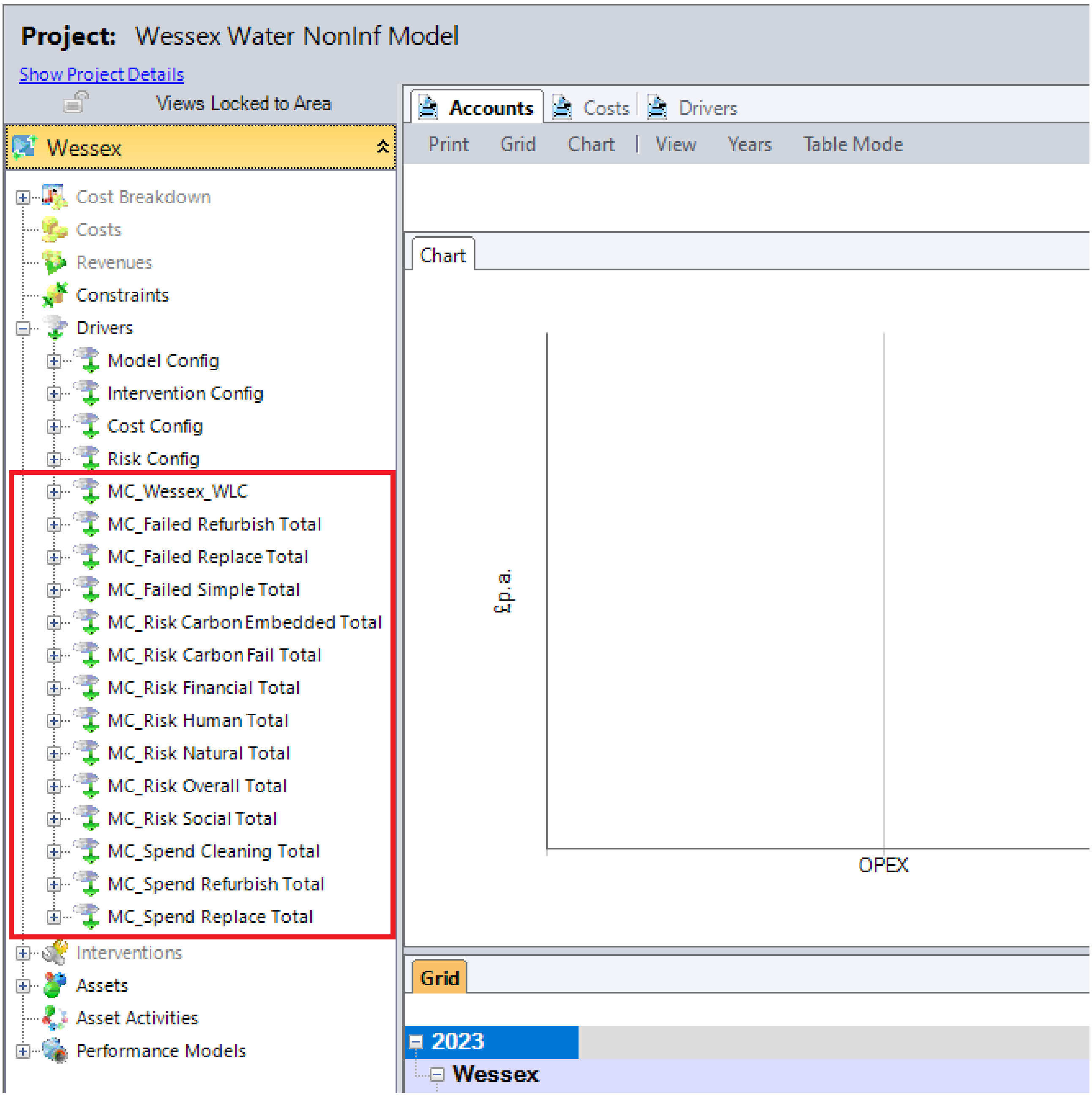


Figure 36 – Accessing Monte-Carlo results measures in the Results Viewer

The basic M-C chart, Figure 37, uses a similar format to the EDA Asset versions but includes additional series showing the baseline position (blue), mean of the M-C variations (red) and the M-C variation itself (green). In addition, each point on the series can be accessed by clicking on it to bring up a secondary chart showing the point variance in that time step, see Figure 38.

The secondary view shares the baseline (blue) and mean (red) series with the primary view but gives a more detailed breakdown of the variance in the output measure. It also provides a means of adding a fitting parameter to the chart if it is appropriate to do so.

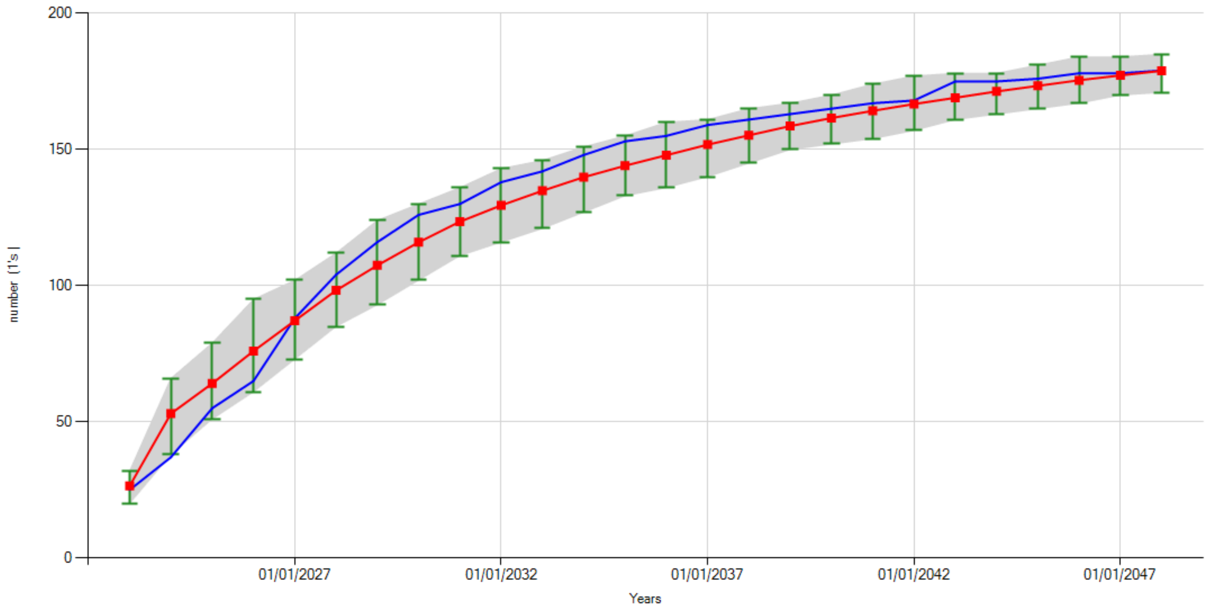


Figure 37 – Monte-Carlo Results Chart

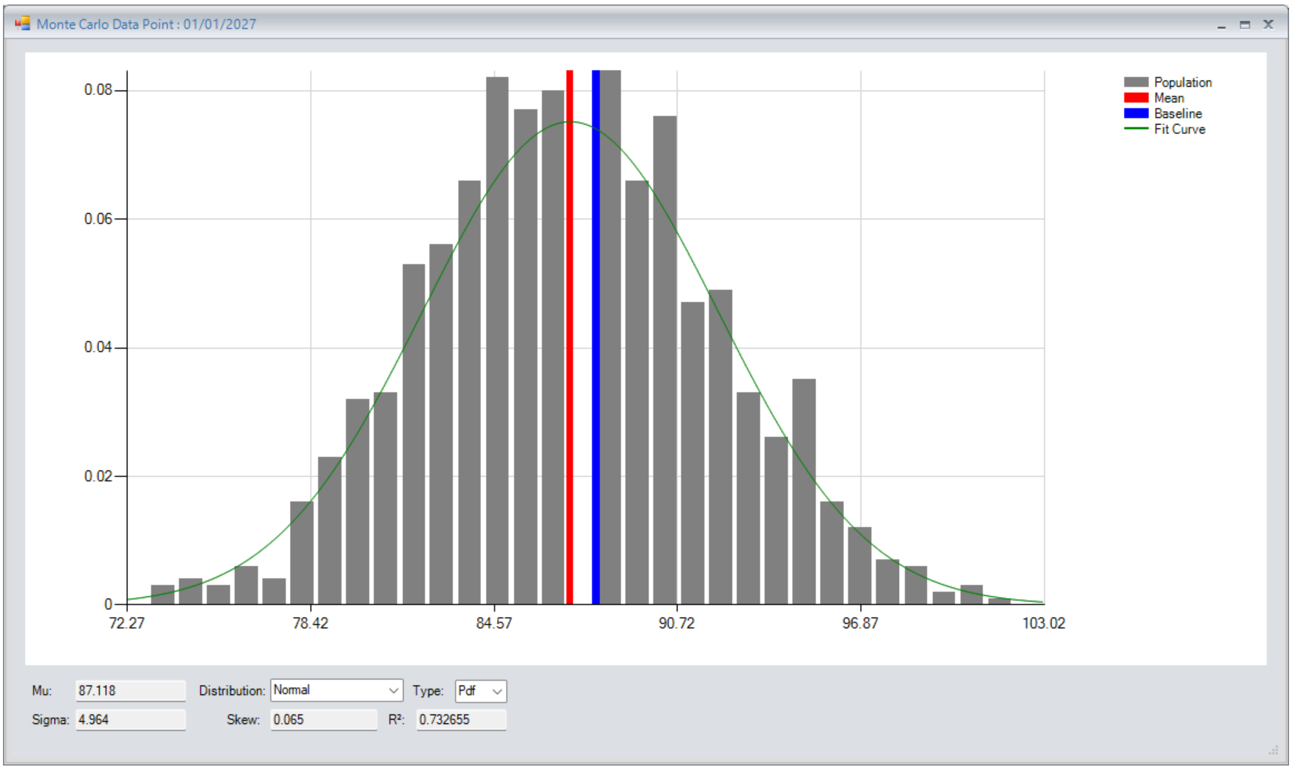


Figure 38 – Monte-Carlo Results Chart "Data Point" secondary view

7 Conclusions and Recommendations

EDA provides Wessex Water with a comprehensive repository for all investments whether historic, ongoing or forecasted, allowing a centralised single source of truth for the baseline business plan (and its variants). Wessex Water are supported by a full stage gated approvals workflow ensuring that only approved investments are taken through to the business plan or considered in optimisation. Thus, Wessex Water can ensure alignment against the Service Measure Framework for all investments, with reduced requirements on other disparate systems such as spreadsheets, aligning to Wessex Water's to-be processes.

Through integration with source systems, Wessex Water are ensured that the data is up to date, supporting re-optimisation as plans and costs change whether in anticipation for the following price review or during within AMP business-as-usual reviews. EDA provides Wessex Water with a consolidated view of investments surfacing from asset modelling, offline sources, Agresso or from the M7 risk system.

Previous to the investment management platform implementation, Wessex Water had 10s of disparate processes around the business. Through the work that Wessex Water have done with Arup in order to define 'to-be' processes in addition to an established service measure framework, there can be an assurance that data will be collated in a defined way, opening the doors to more extensive analysis as mentioned in our recommendations. A single platform ensures that outputs from all areas of the business are collated providing a seamless process for optimisation and planning by business area (department) or holistically.

Optimisation and more automated reporting features will enable Wessex Water to find process efficiencies, which typically have saved up to 80% time and resource on creation of a business plan. Additionally, optimisation will find at the very least the current baseline but should find substantial efficiencies to ensure capital and operational savings on top of current business processes, typically this is within the region of 20% but differs based on the flexibility permitted to the optimiser (fewer mandatory investments, more options against each investment need etc.).

Wessex Water users are fully trained on the use of EDA Portfolio. This has included the creation of an investment need (and solutions), approving and rejecting through the workflows, creating (both templated and new) optimisation scenarios, setting a baseline plan, and EDA's reporting and administrative features. This, coupled with extensive testing through three user acceptance testing cycles, has empowered Wessex Water users, to use the investment management platform in addition to training other end users.

Wessex Water users are also fully trained on the use of EDA Asset. This included sessions on refreshing the data and the model, running model optimisations, viewing the results and creating Dashboard Definitions for the results. It also covered the use of EDA developer to maintain and update the AIP model itself. This, along with two cycles of UAT testing, has enabled Wessex Water users to use the platform and train other users on it.

Through EDA, Wessex Water users can quickly understand differences between new value framework weightings. EDA's scenario editor allows users to test new weightings before they become the baseline. Together with the reporting features, users can understand how a change in weighting could affect not just the total risk (or breakdown by capitals) but also the investments selected based on the weightings applied.

With an extensive use of dropdowns, conditional logic, integrations and consolidated fields, Wessex Water will have a more robust repository of data for use not just in optimisation and baseline planning but also within some of the recommended areas below.

7.1 Uncertainty Analysis

There is an inherent level of uncertainty in every possible scheme that could be delivered throughout the AMP, whether that be leakage control, metering, or a large capital investment. A project may cost more, it may take longer to deliver, and it might not deliver the benefit you expected in the strategic planning.

Within EDA Portfolio, we capture this information within the repository against each combination of service measure and investment need/solution giving a granular view of data sensitivity which can then be used in EDA models and visualisations.

A challenge that other customers have faced is collating the right amount of data on uncertainty. It is necessary to collate this data when collecting the other data against the investment need or solution otherwise it will be left default and be relatively meaningless, rendering visualisations and optimisations on averages rather than true data.

Of course, it is essential to understand uncertainty in order to answer questions such as what is the likelihood of missing a target performance, and how much will this cost Wessex Water? If we spend only £x, what levels of service/performance can we expect?

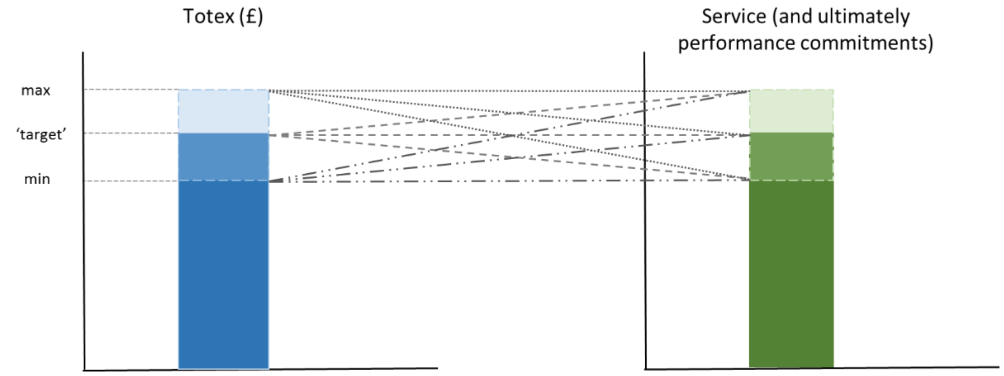


Figure 39 – TOTEX and Service Measures Uncertainty Example

7.1.1 Post Optimisation

The values captured in the repository can be exported using the snapshot functionality, allowing use in dashboard visualisations.

The below allows users to understand the minimum and maximum potential values based on the uncertainty metrics allocated within the EDA Portfolio repository.

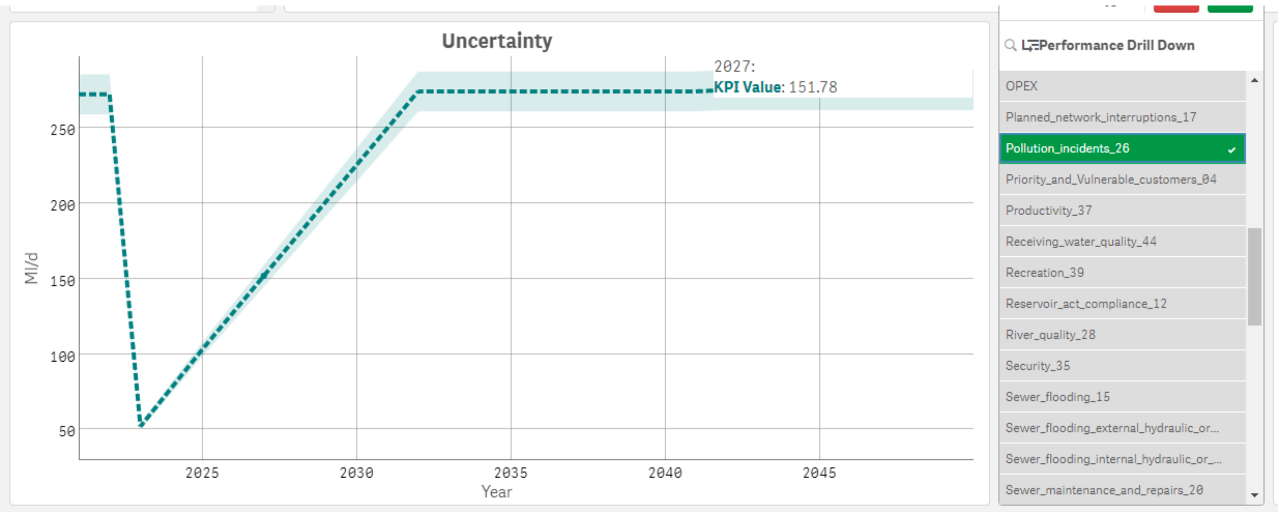
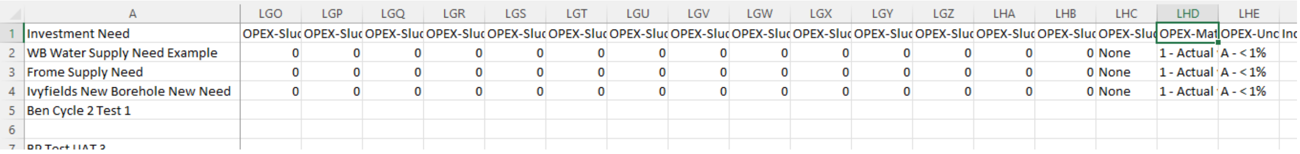


Figure 40 – Uncertainty across pollution incidents

These visualisations can be configured at any aggregated level of the service measure hierarchy and investment hierarchy, allowing users to compare the inherent uncertainty across pollution incidents for example as shown above. This can be compared between scenarios.

An example of the EDA Portfolio snapshot data is below. Using EDA Data Labs, this can easily be converted into a longer format for easier use in dashboard visualisations in a repeatable fashion.



	A	LGO	LGP	LGQ	LGR	LGS	LGT	LGU	LGV	LGW	LGX	LGY	LGZ	LHA	LHB	LHC	LHD	LHE
1	Investment Need	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Sluc	OPEX-Mat	OPEX-Unc
2	WB Water Supply Need Example	0	0	0	0	0	0	0	0	0	0	0	0	0	0	None	1 - Actual	A - < 1%
3	Frome Supply Need	0	0	0	0	0	0	0	0	0	0	0	0	0	0	None	1 - Actual	A - < 1%
4	Ivyfields New Borehole New Need	0	0	0	0	0	0	0	0	0	0	0	0	0	0	None	1 - Actual	A - < 1%
5	Ben Cycle 2 Test 1																	
6																		

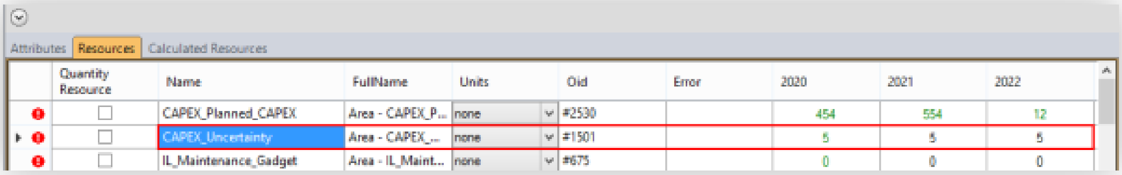
Figure 41 – Example of EDA Portfolio snapshot data

The above has been set up for Wessex Water within a Qlik dashboard and a Data Labs script within the Qlik Transforms project.

7.1.2 Pre-optimisation

Using uncertainty within optimisations requires more extensive thought and was out of the scope for the initial implementation of EDA. Functionality exists but will need to be appropriately designed and configured.

Within EDA Portfolio, users can create snapshots with uncertainty. This ensures that the uncertainty data is carried through into an EDA Snapshot Model for use in the optimisations. The Uncertainty values are taken from the Uncertainty field for both Needs and Solutions that have been selected for the Snapshot. For example, if CAPEX is set as an Uncertainty Driver in the Configuration Editor, then the Uncertainty value set for that driver on a need (or solution) will be included when an uncertainty snapshot is run.



Attributes | Resources | Calculated Resources

Quantity Resource	Name	FullName	Units	Oid	Error	2020	2021	2022
☐	CAPEX_Planned_CAPEX	Area - CAPEX_P...	none	#2530		454	554	12
☐	CAPEX_Uncertainty	Area - CAPEX_...	none	#1501		5	5	5
☐	IL_Maintenance_Gadget	Area - IL_Maint...	none	#675		0	0	0

Figure 42 – Pre-Optimisation Uncertainty Input Example

From here, it is up to the user to decide how to use the uncertainty values in the optimisation. One possible technique would be to calculate an “average uncertainty” value for the whole portfolio which would be a function of all the uncertainty measures held against the needs and solutions. To begin this would be best applied to TOTEX only but could be expanded out to service measures / performance commitments.

If held as a measure in the model, then constraints could be placed upon it. The theory being that a set of investments with little room for uncertainty (i.e. Wessex would be surer of the TOTEX spend in AMP8) could cost something very different than those with a greater freedom of uncertainty (which could be cheaper but higher risk in AMP8). This approach would require changes to the EDA Portfolio template model to ensure the relevant information to calculate the average uncertainty is held within the snapshot.

As previously mentioned, for this to work, the population of the uncertainty values within EDAP would need to be of sufficient quality and granularity to allow the optimiser to select more or less certain solutions depending on how strict a constraint placed upon it.

A further, more exhaustive, example is where the model is iteratively ran based on a sampled view of the uncertainty using a Latin Hypercube or Monte Carlo approach. This approach has been taken by Severn Trent Water for their WRMP and is being actively developed to enhance this to consider other investment types. This method allows visualisations such as the following detailing the frequency in which certain projects are selected based on their uncertainty. This requires a significant amount of design to ensure that the uncertainty and associated visuals are handled correctly.

Figure 43 – Uncertainty Analysis of Project Cost / Benefit / Duration (Green = Selected in Scenario)

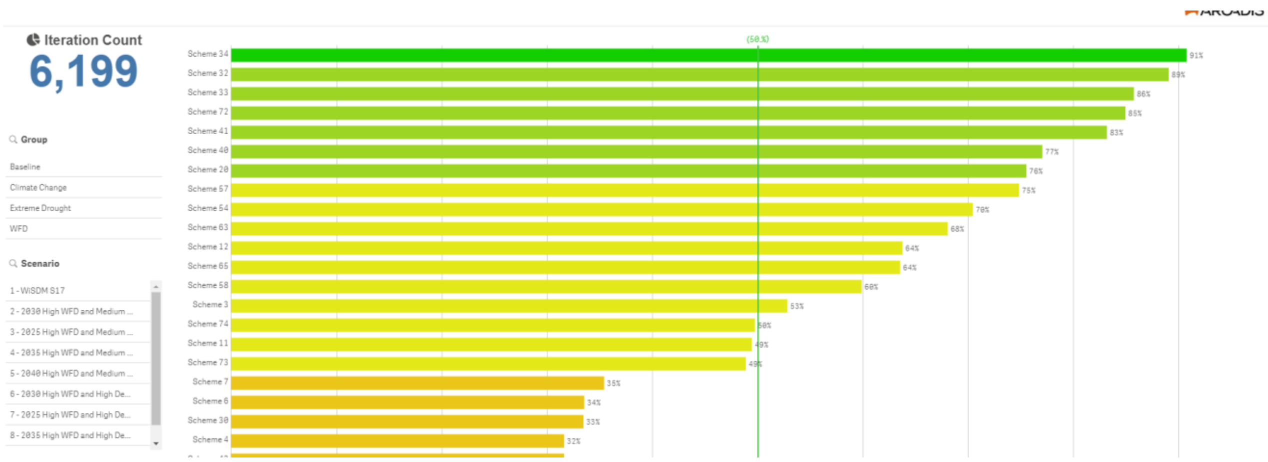


Figure 44 – Frequency Analysis of Projects Selected

Extensive pre-optimisation uncertainty analysis opens the door for advanced adaptive pathway analysis. Arcadis Gen initially begun this analysis with Severn Trent Water (STW) but we have now also commenced work with Wessex Water's Water Resources Management Plan (WRMP) team, using elements of the STW solution to support the identification of "least regrets" schemes. Likewise, we are also expanding on our work at STW to other business areas and we would greatly wish to complete the same with Wessex Water through a collaborative approach.

Regardless of future scenarios we have a high degree of confidence that the schemes delivered will still be cost beneficial despite the uncertainty in cost, duration, and benefit. This approach will allow Wessex Water to be flexible in their decision making by promoting schemes that do not lock them down a certain path for decades to come, thus they can better react to changing futures.

The work we have done around advanced uncertainty analysis, adaptive pathways and real options demonstrates that we have the functionality in EDA to go beyond optimisation of business plans and really push the boundaries in terms of producing resilient plans for the future. These are industry proven and been commended by OFWAT as best in class methodologies at PR19.

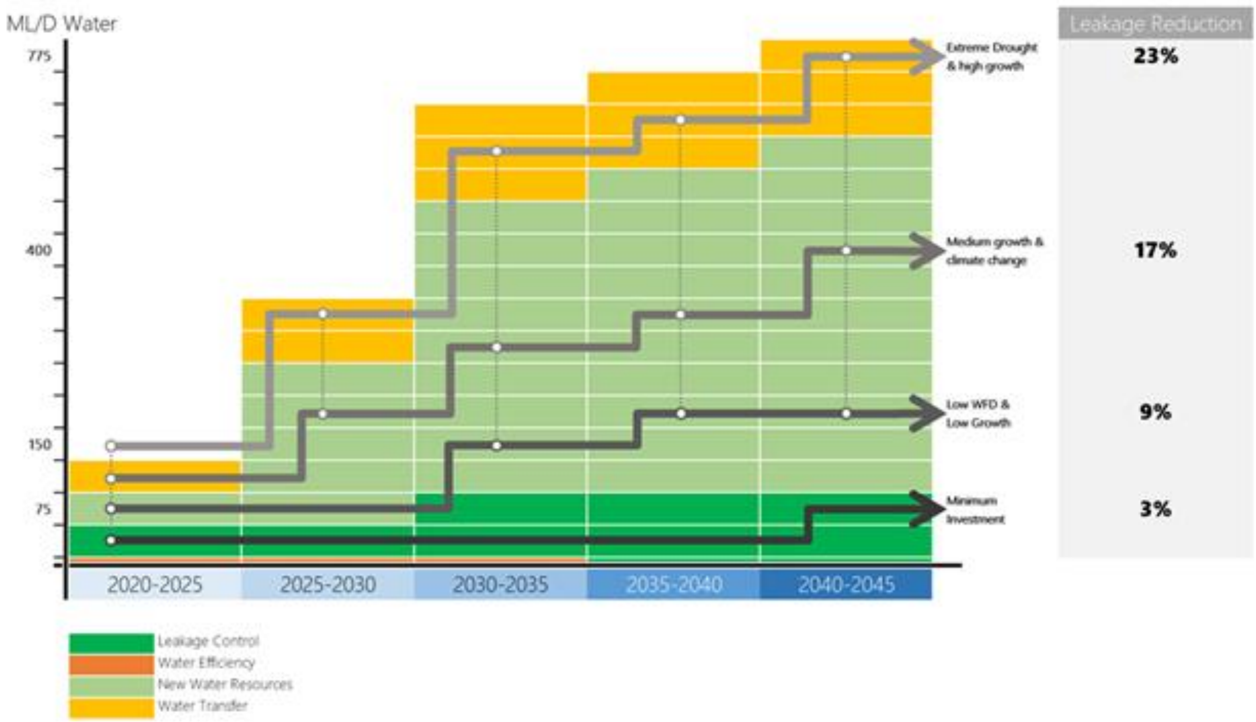


Figure 45 – Adaptive Pathways Example

7.2 Below Ground Asset Modelling

Through Train-the-Trainer for the above ground asset modelling, Wessex Water users will have the tools and training to be able to make both edits to existing models in addition to creating new ones. One area that an additional model could be built is for infrastructure assets, replicating existing Wessex Water models or created from scratch using EDA's model builder and machine learning toolkits.

EDA has been used by a plethora of UK water companies to include below ground asset models. This has included Severn Trent Water, Yorkshire Water and South West Water. Using these models, users can optimise asset replacements in addition to more operational activities (such as cleansing). Furthermore, these models are used to calculate key service measure outputs such as bursts, flooding events and pollution incidents. This in turn can be integrated with EDA Portfolio to create further investment needs based on the modelling, aligned to the service measure framework.

The most extensive infra model configured within EDA, has been created in collaboration with Severn Trent Water where we designed and developed a holistic asset risk model for water pipes, called WiSDM (Water Infrastructure Supply and Demand Model). Strategically the models allow us to optimise which asset/scheme to invest, in what year to meet the overall cost and performance constraints of the business. It provides the TOTEX requirements for the next AMP but also considers 25-80 years into the future to ensure a sustainable plan is submitted.

The model incorporates bursts, customer interruptions (i.e., minutes lost), discolouration and leakage. The model also includes the water supply demand balance (impact of metering/customer education on demand) and all the possible supply schemes such as building a reservoir and water transfer between regions.

Our delivery models incorporate a further level of asset detail, ensuring that strategic decisions are aligned to delivery. For example, we explored what percentage of a DMA could be replaced utilising latest UKWIR leakage research and created a process and solution that automatically bundles neighbouring high-risk pipes into logical schemes for delivery – increasing delivery efficiencies.

The WISDM model was used to support multiple price reviews to industry leading status, including PR19 in which STW achieved fast track status. It is also fundamental to STW water resource plan and ensures consistency between the price review submission. More recently it has been used to provide evidence towards the needs for their green recovery plan which has since been endorsed by OFWAT, leading to an additional £565m of investment and generating 2500 jobs in the local communities.

The WiSDM model demonstrates the breadth of use from strategic through to operations that the same platform can be used for which goes beyond the initial scope of requirements.

Machine Learning and AI

We have 20+ years of asset investment planning experience and through that time have captured industry trends within our tool. Through this, EDA comes with an extensive toolkit for machine learning, primarily within its Data Labs module. Within the current implementation, EDA has taken the outputs of external models, either as the parameters for the asset modelling (such as for costs, failures and consequences), or the output costs and service measures for EDA Portfolio. Wessex Water could look to centralise the refreshing of these models within EDA itself. As an example, clients such as ICON Water, Severn Trent Water and Yorkshire Water, use EDA to create new failure and consequence model parameter predictions based on their own data. These make use of algorithms from simple linear regression to more extensive machine learning such as gradient boosted multivariate regression algorithms.

Example outputs are shown below:

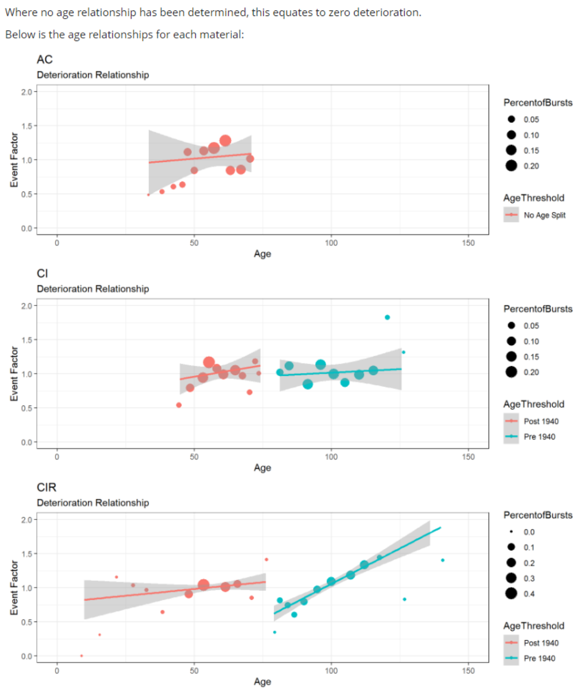


Figure 446 – Bursts Degradation Modelling Example

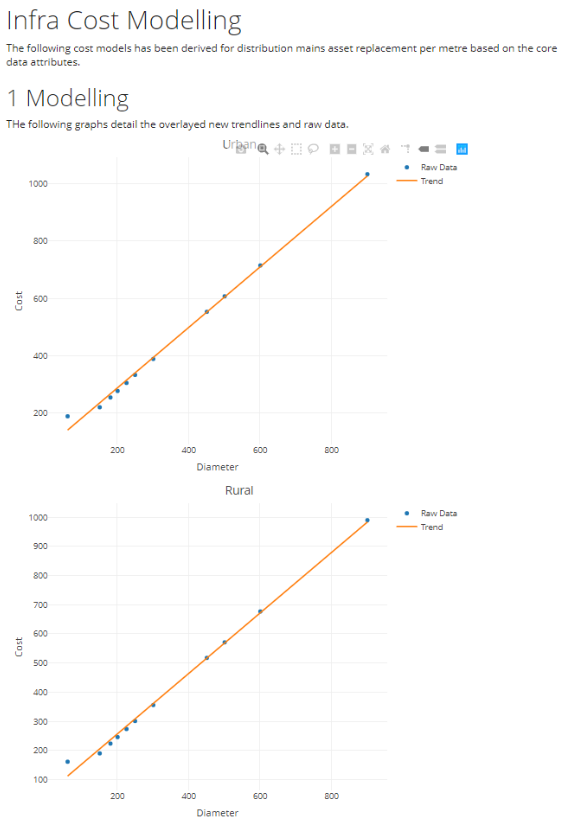


Figure 47 – Cost Modelling Example

EDA provides the ability for users to quickly rerun these analyses at a click of a button, providing the output data (parameters and predictions) in addition to reports as shown above. EDA will allow Wessex Water to extend their use of machine learning and artificial intelligence to future requirements.

Other Solutions of Potential Interest

The following are other solutions within the analytics space developed by Arcadis Gen for other UK clients that could be of future interest to Wessex Water. Arcadis Gen would be happy to demonstrate any of these solutions if they are of benefit.

7.2.1 Real Time Demand Predictions and Production Plan Optimisation (WiSDM-O)

During 2018, the UK water industry was presented with two significant climate challenges: the freeze/thaw following the ‘Beast from the East’ cold weather and the record breaking hot and dry summer. These extreme events demonstrated that there is a clear but complex link between weather and demand which highlighted a critical need for instantaneous company-wide production and demand data to ensure maintenance of supply to customers and protection of the environment. As a trusted partner to STW, Arcadis was approached to help STW explore options for creating an integrated and innovative system with the goal of connecting existing data sets to efficiently process data and produce accurate forecasts. Arcadis Gen would appreciate the chance to expand this solution to Wessex Water, ensuring greater feedback on our existing solution and a collaborative end result.

Using existing EDA software and the underlying logic in the strategic water model, WiSDM-O processes historic and real time data from a range of sources to produce a forecast for the volume of water required across the network – ensuring users have near real time information to support decision making for medium term and delivery planning.

The model processes data from a range of sources including the Central Data Repository, Netbase, eSCADA, SharePoint, and external weather forecast and hydrology data, then creates a forecast and populates a dashboard, refreshing every 15 minutes. The interactive dashboards allow users to easily zoom into specific areas - company, water resource zone and control group levels for: water into supply, production cost, water in storage, actual demand, demand prediction, weather forecast, planned intervention work, production capacity, leakage, supply and demand balance and river flows.

Demand prediction (with uncertainty) is driven by a model developed using advanced machine learning approaches and trained on historic data. Predictions are continuously refined with latest information. We believe that this system represents the first example of such an advanced modelling approach being used daily in production in a water company.

WISDM-O replaced time-consuming manual processes and is used daily by the Water Resources team and Operational Control Centre. It is used strategically to ensure resilience of water supply to their customers, medium term to plan monthly/annually the water production and operationally to gain insight day to day in water demand. It has significantly reduced time required for the following tasks:

1. Review of the supply and demand balance including leakage,
2. Review of both planned intervention work and unplanned restrictions and their impact on production capacity; and
3. Daily production planning considering predicted demand.

There are wider benefits expected for the company beyond the operational efficiencies – STW are now creating a repository of processed data that will be used to underpin PR24 and WRMP24 plans, providing better evidence for medium and long-term decision-making processes and solutions.

WISDM-O demonstrates how EDA can extend beyond asset investment planning and be embraced by entire operations teams.

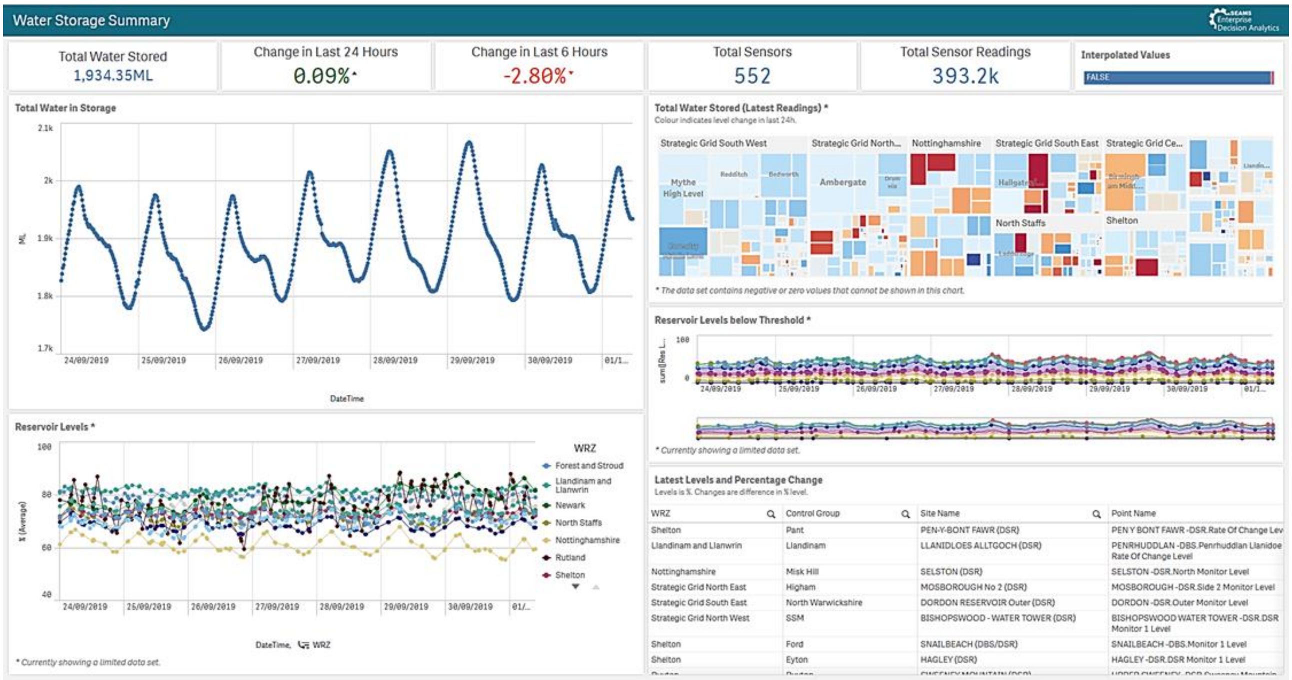


Figure 48 – Real Time Water in Storage Example

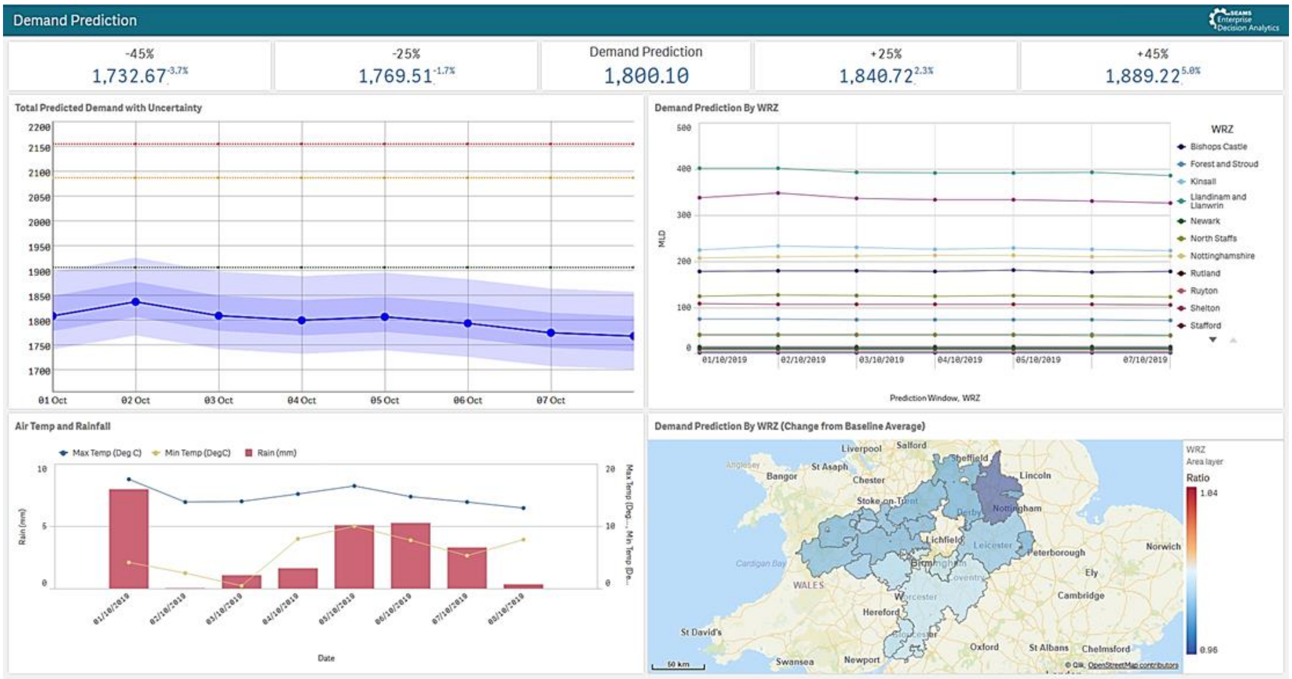


Figure 49 – Weekly Demand Prediction from Weather Forecast Example

7.2.2 Asset Health

Water companies generate terabytes of data about the condition and health of their assets every day. This feeds multiple systems across the business. With our Asset Health solution users can have a single unified view of asset health across every region and every asset in the business. Users can drill down from a given region, through to individual sites, through the asset hierarchy and all the way to individual pieces of equipment to view their real time asset health and condition. This solution is used to help derive “care packages” for assets in poor condition which get delivered through the AMP.

Of particular importance here is the way in which EDA is streaming in live data from multiple sources, including SCADA.

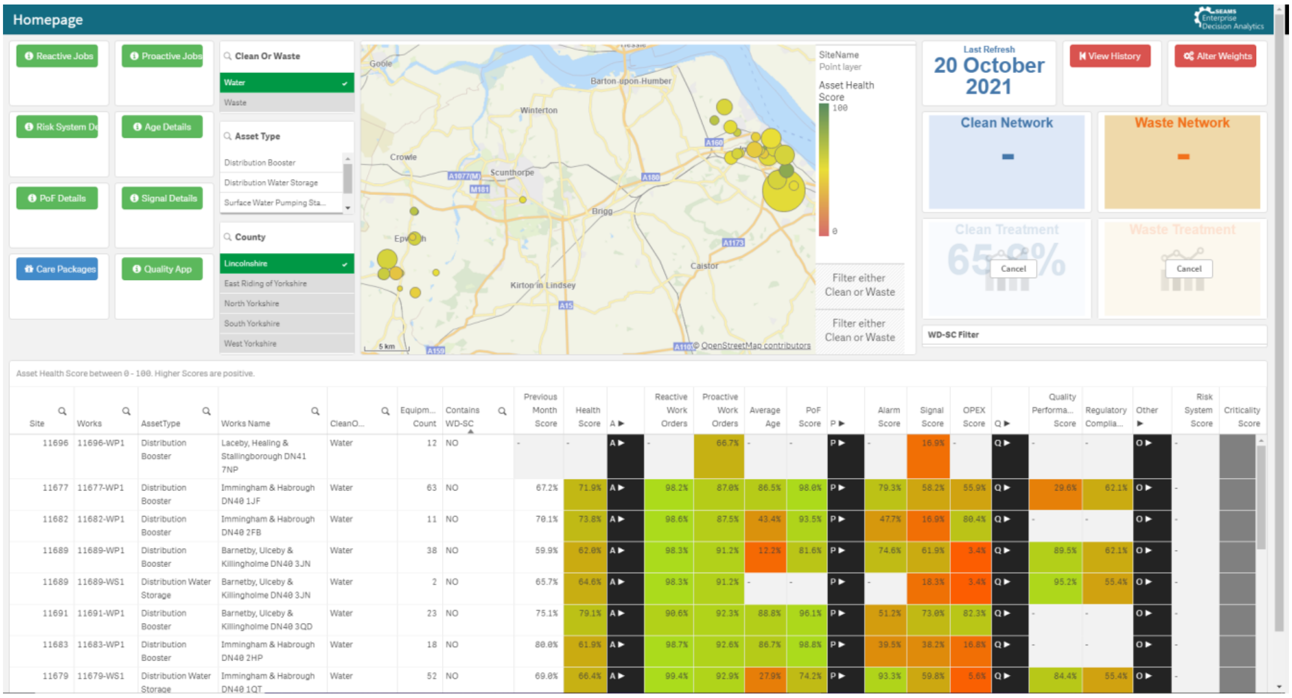


Figure 50 – Asset Health Dashboard Example

7.2.3 Work Planning and Scheduling

The Workforce Management (WFM) market is dominated by Job Scheduling tools that carry out day to day, real time scheduling and assignment of tasks to staff. However, these tools often neglect the strategic and tactical view of workforce planning and are left trying to optimise staff reactively on a day-to-day basis, leading to frustration amongst clients that their workforce planning, and scheduling is inefficient and leading to large backlogs. Clients will often cite the following issues:

- We are using too many external contractors which is costing us a lot of money. Why can we not make better use of our internal staff?
- We are getting a large backlog of work which means we are drowning in issues and leading to an increase in customer complaints.
- We are trying to achieve operational efficiencies and are really struggling to know what to do
- The demand for our work is really peaky which means sometimes we have to pay a lot of overtime and other times our staff are underutilised. Why can't we try smooth this out?
- Despite everyone working hard our workforce just seems to be inefficient and are struggling to improve their utilisation rate.
- We are getting an increase in staff churn and retirement is seeing key skills leaving our organisation – we really need to plan for the future of our staff.
- Our staff are getting demotivated as no matter how hard they try it feels like they are unable to meet their targets.
- We know our staff need training but are not really sure what skills are most important to build for our long-term future success

We have developed and continue to evolve a new and exciting module for EDA called Workforce Planning and Scheduling (WPS) to help clients overcome these issues. Put simply, WPS allows clients to ensure the right people with the right skill sets are assigned to the right job at the right time. It builds on asset investment planning which is used to optimise the best projects and takes it one step further into resource planning.

We have created a prototype and early versions of WPS for a number of water clients, including South West Water and Severn Trent Water. However, it is with Network Rail that we have turned our vision into reality where through 2021-22 we are implementing and further developing our WPS module to full maturity. This is a ground-breaking project not just for Network Rail but for the first time a utility will be linking their asset investment planning to their workforce planning/scheduling, and we are excited to see this new feature grow. We would welcome the opportunity to explore this module further with Wessex Water.

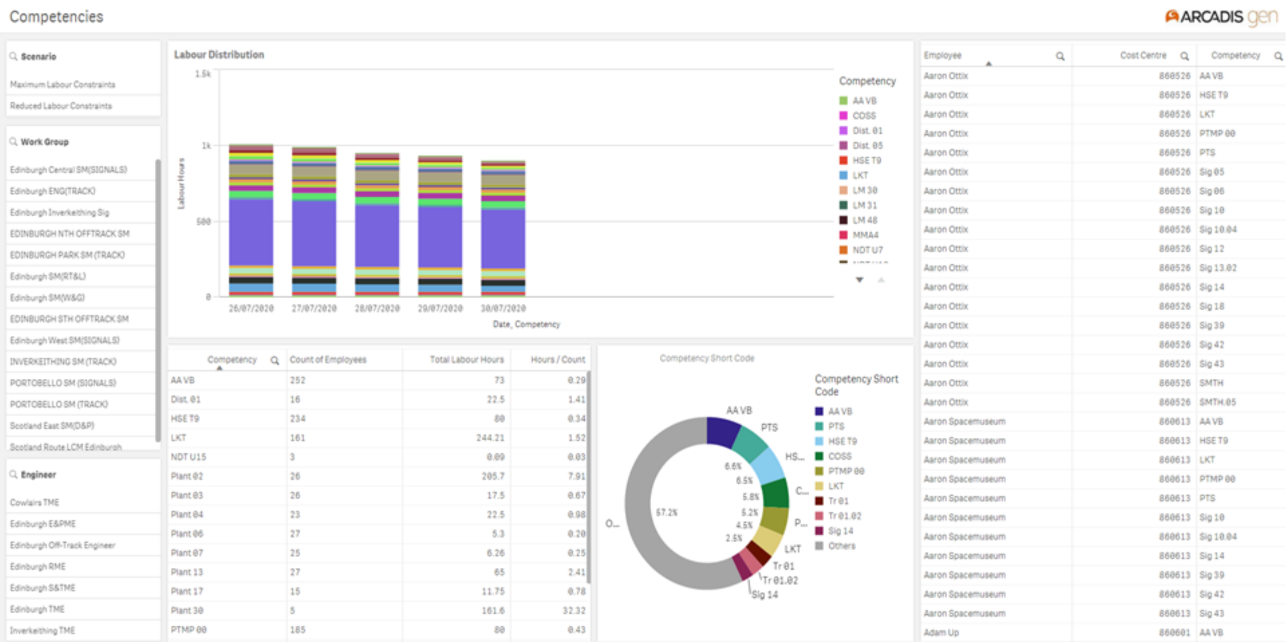


Figure 51 – Work Planning and Scheduling Dashboard Example

A2 Deterioration modelling overview

The Development of Non-infrastructure Asset Deterioration Models in Wessex Water

Introduction

The purpose of these models is to provide a distribution for possible future failure probabilities from historic asset performance, so that future replacement or refurbishment requirements may be forecast.

The principal methodologies used for non-infrastructure deterioration modelling are based on reliability statistics; typically continuous functions using regression curves derived from observations of failures within a population. These are often fitted to known parametric distributions of which the Weibull distribution is the most common. The use of parametric distributions is preferred because it accounts for the distribution of failures over time with respect to asset age rather than average asset life. Average asset life is typically presented by mean time to failure, which assumes a constant or random failure rates.

All deterioration models require some form of validation which is usually done by testing the regression for statistical goodness of fit. The extremely wide variability of failure rates of equipment operating in similar environments and operating conditions has been acknowledged and since the achievement of a statistical goodness of fit test may be due to chance, the need for models to be verified against a working or experiential hypothesis is essential.

Due to historic working practices and information systems, producing asset deterioration models from maintenance records alone with a sufficient degree of validation in terms of goodness of fit has not been possible. As a result the approach to developing these models in Wessex Water has been experiential based using a rigorous process of elicitation and statistics. Further these models have been benchmarked as part of a tri-company benchmarking exercise which included models derived from maintenance records. This structured elicitation approach along with benchmarking means that the models are presented with a high degree of confidence.

Background of the Approach

A number studies of failure patterns have been completed since the 1960’s most notably by Nolan and Heap[1], these studies identified six failure patterns, all of which are variations of the so called bathtub curve containing one or more of the standard failure modes. Namely early or maintenance induced failure, commonly referred to as infant failure, random failures and age related failures, commonly referred to as wear out failures. Any failure pattern can thus be described in terms of their failure modes and a representative failure pattern produced from information provided by technical staff with experience of operating and maintaining the type of asset being analysed. This is the basis of all reliability centred maintenance studies as applied by industries worldwide.

For example determining if the type of asset has a failure pattern which includes any combination of infant, random or wear out failures and the approximate ages at which these occur along with relative proportions provides sufficient information to enable a representative failure pattern to be produced. This failure pattern may then be fitted using a parametric distribution which can be applied to model the failure pattern.

Once this distribution has been produced it can then be used to feedback the results to the information providers and the failure pattern verified against the experiential hypothesis. This can be done by for example observing where the peak of failures occur by viewing the failure density of the distribution or by checked the tail of the cumulative distribution to verify maximum possible life. In addition, the mean time to failure can also be derived and used as a further hypothesis check.

The above has been systemised into a commercially available off the shelf product by adapting the above RCM approaches with supporting analytical software in the form of a Microsoft Excel Add in to produce Weibull parameters which model the described failure pattern. This approach was originally developed for an MSc Thesis in Asset Management at the Robert Gordon University in Aberdeen. The approach has therefore been externally examined and is considered as fit for purpose.

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[1] Reliability-Centered Maintenance, United Airlines, 1978

Application in Wessex Water

The Excel Add In, referred to as the Failure Pattern Estimator (FPE) is designed to allow a user to generate a set of Weibull parameters which can be used to describe the deterioration, probability of failure and reliability of an asset or item of equipment. The approach to populating the FPE is most effective when completed as a facilitated workshop using cross functional teams. Wessex Water completed the workshops with an independent facilitator and individual representatives from asset management, operations and maintenance. Where required subject matter experts where involved for example for instrumentation and UV disinfection assets.

The following summarises the process used in the workshops:

Step 1 – Define the asset

Determine the asset type to be modelled and its characteristics such as size, operating context and duty. For example a compressor may be the description used in the asset register but these may vary from small reciprocating compressors used to maintain pressure in a gas shutdown system to larger units used for grit removal. To enable accurate information to be provided it is essential that the type of asset is clearly defined. This information is recorded on the FPE tool as part of the Asset description. Note that it is likely at this stage that sub divisions of the assets shown in the asset register will be required, depending on asset attributes and operating context.

Step 2 – Define the maximum asset life

Determine the maximum expected life of the asset. This is considered in the context of a population of assets and the longest an asset of this type has lasted for or could last for. At this stage the operating context agreed in step 1 is a key consideration. For example an asset in a duty standby arrangement may only operate for 50% of the time, but its failure pattern in terms of calendar age, can be based on this duty.

Step 3 – Define the failure modes

Determine the most probable failure modes that will cause the asset to fail and require the asset to be renewed or refurbished to an as good as new condition. This is where the components of the failure pattern, namely infant, random and wear out failures are considered. The following structured questioning using the first 4 of 7 steps in a Failure Modes, Effects and Criticality Analysis (FMECA) or Reliability Centred Maintenance (RCM) assessment are used to ensure a consistent approach to this key step:

1. What are the functions and performance standards?
2. In what ways does it fail to fulfil its functions?
3. What causes a functional failure?
4. What happens when each failure occurs?

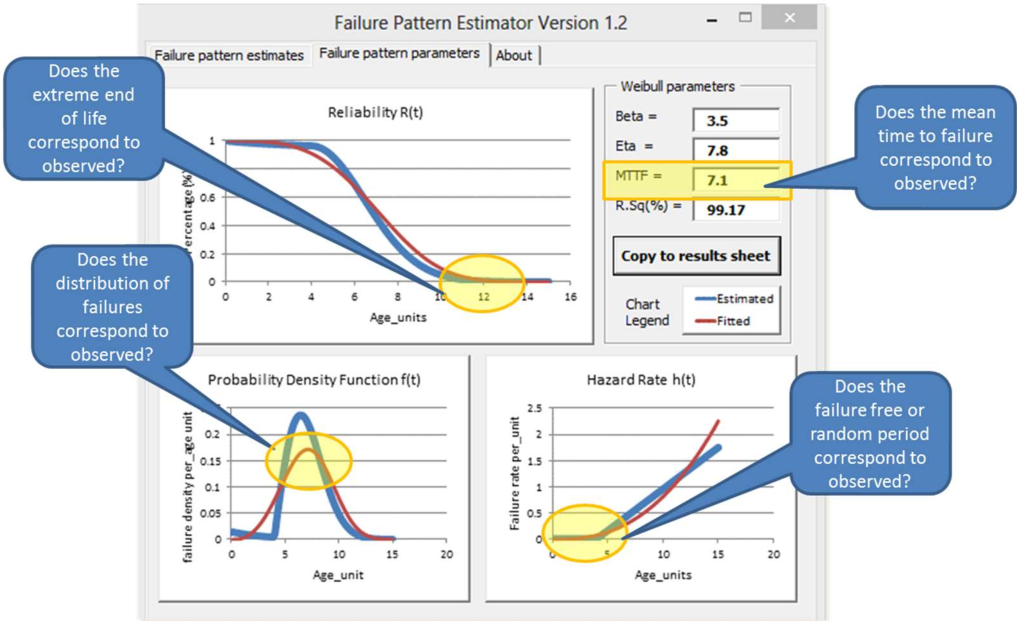
Note that wear out can be taken to include the effects of obsolescence where the cost of repair or refurbishment due to the availability of parts or unacceptable lead times may result in an economic decision to replace that asset. The end of OEM support for an asset is not considered as a failure mode but as an age related factor which can affect the outcome of failure, considered in point 4 above.

Step 4 – Describe the failure pattern

Estimate the approximate ages at which the individual failure modes occur along with relative proportions of each. The approach used during the workshops, was to find references to actual asset failures, replacements or refurbishments and use these as the basis of the estimates.

Step 5 – Verify the outputs

Once the Weibull parameters have been calculated from the information provided the outputs of the resulting parametric distribution need to be verified. The figure below shows the outputs from the FPE tool, which are used as part of the verification process. The thick blue line shows the composite failure pattern as described by the information provided at the workshop and the thin red line the fitted Weibull distribution. The information and questions used as part of the verification process are as show.



Step 6 - Internally cross validation

A number of the assets were assessed separately by different groups, this enabled a cross validation of the information provided on asset deterioration across the company. The resultant models were either combined or where there were significant differences in modelled deterioration rates an investigation to identify the causes was undertaken. If these were found to be due to operating context, asset sizes etc. then the models were sub divided as per step 1. If not the models were reviewed with the benefit of the additional information and any required corrections made to the input information.

Tri-company Benchmarking

After the development of the models Wessex Water participated in a benchmarking exercise with two other water companies which had used Weibull distributions to model asset deterioration for similar types of assets at approximately the equivalent levels in the asset hierarchy.

An independent third party was used to collate the model parameters and assign each model to a common asset classification system which enabled the deterioration models to be compared. Each company then reviewed the reclassification of their assets to ensure the database was correct. From this a standard set of Weibull model parameters was compiled to create a tri-company wide database for asset deterioration which could be used as a benchmark to provide evidence of the reasonableness of each company's individual models. The database provided maximums, minimums and averages for Weibull scale and shape parameters along with standard deviations. Some additional analytics were also included to enable more detailed comparisons to be made such as operating contexts and failure outcomes classified as refurbish or replacement.

Participation in this benchmarking exercise has enabled Wessex Water to confirm its models were in the expected ranges for asset deterioration or where further analysis was required either to confirm the reasons for the differences or where further information was required to improve on the models. In this way confidence in each individual model has been assured.