The Development of a Water Quality Forecasting System for Recreational Coastal Bathing Waters in Ireland

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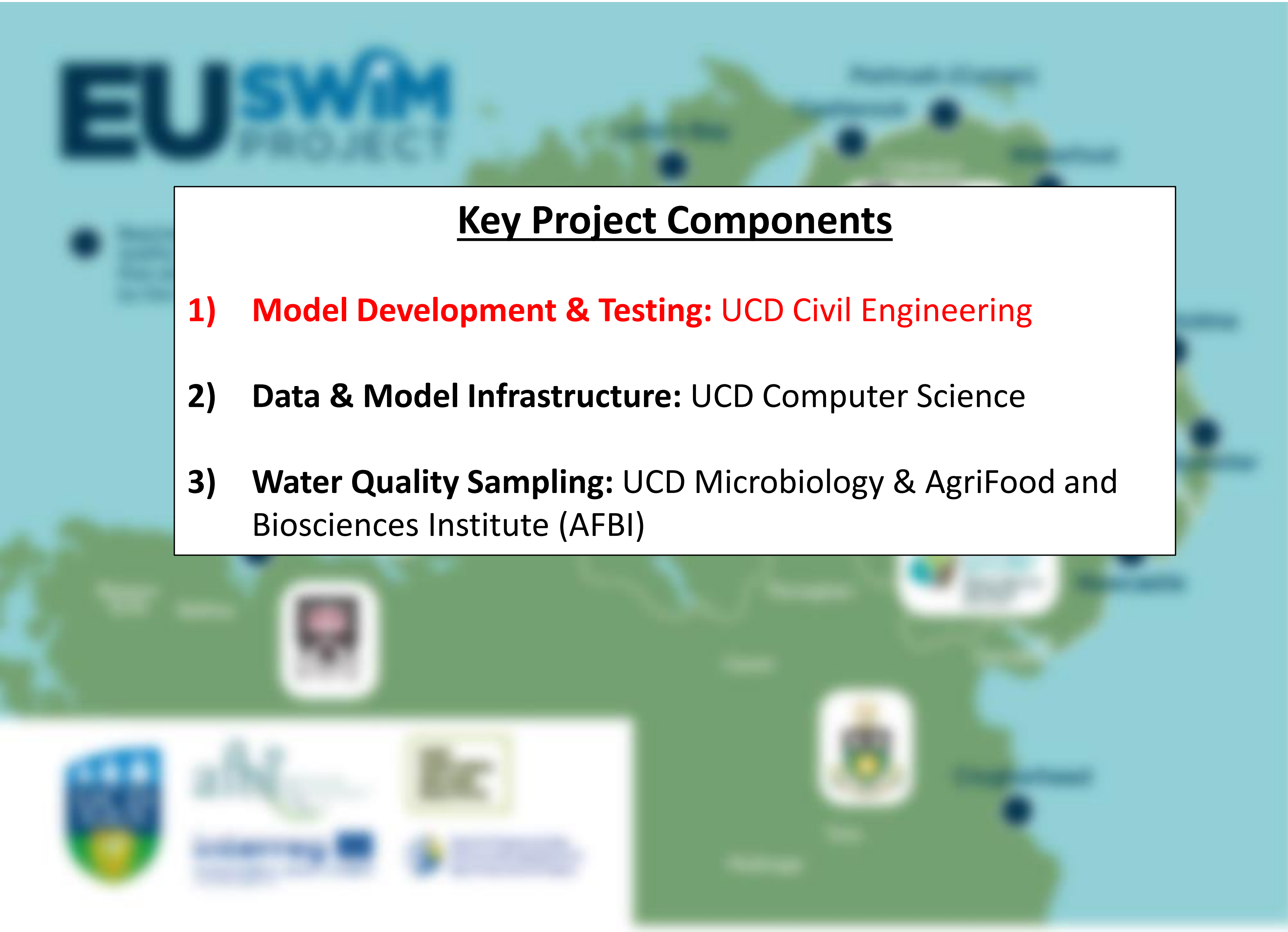
EUROPEAN UNION
Northern Ireland - Ireland - Scotland
European Regional Development Fund

Project Objectives

- European Bathing Water Directive requires the implementation of ***early warning systems for bathing waters*** which are subject to short-term pollution events.

- Coastal water quality prediction models and alert systems are being developed which aim to provide ***short-term forecasts of bathing water***.

- These forecasts are based on the (modeled) relationship between fecal indicator bacteria and ***multiple environmental variables***.



Key Project Components

1) **Model Development & Testing:** UCD Civil Engineering

2) **Data & Model Infrastructure:** UCD Computer Science

3) **Water Quality Sampling:** UCD Microbiology & AgriFood and Biosciences Institute (AFBI)


EU SWIM PROJECT
Beaches where water quality, weather and river flow are being monitored by the SWIM Project
Portrush (Curran)
Castlerock
Lady's Bay
Waterfoot
Coleraine
Causeway Coast & Glens Borough Council
Creeslough
Letterkenny
Derry/Londonderry
Ballymena
Comhairle Contae Dhún na nGall
Donegal County Council
Larne
Strabane
Ballyholme
Ardara
Donegal
Omagh
Ards and North Down Borough Council
Bangor
Belfast
Ballyshannon
Ballywalter
Portadown
Banbridge
Enniscrone
Enniskillen
Sligo
Newcastle
Bangor Erris
Ballina
Monaghan
an Iúir, Mhúrn agus an Dúin
Newry, Mourne and Down District Council
Dundalk
Cavan
Clogherhead
Trim
Mullingar
UCD DUBLIN
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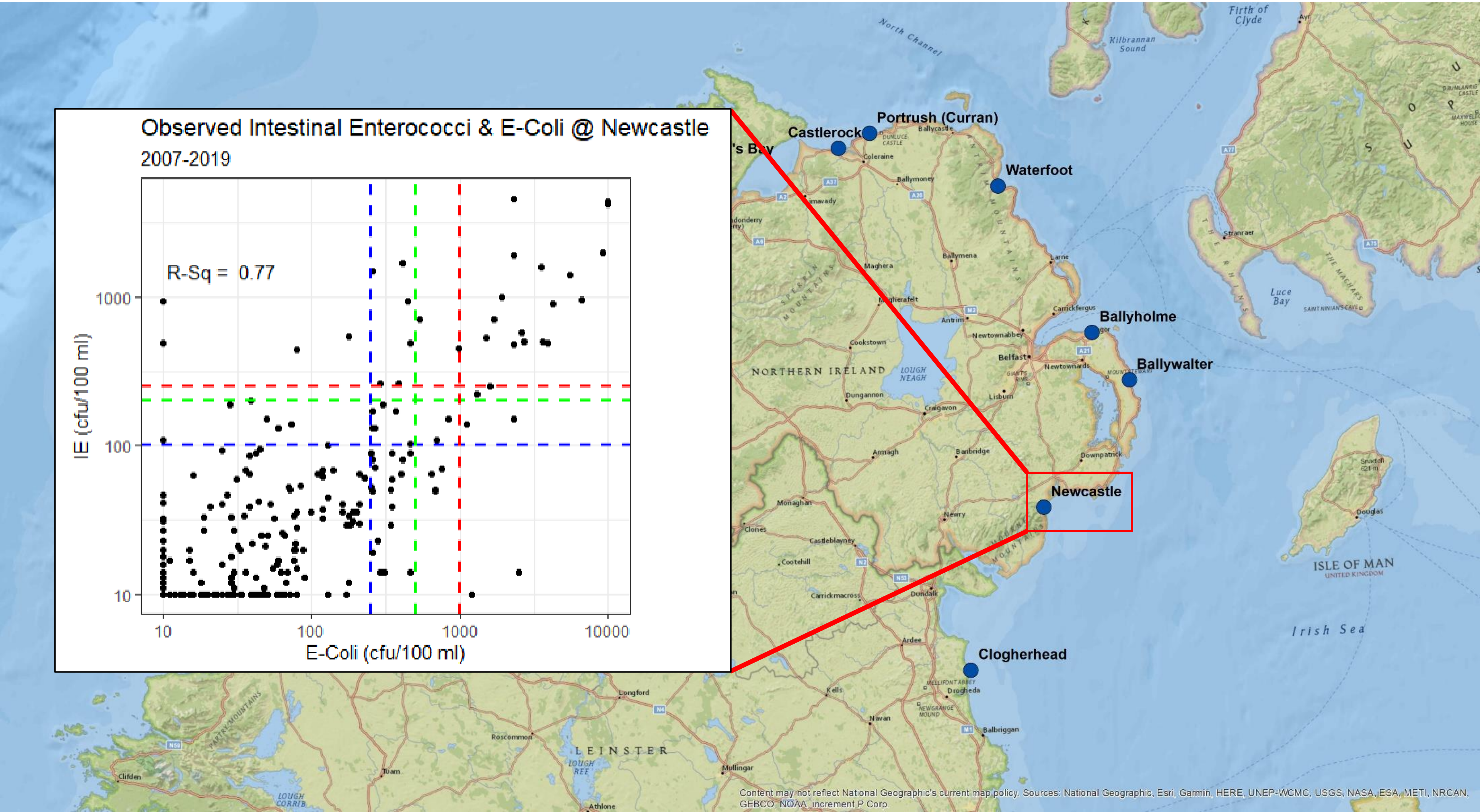
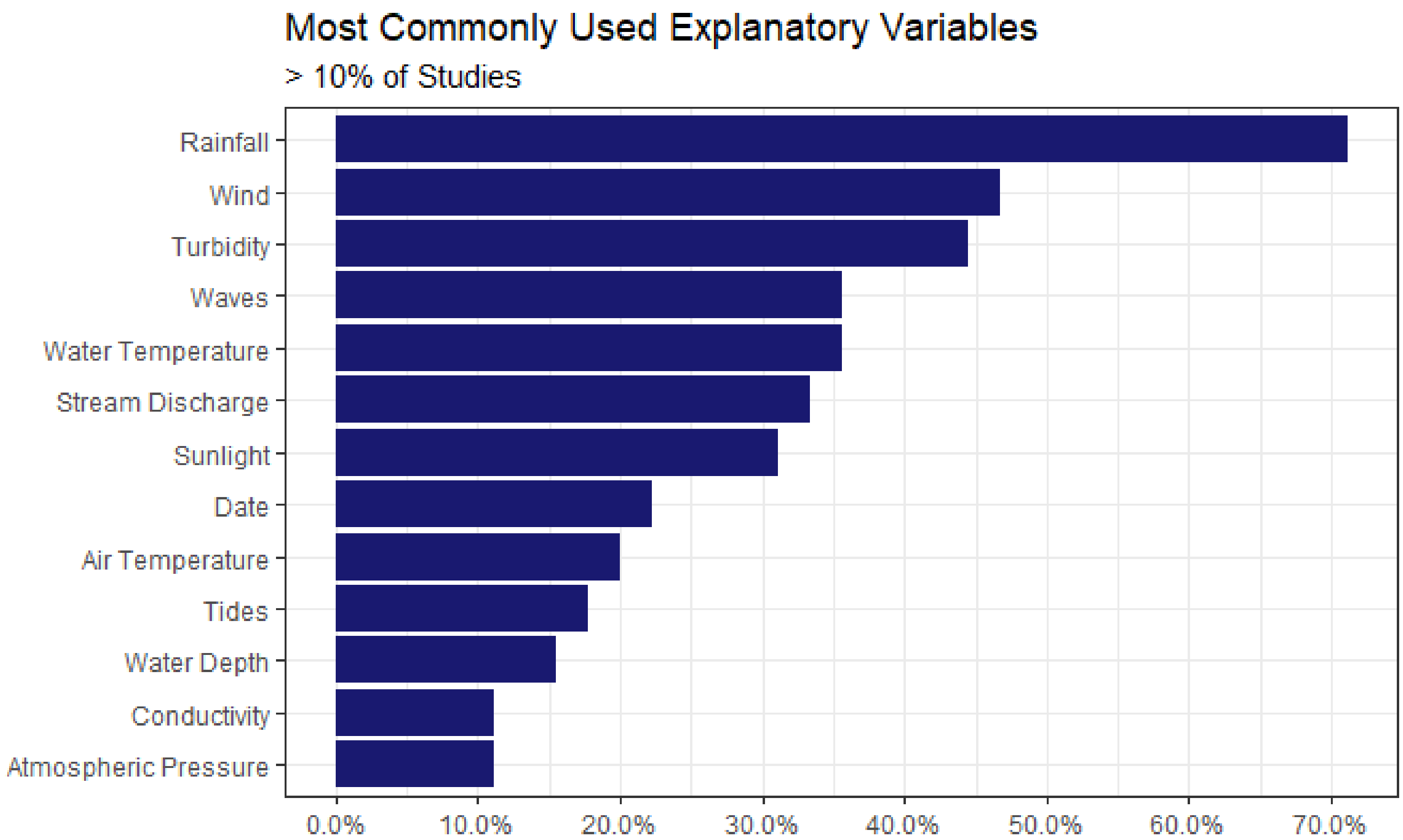
Special EU Programmes Body
Foras Um Chláir Speisialta An AE
Boord O Owre Ocht UE Projecks

Water Quality History Example @ Newcastle Beach

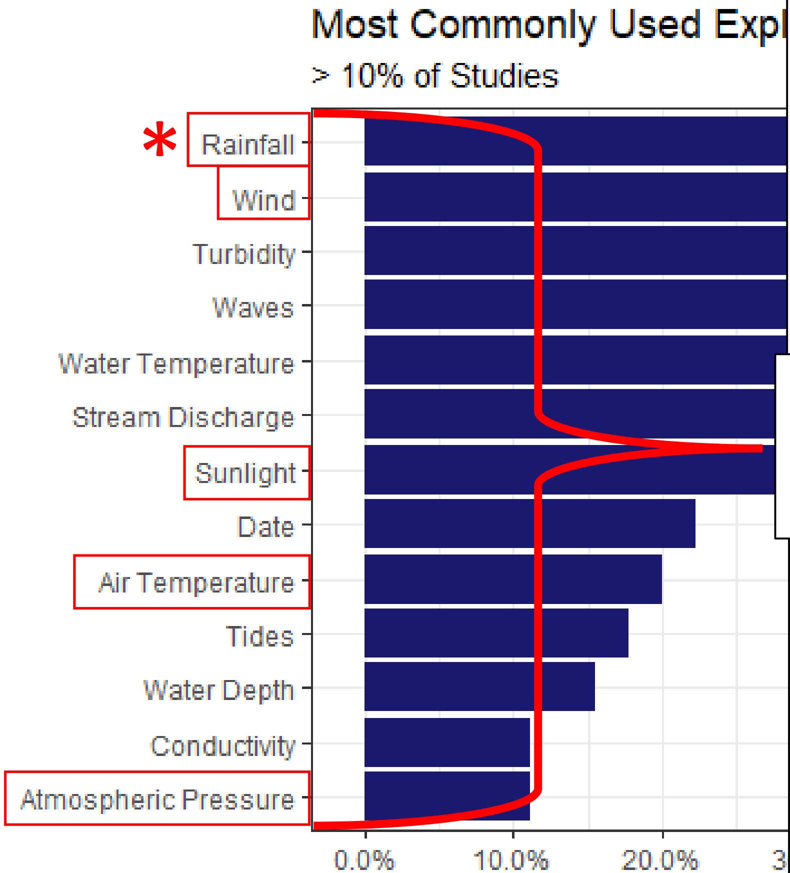


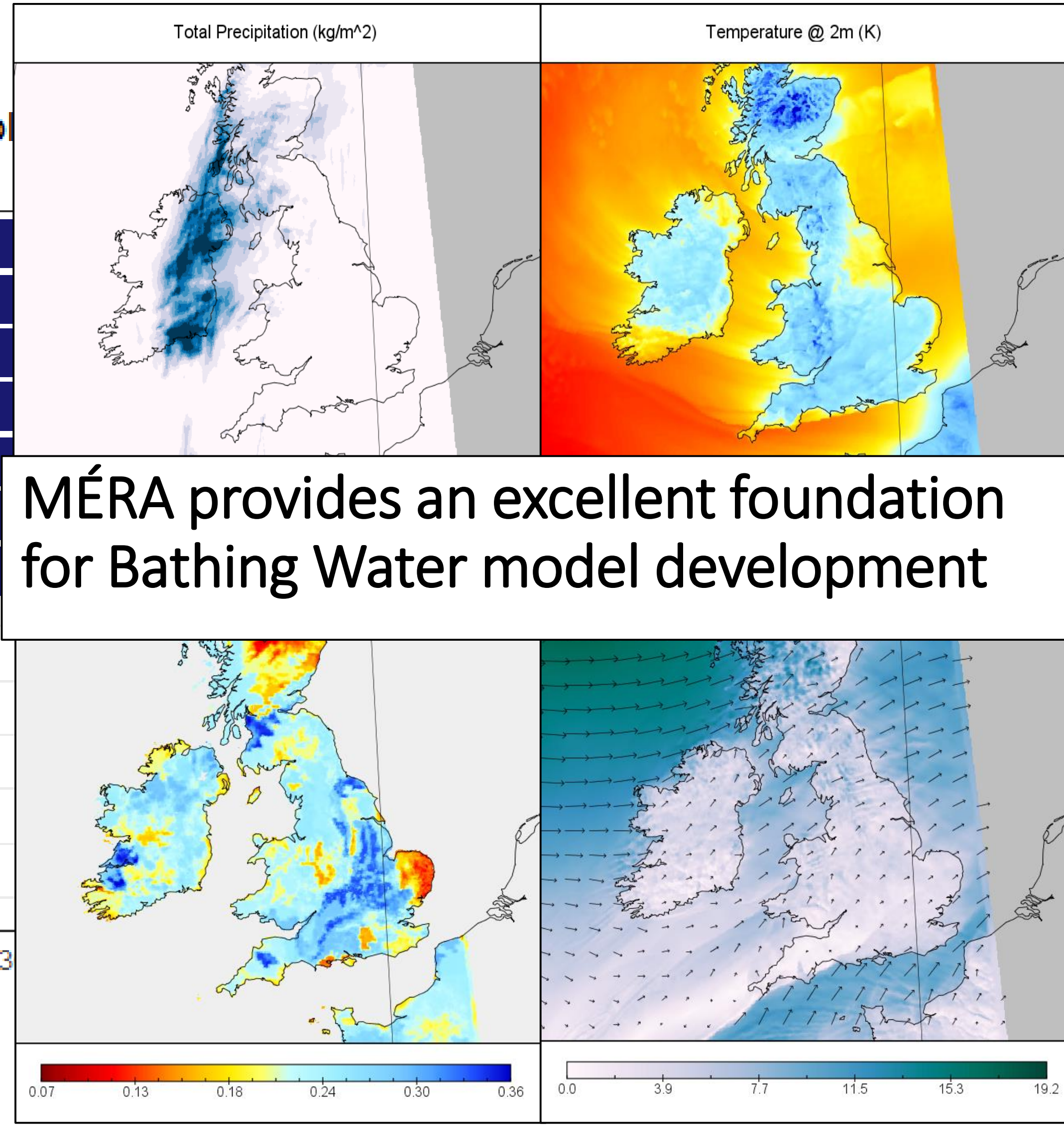
Environmental Variables from Previous Studies



Statistical Models for Bathing Water Prediction
are *Data Hungry*

MÉRA Data

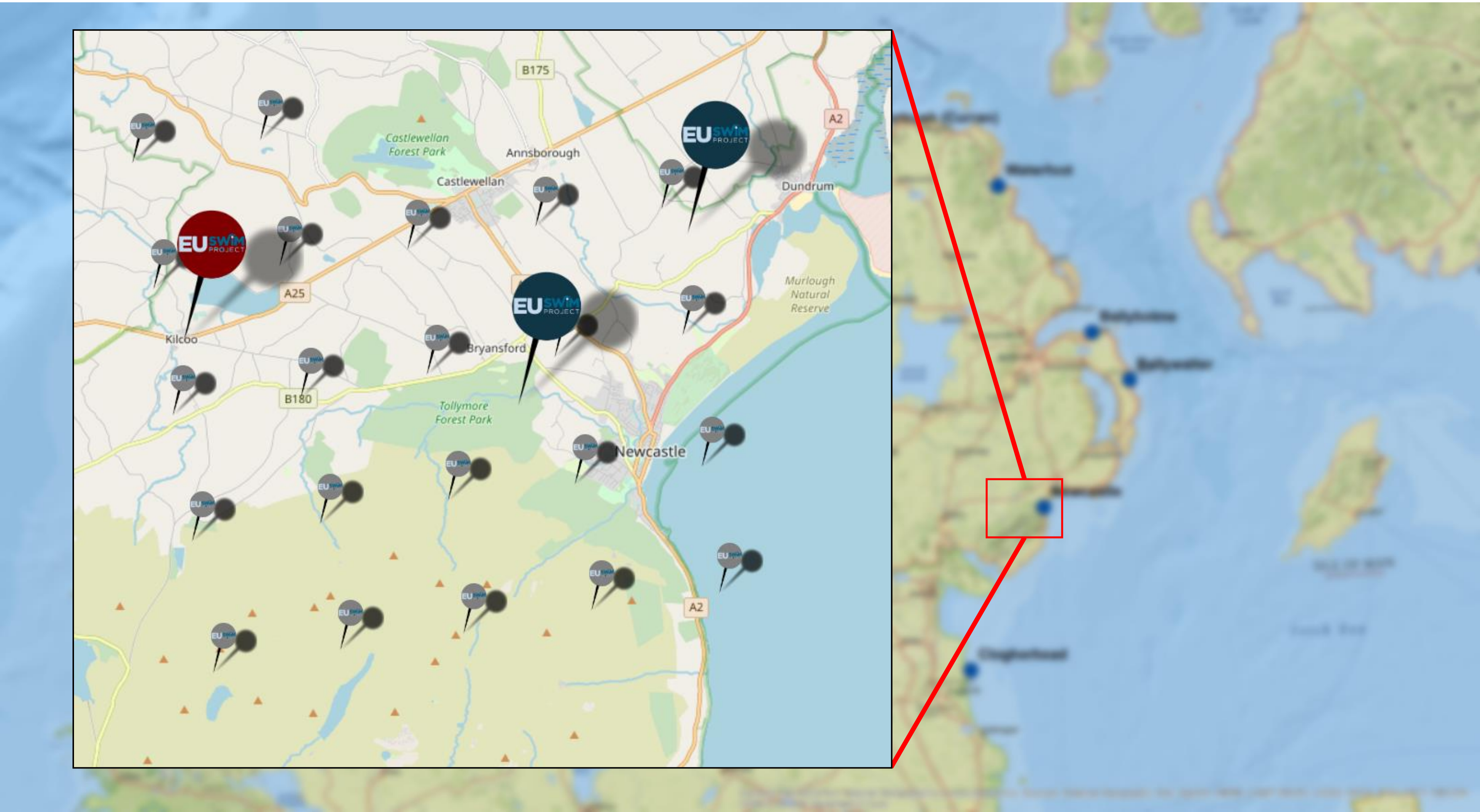




MÉRA provides an excellent foundation for Bathing Water model development

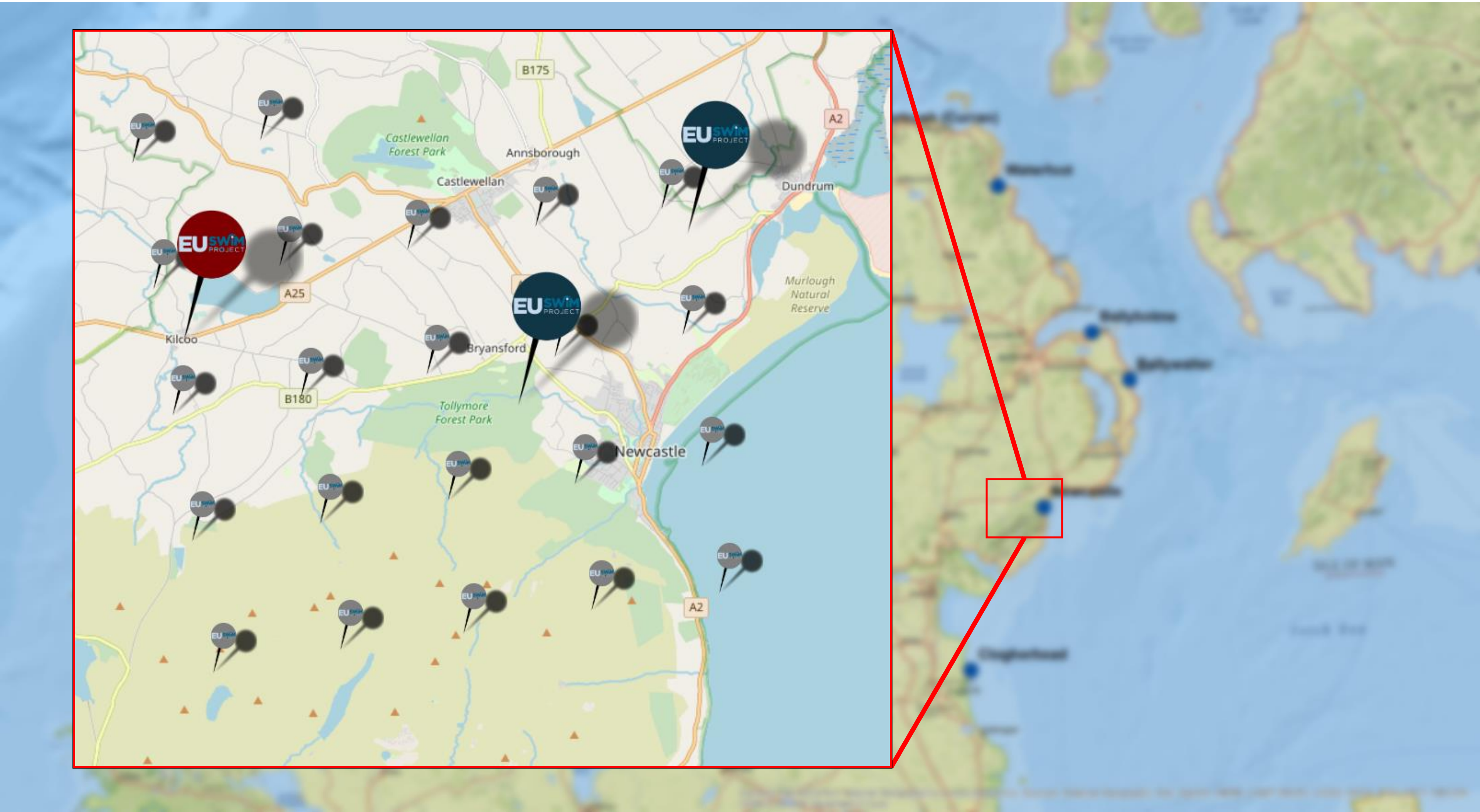
MÉRA Grid Points @ Newcastle Beach

- **Many MÉRA grid points within a target catchment area**
- **Provides high spatial & temporal resolution (far exceeding what could be gathered by gauges)**



MÉRA Grid Points @ Newcastle Beach

- **Precipitation (& soil moisture) used from ALL points within the catchment area.**
- Only the point closest to the sampling point is used for the other variables.



MÉRA Grid Points @ Newcastle Beach

- ❖ Precipitation (& soil moisture) used from ALL points within the catchment area.
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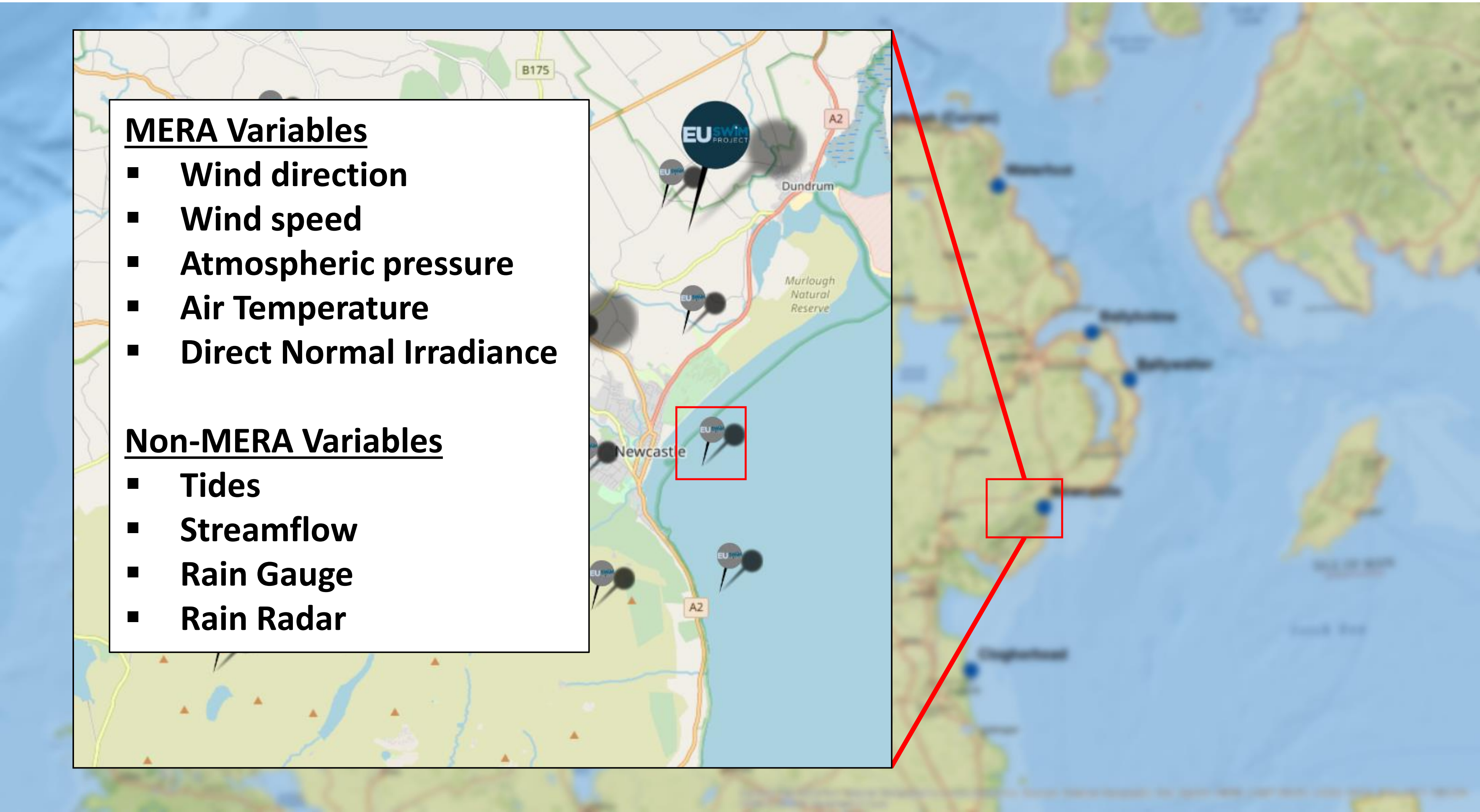


MERA Variables

- Wind direction
- Wind speed
- Atmospheric pressure
- Air Temperature
- Direct Normal Irradiance

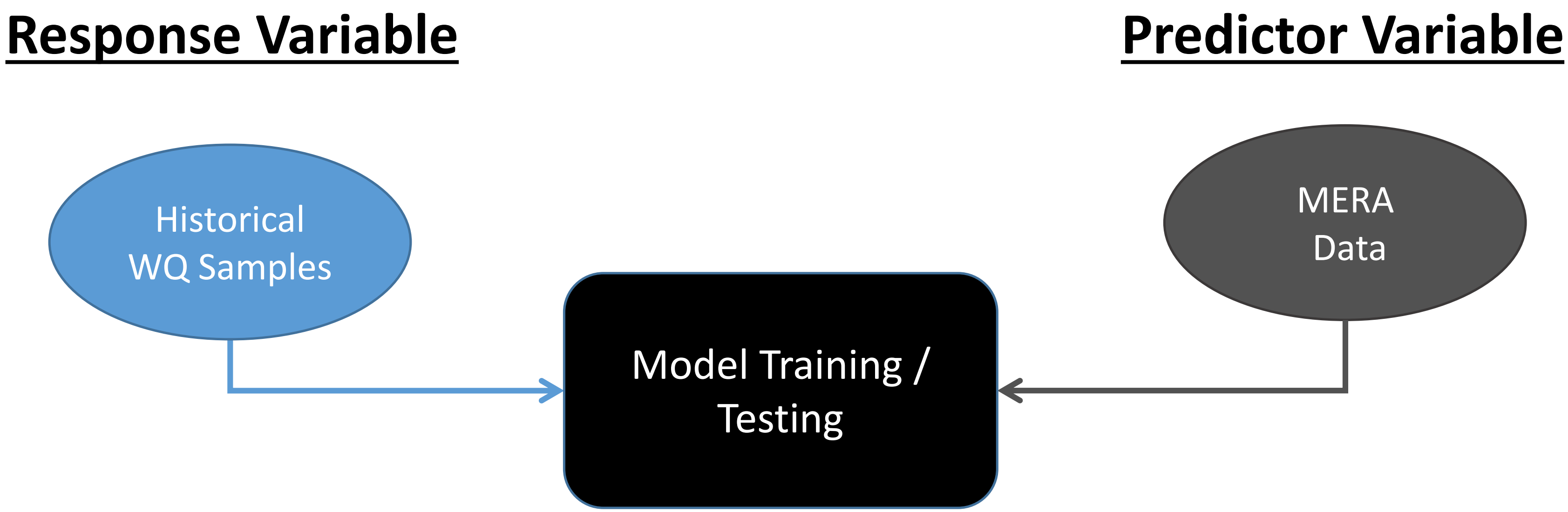
Non-MERA Variables

- Tides
- Streamflow
- Rain Gauge
- Rain Radar

Summary of Modelling Approaches

APPROACH	DESCRIPTION	STRENGTHS	WEAKNESSES
Decision Threshold Optimizer	Determines what level of rainfall / streamflow has correlated with past FIB exceedance levels to predict future occurrences.	• Uses readily available data (e.g. rainfall, streamflow) • Implemented in Excel	• Low correlations between single variables & FIB levels • Does not consider multiple-variable drivers.
Decision Tree Models	Trains models based on past relationship between environmental variables & FIB concentrations to predict future occurrences.	• Can utilize many variables • Can represent non-linear responses.	• Higher data requirements • Can suffer from "over-training"
Ensemble Decision Tree Models	Generates probabilistic predictions of FIB concentrations, based on many individual Decision-Tree models.	• Less susceptible to "over-training" • Improved predictive power	• Driving variables are more difficult to interpret • Higher data & technical requirements.

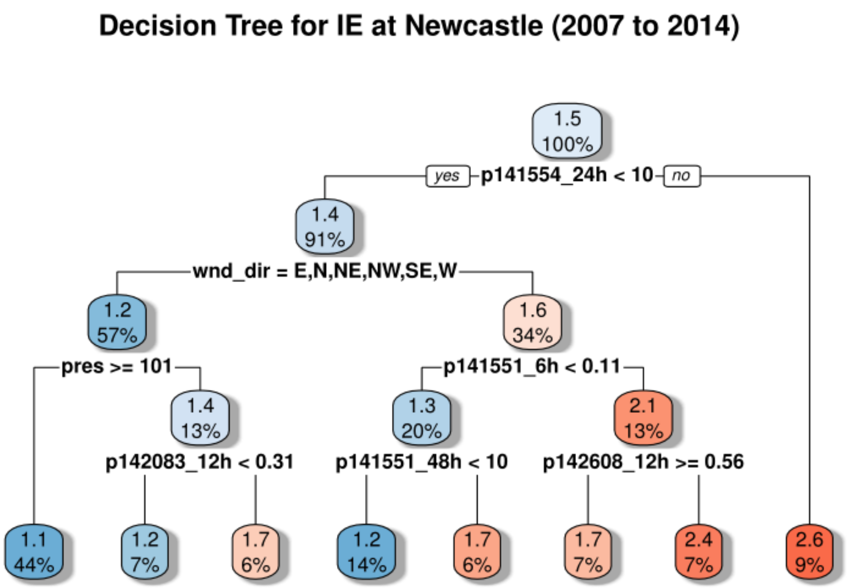
1. Model Development



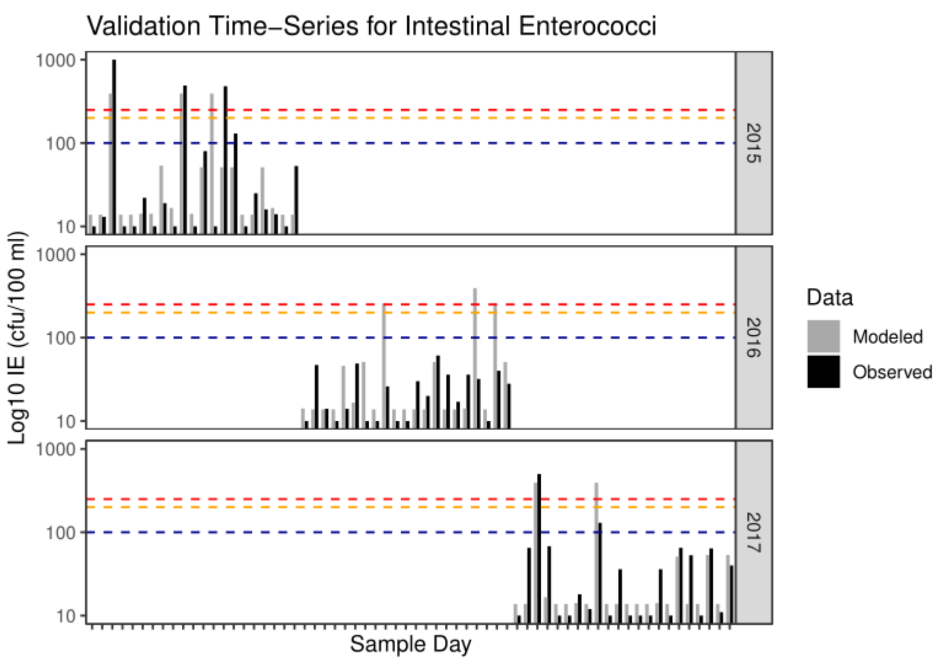
1. Model Development

MÉRA Data

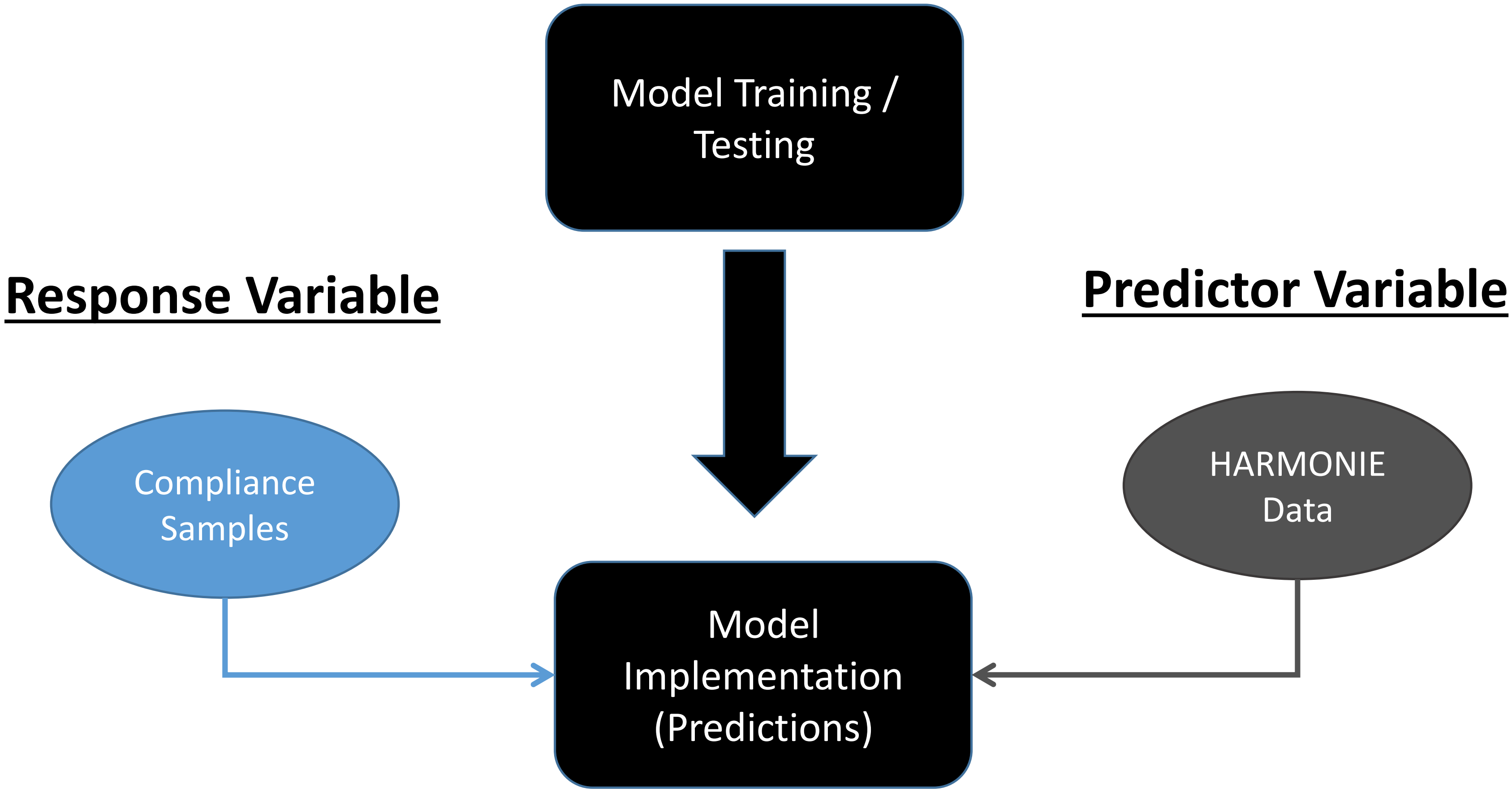
Model Training



Model Testing



2. Model Implementation



2. Model Implementation

Predictions are for Saturday, August 31st 2019

	Ballyholme@11:00	Ballywalter@11:00	Castlerock@11:00	Clogherhead@11:00	Enniscrone@11:00	Ladysbay@11:0	Newcastle@11:0	Portrush@11:00	Waterfoot@11:00
- General Status -	- General Status -	- General Status -	- General Status -	- General Status -	- General Status -	- General Status -	- General Status -	- General Status -	- General Status -
General_Class	EXCELLENT	EXCELLENT	POOR	EXCELLENT	EXCELLENT	EXCELLENT	POOR	EXCELLENT	POOR
General_Bin	PASS	PASS	FAIL	PASS	PASS	PASS	FAIL	PASS	FAIL
- IE Related -	- IE Related -	- IE Related -	- IE Related -	- IE Related -	- IE Related -	- IE Related -	- IE Related -	- IE Related -	- IE Related -
IE_Log	1.539645765	1.646271057	1.340914536	1.094602186	1.138361069	1.620812357	2.964792230	1.281588040	2.522965162
IE_Value	34.645414806	44.286469201	21.923734614	12.433751583	13.751848164	41.764987575	922.130166980	19.124409742	333.399667168
IE_Class	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	POOR	EXCELLENT	POOR
IE_Bin	PASS	PASS	PASS	PASS	PASS	PASS	FAIL	PASS	FAIL
- EC Related -	- EC Related -	- EC Related -	- EC Related -	- EC Related -	- EC Related -	- EC Related -	- EC Related -	- EC Related -	- EC Related -
EC_Log	1.654335810	1.582200637	3.219891747	1.097259954	2.381682193	1.543026367	3.611563517	1.776059005	2.311484358
EC_Value	45.116542439	38.212076337	1659.173286564	12.510076158	240.814255636	34.916151305	4088.495428671	59.711640707	204.872826124
EC_Class	EXCELLENT	EXCELLENT	POOR	EXCELLENT	EXCELLENT	EXCELLENT	POOR	EXCELLENT	EXCELLENT
EC_Bin	PASS	PASS	FAIL	PASS	PASS	PASS	FAIL	PASS	PASS
	end of 11:00:00	end of 11:00:00	end of 11:00:00	end of 11:00:00	end of 11:00:00	end of 11:00:00	end of 11:00:00	end of 11:00:00	end of 11:00:00

Bathing Water Quality Forecasts utilizing HARMONIE Data

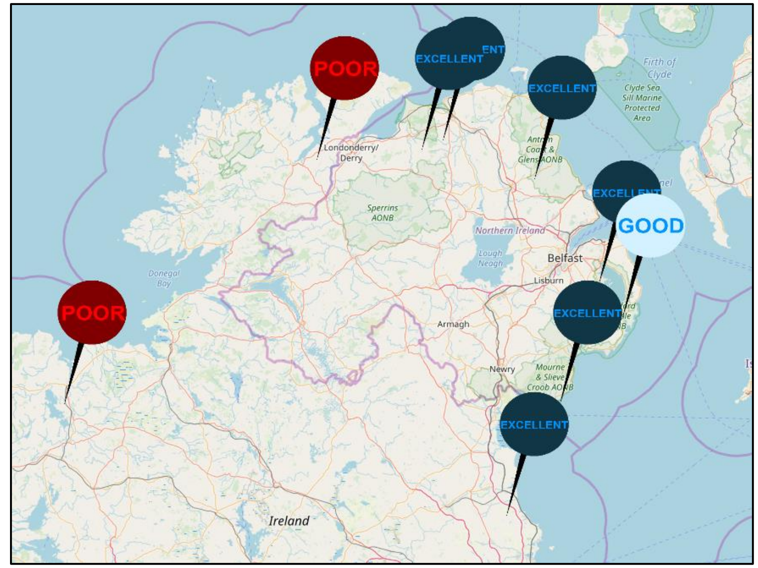
2. Model Implementation: Public Notification

Website

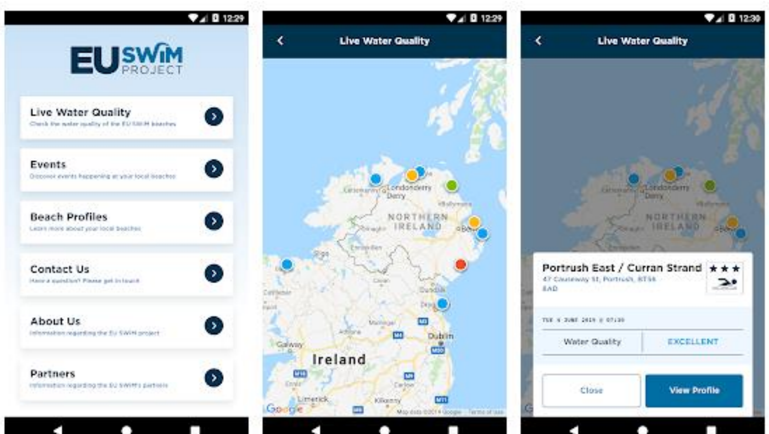
Ballyholme: EXCELLENT @ 28th-Aug
Ballywalter: GOOD @ 28th-Aug
Castlerock: EXCELLENT @ 28th-Aug
Clogherhead: EXCELLENT @ 27th-Aug
Enniscrone: POOR @ 30th-Aug
Lady's Bay: POOR @ 29th-Aug
Newcastle: EXCELLENT @ 30th-Aug
Portrush (Curran): EXCELLENT@27th-Aug
Waterfoot: EXCELLENT @ 30th-Aug

click for map view

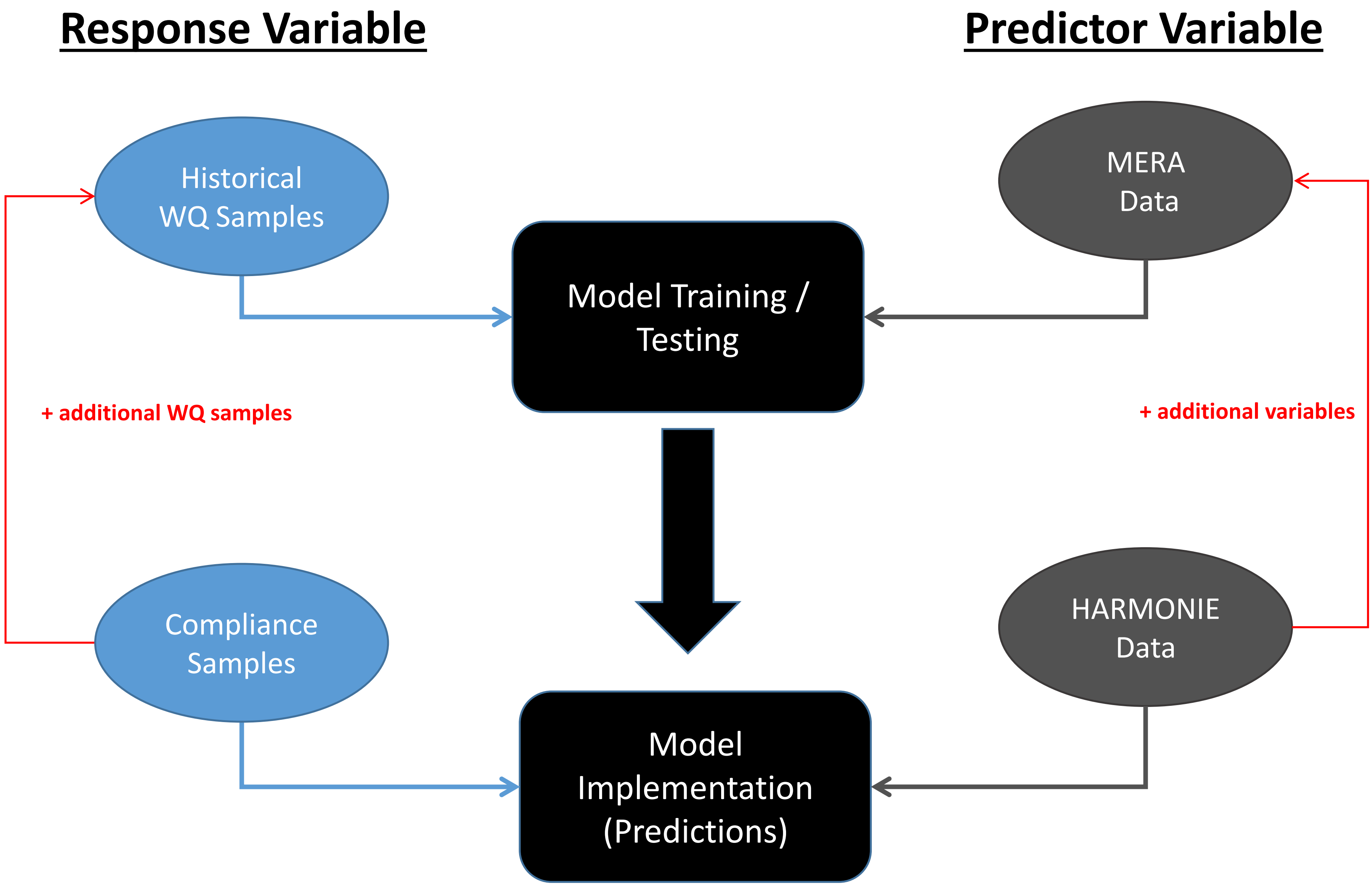
Information based on real water quality test results



Mobile App



3. Model Refinement

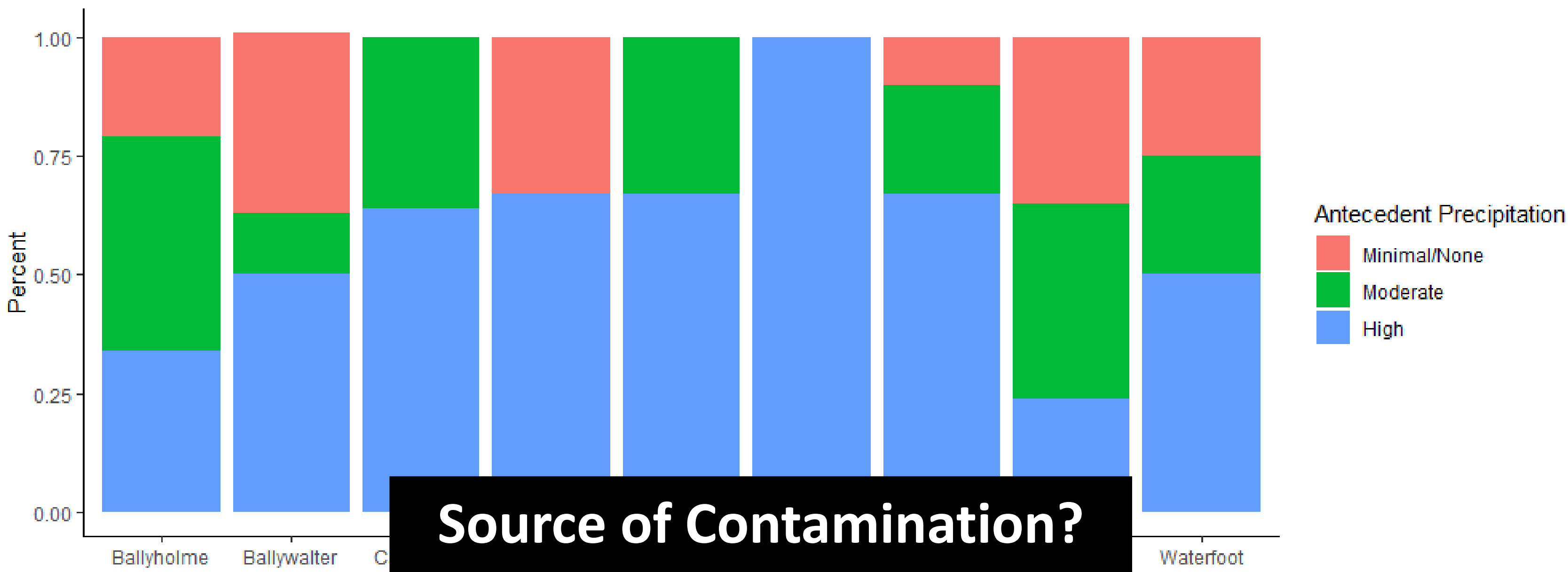


Key Challenge

- Lack of Historical Observed Water Quality Data (2007 – 2018)
  - **Total Water Quality Samples**: 560 to 130 (most sites ~ 300)
  - **Poor Water Quality Samples**: 40 to 2 (most sites ~ 20 to 30)
  - Relatively high proportion of non-meteorologically driven "Poor" samples (~ 20% to 30% at some sites)

- Impact:
  - Too few samples to adequately train the model at some sites.
  - Model is highly sensitive to the train / test split at other locations.
  - Model is confounded by non-meteorologically driven events.
    - ✓ Dogs, Birds, Horses, etc…

Non-Meteorologically Driven WQ Failures can't be predicted (by this type of model)



Source of Contamination?
The Usual Suspects

https://barkpost.com/life/17-dogs-who-will-shamelessly-ruin-your-beach-day/

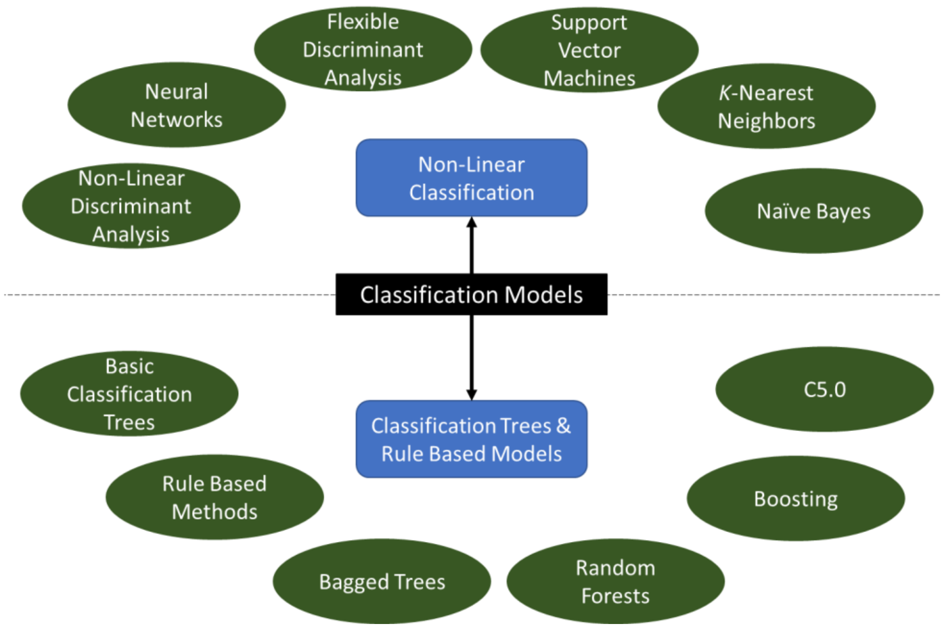
Model Development – Next Steps

Multi-Model Development Framework

- A wide range of non-linear classification and tree-based methods are available which can utilize multi-variate data (e.g. MERA, rain radar, tide).
- A framework for training and testing multiple different models in parallel is under development – utilizing the "Caret" package in R, which contains ~ 240 different machine leaning models.

No Free Lunch Theorem

"There is no such thing as a single, universally-best machine learning algorithm, and there are no context or usage-independent (a priori) reasons to favor one algorithm over all others."



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Boord O Owre Ocht UE Projecks

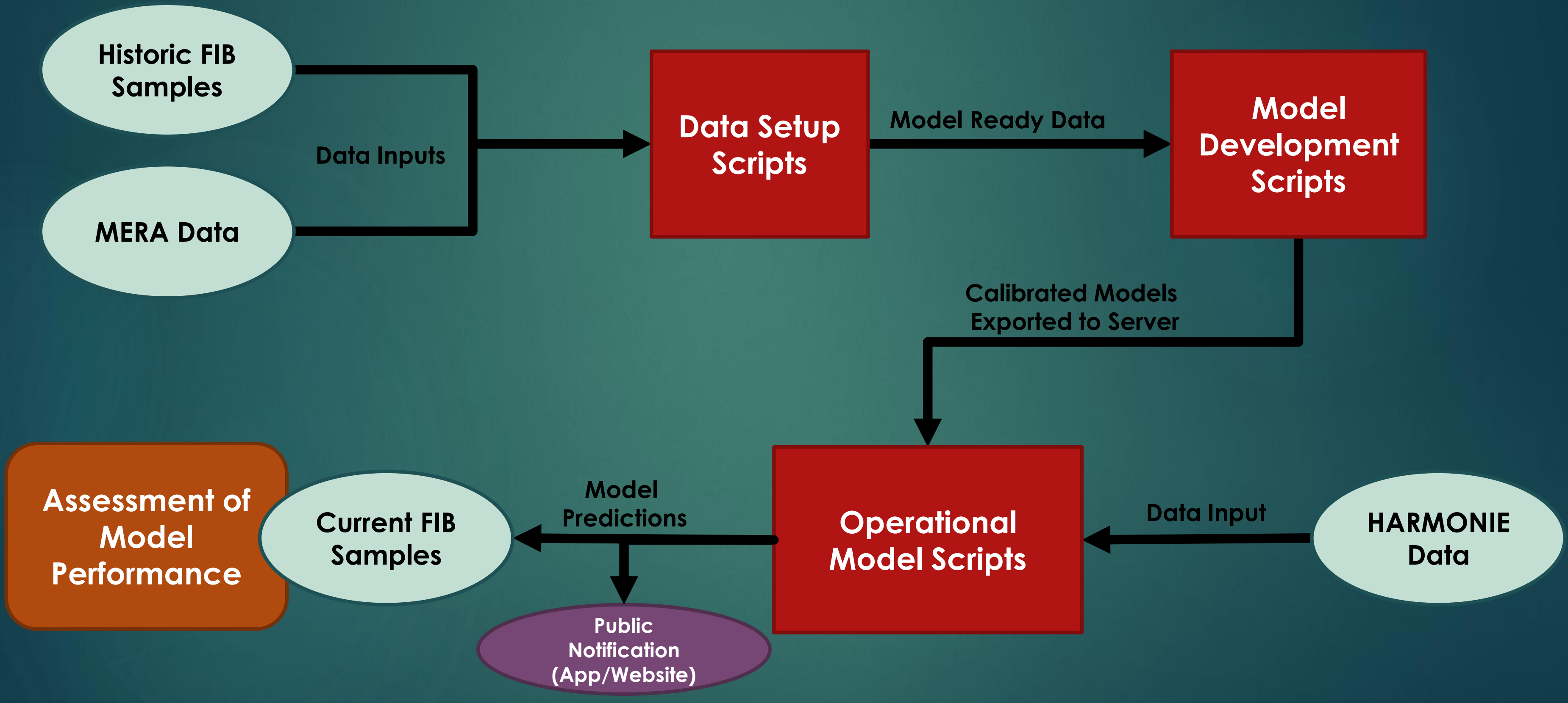
MÉRA Variables

Variable	Units	Variable Type	Location	Temporal Aggregation*	Variables @ Newcastle
Precipitation	mm	Numeric	Catchment	Sum	138**
Soil Moisture	kg/m^3	Numeric	Catchment	Mean	138**
Temperature	°C	Numeric	Sample Point	Mean	6
Atmospheric Pressure	kPA	Numeric	Sample Point	Mean	6
Direct Normal Irradiance	kW/m^2	Numeric	Sample Point	Sum	6
Wind Speed	Beaufort scale	Categorical	Sample Point	Mean	6
Wind Direction	Cardinal Direction	Categorical	Sample Point	Mode	6

* Data was aggregated over periods of 1, 6, 12, 24, 48, and 96 hours from the time of the sample.

** 22 MERA Points in Newcastle Catchment + 1 Catchment Mean x 6 Time Aggregations = 138 variables

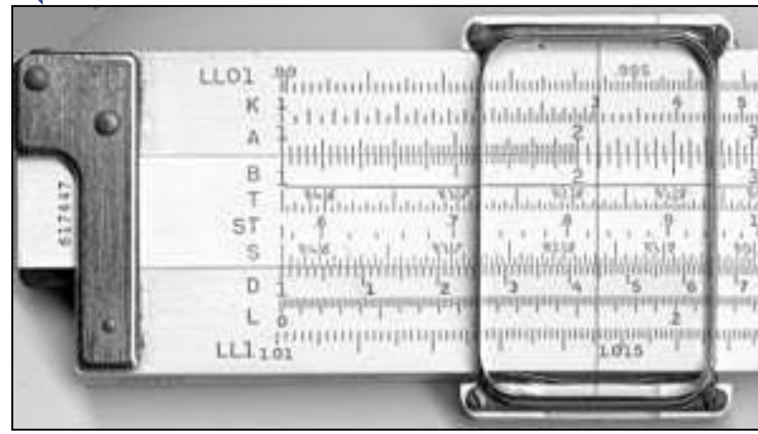
Modelling Flowchart



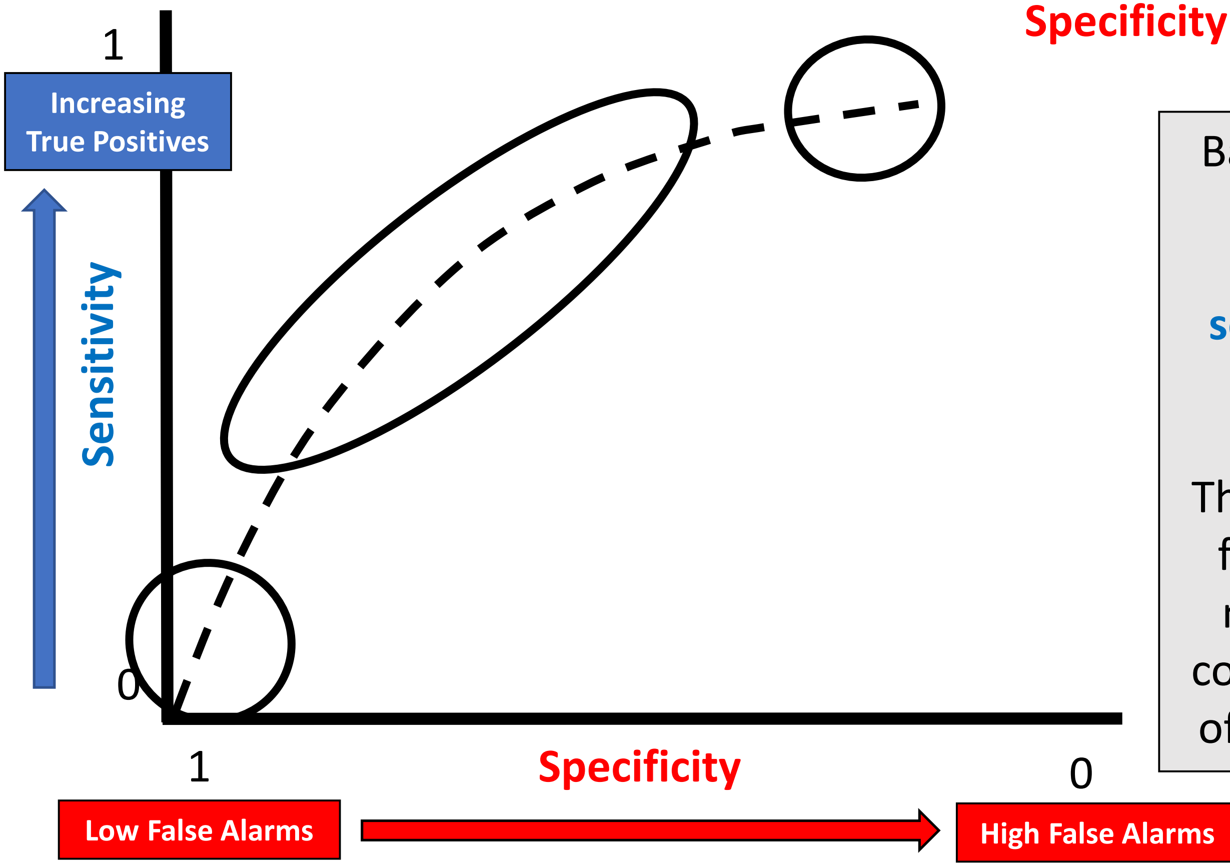
Sensitivity / Specificity Trade-Off

There is typically a trade-off between model **sensitivity** and **specificity**, and increasing one results in a decrease in the other.

Sensitivity



Specificity



Bathing Water Quality models typically achieve high **specificity**, while high **sensitivity** is more difficult to achieve.

This is due to the relatively low frequency of WQ failures (at most sites), complex driving conditions, and the occurrence of non-meteorological drivers.

Model Performance Standards: Sensitivity & Specificity

Source	Sensitivity	Specificity
Thoe *et al.* (2014) *"Predicting water quality at Santa Monica Beach: Evaluation of five different models for public notification of unsafe swimming conditions"*	>30%	>80%
California's "Nowcast" System *https://beachreportcard.org/*	>50%	>85%
Scottish EPA *R. Stidson, personal communication*	>50%	-
UK Environment Agency *D. Tyrell, personal communication*	Scoring System Using a Range of Criteria (0 – 30)	

Following the levels set out by these standards, in our models we seek to maximize ***sensitivity*** while maintaining a minimum ***specificity*** of 0.80.

Example of Model Performance at Different Thresholds

More Conservative – Less Conservative

Newcastle		
Threshold	**Sensitivity**	**Specificity**
None	0.00	1.00
19 mm 2 days	0.17	0.98
8 mm 1 day	0.37	0.95
6 mm 1 day	0.49	0.89
4 mm 1 day	0.51	0.87
7 mm 2 day	0.57	0.82