Linking catchment models with Earth Observation data – risk mapping Dissolved Inorganic Nitrogen (DIN) in Liverpool Bay

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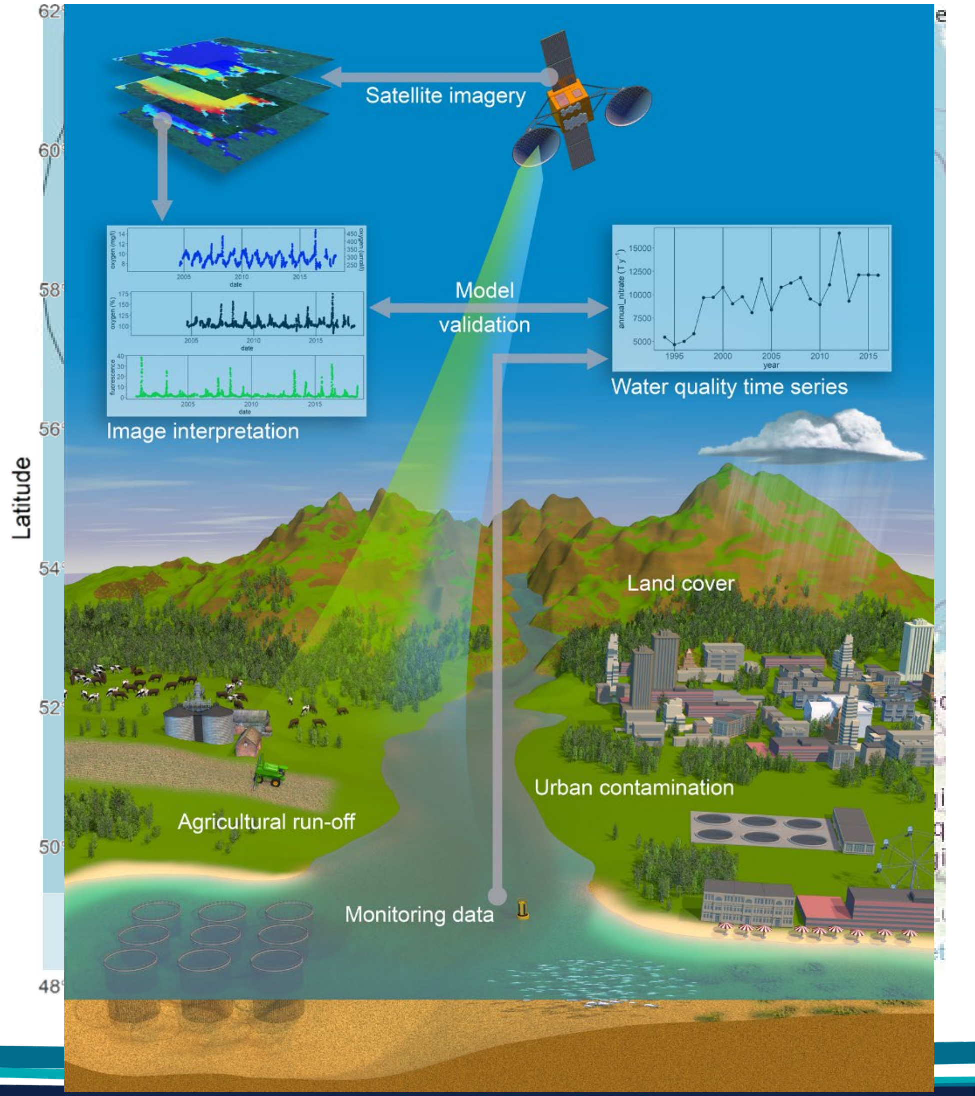
Cefas

Improving the links between land and sea

Motivation: Assessment of water quality in coastal & transitional zones relies on spatially and temporally limited in situ data coupled with simplistic consideration of riverine inputs



Considerations

Objective: Develop an assessment approach that can use the reach of Earth Observation data coupled with river catchment model(s)

- Earth observation data can provide wide spatial and temporal resolution in coastal environments
- Catchment models enable source apportionment and future scenarios to be considered
- Catchment models can help with data gaps

EO versus hydrodynamic models for understanding transport of nutrients in coastal waters

Satellite data

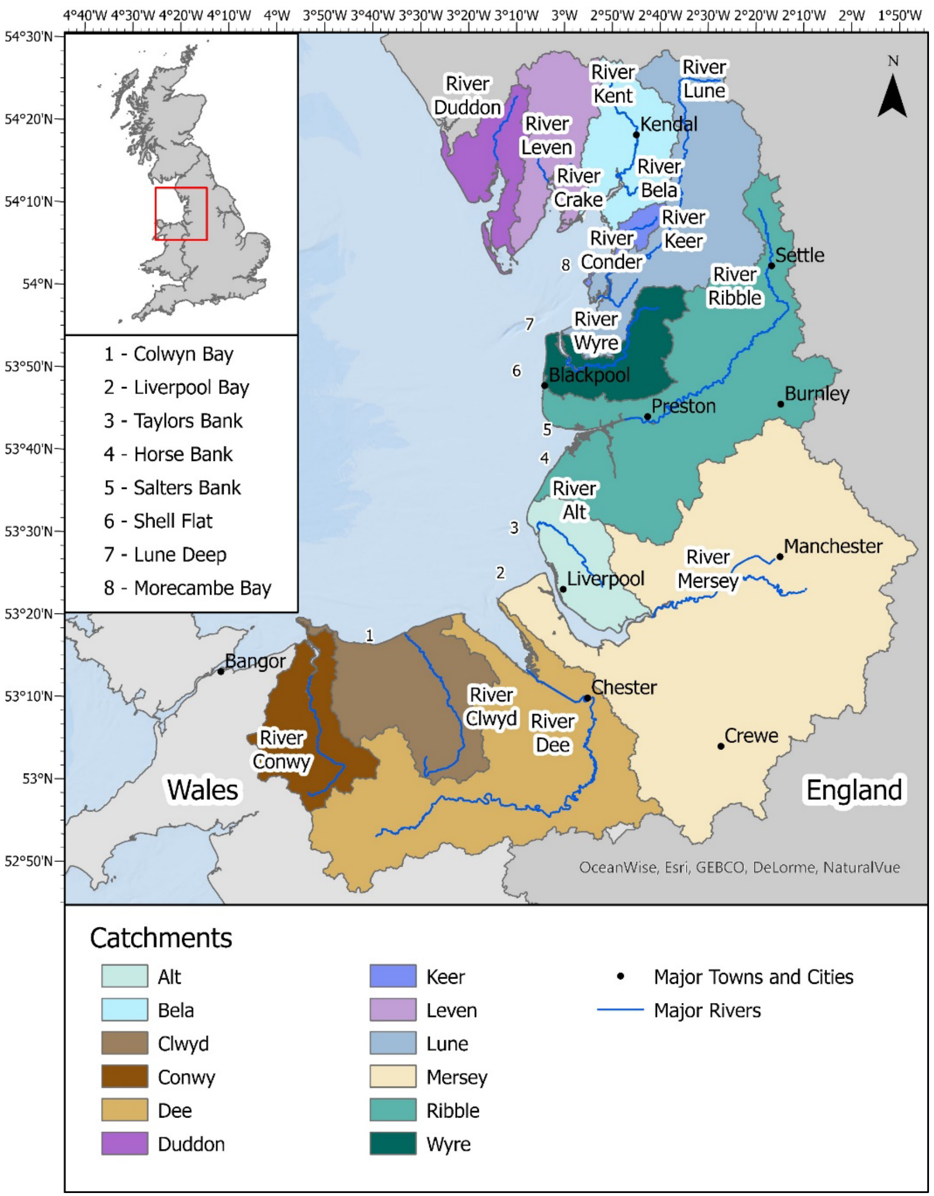
- High spatial extent
- Relatively easy processing demand
- Uses observed data across a large spatial and temporal range
- Cloud cover
- Relies on proxy for nutrient values (e.g. correlation between nutrient and ocean colour)

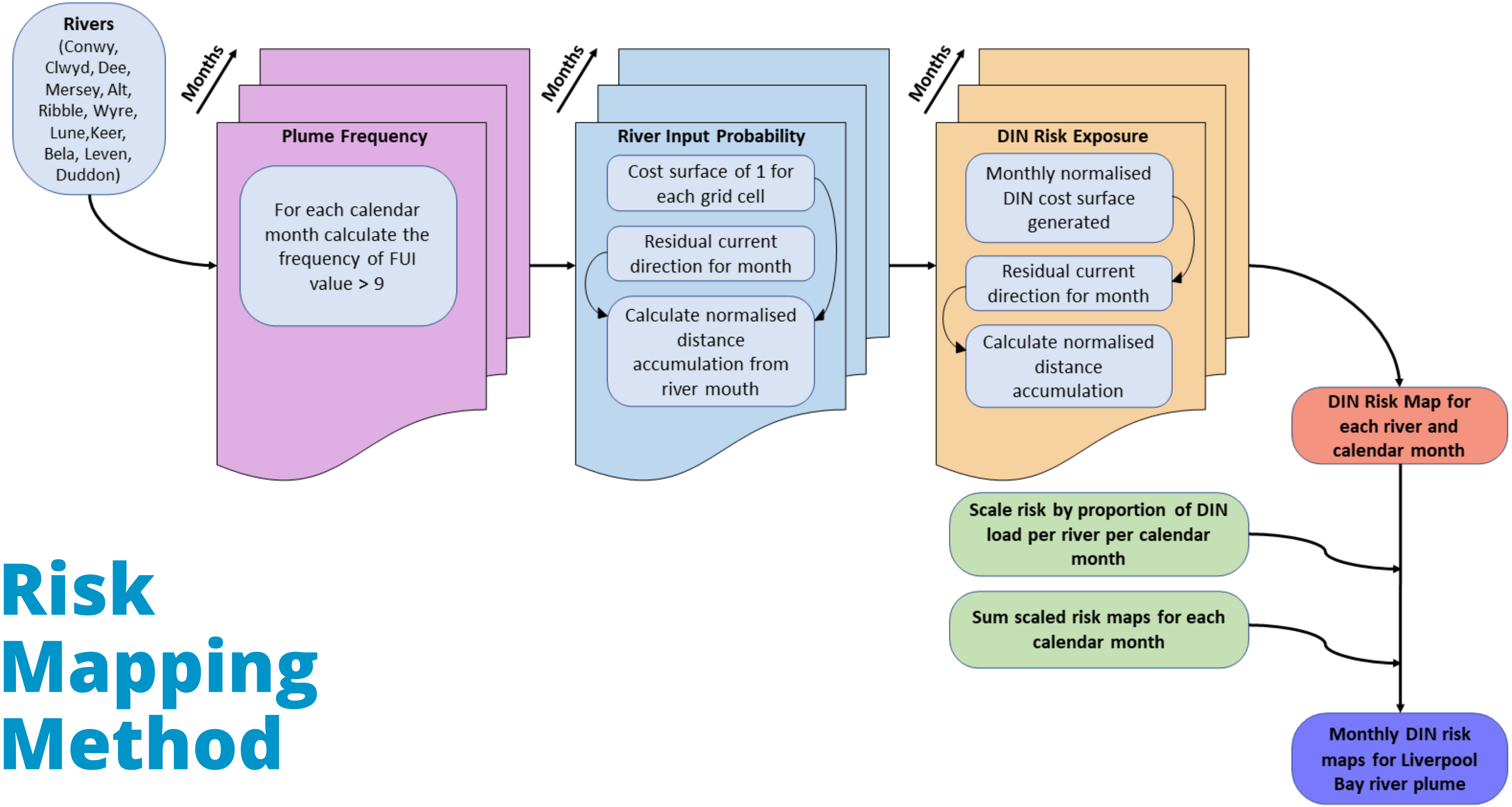
Hydrodynamic models

- Considers the complete water column and potential stratification (3D)
- Tracking of nutrients allow accurate consideration of transit
- Computationally demanding
- Rely on in situ data for validation
- Bespoke

Study area – Liverpool Bay

- Eastern section of the Irish Sea off the North-West coast of England and the North-East coast of Wales
- Shallow bay – less than 50m depth
- Freshwater input from 12 major rivers along the coastline
  - **Clwyd**
  - **Dee**
  - **Mersey**
  - **Ribble**
  - **Wyre**
  - Conwy, Alt, Lune, Keer, Bela (including Kent), Leven & Duddon



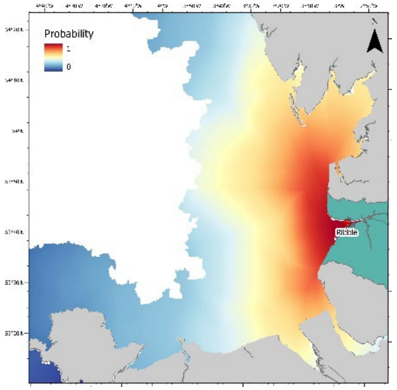


Risk Mapping Method

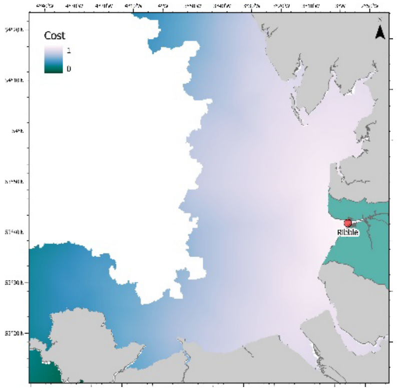
Example DIN exposure risk map

- Monthly DIN exposure risk maps generated (2017 – 2021)

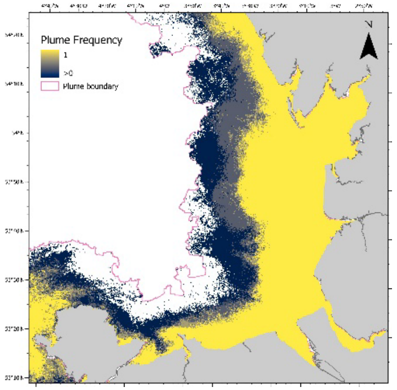
Likelihood location reached by river



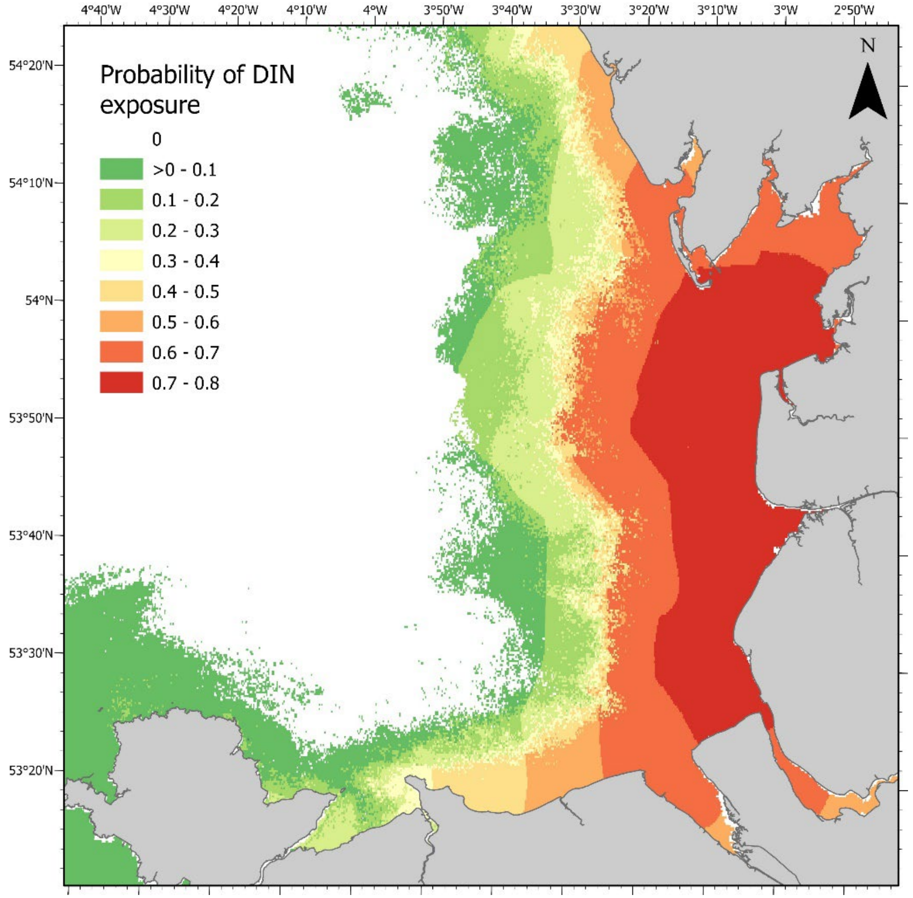
Likely relative DIN level from river



Temporal (monthly) chance of DIN presence



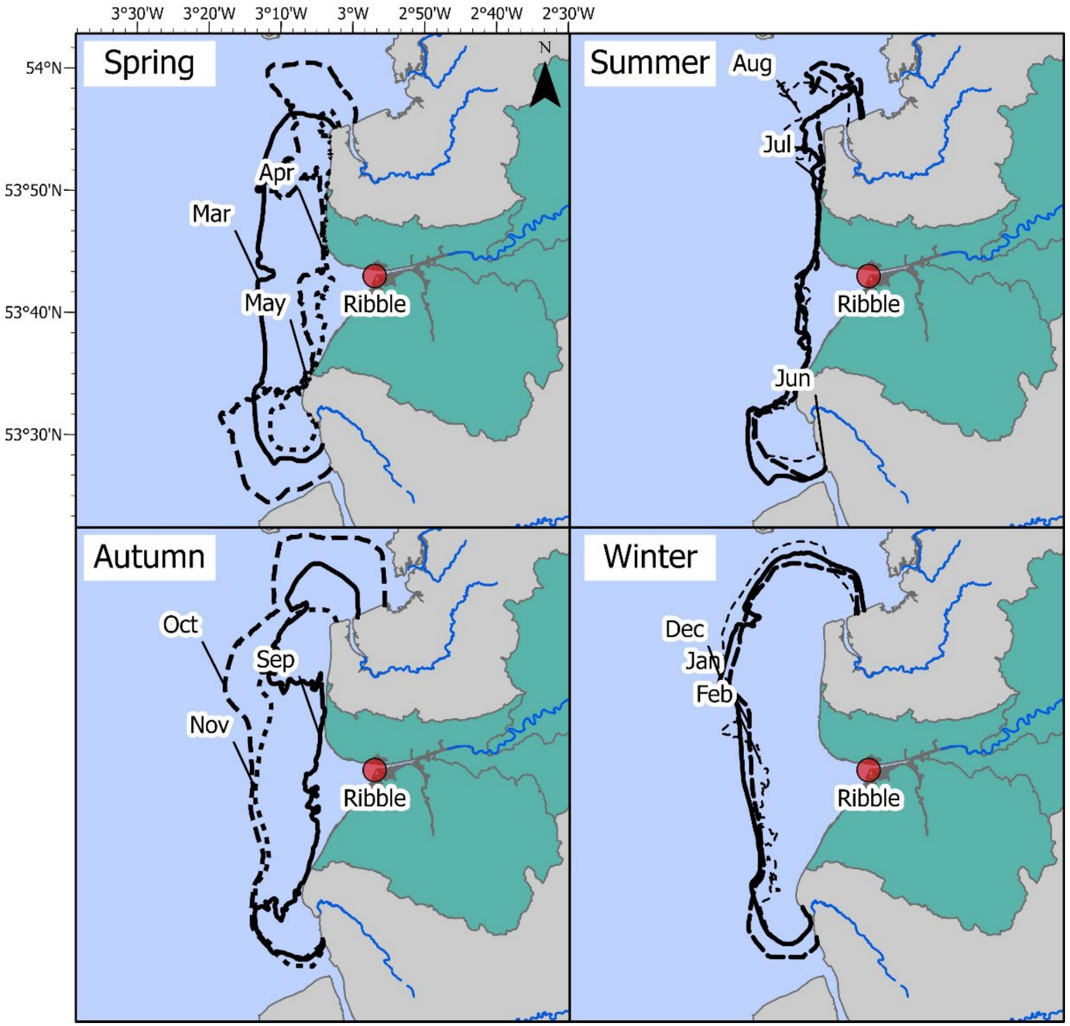
- Example – river Ribble for January



Risk of DIN exposure map

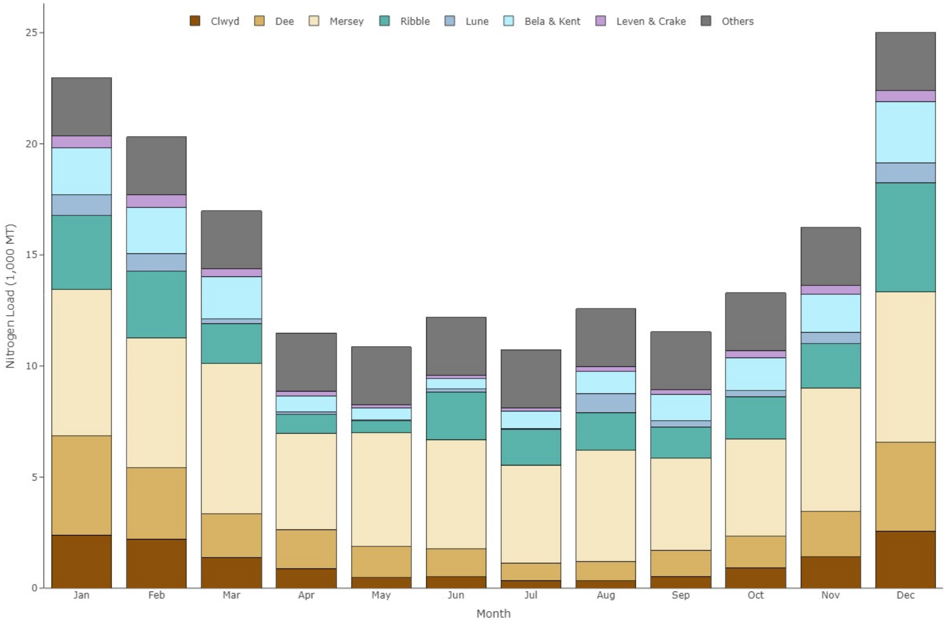
Seasonal DIN Exposure Risk

- Contour lines generated to mark the boundary of coastal waters with a risk > 0.75
- 0.75 risk contour line was restricted to nearshore coastal water north and south of the river mouth
- Extended into the open ocean during the autumn
- Extend was greatest in Nov, Dec, Jan and Feb
- Incursion into nearby Mersey was seen in spring (not at peak extent)

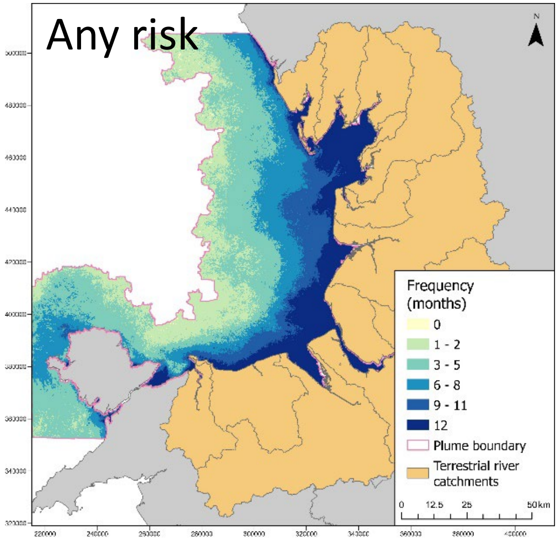


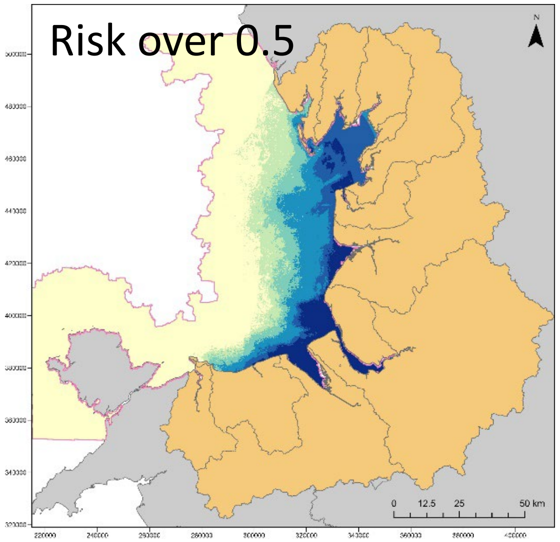
Understanding the influence of all inputs

- Exposure to DIN risk maps generated for all 12 rivers
- Maps scaled according to the relative input of DIN to the bay
  - Based on in situ riverine measurements



- Cumulative risk maps generated for all 12 months/seasonal/annual
- Frequency of risk categories over the year shown opposite



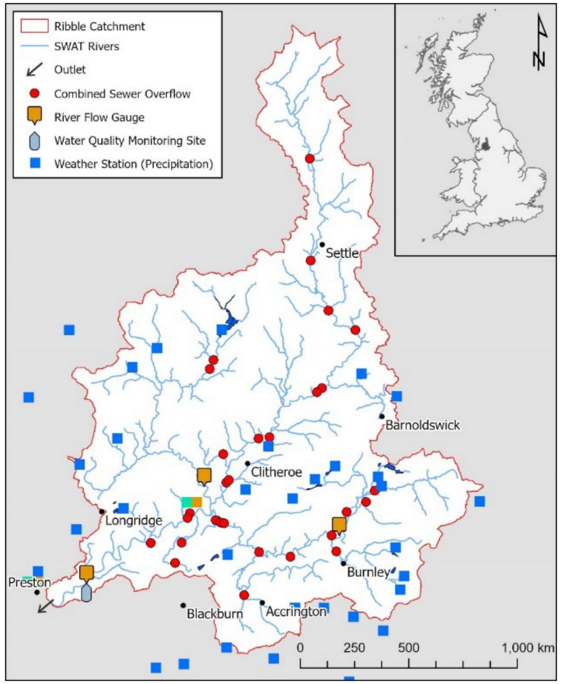


Source apportionment of DIN and climate change modelling

- Catchment models can be used to identify key sources/sinks
  - Need good spatial data
- SWAT+ models generated for all 12 catchments
  - Initial models set up, calibrated and run
  - Promising initial results
- Weather data supplied at defined weather station locations matched to climate change models

Example SWAT+ Model (Ribble)

- Model sensitivity analysis and calibration performed (SWAT Toolbox)
  - Streamflow validation
    - Monthly – NSE 0.71 (pBIAS 13%)
    - Model less responsive on daily basis
  - Nutrient data gap



- Baseline model run with climate change data

Parameter		Value
Catchment area (km^2)		1934.7
Maximum catchment elevation (m)		693
Mean catchment elevation (m)		159
Number of subbasins		14
Catchment land use/land cover (%)	**Urban**	**14.1**
	Agriculture	**65.7**
	Arable	7.5
	Pasture	6.4
	Improved grassland	51.8
	Forest	**1.3**
	Scrub	**9.3**
	Natural grassland	4.9
	Moors and heathland	4.4

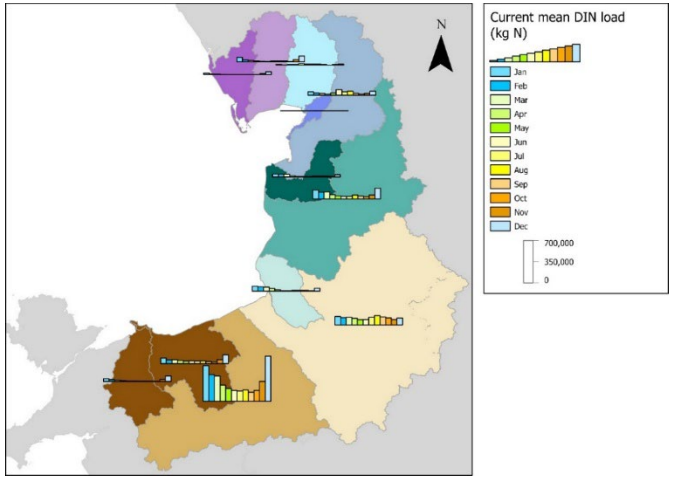
Change in Flow Rate & DIN Loads under r001i1p02123

Statistic		River Catchment											
		Alt	Bela	Conwy	Clwyd	Dee	Duddon	Kent	Leven	Lune	Mersey	Ribble	Wyre
Mean relative* monthly flow rate	Winter	**1.01**	*0.94*	*0.82*	*0.51*	*0.59*	*0.87*	**1.76**	*0.94*	*0.92*	**1.06**	*0.81*	**1.09**
	Spring	**1.16**	**1.14**	**1.02**	*0.72*	*0.69*	*1.03*	**2.22**	*0.94*	**1.32**	*0.93*	**1.24**	**1.70**
	Summer	*0.92*	*0.39*	*0.51*	*0.20*	*0.28*	*0.63*	**2.09**	*0.54*	*0.69*	*0.62*	*0.69*	**1.33**
	Autumn	*0.72*	*0.33*	*0.33*	*0.14*	*0.22*	*0.34*	**1.04**	*0.43*	*0.57*	*0.62*	*0.53*	*0.83*
	Annual	*0.95*	*0.70*	*0.67*	*0.39*	*0.44*	*0.72*	**1.78**	*0.71*	*0.88*	*0.81*	*0.82*	**1.24**
Mean relative* DIN loads	Winter	**1.26**	*0.87*	**1.17**	**1.20**	*0.76*	*0.78*	**1.69**	*0.78*	*0.91*	**2.84**	*0.91*	*0.87*
	Spring	**1.66**	**1.09**	**1.43**	**1.04**	**1.07**	*0.74*	**1.48**	*0.97*	*0.94*	**2.13**	**1.28**	**1.14**
	Summer	**1.43**	**1.63**	**1.72**	*0.40*	*0.74*	*0.54*	**1.30**	**1.04**	**1.13**	**1.86**	*0.93*	*0.98*
	Autumn	*0.85*	*0.77*	*0.65*	*0.41*	*0.20*	*0.14*	**1.12**	*0.52*	**1.05**	*0.97*	*0.64*	*0.59*
	Annual	**1.30**	**1.09**	**1.25**	*0.76*	*0.69*	*0.55*	**1.40**	*0.83*	**1.01**	**1.95**	*0.94*	*0.89*

* - relative values are for predictions under r001i1p02123 versus current day

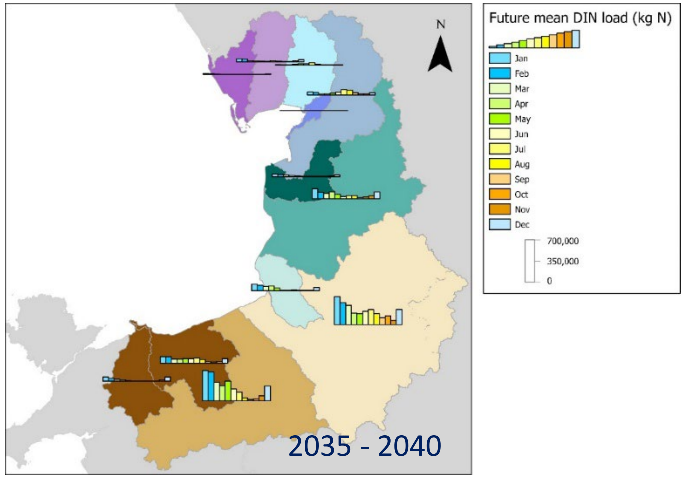
Modelling changes from land use and climate

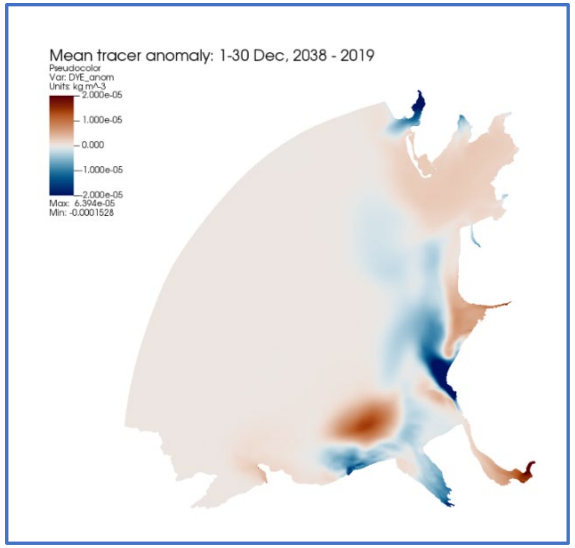
Present day

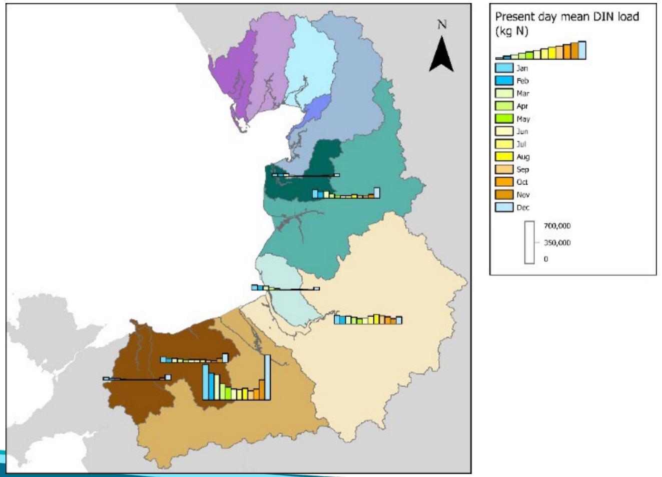


High emissions scenario (RCP 8.5)

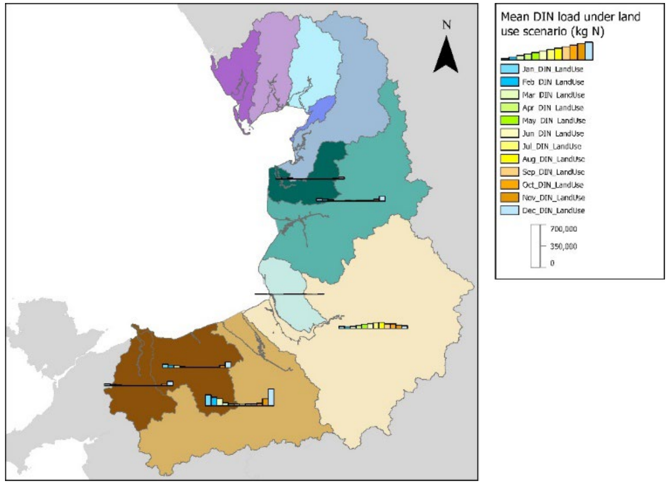
Future





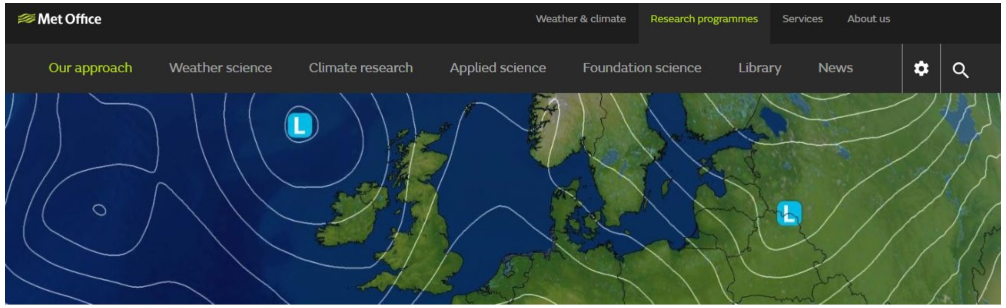


Convert low-grade agricultural land to wetland and transitional woodland



- **Climate:** Higher winter DIN maxima, occurring later, potential impact on spring biomass
- **Land use:** DIN loads to marine environment reduced, notably in winter
- **Potential** for targeted land use change to offset impacts of climate change

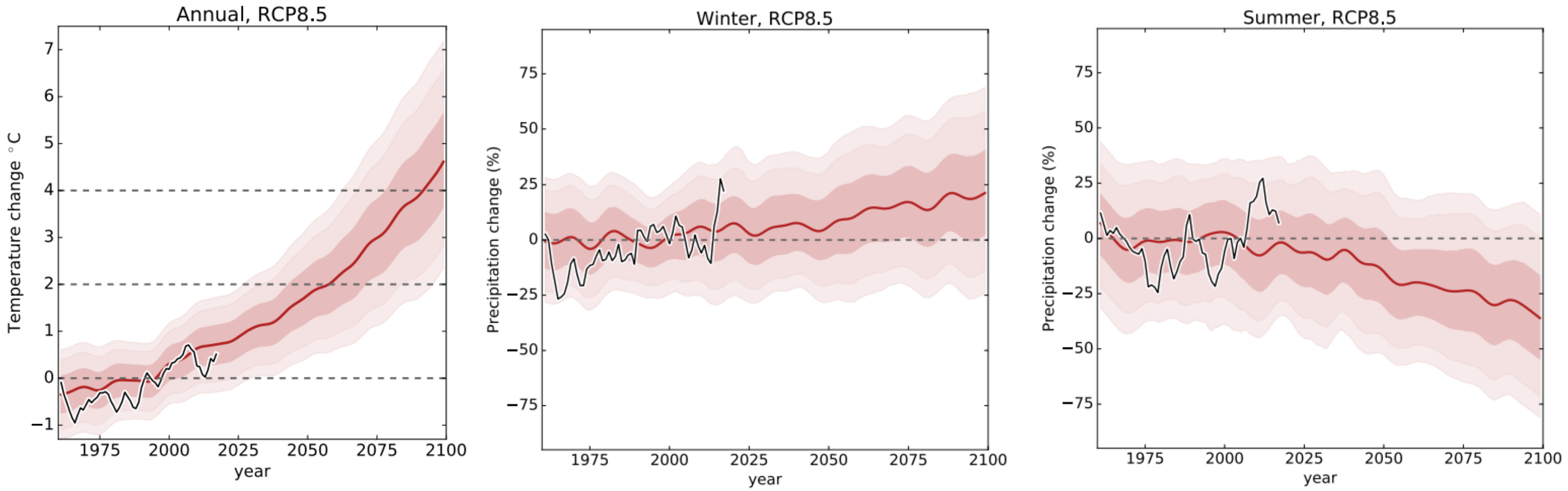
UK Climate Change Projections



UK Climate Projections (UKCP)

https://www.metoffice.gov.uk/research/approach/collaboration/ukcp

- Regional projections using 12 GC3.05 PPE members which are driven by global simulations under RCP8.5.
  - RCP8.5 predicts a 3.9C rise in median annual temperature (2080-2099 versus 1981-2000)
- Projections are on 5km grid for the British Isles (day, month, year)
  - Precipitation, air temp, E & N wind speed, relative humidity, net surface short wave radiation



- Predict:
  - Increase in annual mean temperature
  - Increase in winter precipitation
  - Decrease in summer precipitation

Graphs from Lowe et al., 2018

Summary statistics of climate change precipitation data

Statistic	Current	Future under climate change models (member number)												
		All	00000	01113	01554	01649	01843	01935	02123	02242	02305	02335	024915	02868
Mean Daily (mm)	3.6	**4.1**	**4.2**	**4.2**	**4.1**	**3.9**	**4.1**	**4.3**	*3.6*	**4.1**	**4.2**	**4.0**	**4.0**	**4.6**
Winter	3.8	**5.3**	**5.5**	**4.1**	**4.9**	**5.6**	**5.5**	**6.4**	**4.4**	**5.1**	**5.5**	**5.3**	**5.6**	**5.9**
Spring	3.3	*3.3*	**3.7**	*3.0*	*3.2*	*3.1*	*3.0*	**3.7**	*3.0*	**3.6**	*3.2*	**3.4**	*3.1*	**3.7**
Summer	3.8	*3.2*	*3.3*	*3.7*	*3.7*	*2.2*	*3.5*	*2.9*	*3.3*	*3.0*	**3.9**	*3.1*	*2.5*	*3.4*
Autumn	3.6	**4.6**	**4.4**	**6.0**	**4.5**	**4.6**	**4.3**	**4.4**	**3.7**	**4.9**	**4.3**	**4.2**	**4.7**	**5.4**
High rainfall (95 percentile)	15.7	**18.5**	**19.6**	**18.6**	**19.2**	**18.1**	**18.4**	**19.2**	**16.9**	**18.4**	**19.0**	**17.6**	**18.3**	**19.9**
Mean days per year with no rainfall	41.2	**105.9**	**104.5**	**92.9**	**103.9**	**113.4**	**105.4**	**106.7**	**120.1**	**105.7**	**103.0**	**94.5**	**119.0**	**101.5**
Mean days per year above current mean rainfall	109.3	**114.1**	**113.9**	**117.1**	**114.7**	*106.2*	**112.4**	**119.9**	*102.4*	**115.4**	**117.1**	**114.6**	**110.3**	**125.2**

Ribble Catchment - Change in Flow Rate Statistics

- Using observed and projections on 5km grid for the British Isles (day, month, year)
  - **Pseudo-weather stations at the centroid location**
  - Monthly – NSE 0.90 (pBIAS 9.5%)
- Range of differences in the flow rate change observed
  - Small increase in flow rate at the output that was more marked in Autumn and Winter

Statistic		Future under climate change models (member number)													
		All	00000	01113	01554	01649	01843	01935	02123	02242	02305	02335	024915	02868	
Relative Mean Monthly Flow	Winter	1.28	1.30	1.06	1.21	1.29	1.19	1.63	*0.94*	1.19	1.39	1.49	1.28	1.39	11/12
	Spring	1.14	1.78	1.18	1.07	1.14	*0.93*	1.41	*0.82*	*0.93*	1.16	1.05	1.16	1.02	9/12
	Summer	1.09	*0.47*	*0.68*	*0.77*	*0.25*	1.19	1.73	1.00	1.19	1.23	1.53	1.40	1.64	7/12
	Autumn	1.28	*0.81*	1.28	1.06	*0.75*	1.30	1.82	1.22	1.30	1.07	1.52	1.34	1.93	10/12
	Annual	1.09	1.09	1.05	1.03	*0.86*	1.08	1.30	*0.95*	1.08	*0.89*	1.19	*0.95*	1.58	8/12

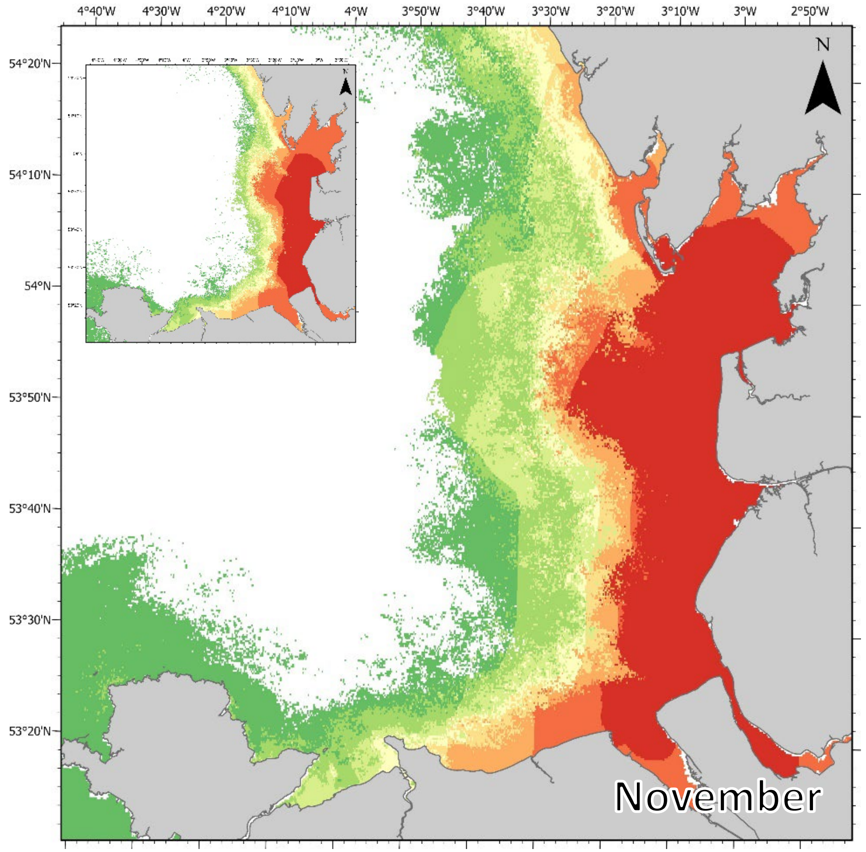
Ribble Catchment - Change in DIN Loads

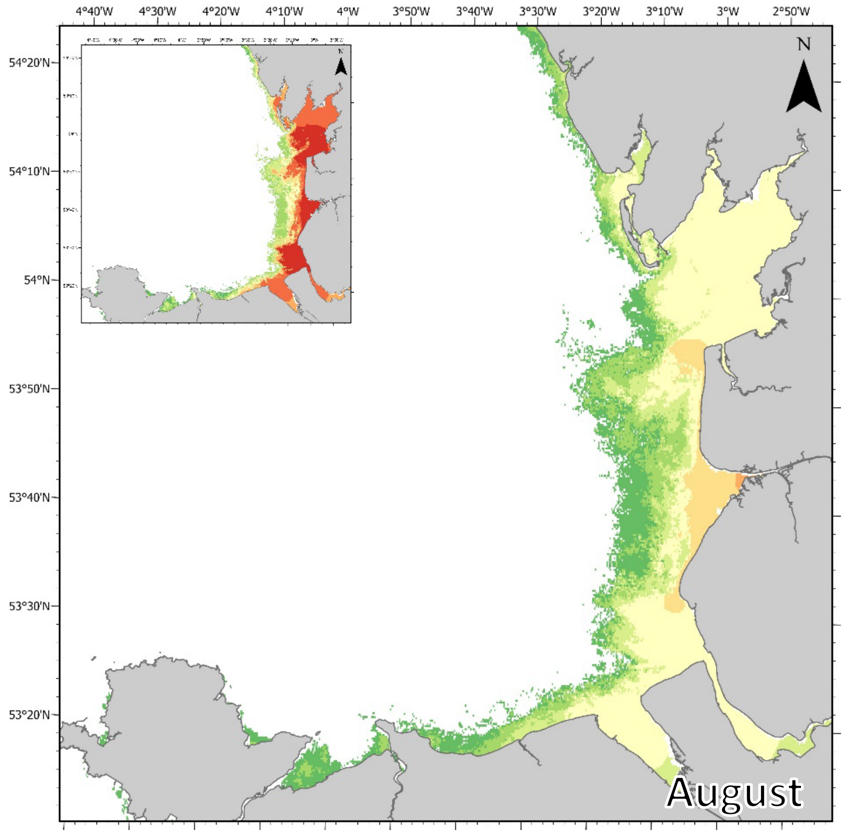
Statistic		Future under climate change models (member number)												
		All	00000	01113	01554	01649	01843	01935	02123	02242	02305	02335	024915	02868
Relative Mean Monthly Flow	Winter	0.86	0.83	0.74	0.86	0.86	0.80	**1.14**	0.73	0.80	**1.00**	0.85	0.93	0.79
	Spring	0.67	0.67	0.61	0.56	0.51	0.60	0.96	0.63	0.60	0.91	0.68	0.76	0.60
	Summer	0.68	0.69	0.83	0.82	0.48	0.54	0.90	0.52	0.54	0.78	0.69	0.72	0.64
	Autumn	0.70	0.72	0.93	0.86	0.75	0.56	0.77	0.65	0.56	0.61	0.57	0.64	0.72
	Annual	0.70	0.73	0.78	0.77	0.65	0.67	0.69	0.77	0.67	0.73	0.62	0.62	0.76

- Decreased DIN output from the catchment under RCP8.5
- Note that the land cover and management practices were the same under the climate change scenarios
  - Currently factoring in different land management approaches based on climate change

DIN Risk Exposure under Climate Change

- Risk is scaled versus the baseline DIN risk exposure
- Results are shown for climate change model r001i1p02123





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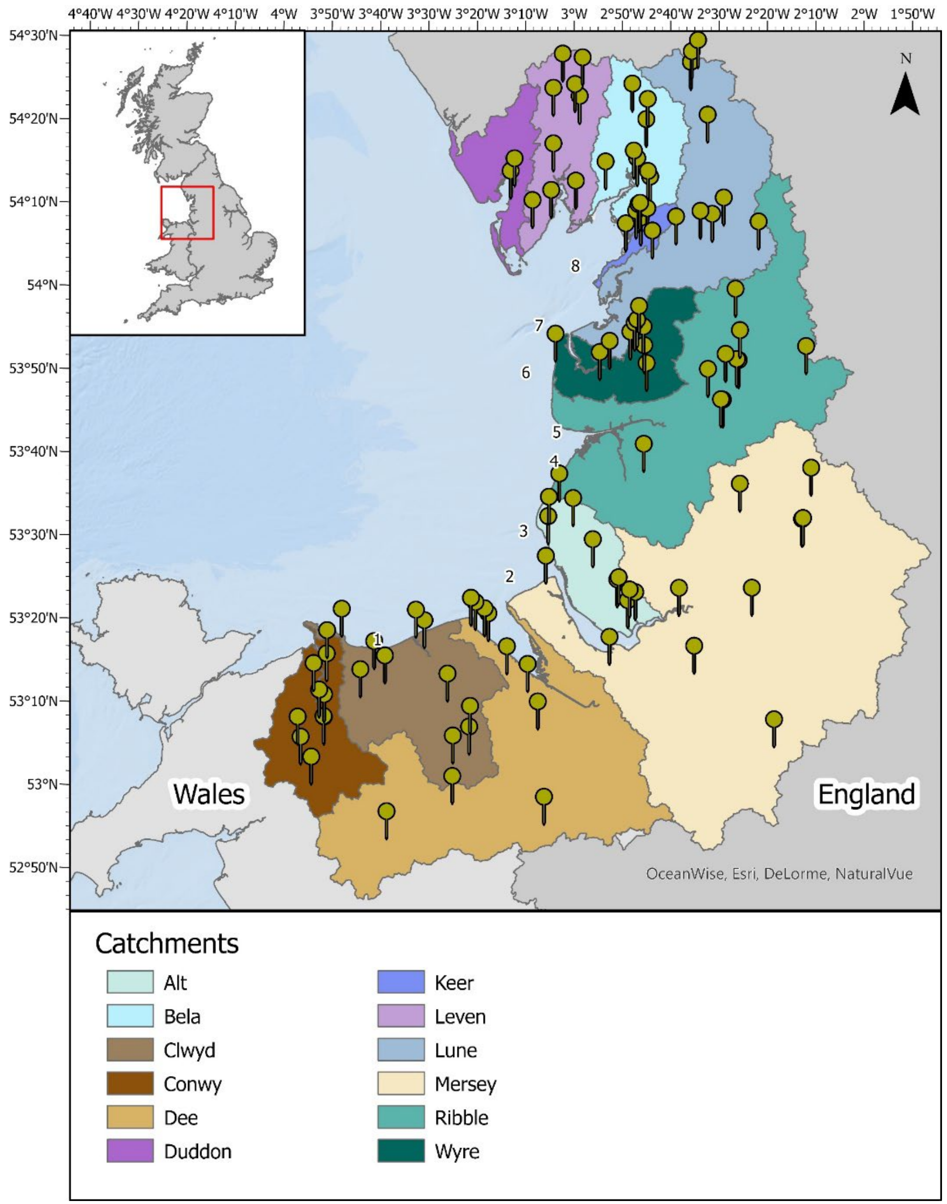
Incorporating point sources

- Combined Sewer Overflows and Waste Water Treatment outfalls incorporated into models
- Data on the exact time and volume of spills into the watercourses is limited



Estimating climate change effect on CSOs

- Using a rainfall trigger to disperse the CSO spills based on the local rainfall to the CSO
- 12 members of UKCP18 RCP8.5 5km local projections were used
- Trigger set at the trigger used in 2020
- Mean is the mean number across the 12 members

Ribble CSO	Number of Spills	
	Current	Climate change
1	201	*169*
2	33	**129**
3	38	*30*
4	59	*56*
5	170	*142*
6	290	**365**
7	330	**365**
8	166	*141*
9	273	**365**
10	32	*22*

Ribble SWAT Model

- ArcSWAT model generated to enable incorporation of CSOs
  - Is this going to be included in SWAT+ soon?
- Currently recalibrating the model
  - Differences between SWAT2012 and SWAT+

Parameter			Ribble
Catchment area (km²)			**1948.2**
Maximum catchment elevation (m)			**693**
Mean catchment elevation (m)			**159**
Number of subbasins			**79**
Catchment land use/land cover (%)	**Urban**		**14.3**
	Agriculture		**63.1**
		Arable	7.3
		Pasture	9.3
		Improved grassland	46.5
	Forest		**3.1**
	Scrub		**10.1**
		Natural grassland	5.2
		Moors and heathland	4.9

Summary

1. Risk mapping approach developed to enable assessment using Earth observation data
2. Coupling of SWAT catchments models to the risk assessment framework to enable source apportionment
3. Demonstrated the use of SWAT model under climate change and land use change scenarios to assess impact in the coastal zone
   - Need to consider uncertainty in climate change models and weather station locations
   - Are SWAT parameters sensitive to climate change?

Next steps…

1. Refinement of the SWAT models to better model nutrient and pathogen transmission
    1. Improvement to CSO spill data – when, how much etc.
    2. Incorporation of WWTW & septic tanks (where known) into the model
    3. Better coverage of land practices
2. Using outputs from the refined models of the 12 catchments to produce cumulative DIN exposure risk maps
3. Development of the risk mapping approach to include spread of pathogen (bacteria) in the coastal waters
    1. Adapt the method to involve die-off within saline waters
4. Application of the process to other UK catchments (Thames)
5. Augmentation of the approach with environmentally vulnerable species, such as maerl, sea grass etc.

References

- Lowe, J.A., Bernie, D., Bett, P., Bricheno, L., Brown, S.J., Calvert, D., Clark, R.T., Eagle, K.E., Edwards, T., Fosser, G., Fung, F., Gohar, L., Good, P., Gregory, J., Harris, G.R., Howard, T.P., Kaye, N., Kendon, E.J., Krijnen, J., Maisey, P., McDonald, R., McInnes, R.N., McSweeney, C.F., Mitchell, J.F.B., Murphy, J.M., Palmer, M., Roberts, C., Rostron, J.W., Sexton, D.M.H., Thornton, H.E., Tinker, J., Tucker, S., Yamazaki, K. & Belcher, S. 2018. *UKCP18 science overview report*. Exeter, England: Met Office Hadley Centre.

remote sensing

MDPI

Article

A probabilistic approach to mapping the contribution of individual riverine discharges into Liverpool Bay using distance accumulation cost methods on satellite derived ocean-colour data.

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Thanks for listening!

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