Developing a Bayesian network model for understanding river catchment resilience under future change scenarios

Supplementary Material

Kerr J. Adams[1, 2], Christopher (Kit) A. J. Macleod[2], Marc J. Metzger[1], Nicola Melville[3], Rachel C. Helliwell[2], Jim Pritchard[3], Miriam Glendell[2]

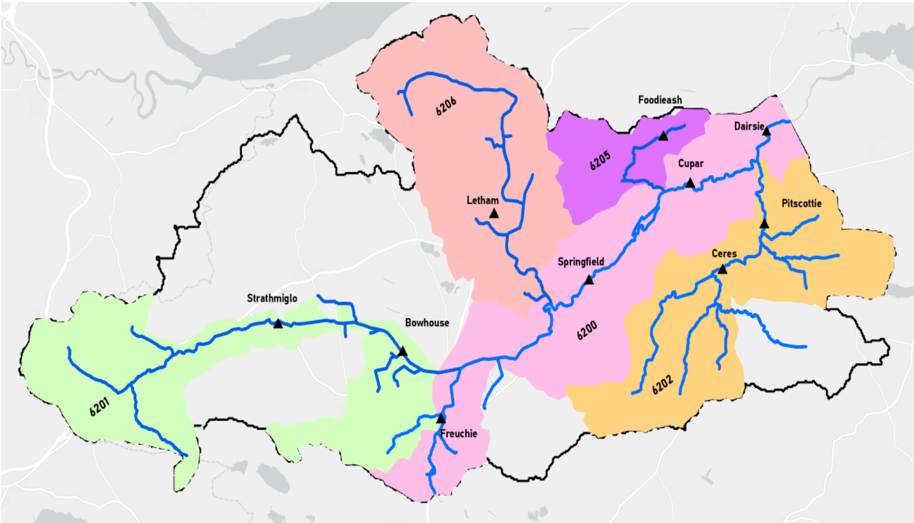
[1]University of Edinburgh, School of Geoscience, Edinburgh, Scotland,

[2]Scottish Environment Protection Agency, Strathallan House, Stirling, Scotland,

[3]The James Hutton Institute, Craigiebuckler, Aberdeen, Scotland

Correspondence to: Kerr J. Adams (kerr.adams@ed.ac.uk)

S1: River Eden waterbody sub-catchments



Key	
(blue line)	Waterbody
▲	Wastewater treatment works
(light pink)	Waterbody sub-catchment 6200
(light green)	Waterbody sub-catchment 6201
(orange)	Waterbody sub-catchment 6202
(purple)	Waterbody sub-catchment 6205
(red)	Waterbody sub-catchment 6206

Figure S1: Eden catchment sub-catchment selected by stakeholders to be included in the Bayesian network model. *Acknowledgements: Catchment boundary provided by National River Flow Archive. River network provided by the EU-Hydro River Network Database (Gallaun et al., 2019) Map created in ArcGISPro (Esri Inc, 2021).*

S2: Participating stakeholders

Table S1: Stakeholder participant code and descriptions

<table>
<tr><th>Stakeholder Code</th><th>Code Description</th><th>Wastewater (WW) Focus Group Participants</th><th>Land Management (LM) Focus Group Participants</th><th>Water Resource (WR) Focus Group Participants</th><th>Workshop 1 Participants</th><th>Workshop 2 Participants</th></tr>
<tr><td>WW</td><td>Stakeholders with knowledge of the wastewater system in the Eden catchment</td><td>WW1</td><td>EP1</td><td>WR1</td><td>WW1[a]</td><td>WW1[a]</td></tr>
<tr><td>LM</td><td>Stakeholders with knowledge of the land management system in the Eden catchment</td><td rowspan="7">WW2</td><td>CM1</td><td>WR2</td><td>WW2[a]</td><td>WW2[a]</td></tr>
<tr><td>WR</td><td>Stakeholders with knowledge of the water resource system in the Eden catchment</td><td>LM1</td><td rowspan="6">WR3</td><td>EP1[a]</td><td>EP2[b]</td></tr>
<tr><td>EP</td><td>Stakeholders with a knowledge of environmental protection (EP)</td><td>LM2</td><td>EP2[b]</td><td>CM2[b]</td></tr>
<tr><td>CM</td><td>Stakeholders with a knowledge of catchment management (CM) and systems</td><td>LM3</td><td>CM1[a]</td><td>LM7[b]</td></tr>
<tr><td>a</td><td>Stakeholders who participated in focus groups</td><td>LM4</td><td>LM6[b]</td><td>LM8[b]</td></tr>
<tr><td rowspan="2">b</td><td rowspan="2">Stakeholders who didn’t participate in focus groups</td><td rowspan="2">LM5</td><td>LM7[b]</td><td rowspan="2">WR4[b]</td></tr>
<tr><td>WR4[b]</td></tr>
</table>

S3: Model description and parameter values

Table S2: Model description.

Node Name	Identifier	Type	Equation	States & Discretisation if applicable.	Supporting Information
Future Change sub-model					
Scenario	i	Deterministic	--	Green Road (GR) Business As Usual (BAU) Fossil Fuelled Development (FFD) Current	Deterministic input node for model simulation under a range of plausible scenario pathways. State identifiers are taken from (O'Neill et al., 2017) and stakeholder interpretations to represent the diverse pathways.
Precipitation Change	j	Deterministic	--	Extreme Low Rainfall (ExLR) Annual Extreme High Rainfall (ExHIR)	Deterministic input node for executing BAU precipitation change, and precipitation change for extreme low (Q5) and high (Q95) precipitation change.
Climate Precipitation Choice	CPC	Deterministic	--	Green Road & ExLR Green Road & BAU Green Road & ExHIR BAU & ExLR BAU & BAU BAU & ExHIR FFD & ExLR FFD & BAU FFD & ExHIR Current & ExLR Current & BAU Current & ExHIR	Deterministic node that combines Precipitation Anomaly with the Simulation node to enable the selection of precipitation anomaly scenarios under the different diverse future pathway scenarios.
Precipitation Change Anomaly (%)	PA	Equation	$PA = \beta_{ij}$	State / From / To ExLR / 0 / 0.75 Annual / 0.75 / 1.1 ExHIR / 1.1 / 2.5	Equation node that selects the precipitation change anomaly distribution β for each future simulation i and precipitation change simulation j. Values for β are derived from the UK Climate Projection User Interface product Anomalies for probabilistic projections (25km) over UK, 1961-2100 (Lowe et al., 2018). Anomalies take the coupled RCP distributions for i and j. Annual temporal averages are used for Annual state to represent the incremental predicted change. To represent shocks to the system, Q95 values for seasonal winter to represent a extreme high precipitation scenario (ExHP) and the summer Q5 value is applied for extreme low precipitation scenario (ExLP) as these represent the most extreme possible changes. The data is selected for the 1981-2010 baseline period, in grid cell 337500.00, 712500.00, during the time slice 2040-2069 (2050's) using all sampling methods.
Population Change	PC	Deterministic	--	GR BAU FFD Current	Deterministic node that sets acquires a population equivalent change values i. Values for derived from the Scottish Water Population Growth Model. The Growth Model provides Real and Raw estimations of Population Equivalents (PE) to the year 2030. For the Green Road scenario (GR), the lower Real PE estimate for 2030 remains consistent for 2050 to reflect as shared-socioeconomic pathway (SSP) narrative which suggests population growth will stagnate in urban areas and migration to more rural areas will increase. For the Business As Usual (BAU) the Real PE trend for 2030 is extrapolated to 2050. For the Fossil Fuelled Development scenario (FFD), the Raw PE value for 2030 is extrapolated to 2050 as RAW PE provides an upper estimate of population growth, particularly in urban areas, which is reflected in the SSP narrative for FFD. Narratives are derived from Pedde, et al., (2021).

Land Cover Change	LCC	Deterministic	--	GR BAU FFD Current	Deterministic variable that sets land cover change values for *i*. Current and project future value are derived from UKCEH land cover vector maps (Morton et al., 2020). Extrapolations of historical land cover change, interpretations from the SSP narratives (Pedde, at al., 2021) and catchment specific knowledge provided by stakeholders were used to create projections for different land cover areas.
Wastewater sub-model					
Dry Weather Flow (Ml/d)	DWf	Equation	$DWf_{ik} = \beta_k + PC_{ik} \times \gamma_k$	State / From / To Resilient / 0 / c L / c / b_l M / b_l / u H / u / inf	Stakeholders highlighted the Dry Weather Flow, *DWf*, at wastewater treatment works (WwTWs), *k,* in the catchment as an important variable that represents the wastewater system. Stakeholders highlighted that changes in PC_{ik} under simulations *i* could influence *DWf* at works *k*. The distribution β represents a truncated distribution of the current *DWf* at WwTW, *k*, derived from effluent flow summary statistics provided in the Scottish Water Strategic Study. We simulated effluent flows using the summary statistics to generate 365 data outputs, then calculated a Q80 value of the outputs, which was highlighted by stakeholders as the values used to derive asset dry weather flow values. We use the Q80 values as the mean and the standard deviations of the values to derive β_k. PC_{ik} is multiplied by γ_k which is the 1 PE value of 200 litres per day wastewater sewage flow contribution (Mara, 2006) fwhich is converted to Ml/d and added to β_k. The 200 litres per day standard was confirmed by participants during model development focus groups. Resilient states threshold *c* is the *DWf* licence condition for *k*. Anything three times greater than the licence condition value is set as the threshold value for high risk (H) *u*. Thresholds for states low (L) and moderate (M) risk, b_l uniformised between *c* and *u* Ml/d.
Daily Effluent Flow (Ml/d)	Ef	Equation	$Ef_{ik} = \beta_k \times PA_{ij} + PC_{ik} \times \gamma_k$	‘’	Stakeholders highlighted that the flow of effluent discharge *Ef* at WwTWs *k* as a significant wastewater system variable. Changes in PA_{ij} and PC_{ik} under different simulations *i* were identified as potentially influencing Ef_{ik}. To measure potential impacts on Ef_{ik} we derived the distribution β_k to represent the current *Ef* distribution for *k*, derived from the Scottish Water Strategic Study. We multiply current *Ef* distributions with the % anomaly change in PA_{ij} which is assumed to lead to a change in run-off and infiltration which currently influence *Ef*. PC_{ik} is multiplied by the 1 PE value of 200 litres per day waste sewage flow γ_k and added to β_k to represent the influence of changes in PC_{ik} on *Ef*. Discretisation of states is based on the >3 *DWf* (*3DWf)* licence condition at setting for storm overflow detailed in the SEPA Supporting Guidance (WAT-SG-13) document which is a standard threshold set for calculating the Flow to Full Treatment (FFT) limit for WwTWs. The FFT for values for each WwTW *k* is described as anything three times greater than DWF leads to the risk of the sewer overflow. The resilient threshold *c* is therefore set as three times the *DWf* at treatment works *k*. The high risk threshold *u* is set at six times the DWF. Thresholds for states low (L) and moderate (M) risk, b_l are uniformised between *c* and *u* Ml/d.
Daily Influent Flow (Ml/d)	If	Equation	$If_{ik} = Ef_{ik} \times \gamma_k$	‘’	The change in influent flow *If* was also highlighted as being influence by PA_{ij} and PC_{ik} by stakeholders. We use an equation node representing the change in influent flow *If* based on the change in *Ef* using the value

<table>
<tr><td></td><td></td><td></td><td></td><td colspan="3"></td><td>γ_k to represent the difference between If and Ef. The value γ_k is used due to the limited If data available in the catchment. The only WwTW in the catchment with If data available was Cupar, where a reduction in flow volume after the treatment process was evident in the annual flow returns data from 2015 – 2019 provided by Scottish Water when comparing influent and effluent flows. We calculated the difference between influent and effluent flows using annual flow returns data to derive γ_k which is applied to each WwTWs k. The If node is discretised using the same methods as Ef.</td></tr>
<tr><td rowspan="5">Spill Event</td><td rowspan="5">SP</td><td rowspan="5">Equation</td><td rowspan="5">$SE_{is} = IF_{eq}(If_{ik})$</td><td>State</td><td>From</td><td>To</td><td rowspan="5">Stakeholders highlight that risk of spill events SE under different simulations i could occur due to changes in If_{ik} in waterbody sub catchments s. Spills (SP_{is}) occur if the node If_{ik} exceeds its c resilience threshold. We use statement equations IF_{eq} to index the prior distributions of parent node If_{ik} based on their discretised state thresholds. Each prior state discrete threshold for If_{ik} resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For SP_{is} the sum of If_{ik} of prior If_{ik} values is as follows: $IF(If_{ik} \geq u, 3, IF(If_{ik} \geq b, 2, IF(If_{ik} \geq c, 1,0)$. We set the resilience threshold c for SP_{is} as a value for one, as anything greater than the value of one would mean at least one treatment works k is likely to spill. The upper value u set as the maximum possible index value of all nodes (3 times the number of parent nodes). Threshold values for high and moderate risk, b_1 and b_2 are uniformised values between c and u.</td></tr>
<tr><td>Resilient</td><td>0</td><td>c</td></tr>
<tr><td>L</td><td>c</td><td>b_1</td></tr>
<tr><td>M</td><td>b_1</td><td>b_2</td></tr>
<tr><td>H</td><td>b_2</td><td>u</td></tr>
<tr><td rowspan="5">Wastewater Phosphorus Load (kg/d)</td><td rowspan="5">P</td><td rowspan="5">Equation</td><td rowspan="5">$P_{ik} = (\beta_k \times (1 + 1 - PA_{ij}) + PC_{ik} \times \gamma_k) \times Ef_{ik}$</td><td>State</td><td>From</td><td>To</td><td rowspan="5">Equation node representing the change in Reactive Phosphorus (P) based on the inverse change in PA_{ij}, change in PC_i and change in Ef.. The current concentration of P is represented using the distribution β for each of the different WwTW k. Current effluent P concentration (mg/l) are taken from the Scottish Water Eden Water Quality Strategic Study. The inverse of PA_{ij} is applied to represent the change in P concentration due to the change in dilution. Lower flows lead to higher concentrations of P, meaning when PA_{ij} decreases the P concentration increases. PC_{ik} is multiplied by the calculated P concentration (mg/l) per PE γ, based on the current PE for WwTW k. The P concentration is multiplied by Ef to provide the daily effluent P load (kg/d). The node is discretised using the current mean P load for each k as the resilient threshold, which is calculated by multiplying the current P concentration by the current Ef. Anything greater than the current P load is seen as an increased risk, as higher loads demonstrate poor outcomes for both the environment and wastewater system. The high risk (H) value u is calculated as 3 times the c. The values for L and M risk are then uniformised between c and u (kg/d).</td></tr>
<tr><td>Resilient</td><td>0</td><td>c</td></tr>
<tr><td>L</td><td>c</td><td>b</td></tr>
<tr><td>M</td><td>b</td><td>u</td></tr>
<tr><td>H</td><td>u</td><td>inf</td></tr>
<tr><td>Bio Resource (m^3/d)</td><td>BR</td><td>Equation</td><td>$BR_{ik} = If_{ik} \times \gamma_k \times 1000$</td><td colspan="3">‘’</td><td>Volumes of Bio resource BR (m^3/d) was identified as a significant wastewater system node. Changes in BR due to the influence was simulations i is measured based on a change in If. Su et al. (2019) highlight that an increase in If_{ik} can lead to an increase in bio resource concentrations and accumulations. The relationship between If and BR volume is derived by analysing the relationship between flows and sludge volumes at WwTW in the catchment to create an average BR_k volume (m^3/d) per If_k (Ml/d) to provide a (m^3/l/d) value o for each k which is represented by γ_k. The γ_k value is multiplied by If_{ik}, then multiplied by 1000 to convert the value to (m^3/d). The BR_{ik} node is discretised by setting the resilient threshold c as the current volume of BR_k. The high risk threshold is set as three times the current c value. Thresholds for states low (L) and moderate (M) risk, b_1 are uniformised between c and u m^3/d.</td></tr>
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<table>
<tr>
<td>Total Phosphorus Load (kg/d)</td>
<td>TPL</td>
<td>Equation</td>
<td>$TPL_{is} = \sum P_{ik} + IF(If_{ik} \geq c, 1.05, 0)$</td>
<td>‘’</td>
<td>Equation node representing the relationship between overflow spills and P_{ik} loads. As the concentration of P is higher for untreated spill events, the P_{ik} load in the event the If exceeds the 3DWf threshold is added to the effluent P load to generate the Total Phosphorus Load (TPL) of WwTWs k in water body sub-catchment s. The Scottish Water Eden Water Quality Strategic Study sets a suitable concentration of 1.05 mg/l of P for spill events, which is multiplied by the spill volume. The discretisation of the TPL_{is} sets the resilient c value as the current TPL for each water body sub catchment s which is derived from the Scottish Water Eden Water Quality Strategic Study, the high risk u value is set as three times the c value. The values for L and M risk are then uniformised between c and u (kg/d).</td>
</tr>
<tr>
<td>Energy Demand Wastewater</td>
<td>EDW</td>
<td>Equation</td>
<td>$EDW_{iks} = \sum IF_{eq}(BR_{ik})$</td>
<td><table>
<tr><td>State</td><td>From</td><td>To</td></tr>
<tr><td>Resilient</td><td>0</td><td>c</td></tr>
<tr><td>L</td><td>c</td><td>b_1</td></tr>
<tr><td>M</td><td>b_1</td><td>b_2</td></tr>
<tr><td>H</td><td>b_2</td><td>u</td></tr>
</table></td>
<td>As energy demands within the wastewater system EDW were highlighted by stakeholders as a manufactured capital resource we measured the potential change in energy demand EDW under the influence of differing simulation i at wastewater treatment works k in waterbody sub catchment s. As the Bio Resource is the final node described by stakeholders in the wastewater system, which is a measure of both flows and accumulations of bio resource materials that require treatment and transportation, we assume any change in bio-resource volumes (m^3/day) under simulation i at wastewater treatment works k BR_{ik} leads to a change in EDW_{ik}. We measure ΔEDW_{ik} using IF statement equations IF_{eq} to index the prior distributions of parent node BR_{ik} based on their discretised state thresholds. Each prior state discrete threshold for BR_{ik}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For EDW_{ik} the IF_{eq} of prior BR_{ik} values is as follows: $IF(BR_{ik} \geq b_2, 3, IF(BR_{ik} \geq b_1, 2, IF(BR_{ik} \geq c, 1, 0)$.
For the indexed node ΔEDW_{ik} the resilient threshold c is set at 25% of the total nodes included in the equation. The 25% value is selected as it ensures that for a capital resource to be resilient, the majority of parent nodes (at least 75%) must fall within a resilient index threshold value. The upper value u set as the maximum possible index value of all nodes (three times the number of parent nodes). Threshold values for high and moderate risk, b_1 and b_2 are uniformised values between c and u.</td>
</tr>
<tr>
<td>Chemical Demand Wastewater</td>
<td>CDW</td>
<td>Equation</td>
<td>$CDW_{is} = IF_{eq}(TPL_{is})$</td>
<td>“</td>
<td>As chemical demands within the wastewater system CDW were highlighted by stakeholders as a manufactured capital resource we measured the potential change in chemical demand CDW under the influence of differing simulation i in waterbody sub catchment s. As there was no data available to measure the current chemical demands at wastewater treatment works we assume that a change in total P loads at under different simulation i in in waterbody sub catchment s TPL_{is} leads to a change in CDW_{is}. We measure CDW_{is} using IF statement equations IF_{eq} to index the prior distributions of parent nodeTPL_{is} based on their discretised state thresholds. Each prior state discrete threshold for TPL_{is} , resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For EDW_{ik} the IF_{eq} of prior TPL_{is} values is as follows: $IF(TPL_{is} \geq b_2, 3, IF(TPL_{is} \geq b_1, 2, IF(TPL_{is} \geq c, 1, 0)$.
For the indexed node ΔCDW_{is} we applied the same discretisation method as EDW_{ik}.</td>
</tr>
<tr>
<td>Asset Compliance and Capability Wastewater</td>
<td>ACW</td>
<td>Equation</td>
<td>$ACW_{is} = \sum IF_{eq}(DWF_{ik}, SP_{is})$</td>
<td>“</td>
<td>The compliance and capability of manufactured assets in the wastewater system ACW was seen as an important manufactured capital resource due to the role of assets in providing wastewater services and meeting</td>
</tr>
</table>

					licence and environmental standards. Stakeholders highlighted that the influence of future simulations i could influence ACW in waterbody sub catchments s in the future. We measure the current and future ability of ACW_{is}, using nodes DWF_{ik} and SP_{is} to determine if assets exceed their DWF licence condition and if they are capable of handling extreme flow events. We calculate ACW_{is} using IF statement equations IF_{eq} to index the prior distributions of parent node DWF_{ik} and SP_{is} based on their discretised state thresholds. Each prior state discrete threshold for both DWF_{ik} and SP_{is}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of *c, u, and b*. For ACW_{is} the sum of IF_{eq} of prior DWF_{ik} and SP_{is} values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$. For the indexed node ACW_{is} we applied the same discretisation method as EDW_{ik}.
Land Management sub-model					
Land Cover (Ha)	LC	Equation	$LC_{ivs} = A_{ivs}$	See Supporting Information	Equation node the represents land cover area A (Ha) for each simulation i were applied to land cover categories v in waterbody sub-catchments s. Changes in Land Cover was highlighted by stakeholders as a factor for future change that would influence future water and chemical demands which would influence water availability and quality. UKCEH land cover vector maps 1990, 2007 and 2019 (Morton et al., 2020) were used to analyse historic land cover change in the catchment. Extrapolations of land cover change, interpretations from both the SSP narratives and catchment specific knowledge provided by stakeholders were used to create projections for different land cover areas A for simulations i. Current conditions for land cover categories v are represented using the 2019 UKCEH land cover vector map data for the catchment. Land cover percentage proportions of v in sub-catchment water bodes s are taken from the Scottish Water Strategic Study to derive the area A of land cover categories v in each sub-catchment s. The BAU narrative continues catchment land cover change trends from the previous 30 years. BAU trends include increased in arable, urban, woodland and semi-natural land covers, while improved grasslands and coniferous land cover area decreases. The GR narrative assumes a more intensive move from improved grassland land cover to woodland and semi-natural grasslands. For GR assumes an increase in arable land due to the nature of the catchment being prime agricultural land. Urban land cover is reduced in the GR narrative as populations move to more rural areas of the catchment. The FFD narrative assumes a more intensive move from to arable and improved grassland land cover. In the FFD narrative to woodland and semi-natural grassland cover decline. Urban land cover increases in the FFD narrative due to population increases in urban areas of the catchment. States and their discretisation were set based on the land cover value for the different simulations i, for different land cover types v in waterbody sub catchments s.
Septic Tanks	ST	Equation	$ST_{is} = T_{is}$	See Supporting Information	The number of septic tanks T for simulation i in waterbody sub-catchments s. Stakeholders identified that septic tanks influence water quality in the catchment. The current number if septic tanks T in water-body sub-catchment s was taken from the Eden Water Quality Strategic Study. The BAU narrative assumes that the number of septic tanks in the catchment will remain the same. A 20% increase in septic tanks is assumed for the GR narrative as more people move to rural areas. For the FFD narrative a 20% decrease

					in septic tank numbers T is assumed due to population intensification in urban areas. States and their discretisation were set based on the number of septic tanks for the different simulations *i*, in waterbody sub catchments *s*.
Land Cover Phosphorus Applications(kg/d)	PD	Equation	$PD_{ivs} = LC_{ivs} \times \gamma_{vs}$	State / From / To Resilient / 0 / *c* L / c / b_1 M / b_1 / u H / u / *inf*	The application demand of P, *PD*, to agricultural land (kg/d) under varying simulations *i* for land cover type *v* in water body sub-catchment *s* was highlighted as an important land management system component. The demand for P is influenced by the proportion of different land cover categories LC_{ivs} and their associated P demands per Ha, which is represented as a coefficient γ_{vs} for different land covers *v* in water body sub catchments *s*. Current P (kg/d) loadings taken from a ADAS UK Ltd model of rural diffuse pollution provided by SEPA. P loadings per Ha of each land cover type *v* in water body sub-catchment *s* are calculated to quantify coefficients for γ_{vs}. The discretisation of PD_{ivs} sets the resilient *c* value as the current P loadings for each land cover type in each water body sub catchment *s* which, the high risk *u* value is set as two times the *c* value. Thresholds for states low (L) and moderate (M) risk, b_1 are uniformised between *c* and *u* (kg/d).
Septic Tank Phosphorus (kg/day)	STP	Equation	$STP_{is} = ST_{is} \times \gamma_{is}$		The volume of P from Septic Tanks, *STP*, (kg/d) under varying simulations *i* was highlighted as an important land management system node. Current P (kg/d) loadings from septic tanks are taken from a ADAS UK Ltd model of rural diffuse pollution provided by SEPA. P loadings per *ST* in water body sub-catchment *s* are calculated to quantify coefficients for γ_{vs}. STP_{is} is calculated by multiplying ST_{is} by γ_{is}. The discretisation of STP_{is} sets the resilient *c* value as the current P loadings for STP_{is}, the high risk *u* value is set as two times the *c* value. Thresholds for states low (L) and moderate (M) risk, b_1 are uniformised between *c* and *u* (kg/d).
Diffuse Phosphorus (kg/d)	DP	Equation	$DP_{ivs} = (PD_{ivs} + STP_{is}) \times PA_{ij}$	‘’	Stakeholders highlighted that the applications of sources PD_{ivs} (kg/d) are a diffuse source of surface water quality issues in the catchment. The volume of diffuse PD_{ivs} sources are likely to be influenced by changes in PA_{ij}, with increases in high intensity rainfall likely to increase the proportion of PD_{ivs} to surface waters (Heathwaite, et al., 2004), which is represented in the equation. The discretisation of PD_{ivs} sets the resilient c value as the current diffuse P loadings for in each water body sub catchment *s* which are provided in the Scottish Water Eden Water Quality Strategic Study, the high risk u value is set as three times the c value. Thresholds for states low (L) and moderate (M) risk, b_1 are uniformised between *c* and *u* (kg/d).
Irrigation Demand (ML/year)	ID	Equation	$ID_{is} = \beta_s \times \Delta LC_{ivs} \times (1 + 1 - PA_{ij})$	‘’	Stakeholders highlighted irrigation demand, *ID*, in the catchment could be influenced by changes in land cover and climate. The node focuses on surface water abstractions as stakeholder's highlighted increases in ID could impact future surface water flows. Current *ID* in each waterbody sub catchment, *s*, is represented as a truncated normal distribution β_s, where mean and standard deviation values are quantified by analysing annual irrigation abstraction licence return data (Ml/year) from 2008-2019 provided by SEPA. To quantify the potential change in ID_{is} the equation node multiplies the current *ID* β_s with the % change in LC_{ivs}, ΔLC_{ivs}, to represent the change in irrigation demand from the change in arable cover which is the main source of irrigation demand the catchment. β_s, is also multiplied by the inverse of PA_{ij} to represent the potential change in ID_{is} due to a reduction of PA_{ij} increasing demand and increases in PA_{ij} increasing demand. The discretisation of ID_{is} sets the resilient *c* value as 50% of the sum of all licence volumes

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>(ML/year) in each waterbody sub catchment s. The high risk value u is set as the total licence volume (ML/day) in each waterbody sub catchment s. The values for L and M risk, b_1, are then uniformised between c and u (ML/day).</td></tr>
<tr><td>Groundwater Nitrate (mg/L)</td><td>GN</td><td>Equation</td><td>$GN_{is} = \beta_s + (\Delta LC_{ivs} \times \gamma_{vs}) \times PA_{ij}$</td><td>‘’</td><td>Stakeholders highlighted that groundwater nitrate concentrations (mg/l), GN, was an important node in the catchment system due to its influences drinking water quality, particularly as the catchment falls within a Nitrate Vulnerable Zone (NVZ). The influence of land cover change and precipitation change were identified as important nodes that could influence drinking water groundwater sources in the future (Smart et al., 2011). Current GN concertation in water bodies sub catchments s which include drinking water boreholes are represented as a truncated normal distribution β_s, where mean and standard deviation values are quantified by analysing groundwater nitrate samples (mg/l) from 2008-2019 provided by SEPA. To quantify the potential change in GN_s the equation node adds the a change in GN concentration to β_s by multiplying the sum of change in ΔLC_{ivs} (Ha) with N loadings per Ha of each land cover type v in water body sub-catchment s calculated to quantify coefficients for γ_{vs}. β_s, is also multiplied by PA_{ij} to represent the potential change in GN_s due to an increase of PA_{ij} increasing Nitrate leaching rates to groundwater, particularly during higher intensity rainfall events. The discretisation of GN_{is} sets the resilient c value as 50% of the mean threshold values indicative of risks to the quality of water being abstracted, or intended to be abstracted, for human consumption (mg/l) (Scottish Government, 2015) . The high risk value u is set as the mean threshold value of 37.5 mg/l. The values for L and M risk, b_1, are then uniformised between c and u (mg/l).</td></tr>
<tr><td>Energy Demand Land Management</td><td>EDLM</td><td>Equation</td><td>$EDLM_{is} = IF_{eq}(ID_{is})$</td><td><table><tr><td>State</td><td>From</td><td>To</td></tr><tr><td>Resilient</td><td>0</td><td>c</td></tr><tr><td>L</td><td>c</td><td>b_1</td></tr><tr><td>M</td><td>b_1</td><td>b_2</td></tr><tr><td>H</td><td>b_2</td><td>u</td></tr></table></td><td>As energy demands within the land management system EDLM were highlighted by stakeholders as a manufactured capital resource we measured the potential change in energy demand EDLM under the influence of differing simulation i in waterbody sub catchment s. Stakeholder identified the irrigation activities as a key source of energy use in the land management system. As there was no data available to measure current energy use from irrigation abstraction, we use the node ID_{is} as a measure of the potential direction of change in $EDLM_{is}$. We calculate $EDLM_{is}$ using IF statement equations IF_{eq} to index the prior distributions of parent node ID_{is} based on their discretised state thresholds. Each prior state discrete threshold for ID_{is}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For $\Delta EDLM_{is}$ the IF_{eq} of prior ID_{is} values is as follows: $IF(ID_{is} \geq b_2, 3, IF(ID_{is} \geq b_1, 2, IF(ID_{is} \geq c, 1,0)$.
For the indexed node $EDLM_{is}$ the resilient threshold c is set at 25% of the total nodes included in the equation. The 25% value is selected as it ensures that for a capital resource to be resilient, the majority of parent nodes (at least 75%) must fall within a resilient index threshold value. The upper value u set as the maximum possible index value of all nodes (3 times the number of parent nodes). Threshold values for high and moderate risk, b_1 and b_2 are uniformised values between c and u.</td></tr>
<tr><td>Chemical Demand Land Management</td><td>CDLM</td><td>Equation</td><td>$CDLM_{is} = IF_{eq}(PD_{ivs})$</td><td>‘’</td><td>As chemical demands within the land management system CDLM were highlighted by stakeholders as a manufactured capital resource we measured the potential change in chemical demand CDLM under the influence of differing simulation i in waterbody sub catchment s. Stakeholder identified the phosphorus applications as a key source of chemical use in the land management system. As there was no data available to measure current chemical use from P applications for land</td></tr>
</table>

					cover types v, we use the node PD_{ivs} for land cover types arable and pasture as a measure of the potential direction of change in $CDLM_{is}$. We calculate $EDLM_{is}$ using IF statement equations IF_{eq} to index the prior distributions of parent node PD_{ivs} based on their discretised state thresholds. Each prior state discrete threshold for PD_{ivs} resilient to high-risk, was assigned a value of zero, one, two or three based on the values of *c, u, and b.* For $CDLM_{is}$ the sum of $\sum_{vs}^{i} IF_{eq}$ of prior PD_{ivs} values for land cover types arable and pasture is as follows: $IF(PD_{ivs} \geq b_2, 3, IF(PD_{ivs} \geq b_1, 2, IF(PD_{ivs} \geq c, 1, 0)$. For the indexed node $CDLM_{is}$ the resilient threshold *c* is set at 25% of the total nodes included in the equation. The 25% value is selected as it ensures that for a capital resource to be resilient, the majority of parent nodes (at least 75%) must fall within a resilient index threshold value. The upper value *u* set as the maximum possible index value of all nodes (3 times the number of parent nodes). Threshold values for high and moderate risk, b_1 and b_2 are uniformised values between *c* and *u*.
Water Resource sub-model					
Public Commercial Demand	PCD	Deterministic	--	GR BAU FFD Current	Deterministic node used to enable varying values for public commercial water resource demand. Stakeholders highlight that the demand for water resource by commercial business could change in the catchment under the varying future pathway simulations *i*. The water utility business, Scottish Water will have to account for potential changes in commercial demand.
Leakage	L	Deterministic	--	GR BAU FFD Current	Deterministic node used to enable varying values for leakage in from assets as part of the water resource delivery system. Stakeholders highlight that leakage rates could change in the future due to aging assets and the influence of high intensity rainfall under the varying future pathway simulations *i*. The water utility business, Scottish Water will have to account for potential changes in leakage rates.
Water Resource Abstraction Demand (Ml/d)	WA	Equation	$WA_{it} = (\beta_t + (PC_{it} \times \gamma)) \times PCD_{it} \times L_{it}$	State / From / To Resilient / 0 / c L / c / b_1 M / b_1 / u H / u / *inf*	Stakeholders highlighted that the demand for drinking water and water resource services *WA* is likely to change in the future due to changes in population served in the catchment *PC,* the demand by commercial business *PCD* and leakage from assets *L*. The current demand for water resources (ML/day) β_t is derived by analysing annual abstraction data for all Scottish Water boreholes in the catchment from 2014-2018 provided by SEPA and Scottish Water. The change in *PC* under simulation *i* for the entire catchment *t* is multiplied by the coefficient γ which represents the normal consumption rate of 165 l/d per person per day identified by Scottish Water to represent the influence of PC on WA for the entire catchment *t*. The β_t distribution is also multiplied by a % change in PCD_{it} and L_{it}. As there is limited data to represent changes in PCD_{it} and L_{it}, therefore % change values for different simulations *i* are used to represent a direction of change associated with interpretations of SSP narratives. A % reduction in demand and leakage is assumed for the GR simulation due to the associated increased efficient use of water described in the narrative. For the BAU and FFD narrative a % increase values are assumed, with a greater % increase value for the FFD simulation. The resilient threshold value *c* is set at 75% of the nominal borehole capacity (Ml/day) of all boreholes in the catchment and the high risk threshold values *u* is set at 95% of the nominal borehole capacity. The values for L and M risk, b_1, are then uniformised between *c* and *u* (ML/day).

Water Resource Supply Capacity (Ml/day)	SC	Equation	$SC_{it} = \beta_a \times AC_{it} \times IF(GN_{is} \geq u, 0, 1)$	State	From	To	Stakeholder identified that the supply capacity (Ml/day) of water resources was a significant component of the catchment system, which could be influenced by groundwater nitrate concentrations GN_{is} (mg/) and changes in the age and condition of assets AC under simulation i. The current borehole capacity β_a (ML/day) is derived by analysing abstraction rate data for all Scottish Water boreholes a in the catchment from 2012-2019 provided by Scottish Water. The β_a is multiplied by AC_{it} to account for the potential impact of future asset conditions. As there was limited data on the conditions of water resource assets in the catchment, a % change value was assigned for AC_{it}. All simulations GR, BAU and FFD assumed a % reduction in capacity due to changes in AC_{it} based on the assumption that as assets age their efficiency decreases. The FFD had a greater % decrease than BAU and BAU has a greater % decrease than GR. Stakeholder highlighted that future GN_{is} concentrations in groundwater was a potential risk as high concentrations would lead to safe drinking water standards being exceeded. An IF statement is used to represent that IF GN_{is} exceeds its high risk value u of 37.5 mg/l then a zero value should be returned as safe drinking water standard would be exceeded. The resilient threshold value c is set at 75% of the nominal borehole capacity (Ml/day) of all boreholes in the catchment and the high risk threshold values u is set at 95% of the nominal borehole capacity. The values for L and M risk, b_1, are then uniformised between c and u (ML/day).
				H	-10	u	
				M	u	b_1	
				L	b_1	c	
				Resilient	c	inf	
Resilience of Eden Supply (Ml/day)	RS	Equation	$RS_{it} = SC_{it} + \beta_{ooc} - WA_{it}$	“			Stakeholders highlight that calculation of future supply and demand would provide the best measure of the resilience of the water resource system supply (Ml/day) RS in simulations i across catchment t. The supply volume is measured by calculating the difference between the supply capacity SC_{it} and the abstraction demand WA_{it}. Stakeholders identified that supply capacity in t is supplemented by a supply source out with the catchment. The volume of water supplied from out of the catchment $RSOC$ is represented by β_{ooc}. A truncated distribution for β_{ooc} was derived using demand for water resources (ML/day) analysing annual abstraction data for the $RSOC$ source from 2014-2018 provided by SEPA and Scottish Water. We use the demand data as a proxy for the supply capacity and is added to SC_{it}. The resilient threshold value c is set at as a positive value where $SC_{it} > WA_{it}$ (Ml/day) and the high risk threshold value u is set at zero where a negative value would suggest $WA_{it} > SC_{it}$ which would lead to a deficit in supply volumes.
Resilience of Outside of Catchment Supply (Ml/day)	RSOC	Equation	$RSOC_{it} = SC_{it} - WA_{it}$	“			Stakeholders highlighted that the abstracted water in the catchment is supplied to populations outside of the catchment boundary $RSOC$. The supply volume is measured by calculating the difference between the supply capacity SC_{it} and the abstraction demand WA_{it}. The outside of catchment supply is not supplemented by any other source and is dependent on the supply from within the Eden catchment. We include $RSOC_{it}$ as a node to measure if there is enough supply capacity SC_{it} (ML/day) to supply populations both inside and outside of the catchment. The resilient threshold value c is set at as a positive value where $SC_{it} > WA_{it}$ (Ml/day) and the high risk threshold value u is set at zero where a negative value would suggest $WA_{it} > SC_{it}$ which would lead to a deficit in supply volumes.
Energy Demand Water Resources	EDWR	Equation	$EDWR_{it} = IF_{eq}(WA_{it})$	State	From	To	As energy demands within the water resource system $EDWR$ were highlighted by stakeholders as a manufactured capital resource we measured the potential change in energy demand $EDWR$ under the influence of differing simulation i across the catchment t. Stakeholder
				Resilient	0	c	

				L	c	b_1	identified the abstraction of drinking water as a key source of energy use in the water resource system. As there was no data available to measure current energy use from drinking water abstraction, we use the node WA_{it} as a measure of the potential direction of change in $EDWR_{it}$. We calculate $EDWR_{it}$ using IF statement equations IF_{eq} to index the prior distributions of parent node WA_{it} based on its discretised state thresholds. Each prior state discrete threshold for WA_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of *c, u, and b.* For $EDWR_{it}$ the IF_{eq} of prior WA_{it} values is as follows: $IF(WA_{it} \geq b_2, 3, IF(WA_{it} \geq b_1, 2, IF(WA_{it} \geq c, 1,0)$. For the indexed node $EDWR_{it}$ the resilient threshold *c* is set at 25% of the total nodes included in the equation. The 25% value is selected as it ensures that for a capital resource to be resilient, the majority of parent nodes (at least 75%) must fall within a resilient index threshold value. The upper value *u* set as the maximum possible index value of all nodes (3 times the number of parent nodes). Threshold values for high and moderate risk, b_1 and b_2 are uniformised values between *c* and *u*.
				M	b_1	b_2	
				H	b_2	u	
Chemical Demand Water Resources	CDWR	Equation	$CDWR_{it} = IF_{eq}(WA_{it})$	‘’			As chemical demands within the water resource system *EDWR* were highlighted by stakeholders as a manufactured capital resource we measured the potential change in chemical demand *CDWR* under the influence of differing simulation *i* across the catchment *t*. Stakeholder identified the treatment of abstracted drinking water as a key source of chemical use in the water resource system. As there was no data available to measure current chemical use from drinking water abstraction, we use the node WA_{it} as a measure of the potential direction of change in $CDWR_{it}$. We calculate $CDWR_{it}$ using IF statement equations IF_{eq} to index the prior distributions of parent node WA_{it} based on its discretised state thresholds. Each prior state discrete threshold for WA_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of *c, u, and b.* For $CDWR_{it}$ the IF_{eq} of prior WA_{it} values is as follows: $IF(WA_{it} \geq b_2, 3, IF(WA_{it} \geq b_1, 2, IF(WA_{it} \geq c, 1,0)$. For the indexed node $\Delta CDWR_{it}$ we applied the same discretisation method as $EDWR_{it}$.
Asset Capability Water Resources	ACWR	Equation	$ACWR_{it} = \sum IF_{eq}(RS_{it}, RSOC_{it})$	‘’			The capability of manufactured assets *ACWR* to supply water resource to populations both within and out with the catchment *t* was identified by stakeholders as a key manufactured capital of the water resource system. Stakeholders highlighted that the influence of future simulations *i* could influence $ACWR_{it}$ in the future. As there was no specific data available to measure current asset capability to supply water resource, we use the nodes RS_{it} and $RSOC_{it}$ as a measure of the current and potential direction of change in $ACWR_{it}$. We calculate $ACWR_{it}$ using IF statement equations IF_{eq} to index the prior distributions of parent node RS_{it} and $RSOC_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for both RS_{it} and $RSOC_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of *c, u, and b.* For $ACWR_{it}$ the sum of IF_{eq} of prior RS_{it} and $RSOC_{it}$ values, which we will denote as α is as follows: $IF(\alpha \geq u, 3, IF(\alpha \geq b, 2, IF(\alpha \geq c, 1,0)$. For the indexed node $ACWR_{it}$ we applied the same discretisation method as $EDWR_{it}$.

<table>
<tr>
<td>Customer Complaints</td>
<td>CuC</td>
<td>Equation</td>
<td>$CuC_{it} = \sum IF_{eq}(RS_{it}, RSOC_{it})$</td>
<td></td>
<td>The potential complaints of customers CuC due to interruptions of water resource both within and out with the catchment t was identified by stakeholders as a key social and intellectual capital risk associated with the water resource system. Stakeholders highlighted that the influence of future simulations i could influenceCuC_{it} in the future. As there was no specific data available to measure current CuC_{it}, we use the nodes RS_{it} and $RSOC_{it}$ as a measure of the current and potential direction of change inCuC_{it}, assuming that if there is no interruption to supply, there will be no complaints and if there is an interruption to supply then there is the potential for complaints. We calculate CuC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent node RS_{it} and $RSOC_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for both RS_{it} and $RSOC_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. ForCuC_{it} the sum of IF_{eq} of prior RS_{it} and $RSOC_{it}$ values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$.
For the indexed node CuC_{it} we applied the same discretisation method as $EDWR_{it}$.</td>
</tr>
<tr>
<td colspan="6">Food Production sub-model</td>
</tr>
<tr>
<td>Crop Cover (Ha)</td>
<td>CC</td>
<td>Equation</td>
<td>$CC_{izt} = A_{izt}$</td>
<td>See supporting information.</td>
<td>Stakeholders highlighted that food production was an important component of the catchment, as it is predominantly covered in arable land. Stakeholders highlighted The area A of different crop types z grown in the catchment CC could vary under different simulations i across the catchment t. The current A_{izt} by calculating the average current % proportion of crop cover z in the catchment based upon analysis of the UKCEH Land Cover® Plus: Crops © 2016-2020 UKCEH. © RSAC. © Crown Copyright 2007, Licence number 100017572. We then convert the % proportion to a Ha proportion using the LC_{ivs} area for arable land cover category for each simulation i. States and their discretisation were set based on the land cover value for the different simulations i, for different crop cover types z</td>
</tr>
<tr>
<td>Crop Yields (t/Ha)</td>
<td>CY</td>
<td>Equation</td>
<td>$CY_{ijzt} = \beta_{ijzt}$</td>
<td><table>
<tr><td>State</td><td>From</td><td>To</td></tr>
<tr><td>H</td><td>0</td><td>u</td></tr>
<tr><td>M</td><td>u</td><td>b_1</td></tr>
<tr><td>L</td><td>b_1</td><td>c</td></tr>
<tr><td>Resilient</td><td>c</td><td>inf</td></tr>
</table></td>
<td>Crop yields CY (t/ha) could for crop type z differ under future change simulations i and precipitation change j across the catchment t. To measure current CY for crop types z we analysed crop yield data from 2010-2019 available from the Scottish Agriculture Tables from the Economic Report 2020 to produce a truncated normal distribution β_{ijzt}. For future simulation types i and precipitation change j we applied a range of crop yield values taken from The Farm Management Handbook 2020/21 produced by SAC Consulting. Lower yield range values are applied to extreme precipitation change simulations from the Farm Management Handbook. For all simulations an increase in yield (t/ha) is applied for each simulation based on UK SSP narratives, with FFD simulation applying the highest yield increase and GR having the lowest yield increase. The resilient threshold value c is set at as the current mean yield (t/ha) for crop types z. The high risk threshold u is set at 50% of the c value (t/ha). The values for L and M risk, b_1, are then uniformised between c and u (t/ha).</td>
</tr>
<tr>
<td>Crop Price (£/t)</td>
<td>CP</td>
<td>Equation</td>
<td>$CP_{izt} = \beta_{izt}$</td>
<td><table>
<tr><td>State</td><td>From</td><td>To</td></tr>
<tr><td>Resilient</td><td>0</td><td>c</td></tr>
<tr><td>L</td><td>c</td><td>b</td></tr>
<tr><td>M</td><td>b</td><td>u</td></tr>
</table></td>
<td>Crop Prices CP (£/t) for crop type z could differ under future change simulations i across the catchment t. To measure current CP for crop types z we analysed crop price data from 2010-2019 available from Scottish Agriculture Tables from the Economic Report 2020 to produce a truncated normal distribution β_{izt}. Future CP_{izt}value assumptions β_{izt} follow an increase in price based on SPP narratives, where FFD</td>
</tr>
</table>

				H	u	inf	assumes the greatest increase (15%), BAU (10%) and GR (5%) to give an estimation of direction of change. The resilient threshold value *c* is set at as the current mean price (£/t) for crop types *z*. The high risk threshold u is set at 50% of the *c* value (£/t). The values for L and M risk are then uniformised between *c* and *u* (£/t).
Fertiliser Costs (£/ha)	FCost	Equation	$FCost_{izt} = \beta_{izt}$	"			Fertiliser Costs *FCost* (£/ha) for crop type *z* could differ under future change simulations *i* across the catchment *t*. To measure current *FCost* for crop types *z* we analysed literature parameters of Fertiliser costs 2016-2020 available from The Farm Management Handbooks produced by SAC Consulting to produce a truncated normal distribution β_{izt}. Future $FCost_{izt}$ β_{izt} value assumptions are based on SPP narratives and the input from stakeholders in regard to concerns regarding future P supplies. The GR simulation assumes a decrease on costs (10%), BAU assumes an increase in costs (10%) and FFD assumes a higher increase (50%).The resilient threshold value *c* is set at as the current mean cost (£/ha) for crop types *z*. The high risk threshold u is set as double the *c* value (£/ha). The values for L and M risk, b_1, are then uniformised between *c* and *u* (£/ha).
Total Crop Margin (£M)	TCM	Equation	$TCM_{ijt} = \sum_z (A_{izt} \times CY_{ijzt} \times CP_{izt}) - (FCost_{izt} \times A_{izt})$	''			The total crop margin *TCM* (£M) was identified as a key representation of food production in the catchment. To calculate the sum of TCM under simulation *i* for precipitation simulation *j* for all crop types *z* for the entire catchment *t* by multiplying the area *A* (ha) of each crop type *z* with the total yield *CY* (t/Ha) for each crop type *z,* to give the total tonnage of each crop type *z* which is then multiplied by the price *CP* (£/t) of each crop type *z* to give the total output (£M). The cost of fertiliser *FCost* (£/ha) for each crop type *z* multiplied by *A* for crop type *z* which is subtracted from the total output (£M). We acknowledge that there are other node and fixed costs which influence the margins of *z* however, there was limited data available to consider these costs. We therefore only consider the nodes we can measure to provide a strategic consideration of how margins, based on the nodes included, will differ between current and future simulations. To measure TCM_{ijt} the equation calculates the sum of income minus costs for all crop types *z*. The resilient threshold value *c* is set at as the current mean cost (£/ha) for crop types *z*. The high risk threshold *u* is set at 50% of the *c* value (£/ha). The values for L and M risk are then uniformised between *c* and *u* (£/ha).
Capital Resources sub-model							
Surface Water Flows (Ml/day)	SWF	Equation	$SWF_{is} = \beta_s \times PA_{ij} - \frac{ID_{is}}{\gamma}$	State	From	To	Stakeholders identified surface water flows *SWF* (ML/day) as a significant natural capital resource in the catchment, which could be influence by future climatic change PA_{ij} and demands for irrigation ID_{is}. Current flows (ML/day) for each waterbody sub catchment s is represented by a customised distribution β_s which was derived by analysing river discharge data 2010-2019 for available waterbodies *s* provided by SEPA. The distribution of β_s is multiplied by the potential anomaly change in PA_{ij}. Simulated changes in ID_{is} - which is converted from Ml/yr to ML/day using γ – is subtracted from SWF_{is}. As there can be high risk of low flows (H1) and high flows (H2), two high risk threshold values u_1, u_2 are derived by taking the Q5 and Q95 (ML/day) values from the analysed river discharge data for waterbodies *s*. The resilient threshold value *c* set as the median value of the river discharge data. The values for L and M are uniformised between *c* and both u_1 and u_2 (ML/day).
				H1	0	u_1	
				M1	u_1	b_1	
				L1	b_1	c	
				Resilient	c	b_2	
				L2	b_2	b_3	
				M2	b_3	u_2	
				H2	u_2	inf	

Surface Water Quality (µg/l)	SWQ	Equation	EQ1. $SWQ_{is} = \frac{TPL_{is}+DP_{ivs}}{SWF_{is}} \times \gamma$ EQ2. $SWQ_{is} = \beta_s \times \Delta TPL_{is} \times \Delta DP_{ivs}$	State	From	To	The quality of surface water *SWQ* was a current issue in the catchment, particularly in regard to P concentrations (µg/l) due to the influence of effluent loads TPL_{is} (kg/day) and diffuse loads DP_{ivs} (kg/day), as highlighted by stakeholders. Surface water flows SWF_{is} (ML/day) were also identified as influencing P concentrations, with higher flows diluting concentrations and low flows having the opposite effect on P concentrations. To simulate both current and future influence of TPL_{is}, DP_{ivs} and SWF_{is} on SWQ_{is} EQ1 where SWF_{is} data was available, applying the unit conversion coefficient γ. Where SWF_{is} wasn't available we use EQ2, which derives a customised distribution β_s for current RP concentrations using random water quality sampling data 2010-2019 provided by SEPA at the end of waterbodies *s*. The influence of future TPL_{is} and DP_{ivs} on SWQ_{is} is estimated by multiplying β_s by the % change in ΔTPL_{is} and ΔDP_{ivs} as a measure of the direction of change in RP concentrations. For both EQ1 and EQ2 the resilient *c* threshold value is set as the good/moderate Water Framework Directive (WFD) status threshold (µg/l) determined by SEPA for each waterbody *s*. The high risk value threshold *u* is set as the poor/bad WFD status threshold. The L and M risk threshold value b_1 is set as the moderate/poor WFD status threshold.
				Resilient	0	c	
				L	c	b_1	
				M	b_1	u	
				H	u	inf	
Soil Erosion	SE	Equation	$SE_{is} = \beta_s \times PA_{ij}$	‘’			Stakeholders highlighted that soil in the catchment is important for supporting and protecting the natural environment and food production. Currently, soil is at risk to the impacts of intense and prolonged rainfall events. The potential future change in extreme rainfall events was seen as an influencing factor on future soil erosion SE_{is}. To measure the current risk of soil erosion we analysed maps of the risk of soil erosion by water produced by Lilly & Baggaley (2018) using ArcGIS pro for each waterbody sub-catchment *s* to produce point raster data for mineral soil risk class. The soil risk maps give each raster point one of nine of the risk classification values which are divided evenly between low, moderate and high. We assigned each risk classification with a value of between zero and eight. Values of risk classification were analysed in each waterbody sub catchment *s* to produce a truncated distribution β_s of current risk of soil erosion by water. To estimate the potential impact of changes in rainfall on SE_{is}, we multiply β_s by PA_{ij}. The resilient *c* threshold value is set at the lowest risk classification value and the high risk threshold values *u* is set using the first high risk classification value. The M risk value b_1 is set using the first moderate risk classification value.
Surface Water Flow	SWFC	Equation	$SWFC_{it} = \sum_s IF_{eq}(SWF_{is})$	State	From	To	As surface water flow SWF_{is} was highlighted by stakeholders as a key natural capital resource. We measured the overall state of *SWF* in the catchment *t* under simulations *i*. We calculate the overall capital resource state values using IF statement equations to index the prior distributions of parent nodes SWF_{is} based in their discretised state thresholds. Each prior state discrete threshold, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u_1, u_2, b_1, b_2, b_3. For $SWFC_t$ the sum $\sum_s^i IF_{eq}$ of prior SWF_{is} values is as follows: $IF(SWF_{is} \leq u_1, 3, IF(SWF_{is} \leq b_1, 2, IF(SWF_{is} \leq c, 1, IF(SWF_{is} \geq u_2, 3, IF(SWF_{is} \geq b_3, 2, IF(SWF_{is} \geq b_2, 1,0)$.
				Resilient	0	c	
				L	c	b_1	
				M	b_1	b_2	
				H	b_2	u	

							For the indexed capital resource node $SWFC_t$ the resilient threshold c is set at 25% of the total nodes included in the equation. The 25% value is selected as it ensures that for a capital resource to be resilient, the majority of parent nodes (at least 75%) must fall within a resilient index threshold value. The upper value u set as the maximum possible index value of all nodes (3 times the number of parent nodes). Threshold values for high and moderate risk, b_1 and b_2 are uniformised values between c and u. The discretisation method is consistent for all capital resources and their capitals.
Surface Water Quality	SWQC	Equation	$SWQC_{it} = \sum_{s} IF_{eq}(SWQ_{is})$	State Resilient L M H	From 0 c b_1 b_2	To c b_1 b_2 u	As surface water quality SWQ_{is} was highlighted by stakeholders as a key natural capital resource we measured the overall state of SWQ in the catchment t under simulations i. We calculate the overall capital resource state values using IF statement equations index the prior distributions of parent nodes SWQ_{is} based on their discretised state thresholds. Each prior state discrete threshold for SWQ_{is}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For $SWQC_{it}$ the sum $\sum_{s}^{i} IF_{eq}$ of prior SWQ_{is} values is as follows: $IF(SWQ_{is} \geq b_2, 3, IF(SWQ_{is} \geq b_1, 2, IF(SWQ_{is} \geq c, 1, 0)$. We apply the same discretisation methods described for all capital resources as described for the node $SWFC$.
Flood Risk	FR	Equation	$FR_{is} = \sum IF_{eq}(SWF_{is})$	"			As stakeholders highlighted the risk of flooding as a potential impacts due to the influence of future change on SWF_{is}, we measure flood risk under differing simulations i in waterbody sub catchment s values FR_{is} using IF statement equations to index the prior distributions of parent nodes SWF_{is} based on their discretised state thresholds. Each prior state discrete threshold, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of, u_2, b_2, b_3 only as lower flows would not influence flood risk. For FR_{is} the sum IF_{eq} of prior SWF_{is} values is as follows: $IF(SWF_{is} \geq u_2, 3, IF(SWF_{is} \geq b_3, 2, IF(SWF_{is} \geq b_2, 1, 0)$. We apply the same discretisation methods described for all capital resources as described for the node $SWFC$.
Soil	S	Equation	$S_{it} = \sum_{s} IF_{eq}(SE_{is})$	"			As soil was highlighted as a key natural capital resource, we use the same equation as $SWQC_{it}$ provide a measure of the state of soils under the influence future simulations i for the overall conditions in the catchment t. We apply the same discretisation methods described for all capital resources as described for the node $SWFC_{it}$.
Air Quality	AQ	Equation	$AQ_{it} = \sum_{st} IF_{eq}(EDW_{is} EDLM_{is} EDWR_{it})$	"			Air quality AQ was identified as a key natural capital resource, summarised by stakeholders as a reflection of the amount of emissions produced in the catchment t. Stakeholders highlighted that the influence of future simulations i could influence AQ_{it} in the future. As there was no specific data available to measure current AQ_{it}, we use the nodes EDW_{is}, $EDLM_{is}$ and $EDWR_{it}$ as to measure of the potential direction of change in AQ_{it} as stakeholder identified the relationship between energy demand and emissions. We calculate AQ_{it} using IF statement equations IF_{eq} to index the prior distributions of parent node EDW_{is}, $EDLM_{is}$ and $EDWR_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for EDW_{is}, $EDLM_{is}$ and $EDWR_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For AQ_{it} the sum of IF_{eq} of prior EDW_{is}, $EDLM_{is}$ and $EDWR_{it}$ values, which we will denote as α is as follows: : $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1, 0)$.

					For the indexed node AQ_{it} we applied the same discretisation method as *SWFC*.
Groundwater Quality	GWQ	Equation	$GWQ_{it} = \sum_{s} IF_{eq}(GN_{is})$	"	Air quality *GWQ* was identified as a key natural capital resource, summarised by stakeholders as a reflection of the amount of emissions produced. Stakeholders highlighted that the influence of future simulations *i* could influence *GWQ* in the catchment *t* GWQ_{it}in the future. As stakeholders specifically highlight GN_{is} as the specific compound of interest when discussing *GWQ*. The proportions of the catchment are also designated as a Nitrate Vulnerable Zone (NVZ). To measure of the current conditions and potential direction of change we use GN_{is} as an indicator of GWQ_{it}. We calculate GWQ_{it} using IF statement equations $IF_{eq}$to index the prior distributions of parent node GN_{is} based on their discretised state thresholds. Each prior state discrete threshold for GN_{is}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For GWQ_{it} apply a IF_{eq} of prior GN_{is} values, as follows: $IF(GN_{is} \geq b_2, 3, IF(GN_{is} \geq b_1, 2, IF(GN_{is} \geq c, 1,0)$. For the indexed node GWQ_{it} we applied the same discretisation method as *SWFC*.
Energy Demand Change SW	SWED	Equation	$SWED_{it} = \sum_{st} IF_{eq}(EDW_{is}, EDWR_{it})$	"	The change in energy demand, specifically for Scottish Water assets, was identified as a key manufactured capital resource *SWED*. Stakeholders required an overall understanding of the change in energy demand under simulations *i* for all Scottish Water related systems in the catchment *t*, $SWED_{it}$. Differentiating the energy demand across different sectors in the catchment would allow for the extent of the influence on each sector to be measured. We used the nodes $EDW_{is}$and $EDWR_{it}$ to measure of the potential direction of change in $SWED_{it}$ We calculate $SWED_{it}$using IF statement equations $IF_{eq}$to index the prior distributions of parent node EDW_{is} and $EDWR_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for EDW_{is} and $EDWR_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For$SWED_{it}$ the sum of IF_{eq} of prior EDW_{is} and $EDWR_{it}$ values, which we will denote as *α* is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$. For the indexed node $SWED_{it}$ we applied the same discretisation method as *SWFC*.
Chemical Demand Change SW	SWCD	Equation	$SWCD_{it} = \sum_{st} IF_{eq}(CDW_{is}, CDWR_{it})$	"	The change in chemical demand, specifically for Scottish Water related systems, was identified as a key manufactured capital resource *SWCD*. Stakeholders required an overall understanding of the change in chemical demand under simulations *i* for all Scottish Water related systems in the catchment *t*, $SWCD_{it}$. Differentiating the chemical demand across different sectors in the catchment would allow for the extent of the influence on each sector to be measured. We used the nodes $CDW_{is}$and $CDWR_{it}$ to measure of the potential direction of change in $SWCD_{it}$ We calculate $SWCD_{it}$using IF statement equations $IF_{eq}$to index the prior distributions of parent node CDW_{is} and $CDWR_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for CDW_{is} and $CDWR_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For$SWCD_{it}$ the sum of IF_{eq} of prior CDW_{is} and $CDWR_{it}$ values, which we will denote as *α* is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$. For the indexed node $SWCD_{it}$ we applied the same discretisation method as *SWFC*.

Asset Compliance & Capability	ACC	Equation	$ACC_{it} = \sum_{st} IF_{eq}(ACW_{is}, ACWR_{it})$	"	Stakeholders required an overall understanding of the change in asset compliance and capability under simulations *i* for related Scottish Water related systems in the catchment *t*, ACC_{it}. We used the nodes ACW_{is} and $ACWR_{it}$ to measure of the potential direction of change in ACC_{it} We calculate ACC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent node ACW_{is} and $ACWR_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for CDW_{is} and $CDWR_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For ACC_{it} the sum of IF_{eq} of prior ACW_{is} and $ACWR_{it}$ values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1, 0)$. For the indexed node ACC_{it} we applied the same discretisation method as *SWFC*.
Energy Demand Change LM	LMED	Equation	$LMED_{it} = \sum_{s} IF_{eq}(EDLM_{is})$	"	The change in energy demand, specifically for the land management system, was identified as a key manufactured capital resource *LMED*. Stakeholders required an overall understanding of the change in energy demand under simulations *i* for all land management systems in the catchment *t*, $SWED_{it}$. Differentiating the energy demand across different sectors in the catchment would allow for the extent of the influence on each sector to be measured. We used the node $EDLM_{is}$ to measure of the potential direction of change in $LMED_{it}$ We calculate $LMED_{it}$ using IF statement equations IF_{eq} to index the prior distributions of parent node $EDLM_{is}$ based on their discretised state thresholds. Each prior state discrete threshold for $EDLM_{is}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For $LMED_{it}$ the sum of IF_{eq} of prior $EDLM_{is}$ values, which we will denote as α is as follows: $IF(EDLM_{is} \geq b_2, 3, IF(EDLM_{is} \geq b_1, 2, IF(EDLM_{is} \geq c, 1, 0)$. For the indexed node $LMED_{it}$ we applied the same discretisation method as *SWFC*.
Chemical Demand Change LM	LMCD	Equation	$LMCD_{it} = \sum_{s} IF_{eq}(CDLM_{is})$	"	The change in energy demand, specifically for the land management system, was identified as a key manufactured capital resource *LMED*. Stakeholders required an overall understanding of the change in energy demand under simulations *i* for all land management systems in the catchment *t*, $SWED_{it}$. Differentiating the energy demand across different sectors in the catchment would allow for the extent of the influence on each sector to be measured. We used the node $EDLM_{is}$ to measure of the potential direction of change in $LMED_{it}$ We calculate $LMED_{it}$ using IF statement equations IF_{eq} to index the prior distributions of parent node $EDLM_{is}$ based on their discretised state thresholds. Each prior state discrete threshold for $EDLM_{is}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For $LMED_{it}$ the sum of IF_{eq} of prior $EDLM_{is}$ values, which is as follows: $IF(EDLM_{is} \geq b_2, 3, IF(EDLM_{is} \geq b_1, 2, IF(EDLM_{is} \geq c, 1, 0)$. For the indexed node $LMED_{it}$ we applied the same discretisation method as *SWFC*.
Community Relationship	CRS	Equation	$CRS_{it} = \sum_{st} IF_{eq}(SP_{is}, FR_{is}, SWQ_{it}, AQ_{it}, CuC_{it})$	"	The relationship with local communities *CRS* in the catchment *t* was identified as a key social capital resource by stakeholders. Stakeholders highlight that the influence of simulations *i* for could influence CRS_{it} in the future. As there is no specific measure for community relationship, stakeholders highlighted that current and future conditions of nodes $SP_{is}, FR_{is}, SWQ_{it}, AQ_{it}$ and CuC_{it} could influence CRS_{it}. We calculate CRS_{it} using IF statement equations IF_{eq} to index the prior distributions of parent nodes $SP_{is}, FR_{is}, SWQ_{it}, AQ_{it}$ and CuC_{it} based on their

					discretised state thresholds. Each prior state discrete threshold for $SP_{is}, FR_{is}, SWQ_{it}, AQ_{it}$ and CuC_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. ForCRS_{it} the sum of IF_{eq} of prior CRS_{it} values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1, 0)$. For the indexed node CRS_{it} we applied the same discretisation method as *SWFC*.
Water Treatment & Supply Costs	WTS	Equation	$WTS_{it} = \sum IF_{eq}(SWED_{it}, SWCD_{it}, ACC_{it})$	"	Changes in costs associated with the treatment and supply of water resources *WTS* in the catchment *t* was identified as a key financial capital resource by stakeholders. Stakeholders highlight that the influence of simulations *i* for could influence WTS_{it} in the future. Stakeholders identified that future conditions of nodes $SWED_{it}, SWCD_{it}$ and ACC_{it} could influence WTS_{it}. We calculate WTS_{it} using IF statement equations $IF_{eq}$to index the prior distributions of parent nodes $SWED_{it}, SWCD_{it}$ and ACC_{it} based on their discretised state thresholds. Each prior state discrete threshold for $SWED_{it}, SWCD_{it}$ and ACC_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For WTS_{it} the sum of IF_{eq} of prior $SWED_{it}, SWCD_{it}$ and ACC_{it} values, which we will denote as α is as follows: $IF(\alpha \geq u, 3, IF(\alpha \geq b, 2, IF(\alpha \geq c, 1, 0)$. For the indexed node ACC_{it} we applied the same discretisation method as *SWFC*.
Food Production	FPF	Equation	$FPF_{it} = \sum IF_{eq}(TCM_{ijt}, LMED_{it}, LMCD_{it},)$	"	Changes in income and costs associated with food production *FPF* in the catchment *t* was identified as a key financial capital resource by stakeholders. Stakeholders highlight that the influence of simulations *i* for could influence FPF_{it} in the future. Stakeholders identified that current and future conditions of nodes $TCM_{ijt}, LMED_{it}$ and $LMCD_{it}$ could influence FPF_{it}. We calculate FPF_{it} using IF statement equations $IF_{eq}$to index the prior distributions of parent nodes $TCM_{ijt}, LMED_{it}$ and $LMCD_{it}$ based on their discretised state thresholds. Each prior state discrete threshold for $TCM_{ijt}, LMED_{it}$ and $LMCD_{it}$, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For FPF_{it} the sum of IF_{eq} of prior $TCM_{ijt}, LMED_{it}$ and $LMCD_{it}$values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1, 0)$. For the indexed node FPF_{it} we applied the same discretisation method as *SWFC*
Reputation	R	Equation	$R_{it} = \sum_{st} IF_{eq}(SP_{is}, FR_{is}, CuC_{it})$	"	The reputation of sectors *R* in in the catchment *t* was identified as a key intellectual capital resource by stakeholders. Stakeholders highlighted that the influence of simulations *i* for could influence R_{it} in the future. As there was no specific measure of reputation, we used the nodes identified by stakeholders that they believe influence reputation. Stakeholders identified SP_{is}, FR_{is} and CuC_{it} could influence R_{it}. We calculate R_{it} using IF statement equations $IF_{eq}$to index the prior distributions of parent nodes SP_{is}, FR_{is} and CuC_{it} based on their discretised state thresholds. Each prior state discrete threshold forSP_{is}, FR_{is} and CuC_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For R_{it} the sum of IF_{eq} of prior SP_{is}, FR_{is} and CuC_{it}values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1, 0)$. For the indexed node R_{it} we applied the same discretisation method as *SWFC*
Capital Ouputs					

Natural Capital	NC	Equation	$NC_{it} = \sum IF_{eq}(SWQC_{it}, SWFC_{it}, AQ_{it}, S_{it}, GW($	"	The overall measure of natural capital *NC* in in the catchment *t* was required by stakeholders. Stakeholders highlighted that the influence of simulations *i* for could influence NC_{it} in the future. As there was no specific measure of natural capital, we used the natural capital resource nodes identified by stakeholders to measure both the current and future condition of natural capital NC_{it}. Stakeholders identified $SWQC_{it}, SWFC_{it}, AQ_{it}, S_{it}$ and GWQ_{it} as capital resources for NC_{it}. We calculate NC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent nodes $SWQC_{it}, SWFC_{it}, AQ_{it}, S_{it}$ and GWQ_{it} based on their discretised state thresholds. Each prior state discrete threshold for $SWQC_{it}, SWFC_{it}, AQ_{it}, S_{it}$ and GWQ_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For NC_{it} the sum of IF_{eq} of prior $SWQC_{it}, SWFC_{it}, AQ_{it}, S_{it}$ and GWQ_{it} values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$. For the indexed node NC_{it} we applied the same discretisation method as *SWFC*
Social Capital	SC	Equation	$SC_{it} = IF_{eq}(CRS_{it})$	"	The overall measure of social capital *SC* in in the catchment *t* was required by stakeholders. Stakeholders highlighted that the influence of simulations *i* for could influence SC_{it} in the future. As there was no specific measure of social capital, we used the social capital resource node CRS_{it} identified by stakeholders to measure both the current and future condition of social capital SC_{it}. We calculate SC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent node CRS_{it} based on their discretised state thresholds. Each prior state discrete threshold for CRS_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For SC_{it} the IF_{eq} of prior CRS_{it} values is as follows: $IF(CRS_{it} \geq b_2, 3, IF(CRS_{it} \geq b_1, 2, IF(CRS_{it} \geq c, 1,0)$. The overall discretised output for SC_{it} will be equal to CRS_{it}, however, we retain both nodes to ensure model structure continuity. For the indexed node SC_{it} we applied the same discretisation method as *SWFC.*
Manufactured Capital	MC	Equation	$MC_{it} = \sum IF_{eq}(SWED_{it}, SWCD_{it}, LMED_{it}, LMC$	"	The overall measure of manufactured capital *MC* in in the catchment *t* was required by stakeholders. Stakeholders highlighted that the influence of simulations *i* for could influence MC_{it} in the future. As there was no specific measure of manufactured capital, we used the manufactured capital resource nodes identified by stakeholders to measure both the current and future condition of manufactured capital MC_{it}. Stakeholders identified $SWED_{it}, SWCD_{it}, LMED_{it}, LMCD_{it}$ and ACC_{it} as manufactured capital resources for MC_{it}. We calculate MC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent nodes $SWED_{it}, SWCD_{it}, LMED_{it}, LMCD_{it}$ and ACC_{it} based on their discretised state thresholds. Each prior state discrete threshold for $SWED_{it}, SWCD_{it}, LMED_{it}, LMCD_{it}$ and ACC_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For MC_{it} the sum of IF_{eq} of prior $SWED_{it}, SWCD_{it}, LMED_{it}, LMCD_{it}$ and ACC_{it} values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$. For the indexed node MC_{it} we applied the same discretisation method as *SWFC.*
Financial Capital	FC	Equation	$FC_{it} = \sum IF_{eq}(WTS_{it}, FPF_{it})$	"	The overall measure financial capital *FC* in in the catchment *t* was required by stakeholders. Stakeholders highlighted that the influence of

					simulations i for could influence FC_{it} in the future. As there was no specific measure of financial capital, we used the financial capital resource nodes identified by stakeholders to measure both the current and future condition of financial capital FC_{it}. Stakeholders identified WTS_{it} and FPF_{it} as financial capital resources for FC_{it}. We calculate FC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent nodes WTS_{it} and FPF_{it} based on their discretised state thresholds. Each prior state discrete threshold for WTS_{it} and FPF_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For FC_{it} the sum of IF_{eq} of prior WTS_{it} and FPF_{it} values, which we will denote as α is as follows: $IF(\alpha \geq b_2, 3, IF(\alpha \geq b_1, 2, IF(\alpha \geq c, 1,0)$. For the indexed node FC_{it} we applied the same discretisation method as *SWFC.*
Intellectual Capital	IC	Equation	$IC_{it} = IF_{eq}(R_{it})$	“	The overall measure of intellectual capital *SC* in in the catchment *t* was required by stakeholders. Stakeholders highlighted that the influence of simulations i for could influence IC_{it} in the future. As there was no specific measure of intellectual capital, we used the intellectual capital resource node R_{it} identified by stakeholders to measure both the current and future condition of intellectual capital IC_{it}. We calculate IC_{it} using IF statement equations IF_{eq} to index the prior distributions of parent node R_{it} based on their discretised state thresholds. Each prior state discrete threshold for R_{it}, resilient to high-risk, was assigned a value of zero, one, two or three based on the values of c, u, and b. For IC_{it} the IF_{eq} of prior R_{it} values is as follows: $IF(R_{it} \geq b_2, 3, IF(R_{it} \geq b_1, 2, IF(R_{it} \geq c, 1,0)$. The overall discretised output for IC_{it} will be equal to R_{it}, however, we retain both nodes to ensure model structure continuity. For the indexed node IC_{it} we applied the same discretisation method as *SWFC.*

Table S3: Node parameter values.

Node	Parameter Values														Parameter Source	Discretisation			
	i	*j*	*k*	*s/a*	*v*	*z*	β[1]			γ	PC/A/T					c	b_1	b_2	*u*
							M	SD	Trunc		GR	BAU	FFD	Current					
Precipitation Change Anomaly (%)	GR	ExLR	--	--	--	--	0.74	0.03	--	--	--	--	--	--	UK Climate Projection User Interface product Anomalies for probabilistic projections (25km) over UK, 1961-2100 for *β*.	States are discretised based on *j* values and are available in SMTable 1.			
	GR	BAU	--	--	--	--	1.044	0.05	--	--	--	--	--	--					
	GR	ExHIR	--	--	--	--	1.36	0.06	--	--	--	--	--	--					
	BAU	ExLR	--	--	--	--	0.72	0.04	--	--	--	--	--	--					
	BAU	BAU	--	--	--	--	1.048	0.05	--	--	--	--	--	--					
	BAU	ExHIR	--	--	--	--	1.4	0.05	--	--	--	--	--	--					
	FFD	ExLR	--	--	--	--	0.67	0.04	--	--	--	--	--	--					
	FFD	BAU					1.056	0.06											
	FFD	ExHIR	--	--	--	--	1.49	0.07	--	--	--	--	--	--					

[1] M represents the mean value, SD represents the standard deviation and Trunc represents the truncated values for the distribution which is typically zero to prevent values being non-negative.

Dry Weather Flow (Ml/day)	--	--	Cupar	6200	--	--	1.39	0.4	0	0.002	1408	2816	5554	0	Scottish Water Eden Water Quality Strategic Study. We simulated effluent flows using effluent flow summary statistics to generate Q80 value of the outputs to derive β. SMTable 1 for γ. PC Values for GR, BAU and FFD are derived from Scottish Water Growth Model outputs.	3.2	6.4	--	9.6
	--	--	Springfield	6200	--	--	0.89	0.13	0	0.002	6	12	668	0		1.17	2.34	--	3.51
	--	--	Freuchie	6200	--	--	0.26	0.07	0	0.002	-176	-352	-387	0		0.28	0.56	--	0.84
	--	--	Dairsie	6200	--	--	0.09	0.01	0	0.002	37	74	178	0		0.1	0.2	--	0.3
	--	--	Strathmiglo	6201	--	--	0.56	0.08	0	0.002	-153	-306	-367	0		0.28	0.56	--	0.84
	--	--	Bowhouse	6201	--	--	1.53	0.24	0	0.002	-178	-356	1116	0		1.94	3.89	--	5.83
	--	--	Ceres	6202	--	--	0.25	0.03	0	0.002	-170	-340	-374	0		0.27	0.54	--	0.81
	--	--	Pitscottie	6202	--	--	0.03	0.005	0	0.002	-15	-30	-36	0		0.04	0.08	--	0.12
	--	--	Letham	6206	--	--	0.06	0.009	0	0.002	-27	-54	-65	0		0.07	0.14	--	0.21
Daily Effluent Flow (Ml/day)	--	--	Cupar	6200	--	--	2.27	1.14	0	0.002	1408	2816	5554	0	Scottish Water Eden Water Quality Strategic Study. We used survey samples where available and SAGIS outputs in absent survey statistics for β. SMTable 1 for γ.	9.6	14.4	--	19.2
	--	--	Springfield	6200	--	--	1.14	0.29	0	0.002	6	12	668	0		3.51	5.27	--	7.02
	--	--	Freuchie	6200	--	--	0.66	0.18	0	0.002	-176	-352	-387	0		0.84	1.26	--	1.68
	--	--	Dairsie	6200	--	--	0.13	0.07	0	0.002	37	74	178	0		0.3	0.45	--	0.6
	--	--	Strathmiglo	6201	--	--	0.81	0.42	0	0.002	-153	-306	-367	0		0.84	1.26	--	1.68
	--	--	Bowhouse	6201	--	--	2.16	1.02	0	0.002	-178	-356	1116	0		5.83	8.73	--	11.64
	--	--	Ceres	6202	--	--	0.35	0.175	0	0.002	-170	-340	-374	0		0.81	1.22	--	1.62
	--	--	Pitscottie	6202	--	--	0.05	0.025	0	0.002	-15	-30	-36	0		0.12	0.18	--	0.24
	--	--	Letham	6206	--	--	0.117	0.04	0	0.002	-27	-54	-65	0		0.21	0.32	--	0.42
Daily Influent Flow (Ml/day)															--	Daily Influent Flow nodes follow the same discretisation as Daily Effluent Flow.			
Spill Event	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	1	4.67	8.33	12
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
Phosphorus Load (kg/d)	--	--	Cupar	6200	--	--	2.6	1.6	0	0.0002	1408	2816	5554	0	Values for the current effluent P concentration (mg/l) β are taken from the Scottish Water Eden Water Quality Strategic Study. SMTable 1 for γ.	5.4	10.8	--	16.2
	--	--	Springfield	6200	--	--	3.7	1.6	0	0.0004	6	12	668	0		5.96	11.92	--	17.88
	--	--	Freuchie	6200	--	--	4.42	2.59	0	0.0032	-176	-352	-387	0		2.46	4.92	--	7.38
	--	--	Dairsie	6200	--	--	2.7	1.8	0	0.0002	37	74	178	0		0.34	0.68	--	1.02
	--	--	Strathmiglo	6201	--	--	2.1	1.3	0	0.0014	-153	-306	-367	0		1.54	3.08	--	4.62
	--	--	Bowhouse	6201	--	--	2.8	1.4	0	0.0003	-178	-356	1116	0		5.94	11.88	--	17.82
	--	--	Ceres	6202	--	--	2.5	1.5	0	0.0016	-170	-340	-374	0		0.8	1.6	--	2.4
	--	--	Pitscottie	6202	--	--	4.2	2.5	0	0.0191	-15	-30	-36	0		0.19	0.38	--	0.57
	--	--	Letham	6206	--	--	2.3	1.4	0	0.0002	-27	-54	-65	0		0.24	0.48	--	0.72
Bio Resource (m^3/day)	--	--	Cupar	6200	--	--	--	--	--	0.003	--	--	--	--	SMTable 1 for γ.	6.7	13.4	--	20.1
	--	--	Springfield	6200	--	--	--	--	--	0.0091	--	--	--	--		10.33	20.66	--	30.99
	--	--	Freuchie	6200	--	--	--	--	--	0.0014	--	--	--	--		0.94	1.88	--	2.82
	--	--	Dairsie	6200	--	--	--	--	--	0.0053	--	--	--	--		0.8	1.38	--	2.07
	--	--	Strathmiglo	6201	--	--	--	--	--	0.0004	--	--	--	--		0.43	0.86	--	1.29

	--	--	Bowhouse	6201	--	--	--	--	--	0.0009	--	--	--	--		1.98	3.96	--	5.94
	--	--	Ceres	6202	--	--	--	--	--	0.0026	--	--	--	--		0.95	1.9	--	2.85
	--	--	Pitscottie	6202	--	--	--	--	--	0.011	--	--	--	--		0.58	1.16	--	1.74
	--	--	Letham	6206	--	--	--	--	--	0.0032	--	--	--	--		0.4	0.8	--	1.2
Total Phosphorus Load (kg/day)	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	21.5	43	--	64.5
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		7.8	15.6	--	23.4
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		1.04	2.08	--	3.12
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.24	0.48	--	0.72
Energy Demand Wastewater	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	1	4.62	8.33	12
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
Chemical Demand Wastewater	--	--	--	6200	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
Asset Compliance and Capability Wastewater				6200												1.25	5.83	10.42	15
				6201												0.75	3.5	6.25	9
				6202												0.75	3.5	6.25	9
				6205												0.5	2.33	4.17	6
Land Cover (Ha)	--	--	--	6200	Arable	--	--	--	--	--	3589	3729	3833	3485	UKCEH land cover vector maps (Morton et al., 2019) used to determine *A*.	States are discretised based on *A* values and are available in SMTable 1.			
	--	--	--	6200	Pasture	--	--	--	--	--	442	531	885	885					
	--	--	--	6200	Urban	--	--	--	--	--	546	642	728	520					
	--	--	--	6201	Arable	--	--	--	--	--	2834	2944	3081	2751					
	--	--	--	6201	Pasture	--	--	--	--	--	551	937	1191	1103					
	--	--	--	6201	Urban	--	--	--	--	--	174	132	270	193					
	--	--	--	6202	Arable	--	--	--	--	--	2573	2673	2773	2499					
	--	--	--	6202	Pasture	--	--	--	--	--	1061	1388	1715	1633					
	--	--	--	6205	Arable	--	--	--	--	--	1007	1027	1057	997					
	--	--	--	6205	Pasture	--	--	--	--	--	94	140	168	187					
	--	--	--	6205	Urban	--	--	--	--	--	116	119	124	111					
	--	--	--	6206	Arable	--	--	--	--	--	2433	2528	2669	2362					
	--	--	--	6206	Pasture	--	--	--	--	--	1025	1340	1703	1576					
	--	--	--	6206	Urban	--	--	--	--	--	--	--	--	--					
Septic Tanks (No of)	--	--	--	6200	--	--	--	--	--	--	136	113	90	113	Scottish Water Eden Water Quality Strategic Study provided the current no of T. See SMTable1 for GR, BAU and FFD values.	States are discretised based on *j A* values and are available in SMTable 1.			
	--	--	--	6201	--	--	--	--	--	--	73	61	49	61					
	--	--	--	6202	--	--	--	--	--	--	56	47	38	47					
	--	--	--	6205	--	--	--	--	--	--	24	14	8	14					
	--	--	--	6206	--	--	--	--	--	--	74	62	50	62					
Phosphorus Applications (kg/day)	--	--	--	6200	Arable	--	--	--	--	0.0037	--	--	--	--	Values for γ taken from the ADAS UK Ltd model of rural diffuse pollution provided by SEPA.	12.77	19.16	--	25.54
	--	--	--	6200	Pasture	--	--	--	--	0.0064	--	--	--	--		5.7	8.55	--	11.4
	--	--	--	6200	Urban	--	--	--	--	0.00057	--	--	--	--		0.3	0.45	--	0.6
	--	--	--	6200	Septic Tank	--	--	--	--	0.073	--	--	--	--		8.3	12.45	--	16.6
	--	--	--	6201	Arable	--	--	--	--	0.00042	--	--	--	--		1.5	2.25	--	3
	--	--	--	6201	Pasture	--	--	--	--	0.0008	--	--	--	--		0.83	1.25	--	1.66
	--	--	--	6201	Septic Tank	--	--	--	--	0.015	--	--	--	--		0.93	1.4	--	1.86
	--	--	--	6202	Arable	--	--	--	--	0.0011	--	--	--	--		2.8	4.2	--	5.6

	--	--	--	6202	Pasture	--	--	--	--	0.0014	--	--	--	--		2.23	3.35	--	4.46
	--	--	--	6202	Septic Tank	--	--	--	--	0.018	--	--	--	--		0.83	1.25	--	1.66
	--	--	--	6205	Arable	--	--	--	--	0.0005	--	--	--	--		0.52	0.78	--	1.04
	--	--	--	6205	Pasture	--	--	--	--	0.00017	--	--	--	--		0.03	0.045	--	0.06
	--	--	--	6205	Urban	--	--	--	--	0.00007	--	--	--	--		0.01	0.015	--	0.02
	--	--	--	6205	Septic Tank	--	--	--	--	0.015	--	--	--	--		0.21	0.32	--	0.42
	--	--	--	6206	Arable	--	--	--	--	0.000015	--	--	--	--		0.034	0.056	--	0.078
	--	--	--	6206	Pasture	--	--	--	--	0.000011	--	--	--	--		0.017	0.026	--	0.034
	--	--	--	6206	Septic Tank	--	--	--	--	0.0008	--	--	--	--		0.05	0.08	--	0.1
Total Diffuse Phosphorus (kg/day)	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	27	36	--	54
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		2.9	4.35	--	5.8
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		5.84	8.76	--	11.68
	--	--	--	6205	--	--	--	--	--	--	--	--	--	--		0.77	1.16	--	1.54
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.1	0.15	--	0.2
Groundwater Nitrate (mg/l)	--	--	--	6201	Arable	--	3.41	0.29	--	0.001	--	--	--	--	Values for β and γ derived using groundwater nitrate samples (mg/l) from 2008-2019 provided by SEPA.	18.75	28.13	--	37.5
	--	--	--		Urban					0.0001									
	--	--	--		Septic Tank					0.00006									
	--	--	--	6201	Arable	--	4.07	0.2	--	0.0013	--	--	--	--		18.75	28.13	--	37.5
					Urban					0.00013									
					Septic Tank					0.00007									
Irrigation Demand (ML/year)	--	--	--	6200	--	--	93	82	0	--	--	--	--	--	Values for β derived using annual irrigation abstraction licence return data (Ml/year) from 2008-2019 provided by SEPA.	625	937.5	--	1250
	--	--	--	6201	--	--	44	57	0	--	--	--	--	--		542	813	--	1084
	--	--	--	6202	--	--	55	75	0	--	--	--	--	--		193.5	290.3	--	387
	--	--	--	6206	--	--	21	16	0	--	--	--	--	--		96.5	144.8	--	193
Energy Demand Land Management	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	0.25	1.17	2.08	3
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
Chemical Demand Land Management	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	0.5	2.33	4.17	6
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6202	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6205	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
	--	--	--	6206	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
Public Commercial Demand	GR	--	--	--	--	--	--	--	--	0.95	--	--	--	--	Values γ are used for node PCD_{it} in the equation for node WA (see SMTable 1).	As the node is deterministic in the model there is no discretisation.			
	BAU	--	--	--	--	--	--	--	--	1.05	--	--	--	--					
	FFD	--	--	--	--	--	--	--	--	1.1	--	--	--	--					
	Current	--	--	--	--	--	--	--	--	1	--	--	--	--					
Leakage	GR	--	--	--	--	--	--	--	--	0.95	--	--	--	--	Values γ are used for node L_{it} in the equation for node WA (see SMTable 1).	As the node is deterministic in the model there is no discretisation.			
	BAU	--	--	--	--	--	--	--	--	1	--	--	--	--					
	FFD	--	--	--	--	--	--	--	--	1.05	--	--	--	--					
	Current	--	--	--	--	--	--	--	--	1	--	--	--	--					
Water Resource Abstraction	--	--	--	--	--	--	7.71	0.58	--	0.000165	743	1,486	6,339	0	Values for β derived using annual abstraction data for all	7.5	8.5	--	9.5

Demand (Ml/day)															Scottish Water boreholes in the catchment from 2014-2018 provided by SEPA and Scottish Water. The coefficient γ which represents the normal consumption rate of 165 l/d per person per day identified by Scottish Water				
Asset Conditions	GR	--	--	--	--	--	--	--	--	0.98	--	--	--	--	Values γ are used for node AC_{it} in the equation for node SC (see SMTable 1).	As the node is deterministic in the model there is no discretisation.			
	BAU	--	--	--	--	--	--	--	--	0.98	--	--	--	--					
	FFD	--	--	--	--	--	--	--	--	0.95	--	--	--	--					
	Current	--	--	--	--	--	--	--	--	1	--	--	--	--					
Water Resource Supply Capacity	--	--	--	a1	--	--	Custom			--	--	--	--	--	Custom values for β derived using annual abstraction rate data for all Scottish Water boreholes a in the catchment from 2012-2019 provided by Scottish Water	5	3	--	1
	--	--	--	a2	--	--	Custom			--	--	--	--	--		5	3	--	1
Resilience of Eden Supply (Ml/day)	--	--	--	--	--	--	0.97	0.12	0	--	--	--	--	--	The β values represent β_{ooc} used in the RS node equation are derived from the 2014-2018 abstraction data provided by SEPA and Scottish Water (see SMTable 1).	0.5	0.25	--	0
Resilience of Out of Catchment Supply (Ml/day)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.5	0.25	--	0
Energy Demand Water Resources	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
Chemical Demand Water Resources	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3
Asset Capability Water Resources	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
Customer Complaints Water Resources	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.5	2.33	4.17	6
Crop Cover (Ha)	--	--	--	--	--	Wheat	--	--	--	--	5595	5758	5866	5432	Values for A we use the UKCEH Land Cover® Plus: Crops ©	States are discretised based on current A values for z.			
	--	--	--	--	--	Barley	--	--	--	--	6700	6896	7026	6505					
	--	--	--	--	--	Potato	--	--	--	--	1233	1269	1293	1197					

	--	--	--	--	--	Oilseed	--	--	--	--	412	423	431	399	2016-2020 maps and SSP narratives.				
Crop Yield (t/Ha)	GR	BAU	--	--	--	Wheat	8.62	0.94	0	--	--	--	--	--	For β values we use a combination of crop yield data from 2010-2019 available from the Scottish Agriculture Tables from the Economic Report 2020 and crop yield values taken from The Farm Management Handbook 2020/21 produced by SAC Consulting.	8.1	6.1	--	4.1
	BAU	BAU	--	--	--	Wheat	9.03	0.94	0	--	--	--	--	--					
	FFD	BAU	--	--	--	Wheat	10	0.94	0	--	--	--	--	--					
	Current	BAU	--	--	--	Wheat	8.21	0.94	0	--	--	--	--	--					
	All	ExLR/ExHIR	--	--	--	Wheat	6	0.94	0	--	--	--	--	--					
	GR	BAU	--	--	--	Barley	6.33	0.48	0	--	--	--	--	--		6.03	4.52	--	3.02
	BAU	BAU	--	--	--	Barley	6.63	0.48	0	--	--	--	--	--					
	FFD	BAU	--	--	--	Barley	7.5	0.48	0	--	--	--	--	--					
	Current	BAU	--	--	--	Barley	6.03	0.48	0	--	--	--	--	--					
	All	ExLR/ExHIR	--	--	--	Barley	4	0.48	0	--	--	--	--	--					
	GR	BAU	--	--	--	Potato	36.31	1.9	0	--	--	--	--	--		42.2	31.65	--	21.1
	BAU	BAU	--	--	--	Potato	38	1.9	0	--	--	--	--	--					
	FFD	BAU	--	--	--	Potato	39.78	1.9	0	--	--	--	--	--					
	Current	BAU	--	--	--	Potato	34.8	1.9	0	--	--	--	--	--					
	All	ExLR/ExHIR	--	--	--	Potato	30	1.9	0	--	--	--	--	--					
	GR	BAU	--	--	--	Oilseed	3.91	0.44	0	--	--	--	--	--		3.72	2.79	--	1.86
	BAU	BAU	--	--	--	Oilseed	4.1	0.44	0	--	--	--	--	--					
	FFD	BAU	--	--	--	Oilseed	5	0.44	0	--	--	--	--	--					
	Current	BAU	--	--	--	Oilseed	3.72	0.44	0	--	--	--	--	--					
	All	ExLR/ExHIR	--	--	--	Oilseed	3	0.44	0	--	--	--	--	--					
Crop Price (£/t)	GR	--	--	--	--	Wheat	152.99	23.14	0	--	--	--	--	--	For β values we use crop price data from 2010-2019 available from Scottish Agriculture Tables from the Economic Report 2020	145.7	109.2	--	72.9
	BAU	--	--	--	--	Wheat	160.27	23.14	0	--	--	--	--	--					
	FFD	--	--	--	--	Wheat	167.56	23.14	0	--	--	--	--	--					
	Current	--	--	--	--	Wheat	145.7	23.14	0	--	--	--	--	--					
	GR	--	--	--	--	Barley	146.27	28.4	0	--	--	--	--	--		139.3	104.5	--	69.7
	BAU	--	--	--	--	Barley	153.23	28.4	0	--	--	--	--	--					
	FFD	--	--	--	--	Barley	160.12	28.4	0	--	--	--	--	--					
	Current	--	--	--	--	Barley	139.3	28.4	0	--	--	--	--	--					
	GR	--	--	--	--	Potato	174.1	23.5	0	--	--	--	--	--		165.8	124.4	--	82.9
	BAU	--	--	--	--	Potato	182.38	23.5	0	--	--	--	--	--					
	FFD	--	--	--	--	Potato	190.67	23.5	0	--	--	--	--	--					
	Current	--	--	--	--	Potato	165.8	23.5	0	--	--	--	--	--					
	GR	--	--	--	--	Oilseed	322.82	40.4	0	--	--	--	--	--		308.4	231.3	--	154.2
	BAU	--	--	--	--	Oilseed	339.24	40.4	0	--	--	--	--	--					
	FFD	--	--	--	--	Oilseed	354.66	40.4	0	--	--	--	--	--					
	Current	--	--	--	--	Oilseed	308.4	40.4	0	--	--	--	--	--					

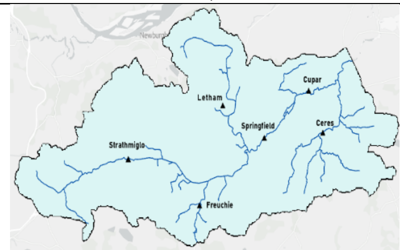
Fertiliser Cost (£/ha)	GR	--	--	--	--	Wheat	161.1	23.75	0	--	--	--	--	--	For β values we use literature parameters of Fertiliser costs 2016-2020 available from The Farm Management Handbooks produced by SAC Consulting.	179.4	269.1	--	358.8
	BAU	--	--	--	--	Wheat	188.37	23.75	0	--	--	--	--	--					
	FFD	--	--	--	--	Wheat	296	23.75	0	--	--	--	--	--					
	Current	--	--	--	--	Wheat	179.4	23.75	0	--	--	--	--	--					
	GR	--	--	--	--	Barley	150.21	21.71	0	--	--	--	--	--		166.9	250.4	--	333.8
	BAU	--	--	--	--	Barley	175.25	21.71	0	--	--	--	--	--					
	FFD	--	--	--	--	Barley	250.35	21.71	0	--	--	--	--	--					
	Current	--	--	--	--	Barley	166.9	21.71	0	--	--	--	--	--					
	GR	--	--	--	--	Potato	177.84	21.27	0	--	--	--	--	--		197.6	296.4	--	395.2
	BAU	--	--	--	--	Potato	207.5	21.27	0	--	--	--	--	--					
	FFD	--	--	--	--	Potato	296.4	21.27	0	--	--	--	--	--					
	Current	--	--	--	--	Potato	197.6	21.27	0	--	--	--	--	--					
	GR	--	--	--	--	Oilseed	117.36	18.8	0	--	--	--	--	--		130.4	195.6	--	260.8
	BAU	--	--	--	--	Oilseed	136.92	18.8	0	--	--	--	--	--					
	FFD	--	--	--	--	Oilseed	195.6	18.8	0	--	--	--	--	--					
	Current	--	--	--	--	Oilseed	130.4	18.8	0	--	--	--	--	--					
Total Crop Margin (£M)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	17	12.75		8.5
Surface Water Flows (Ml/day)	--	--	--	6200	--	--	Custom			--	365	--	--	--	Custom values for β derived from river discharge data 2010-2019 provided by SEPA.	[2]			
	--	--	--	6201	--	--	Custom			--	365	--	--	--					
Surface Water Quality (µg/l)	--	--	--	6200	--	--	--	--	--	1000	--	--	--	--	Custom values for β derived from water quality sampling data 2010-2019 provided by SEPA.	78	191	--	1046
	--	--	--	6201	--	--	--	--	--	1000	--	--	--	--		67	170	--	996
	--	--	--	6202	--	--	Custom			--	--	--	--	--		75	186	--	1034
	--	--	--	6205	--	--	Custom			--	--	--	--	--		72	197	--	1015
	--	--	--	6206	--	--	Custom			--	--	--	--	--		71	178	--	1015
Soil Erosion	--	--	--	6200	--	--	3.1	1.1	0	--	--	--	--	--	Values for β derived from maps of the risk of soil erosion by water produced by Lilly & Baggaley (2018).	1	3	--	5
	--	--	--	6201	--	--	3.6	1.14	0	--	--	--	--	--		1	3	--	5
	--	--	--	6202	--	--	3.62	1.1	0	--	--	--	--	--		1	3	--	5
	--	--	--	6205	--	--	3.7	0.96	0	--	--	--	--	--		1	3	--	5
	--	--	--	6206	--	--	3.93	1.45	0	--	--	--	--	--		1	3	--	5
Surface Water Flow (Capital Resource)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.5	2.33	4.17	6
Surface Water Quality (Capital Resource)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Flood Risk	--	--	--	6200	--	--	--	--	--	--	--	--	--	--	--	0.25	1.17	2.08	3
	--	--	--	6201	--	--	--	--	--	--	--	--	--	--		0.25	1.17	2.08	3

[2] Surface water flows node is discretised using c, u_1, u_2, b_1, b_2 and b_3 values (see SMTable1). For sub catchment 6200, the values are as follows: $u_1 = 98.5$, $b_1 = 172.75$, $c = 247$, $b_2 = 679.5$, $b_3 = 895.75$, $u_2 = 1112$. For sub catchment 6201, the values are as follows: $u_1 = 10.54$, $b_1 = 19.87$, $c = 29.2$, $b_2 = 63.64$, $b_3 = 98.67$, $u_2 = 133.41$.

Soil (Capital Resource)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Air Quality	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Groundwater Quality	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.5	2.33	4.17	6
Energy Demand Change SW	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Chemical Demand Change SW	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Asset Compliance & Capability (Capital Resource)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Energy Demand Change LM	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	4.67	8.33	12
Chemical Demand Change LM	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Community Relationship	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.75	8.17	15.58	21
Water Treatment & Supply Costs	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.75	3.5	6.25	9
Food Production	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.75	3.5	6.25	9
Reputation	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Natural Capital	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Social Capital	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.25	1.17	2.08	3
Manufactured Capital	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.25	5.83	10.42	15
Financial Capital	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	2.67	4.33	6
Intellectual Capital	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.25	1.17	2.08	3

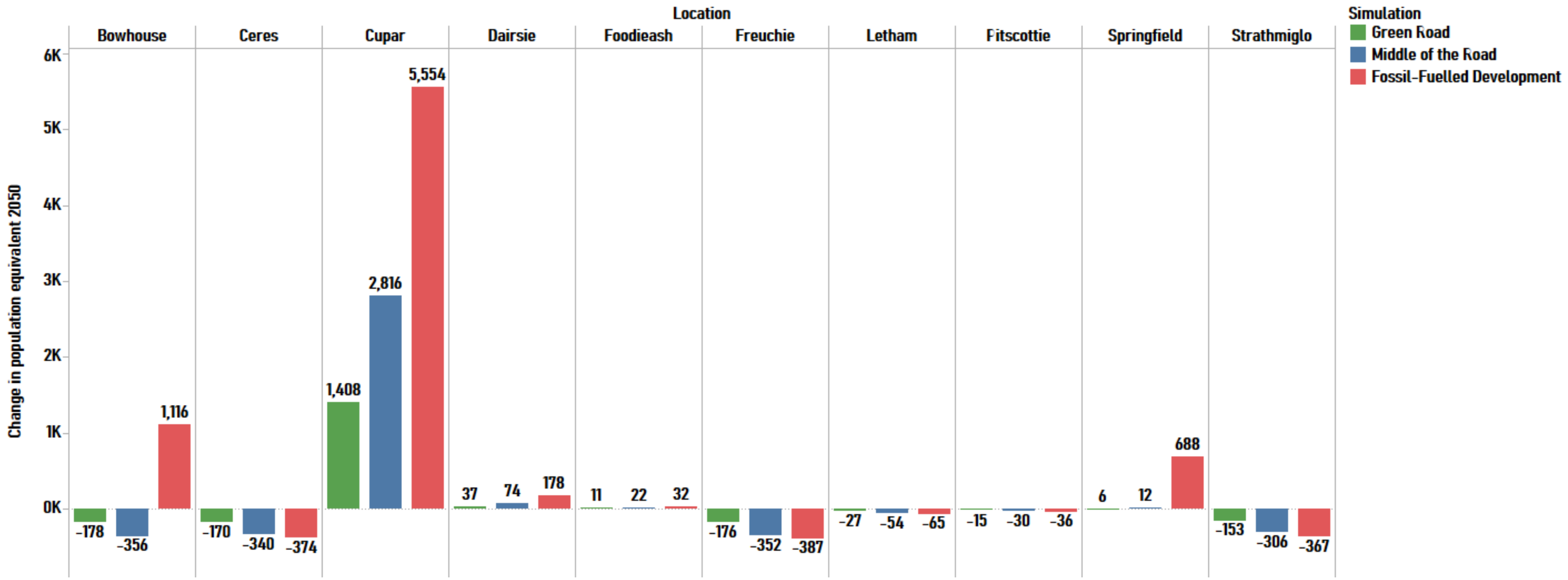
S4: Scenario Assumptions

Table S4: Precipitation rate anomaly (%) in the Eden catchment under multiple future simulations (Lowe, et al., 2018).

Simulation	Extreme Low Rainfall	Business As Usual	Extreme High Rainfall
Green Road	 RCP 2.6, summer months, 5th percentile.	 RCP 2.6, annual, 50th percentile.	 RCP 2.6, winter months, 95th percentile.
% Mean, Standard Deviation	-26, 3.3	4.38, 5.28	36.31, 6.11
Business As Usual	 RCP 6, summer months, 5th percentile.	 RCP 6, annual, 50th percentile.	 RCP 6, winter months, 95th percentile.
% Mean, Standard Deviation	-27.15, 3.6	4.76, 5.42	40.33, 5.04
Fossil Fuelled Development	 RCP 8.5, summer months, 5th percentile.	 RCP 8.5, annual, 50th percentile.	 RCP 8.5, winter months, 95th percentile.
% Mean, Standard Deviation	-32.94, 3.64	5.63, 5.93	48.51, 6.68
Precipitation Anomaly (%) Scale			

TableS5: Average population equivalent at locations within the Eden catchment. Data provided by Scottish Water data 2016-2019.

Location	Bowhouse	Ceres	Cupar	Dairsie	Foodieash	Freuchie	Letham	Pitscottie	Springfield	Strathmiglo
Current Population Equivalent	5731	1301	13712	424	38	1350	403	106	7650	1102



FigS2: Projected change in population equivalent numbers for each simulation to 2050 in comparison to current population equivalents at locations within the Eden. Projections are derived from Scottish Water growth model. Acknowledgement: Figure created using Tableau Software LLC 2021 (version 2020.4.1)

Table S6: 2019 land cover in hectares (Ha) and % in Eden catchment (Morton, et al., 2020).

Land Cover	Arable	Broadleaf Woodland	Coniferous Woodland	Freshwater	Heath/Bog	Improved Grassland	Semi-Natural Grassland	Urban
Current Area (Ha)	16081	3300	1079	86	147	8893	543	1206
Current %	51	11	3	0.3	0.5	28	2	4

Figure S3: Projected difference in land cover in hectares (Ha) in 2050 in the Eden catchment for each simulation in comparison to current land cover (Morton, et al., 2020). Acknowledgement: Figure created using Tableau Software LLC 2021 (version 2020.4.1)

S5: Capital indexing method

Capital & Capital Resource Discrete Indexing Method

Surface water quality example

Stakeholders wish to know the overall resilience of surface water quality in the catchment. For the multiple waterbodies in catchment the project team have define the measure for surface water quality to be the concentration if RP (µg/l). Each waterbody has a distinct state boundaries to determine their state based on WFD directive status:

Table S7: Discrete state boundary example for reactive phosphorus concentrations at each sub-catchment waterbody

Waterbody	6200 – Discrete RP Concentration State Boundary Values (µg/l)		6201- Discrete RP Concentration State Boundary Values (µg/l)		6202 - Discrete RP Concentration State Boundary Values (µg/l)		6205 - Discrete RP Concentration State Boundary Values (µg/l)		6206 - Discrete RP Concentration State Boundary Values (µg/l)	
State	From	To	From	To	From	To	From	To	From	To
Resilient	0	78	0	67	0	75	0	72	0	71
Low Risk	78	191	67	170	75	186	72	179	71	178
Moderate Risk	191	1048	170	996	186	1034	179	1015	178	1015
High Risk	1048	4184	996	3984	1034	3102	1015	4060	1015	4060

There is no measure of overall catchment surface water quality, therefore we index the resilience for surface water quality in each waterbody using IF statements, as explained for waterbody 6200 below:

Table S8: IF statement indexing values based on discrete boundary values for reactive phosphorus concentration in waterbody sub-catchment 6200

Waterbody	6200 – Discrete RP Concentration State Boundary Values (µg/l)		IF Statement Value
State	From	To	
Resilient	0	78	0
Low Risk	78	191	1
Moderate Risk	191	1048	2
High Risk	1048	4184	3

The IF statement equation for 6200 would be:

IF 6200 RP > 78, 1, IF 6200 RP > 191, 2, IF 6200 RP > 1048, 3, ELSE, 0.

For overall surface water quality, we take the sum of all IF statements for each of the waterbodies included in the study and discretise the node surface water quality as:

Table S9: IF statement indexing values based on discrete boundary values for overall surface water quality

Capital Resource Surface Water Quality			IF Statement Value
State	From	To	
Resilient	0	1.25	0
Low Risk	1.25	5.83	1
Moderate Risk	5.83	10.42	2
High Risk	10.42	15	3

As there are five waterbody parent nodes for capital resource SWQ, the maximum sum of IF statements is 15.

The resilient threshold value is set at 25% of the total number of parent node nodes. 25% of 5 = 1.25.

Therefore, for a capital resource, or capital, to be considered resilient overall, 75% of the parent nodes must also be resilient.

Low and moderate risk upper threshold values are uniformised between 1.25 and 15.

An example simulation is demonstrated below:

Table S10: Sum if IF statement indexing example for overall surface water quality

RP simulation outputs at waterbodies	Index IF statement value	Sum of IF statement values	Capital resource surface water quality
RP in 6200 = 104 µg/l RP in 6201 = 190 µg/l RP in 6202 = 60 µg/l RP in 6205 = 97 µg/l RP in 6206 = 40 µg/l	6200 = 1 6201 = 2 6202 = 0 6205 = 1 6206 = 0	4	Overall surface water quality is at low risk

Surface water quality is a parent node of natural capital, in the above example, surface water quality would carry an index IF statement value of 1 into the sum of IF statement equation with all other natural capital parent nodes.

S6: References

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