A next-generation national critical source area map of phosphorus losses in Irish agricultural catchments for decision support

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Nutrient Transfer Continuum

Source

Mobilisation

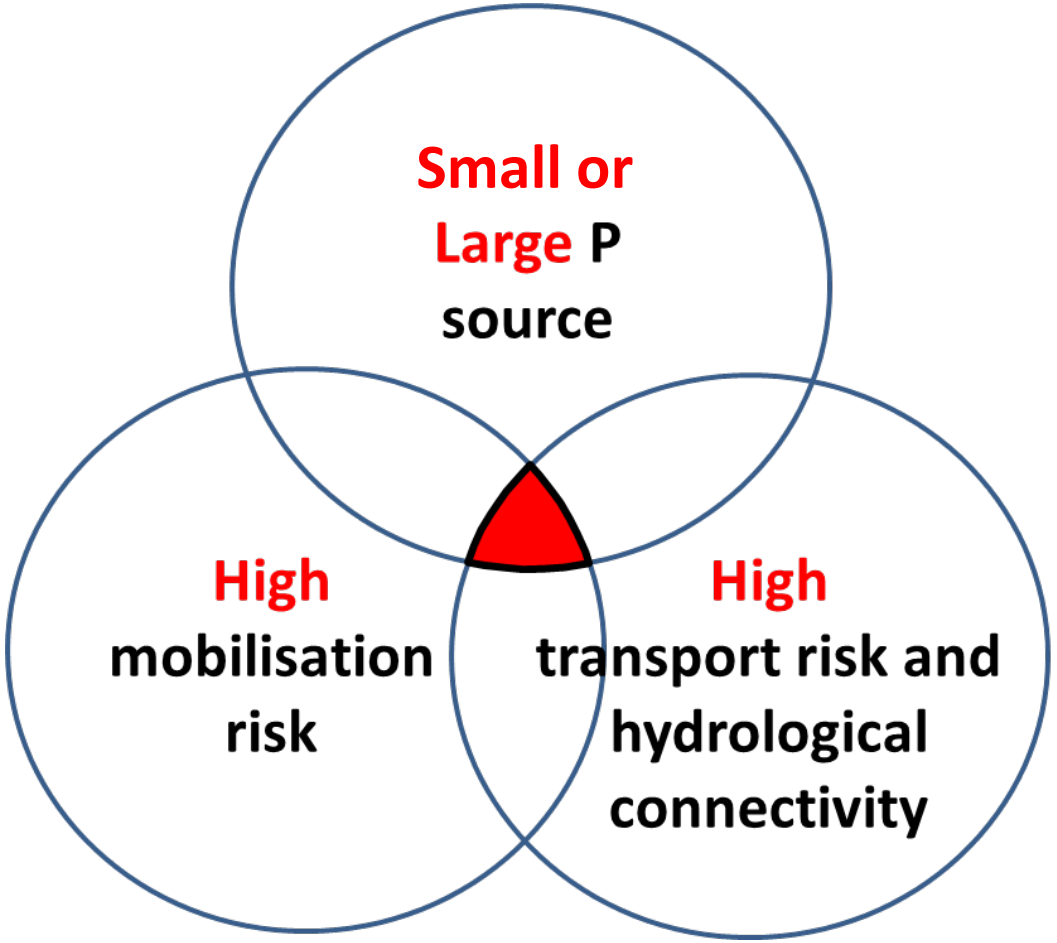
Transport

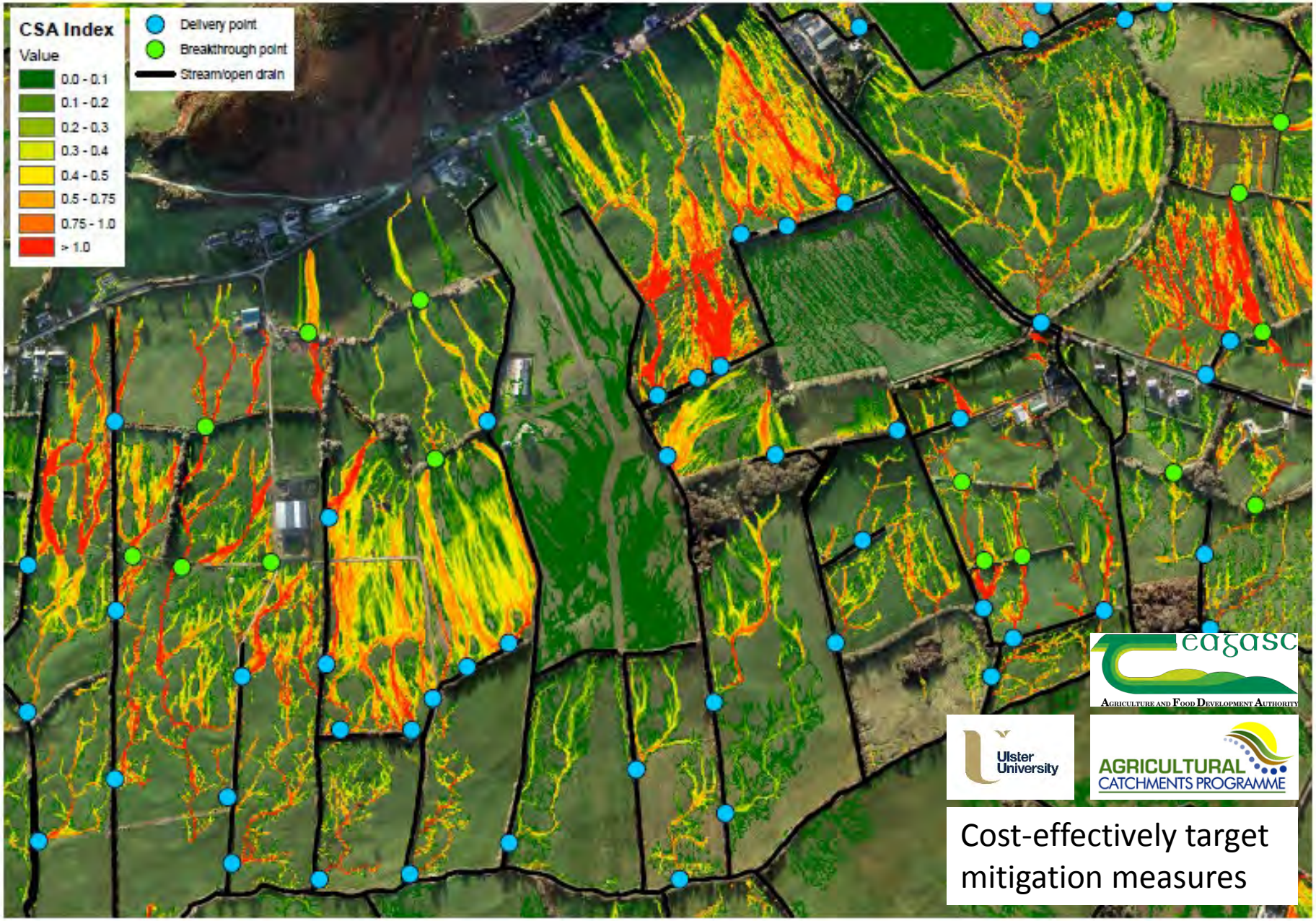
Hydrological connectivity

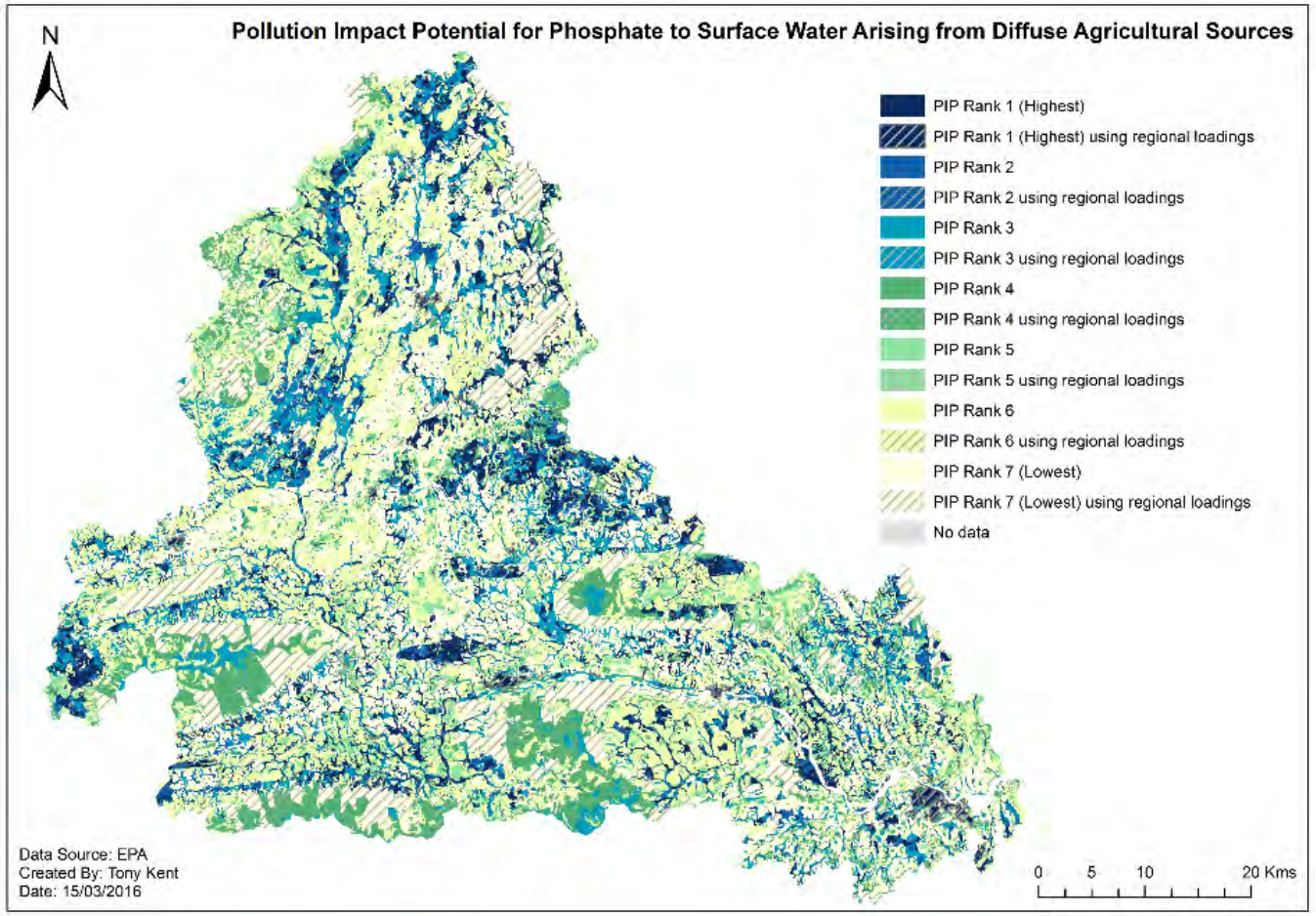
Delivery

Impact

Critical Source Areas



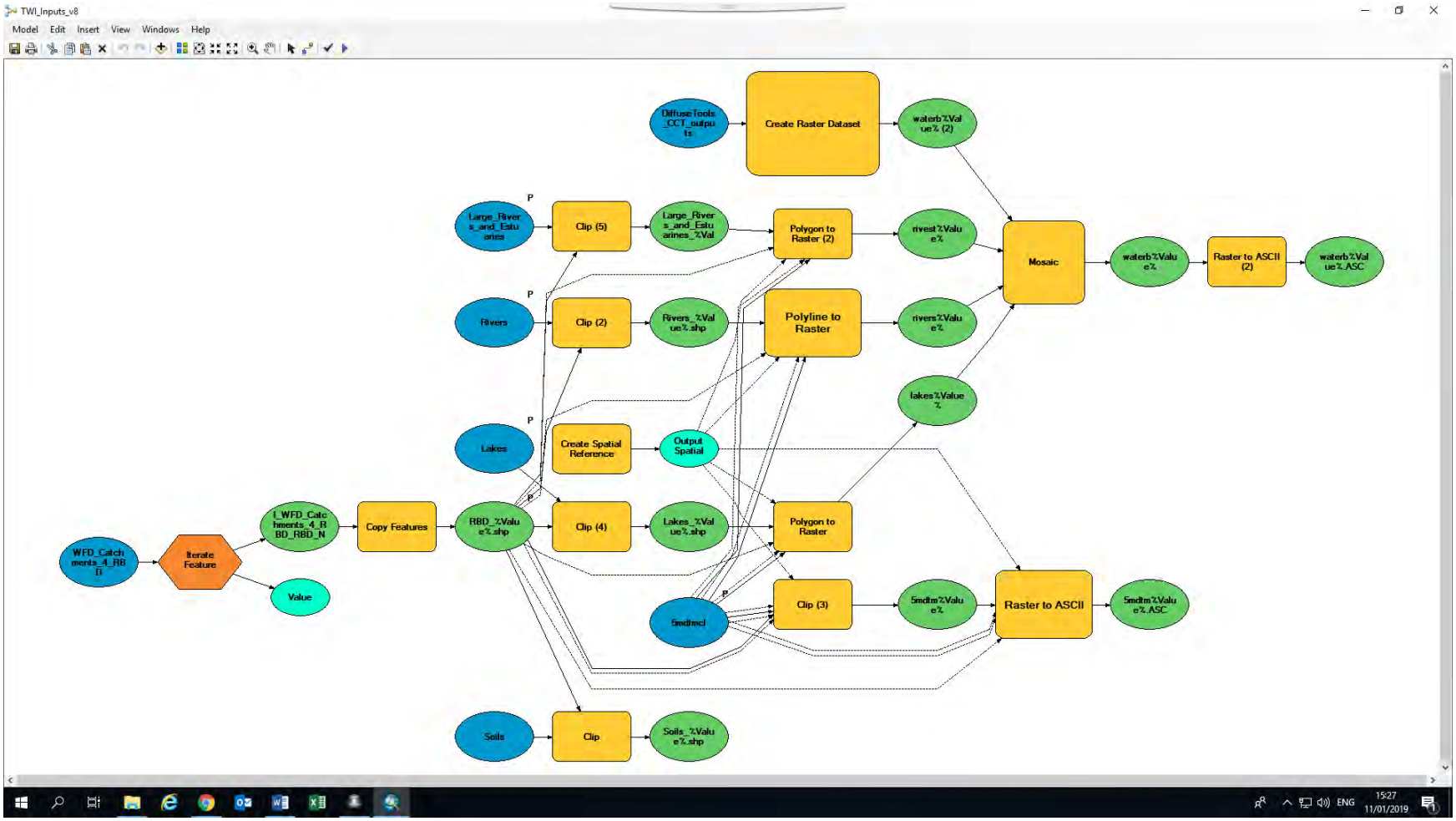

CSA Index
Value
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
Delivery point
Breakthrough point
Stream/open drain
teagasc
Agriculture and Food Development Authority
Ulster University
AGRICULTURAL CATCHMENTS PROGRAMME
Cost-effectively target mitigation measures



Research proposal

- Update **Catchment Characterisation Tool (CCT)** using new datasets/science
- Improve the predictions of P losses from each field in Ireland
- Cost-effectively target farm-specific mitigation measures
- Inform other policy decisions (e.g. redistribution of excess P)

ArcGIS ModelBuilder framework

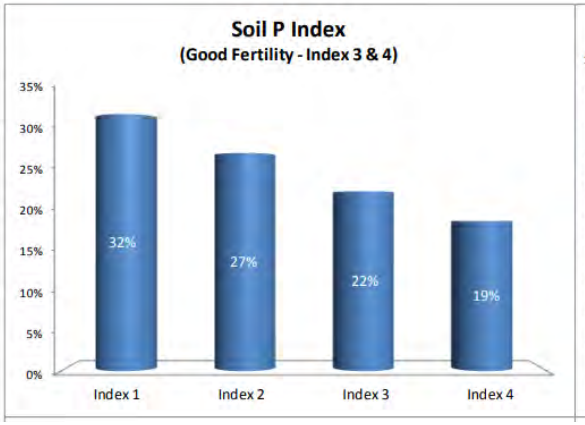


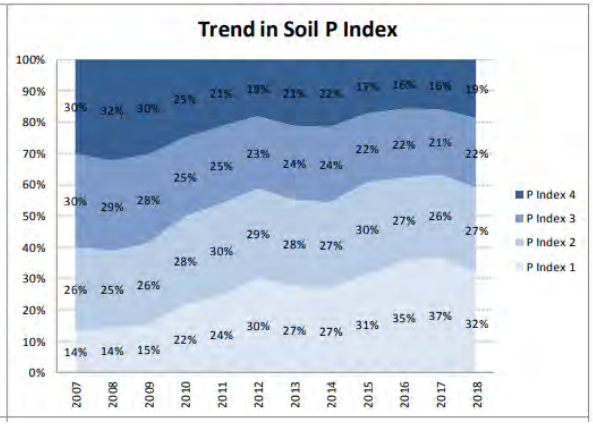
Teagasc National Soil P Sampling Results

Table 4: The P index system		
Soil P Ranges (mg/l)		
Soil P Index	Grassland crops	Other crops
1	0.0 - 3.0	0.0 - 3.0
2	3.1 - 5.0	3.1 - 6.0
3	5.1 - 8.0	6.1 - 10
4	Above 8.0	Above 10.0

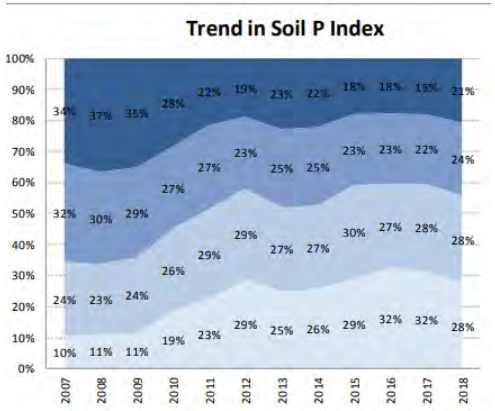
Soil Analysis Status and Trends

County	All Counties
Year	2018
Enterprise	All Farms
Number of Samples	45,157



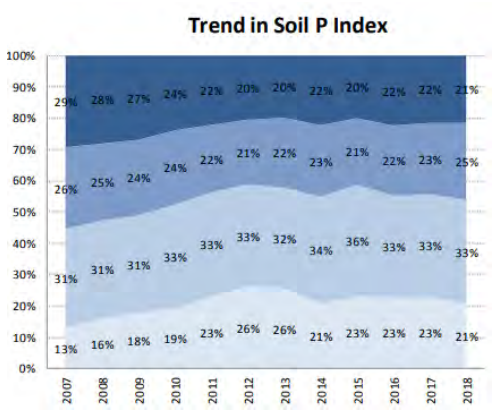


Dairy

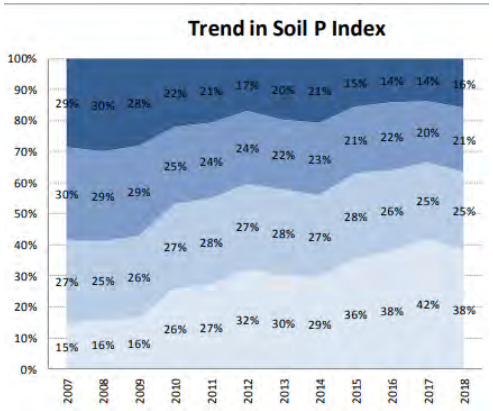


P Index 4
P Index 3
P Index 2
P Index 1

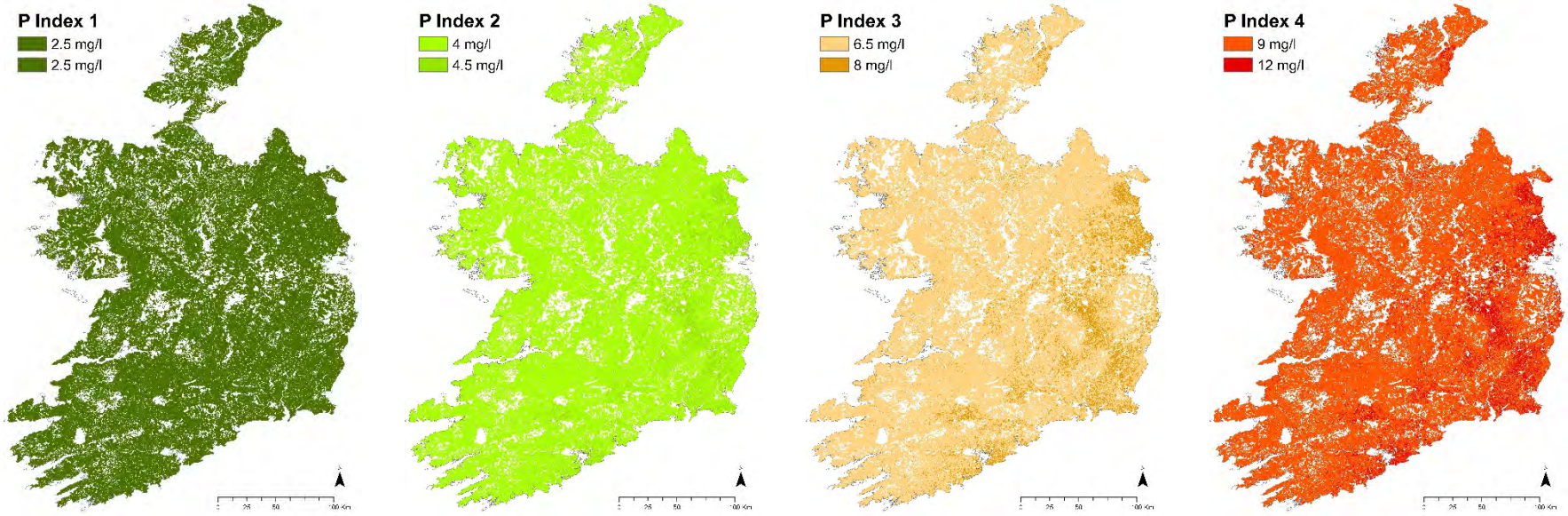
Tillage



Drystock

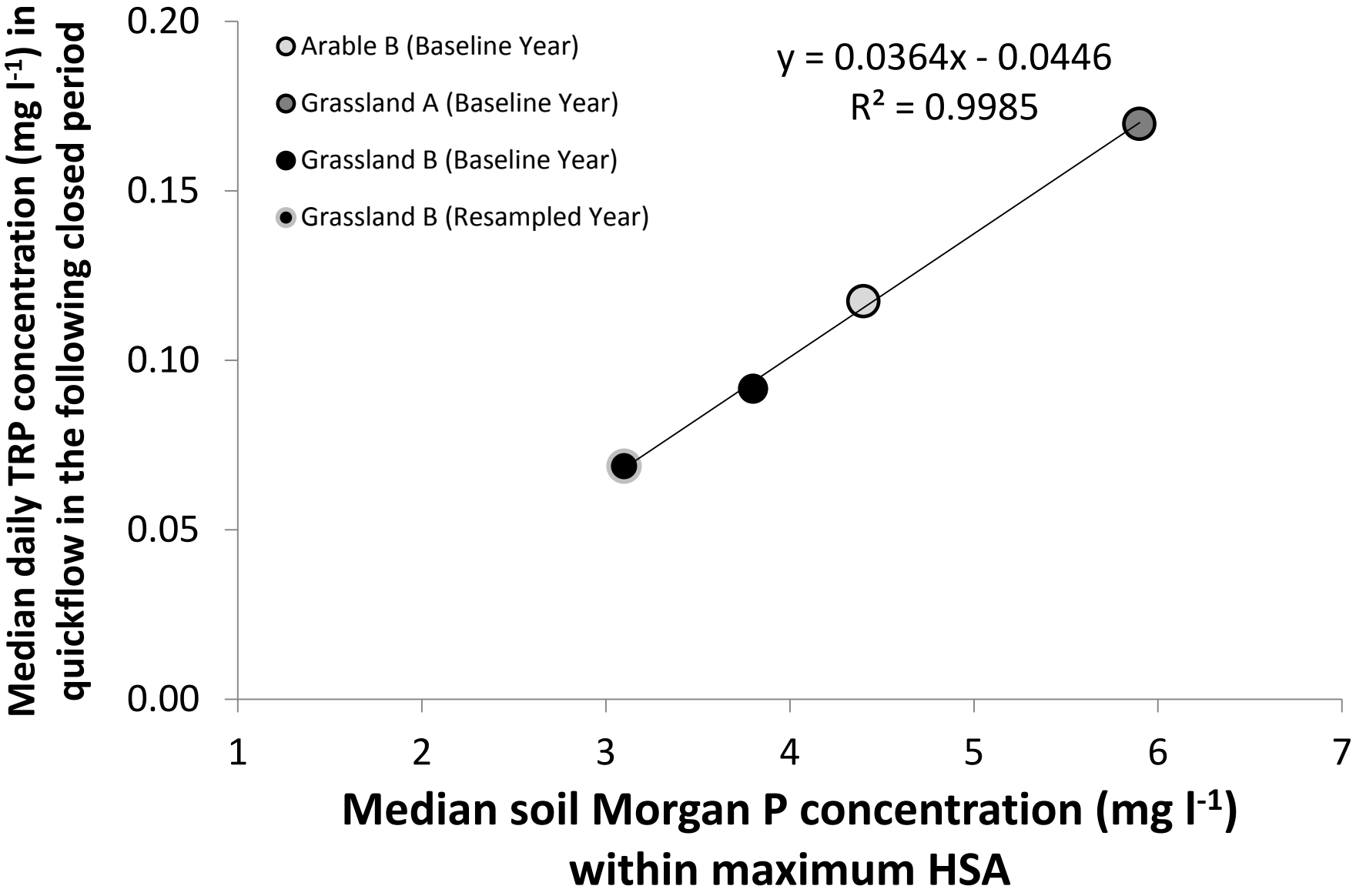


https://www.teagasc.ie/crops/soil--soil-fertility/soil-analysis/soil-results/

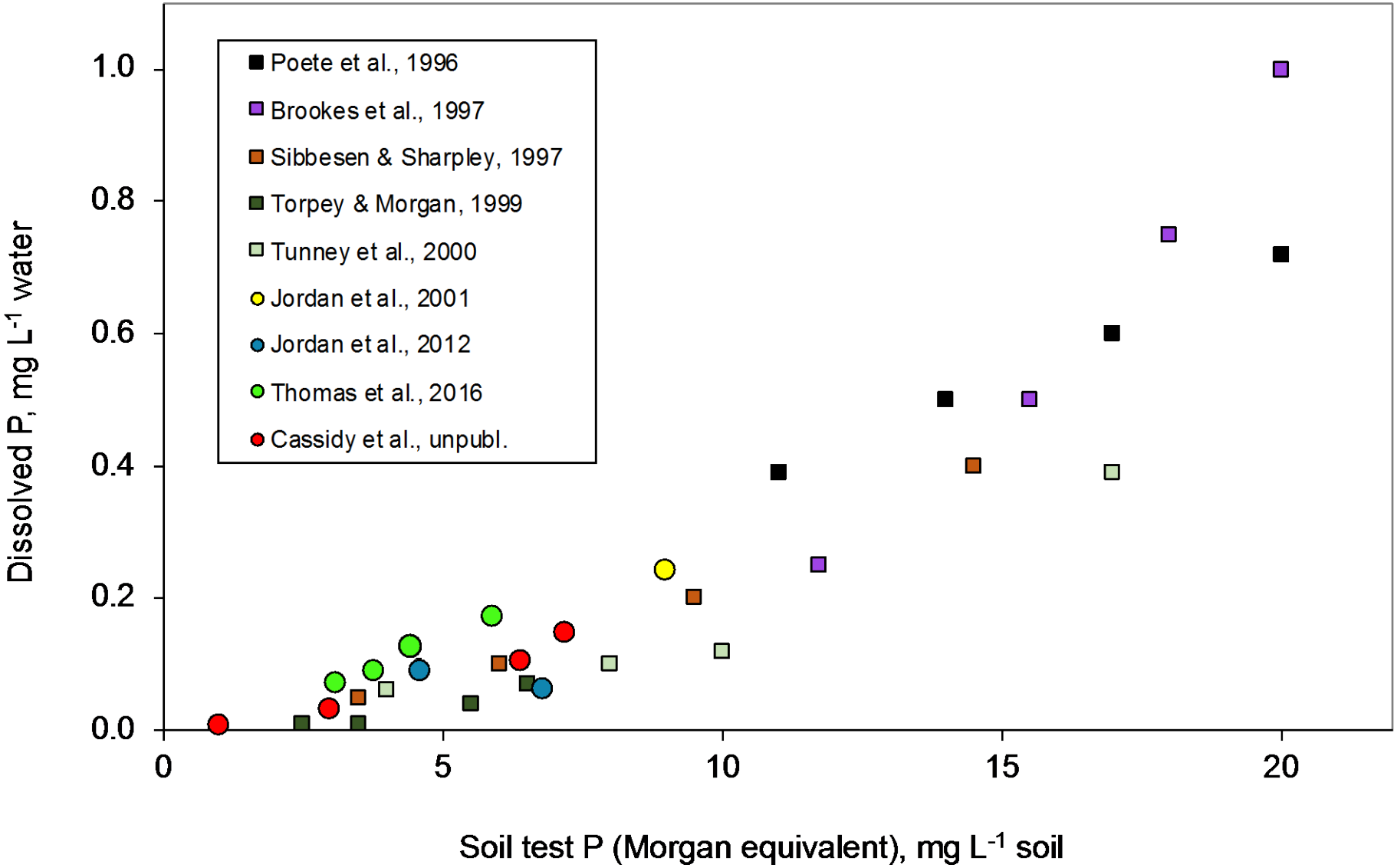


Four P Index scenarios

Model runs assuming all agricultural soils have soil P concentrations in mid-point of the P Index (which depends on grassland or arable land use)


Median daily TRP concentration (mg l-1) in quickflow in the following closed period
0.20
0.15
0.10
0.05
0.00
Arable B (Baseline Year)
Grassland A (Baseline Year)
Grassland B (Baseline Year)
Grassland B (Resampled Year)
y = 0.0364x - 0.0446
R² = 0.9985
1
2
3
4
5
6
7
Median soil Morgan P concentration (mg l-1) within maximum HSA

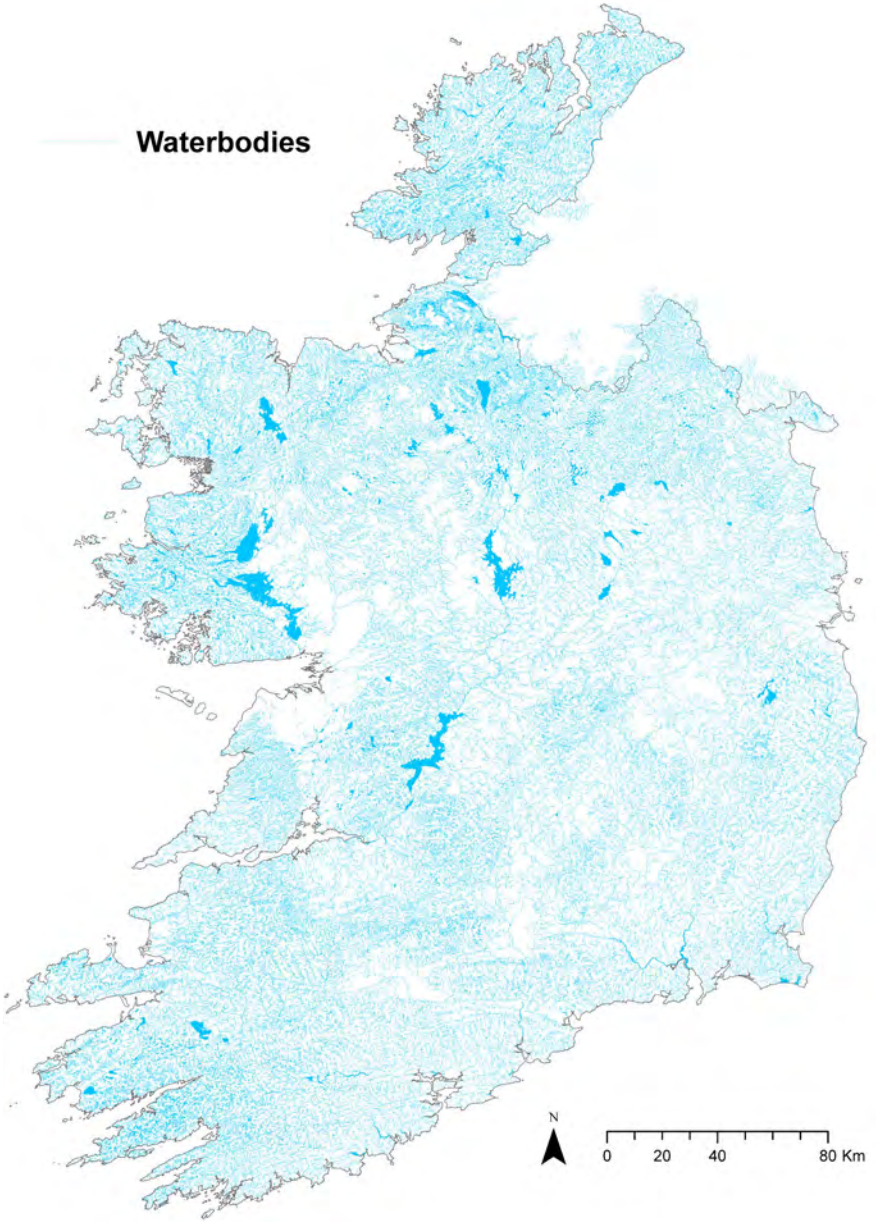
Acknowledgement: Prof Phil Jordan, Ulster University LuWQ2019 conference



P transport

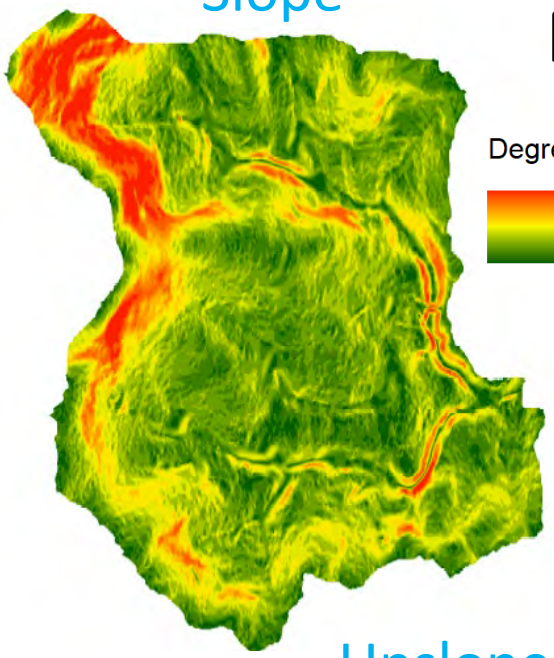
5m Digital Elevation Model (DEM)

Hydrological correction by ‘burning’ in drainage channels

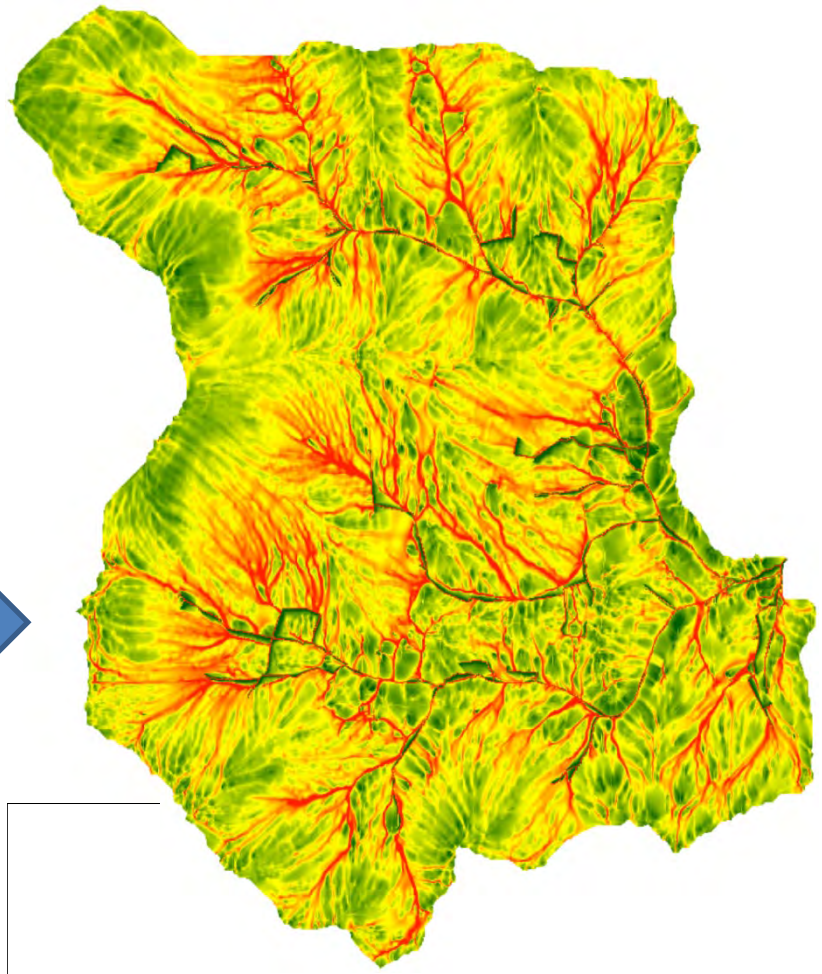


Modelling P transport risk using DEM

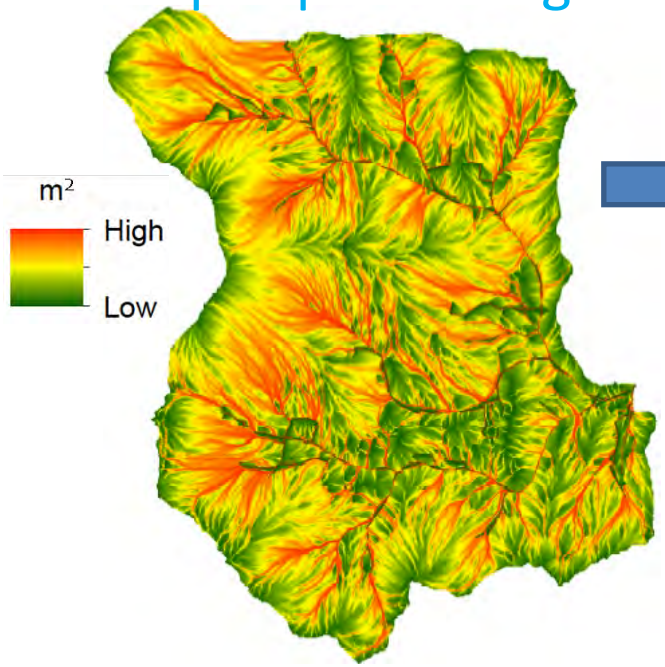
Slope

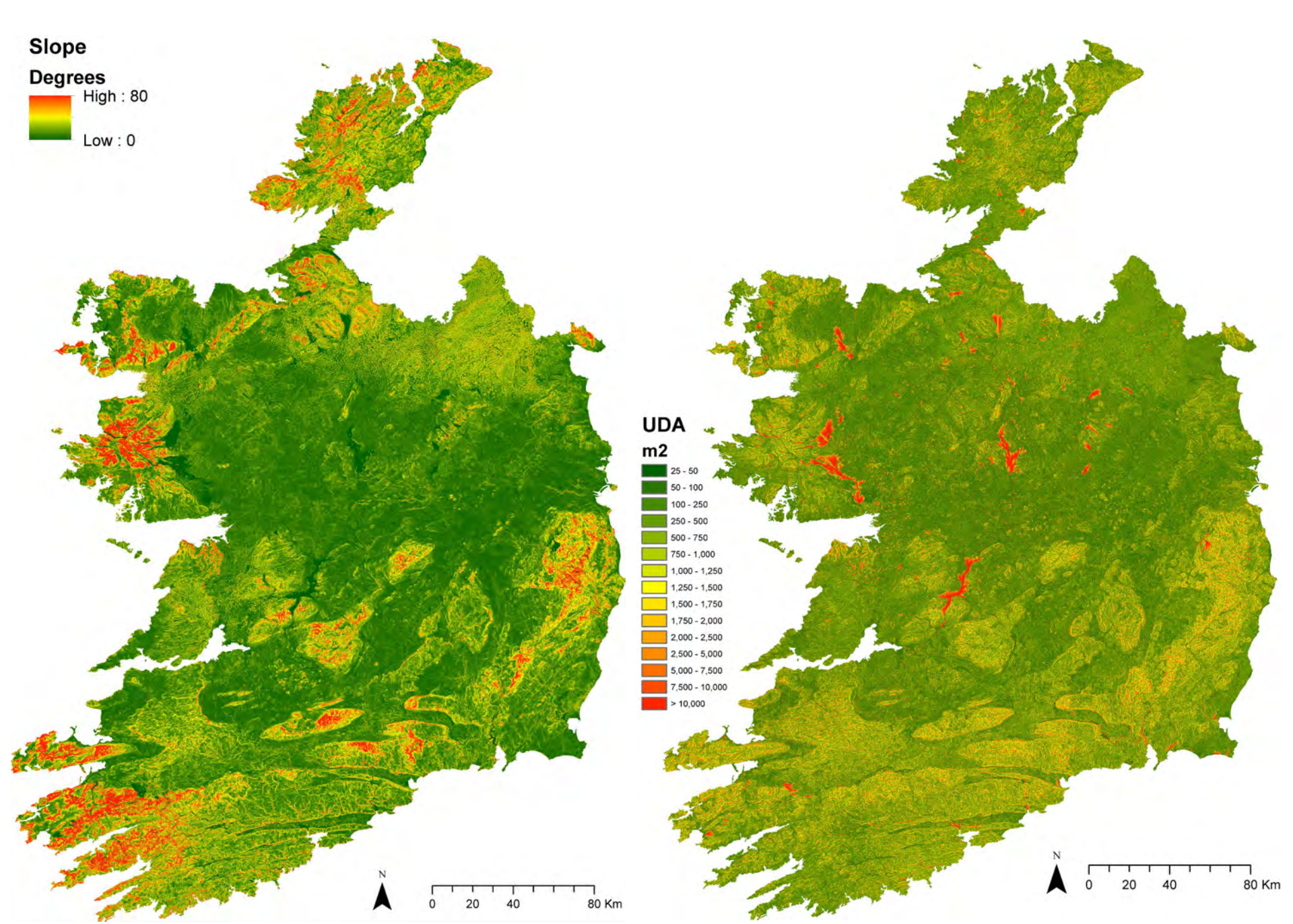


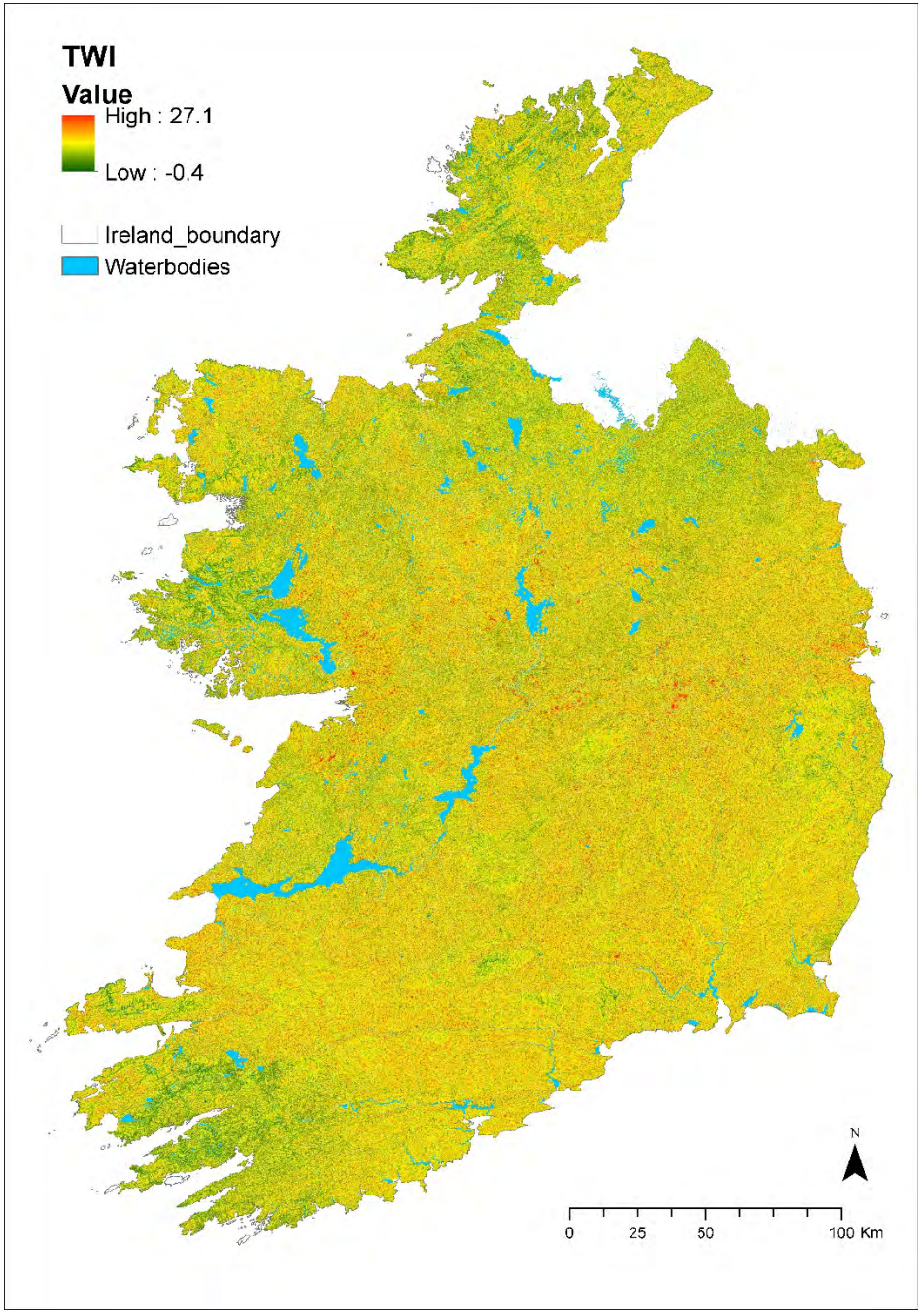
Topographic Wetness Index (TWI)

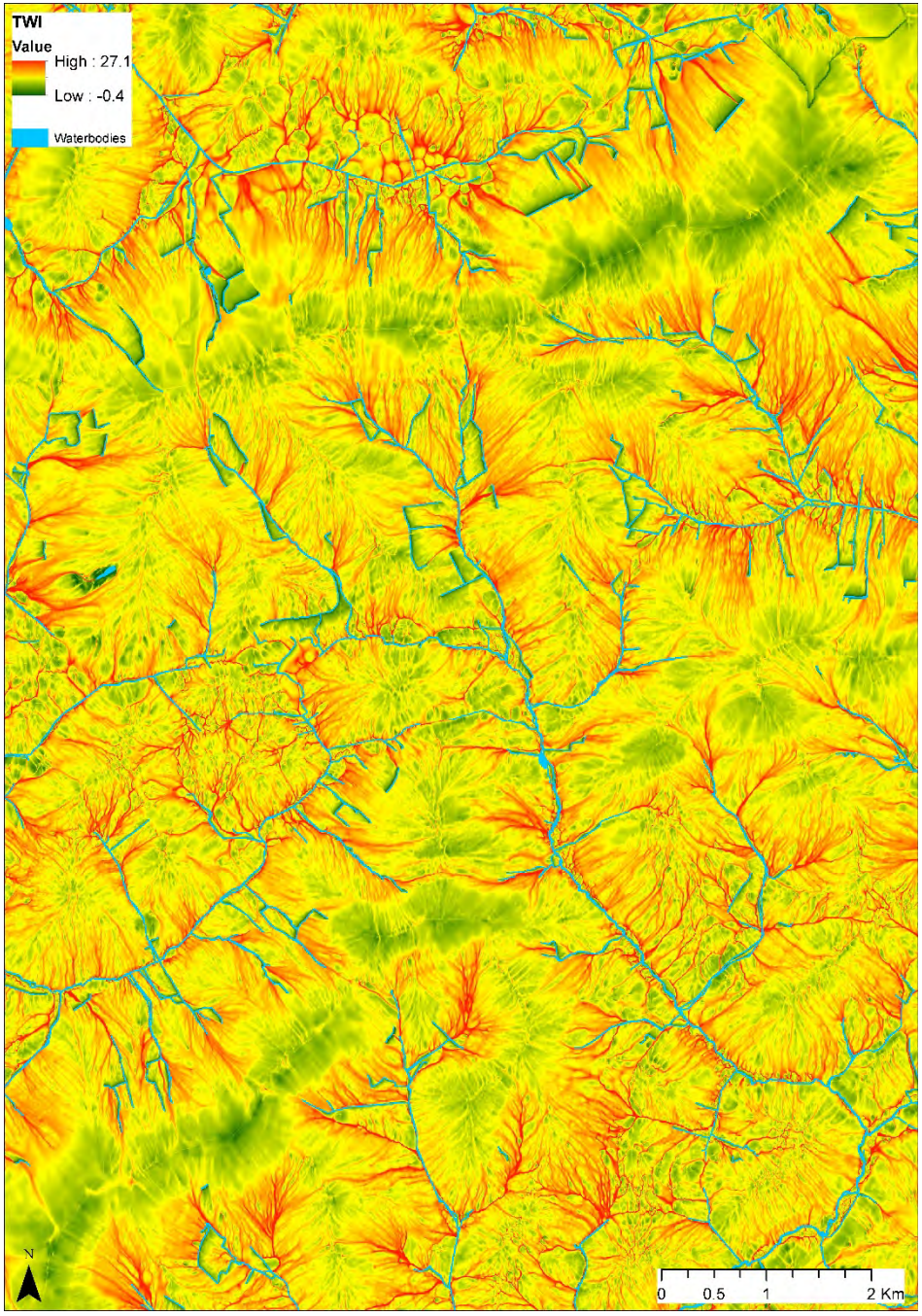


Upslope drainage area

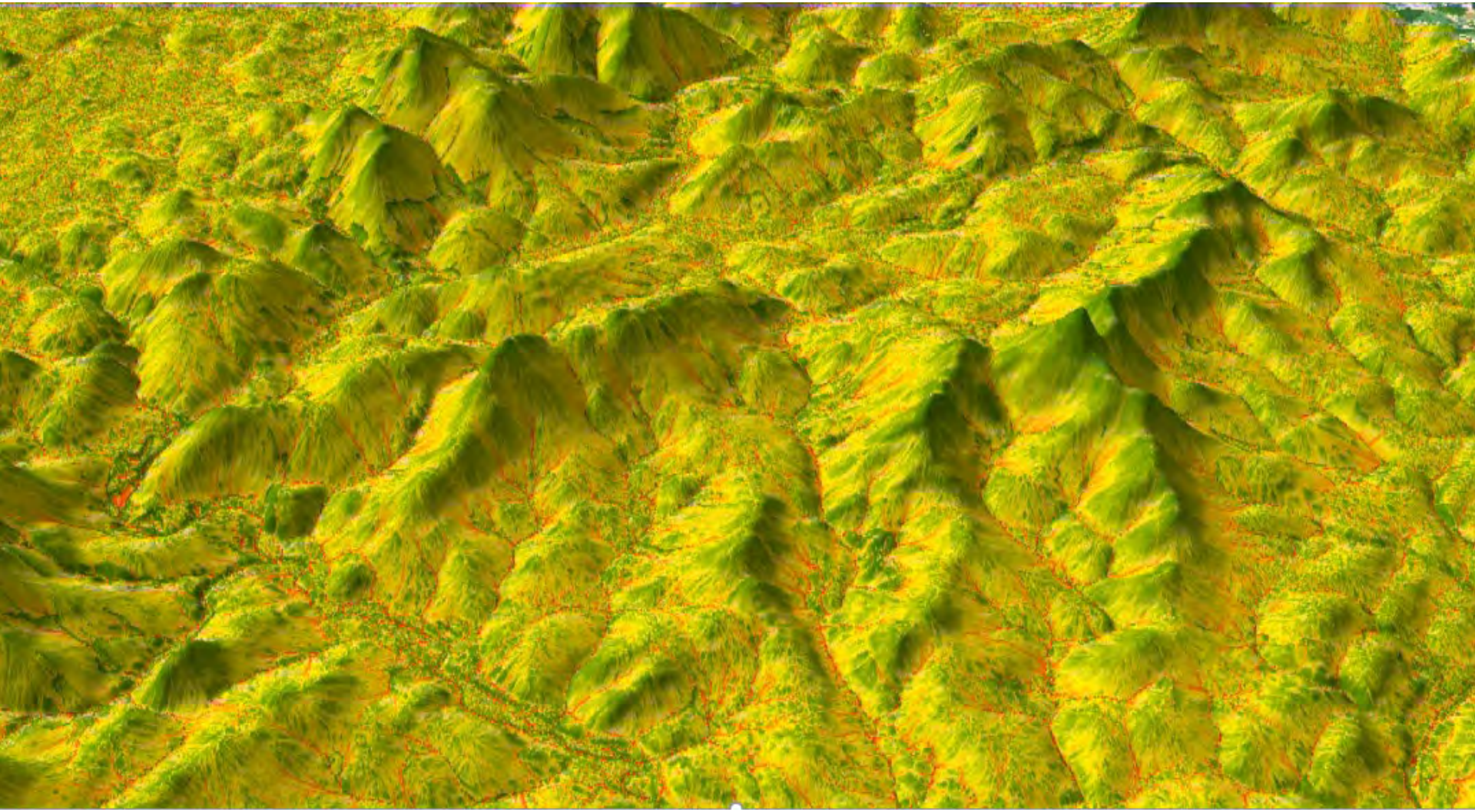


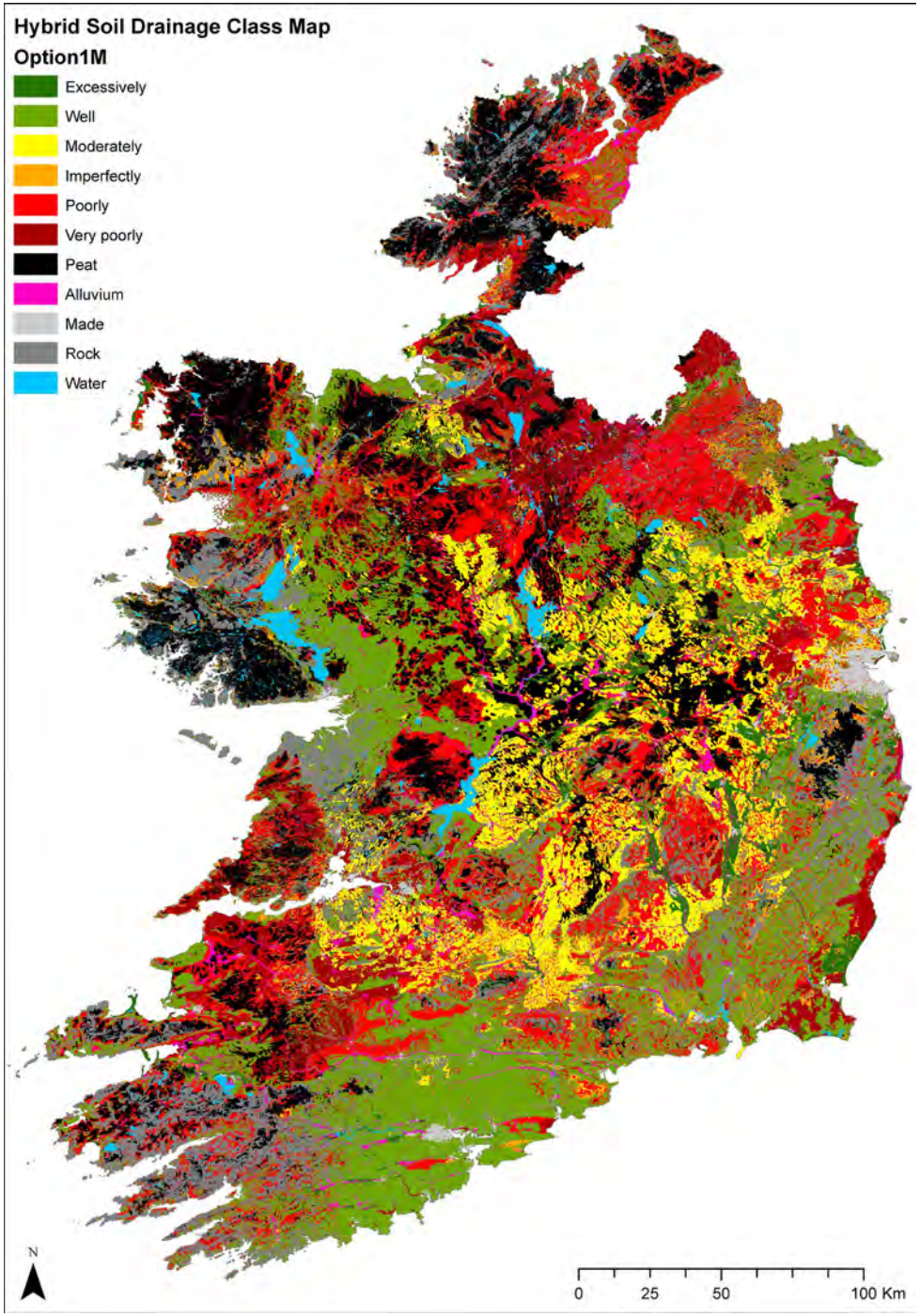

Slope
Degrees
High : 80
Low : 0
N
0 20 40 80 Km
UDA
m2
25 - 50
50 - 100
100 - 250
250 - 500
500 - 750
750 - 1,000
1,000 - 1,250
1,250 - 1,500
1,500 - 1,750
1,750 - 2,000
2,000 - 2,500
2,500 - 5,000
5,000 - 7,500
7,500 - 10,000
> 10,000
N
0 20 40 80 Km


TWI
Value
High : 27.1
Low : -0.4
Ireland_boundary
Waterbodies
N
0
25
50
100 Km


TWI
Value
High : 27.1
Low : -0.4
Waterbodies
N
0
0.5
1
2 Km

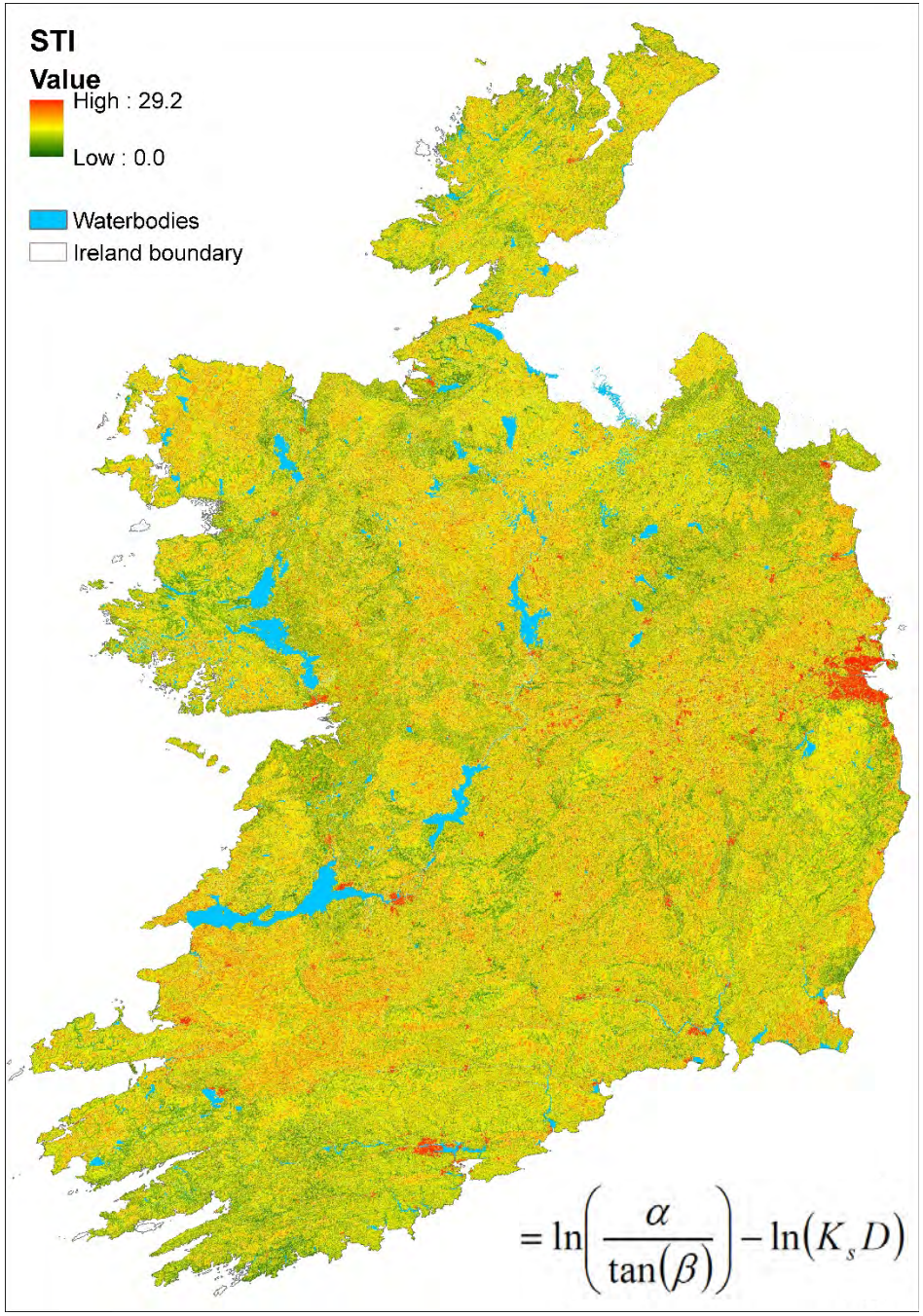
3D video visualisation of 5m TWI

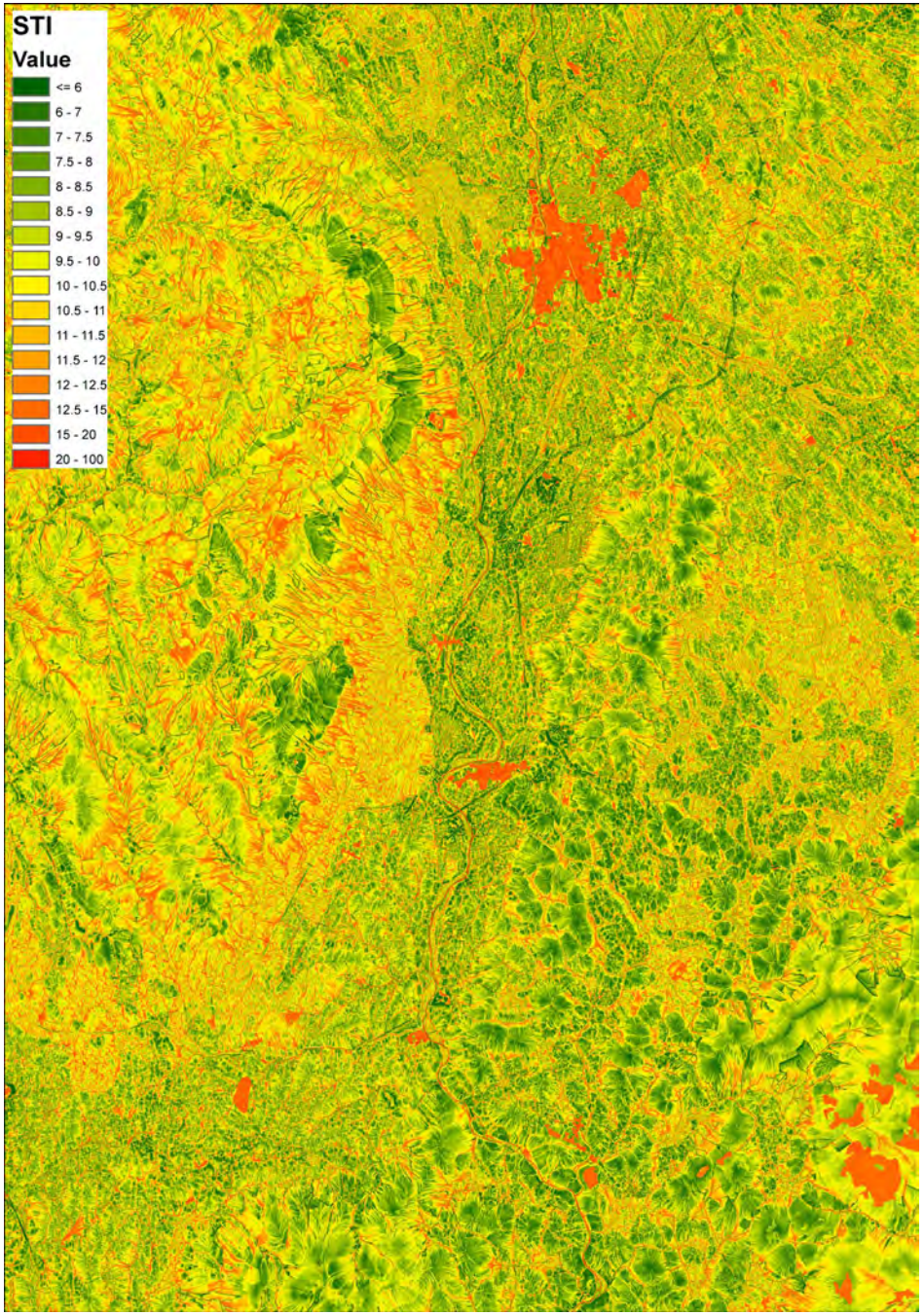




New National Soil Drainage Map

Soil Drainage Class	LnKsD
Excessively	0
Well	-0.5
Moderately	-1
Imperfectly	-1.5
Poorly	-2
Very poorly	-2.5
Peat	-2
Alluvium	-2
Made	-5


STI
Value
High : 29.2
Low : 0.0
Waterbodies
Ireland boundary
$= \ln\left(\frac{\alpha}{\tan(\beta)}\right) - \ln(K_s D)$

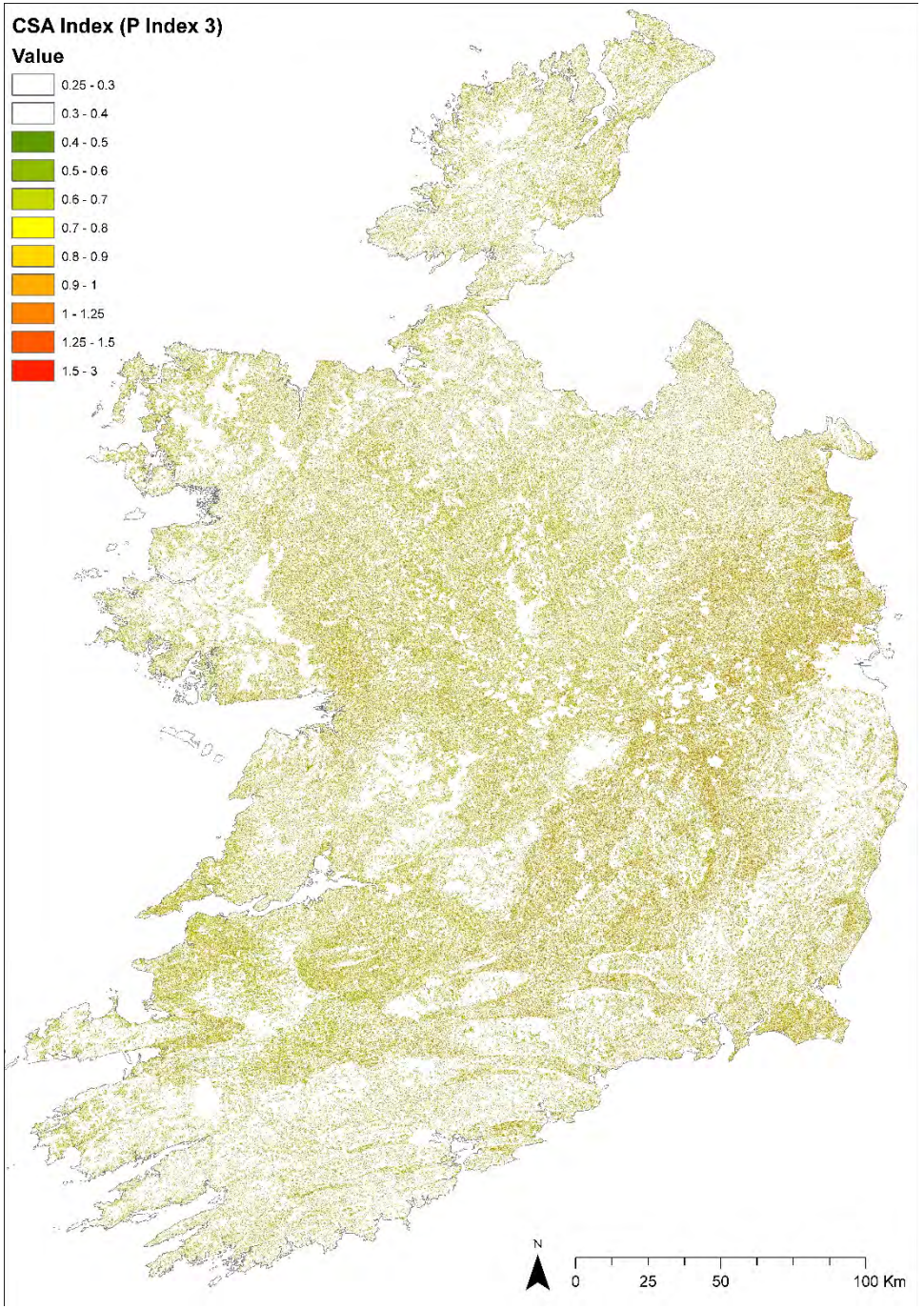

STI
Value
<= 6
6 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
9.5 - 10
10 - 10.5
10.5 - 11
11 - 11.5
11.5 - 12
12 - 12.5
12.5 - 15
15 - 20
20 - 100

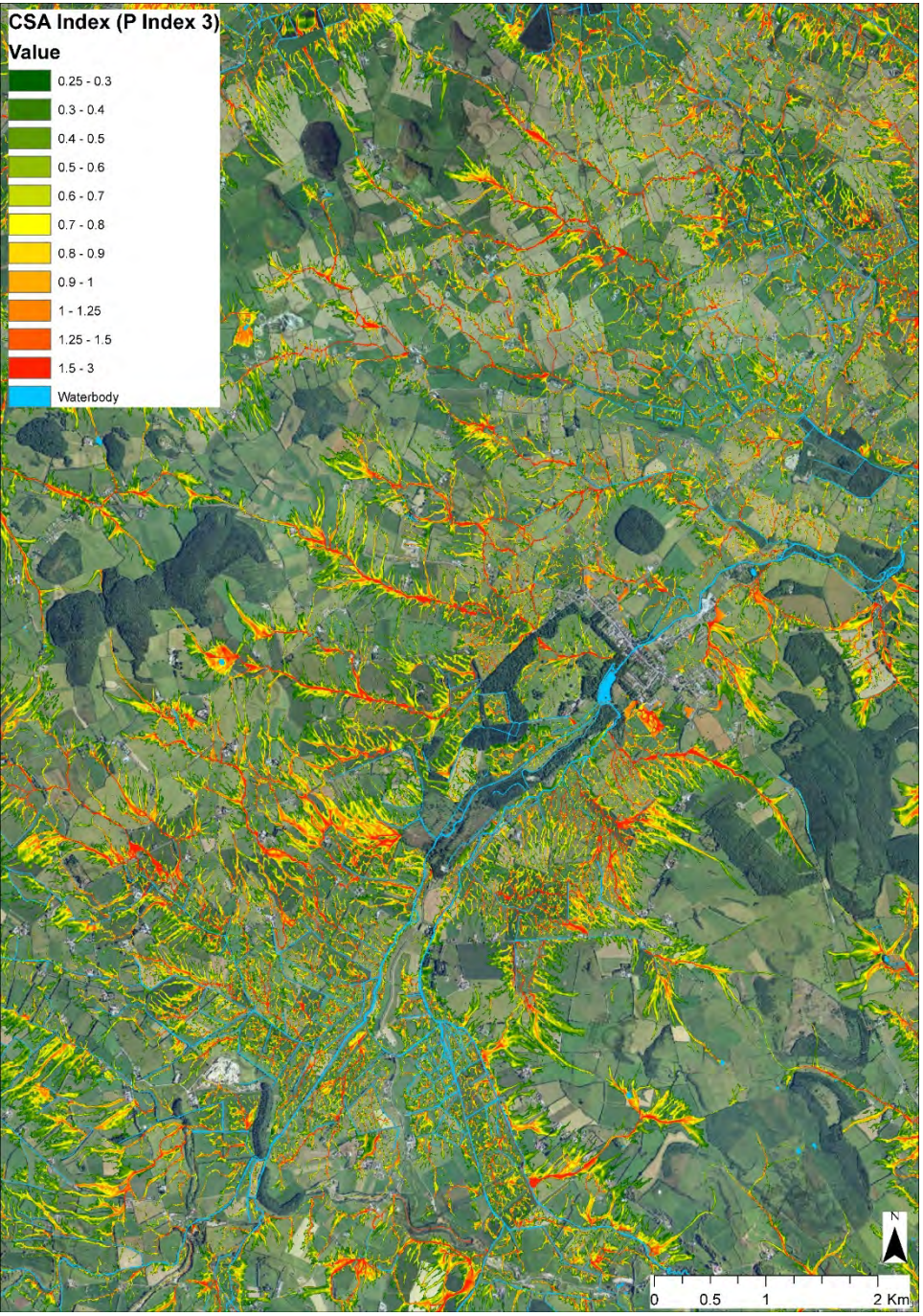
CSA Index =

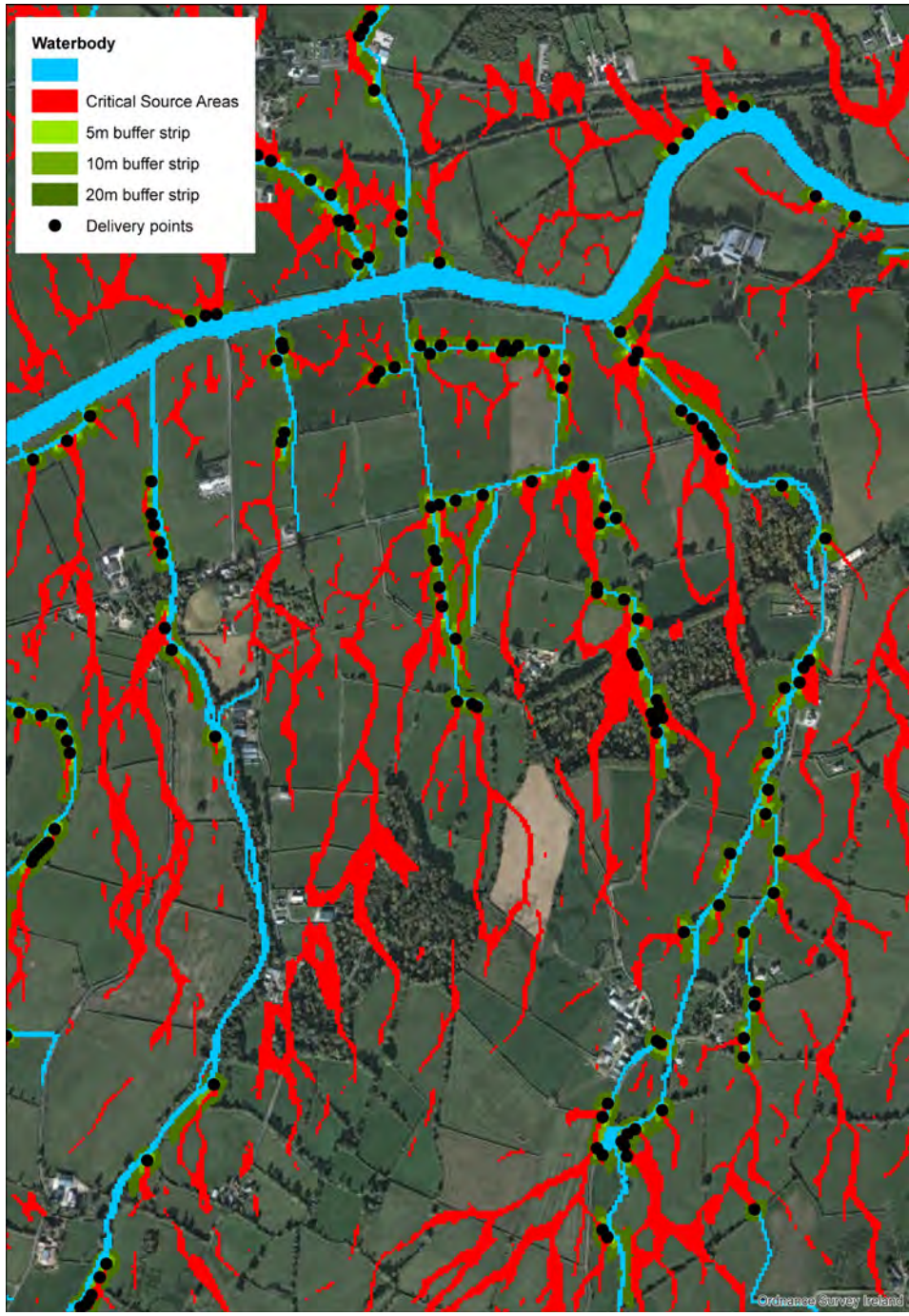
predicted runoff P concentration (mg/l) x Soil Topographic Index

Proxy

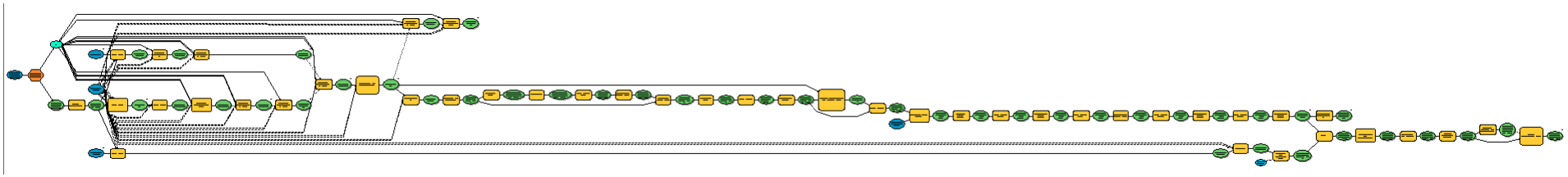
Runoff P load (mg) = runoff P concentration (mg/l) x runoff volume (l)




CSA Index (P Index 3)
Value
0.25 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1
1 - 1.25
1.25 - 1.5
1.5 - 3
Waterbody
N
0
0.5
1
2 Km


Waterbody
Critical Source Areas
5m buffer strip
10m buffer strip
20m buffer strip
Delivery points
Ordnance Survey Ireland

National automated identification of CSAs and delivery points for targeting P loss mitigation measures



The model delineates CSAs and delivery points to waterbodies, and calculates CSA attributes to further prioritise the targeting mitigation measures.
Attributes include:

- CSA area
- Mean, max and total CSA Index value
- Runoff P load (kg and kg/ha)
- Receiving waterbody status (e.g. priority status, risk status, water quality status, pearl mussel site) and pressure type (e.g. agriculture, forestry)

CSA Attribute Table to Prioritise Worst CSAs

CSA ID

CSA Index summary stats

WFD river subbasin info

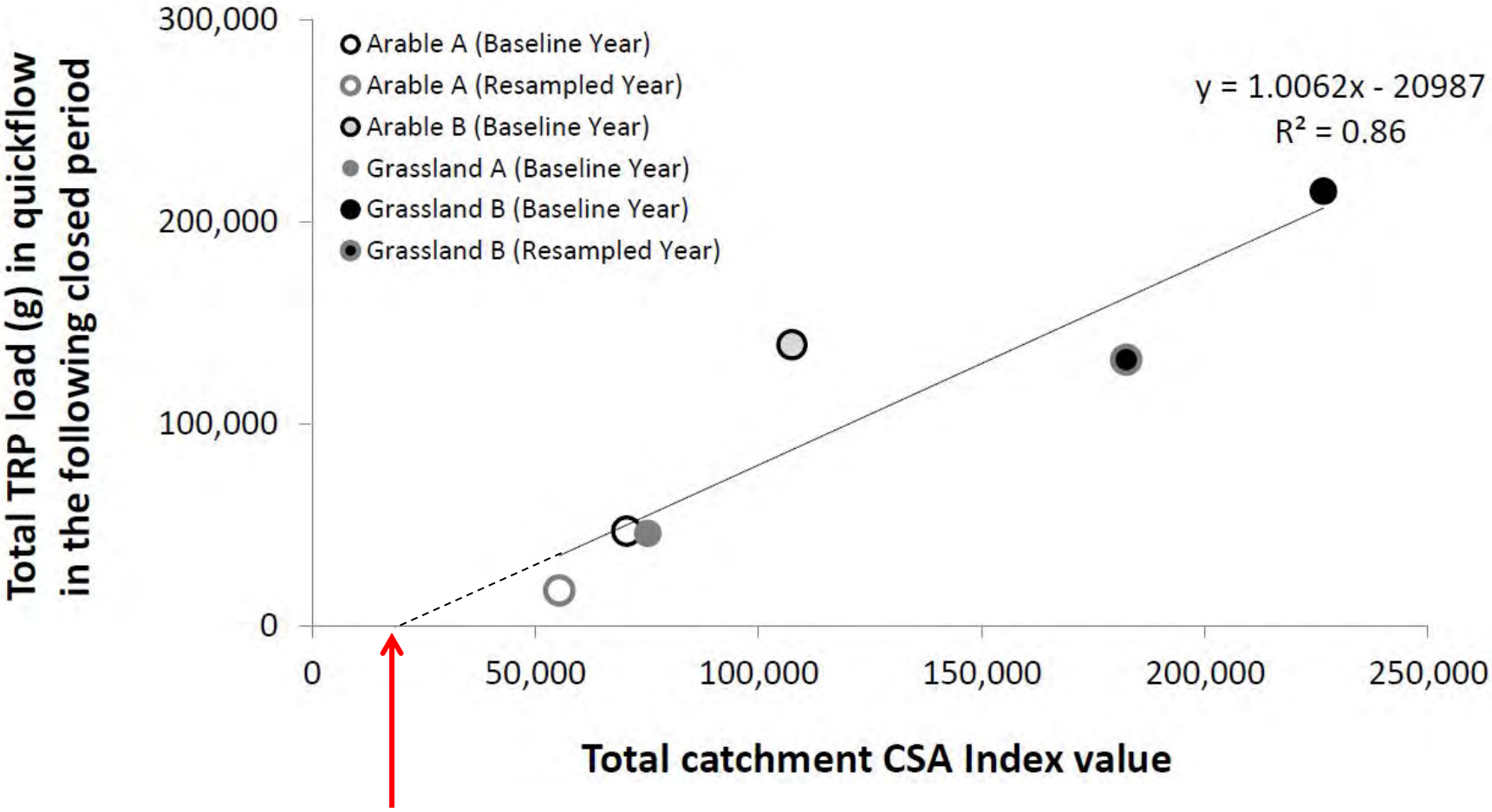
CSA area (ha) and P loss (kg and kg/ha)

CSAs

OBJECTID *	Shape *	CSA_ID	csa_area	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	NAME	EU_CD	ORDER_	BASIN_CD	Ms_CD	RBD	SUM_2m	csa_areaha	CSAPloadkg	CSAPlkgha
4099937	Polygon	209063	4949075	197963	494907	0.250001	1.192	0.941999	0.455337	0.174672	90139.87121			0		<Null>		563374	494.908	566.867	1.1454
668680	Polygon	84461	4672750	186910	467275	0.250001	1.192	0.941999	0.451034	0.185821	84302.68410			0		<Null>		526892	467.275	530.159	1.13458
2866201	Polygon	120651	4396675	175867	439667	0.250001	1.192	0.941999	0.407781	0.138426	71715.24612			0		<Null>		448220	439.668	450.999	1.02577
2745284	Polygon	103824	3825800	153032	382580	0.250001	1.192	0.941999	0.433478	0.174999	66336.03127			0		<Null>		414600	382.58	417.171	1.09042
1158951	Polygon	74695	3626475	145059	362647	0.250001	1.192	0.941999	0.448417	0.184525	65046.89908			0		<Null>		406543	362.647	409.064	1.128
2080869	Polygon	335354	2745000	109800	274500	0.250005	1.192	0.941995	0.491653	0.219147	53983.53767			0		<Null>		337397	274.5	339.489	1.23675
923240	Polygon	34034	3123825	124953	312382	0.25	1.192	0.942	0.428492	0.176929	53541.41127			0		<Null>		334634	312.383	336.709	1.07787
2081885	Polygon	336370	2511225	100449	251122	0.250005	1.192	0.941996	0.518876	0.18678	52120.57034			0		<Null>		325754	251.122	327.774	1.30524
4562248	Polygon	279131	2572525	102901	257252	0.250003	1.192	0.941997	0.49937	0.204273	51385.63094			0		<Null>		321160	257.253	323.151	1.25616
678047	Polygon	93828	2692925	107717	269292	0.250002	1.192	0.941998	0.471342	0.207308	50771.51172			0		<Null>		317322	269.293	319.289	1.18566
910002	Polygon	20796	2777675	111107	277767	0.250002	1.192	0.941998	0.43798	0.176698	48662.67972	BRACKAN_010	IE_SE_11B040200	4	177 Owenav	<Null>	IESE	304142	277.767	306.028	1.10174
923186	Polygon	33980	2703125	108125	270312	0.250003	1.192	0.941997	0.43699	0.184368	47249.59213			0		<Null>		295310	270.313	297.141	1.09925
2081239	Polygon	335724	2288100	91524	228810	0.250001	1.192	0.941999	0.506988	0.239966	46401.58915			0		<Null>		290010	228.81	291.808	1.27533
2745337	Polygon	103877	2541550	101662	254155	0.250006	1.01	0.759994	0.431244	0.177803	43841.08192			0		<Null>		274007	254.155	275.706	1.08479
5908765	Polygon	157331	2291700	91668	229170	0.250002	1.01	0.759998	0.477019	0.170326	43727.40091			0		<Null>		273296	229.17	274.99	1.19994
1769769	Polygon	24254	2160275	86411	216027	0.250002	1.192	0.941998	0.505441	0.215529	43675.64632			0		<Null>		272973	216.027	274.665	1.27144
4562027	Polygon	278910	2224875	88995	222487	0.250003	1.192	0.941997	0.489455	0.205663	43559.00462			0		<Null>		272244	222.488	273.932	1.23122
1490647	Polygon	331243	2341125	93645	234112	0.250001	1.192	0.941999	0.458018	0.201159	42891.07339			0		<Null>		268069	234.113	269.731	1.15214
678060	Polygon	93841	2297125	91885	229712	0.25	1.192	0.942	0.466462	0.19229	42860.89151			0		<Null>		267881	229.712	269.542	1.17339
5671474	Polygon	111188	2203750	88150	220375	0.250005	1.01364	0.763635	0.482619	0.201599	42542.85756			0		<Null>		265893	220.375	267.542	1.21403
4562294	Polygon	279176	2145200	85808	214520	0.250001	1.192	0.941999	0.495274	0.20536	42498.44931			0		<Null>		265615	214.52	267.262	1.24586
1492963	Polygon	333559	2151925	86077	215192	0.250002	1.192	0.941998	0.493066	0.201269	42441.65734			0		<Null>		265260	215.193	266.905	1.24031
3101132	Polygon	220889	2338900	93556	233890	0.250001	1.192	0.941999	0.444853	0.17774	41618.63341			0		<Null>		260116	233.89	261.729	1.11903
4562249	Polygon	279131	2125750	85030	212575	0.250005	1.192	0.941995	0.483591	0.20136	41119.72575			0		<Null>		256998	212.575	258.591	1.21647
2435613	Polygon	116842	1999050	79962	199905	0.250002	1.192	0.941998	0.50569	0.222396	40436.01391			0		<Null>		252725	199.905	254.292	1.27206
2082169	Polygon	336654	1994300	79772	199430	0.250012	1.192	0.941988	0.498998	0.216142	39806.10190			0		<Null>		248788	199.43	250.33	1.25523
2317872	Polygon	181838	1904700	76188	190470	0.250007	1.192	0.941993	0.514656	0.236512	39210.63838			0		<Null>		245066	190.47	246.585	1.29461
4562099	Polygon	278982	2004075	80163	200407	0.250018	1.192	0.941982	0.474371	0.172827	38027.02781			0		<Null>		237669	200.408	239.143	1.19328
3101237	Polygon	220994	2044200	81768	204420	0.25	1.192	0.942	0.44202	0.173727	36143.07940			0		<Null>		225894	204.42	227.295	1.1119
4562325	Polygon	279206	1860075	74403	186007	0.250001	1.192	0.941999	0.474554	0.18668	35308.26816			0		<Null>		220677	186.008	222.045	1.19374
3735261	Polygon	25613	1981750	79270	198175	0.250011	1.01	0.759989	0.444222	0.17281	35213.45144	SCRAMOGE_01	IE_SH_26S010050	3	155a Shanno	<Null>	IEGBNISH	220084	198.175	221.449	1.11744
923242	Polygon	34036	2065150	82606	206515	0.250001	1.192	0.941999	0.423983	0.169668	35023.57976			0		<Null>		218897	206.515	220.254	1.06653
4002581	Polygon	111707	1664225	66569	166422	0.250002	1.01	0.759998	0.524339	0.184205	34904.74952			0		<Null>		218155	166.423	219.508	1.31898
1159257	Polygon	75001	1947875	77915	194787	0.250001	1.192	0.941999	0.443555	0.186022	34559.56213			0		<Null>		215997	194.788	217.336	1.11576
2080864	Polygon	335349	1694350	67774	169435	0.250026	1.192	0.941974	0.49693	0.22086	33678.90603			0		<Null>		210493	169.435	211.798	1.25003
3665320	Polygon	35096	1917225	76689	191722	0.250008	1.192	0.941992	0.431579	0.156291	33097.32742			0		<Null>		206858	191.723	208.141	1.08563
1159049	Polygon	74793	1931350	77254	193135	0.250002	1.192	0.941998	0.425968	0.156023	32907.75225	CLERISTOWN S	IE_SE_13C040400	3	179 Stream	<Null>	IESE	205673	193.135	206.948	1.07152

0 (0 out of 5965614 Selected)

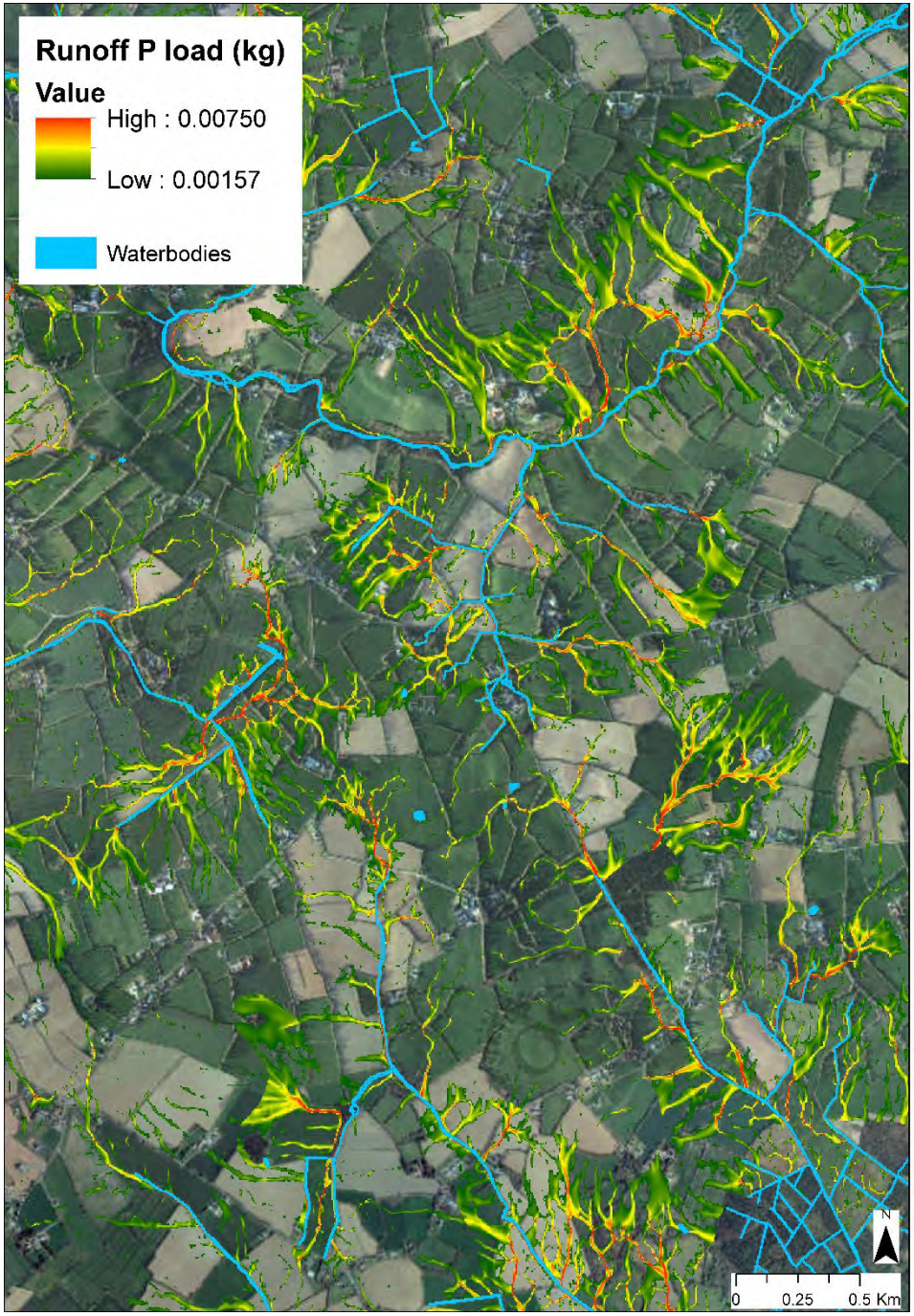
Relationship between total catchment CSA Index value and total runoff P loads

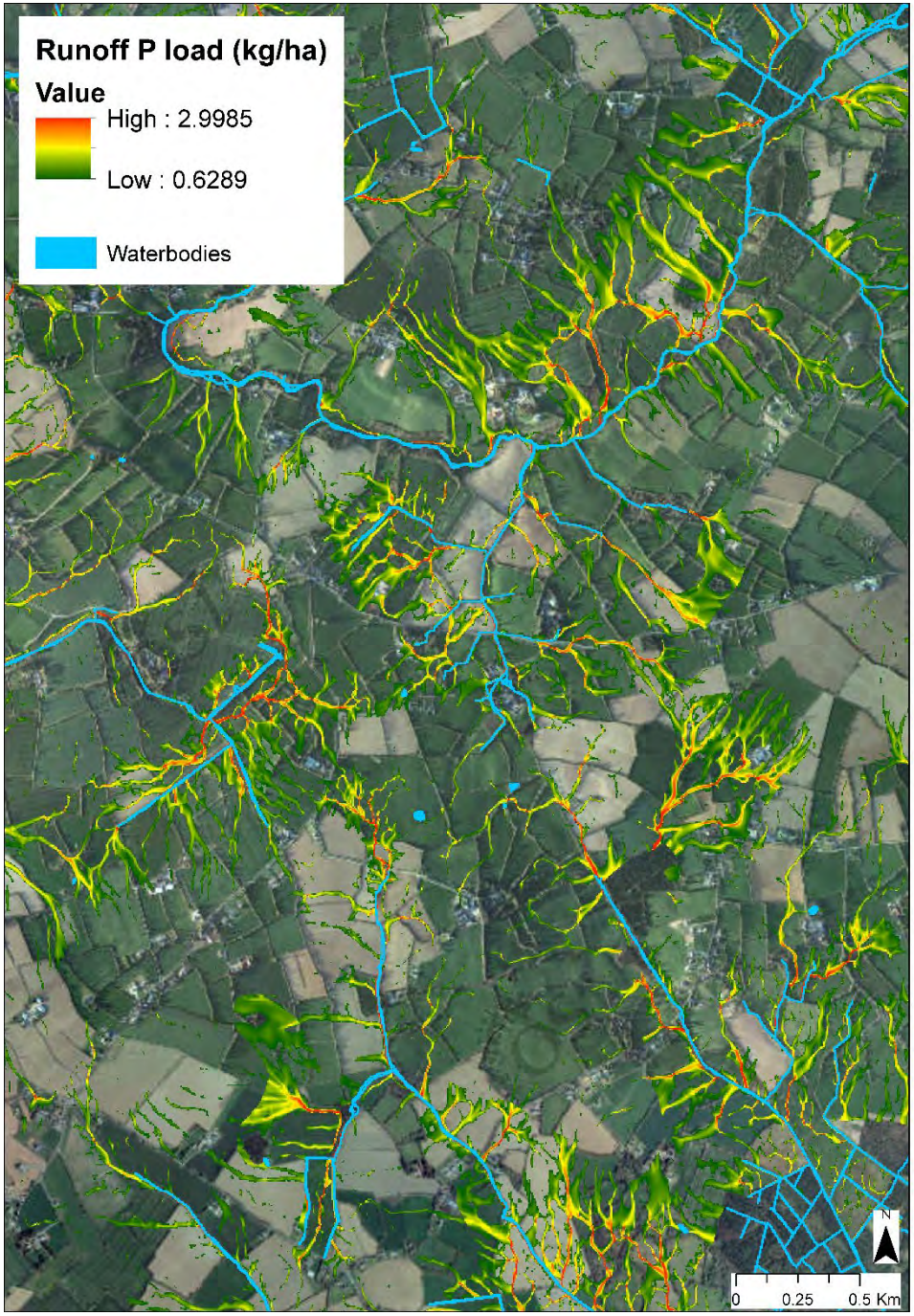


X intercept: 20,858.68

CSA Index threshold > 0.25 are CSAs

Thomas, I.A., Mellander, P.-E., Murphy, P.N.C., Fenton, O., Shine, O., Djodjic, F., Dunlop, P., Jordan, P., 2016b. A sub-field scale critical source area index for legacy phosphorus management using high resolution data. Agriculture, Ecosystems and Environment 233, 238-252.


Runoff P load (kg)
Value
High : 0.00750
Low : 0.00157
Waterbodies
N
0 0.25 0.5 Km


Runoff P load (kg/ha)
Value
High : 2.9985
Low : 0.6289
Waterbodies
N
0 0.25 0.5 Km

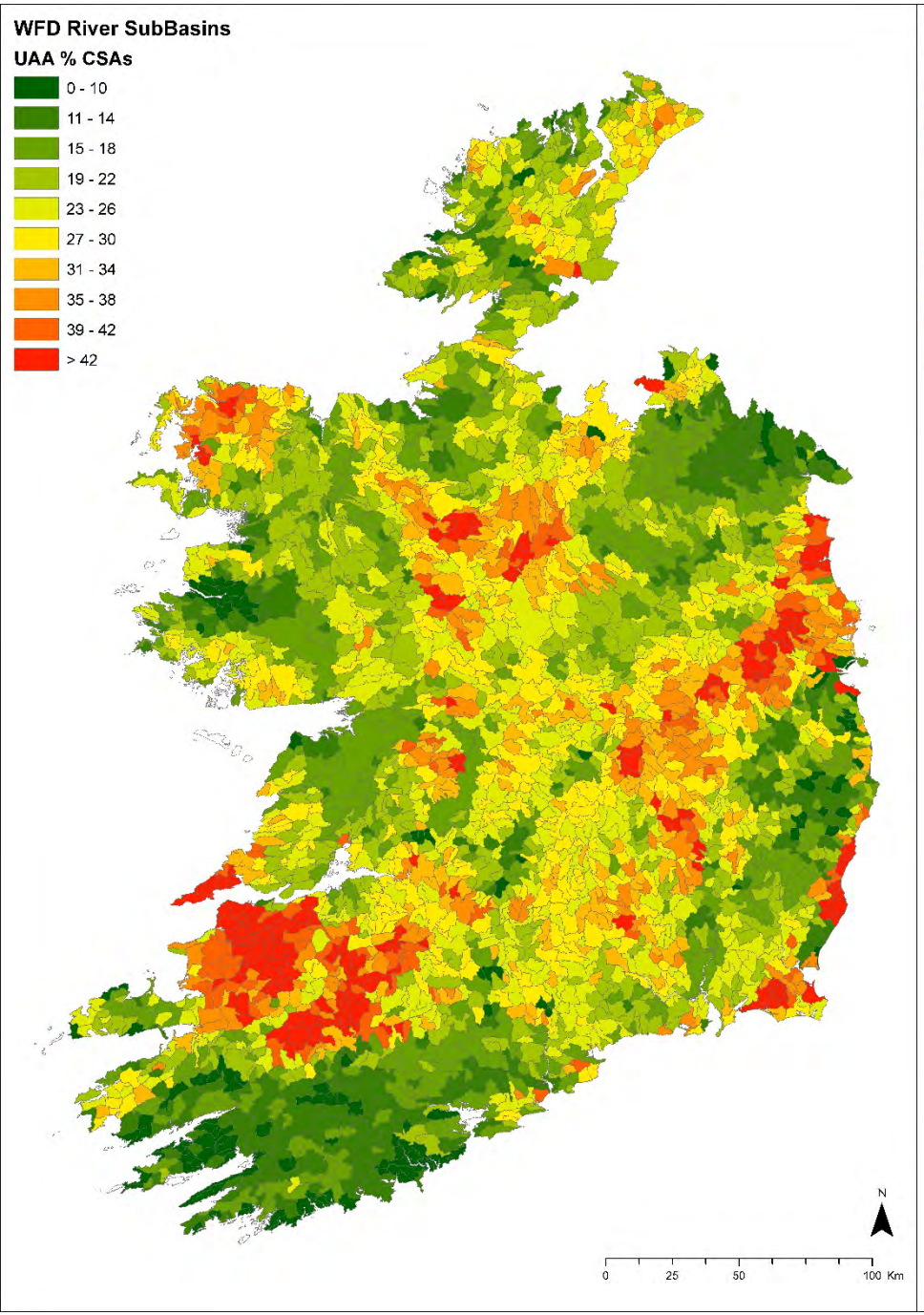

N
0 0.075 0.15 0.3 Km

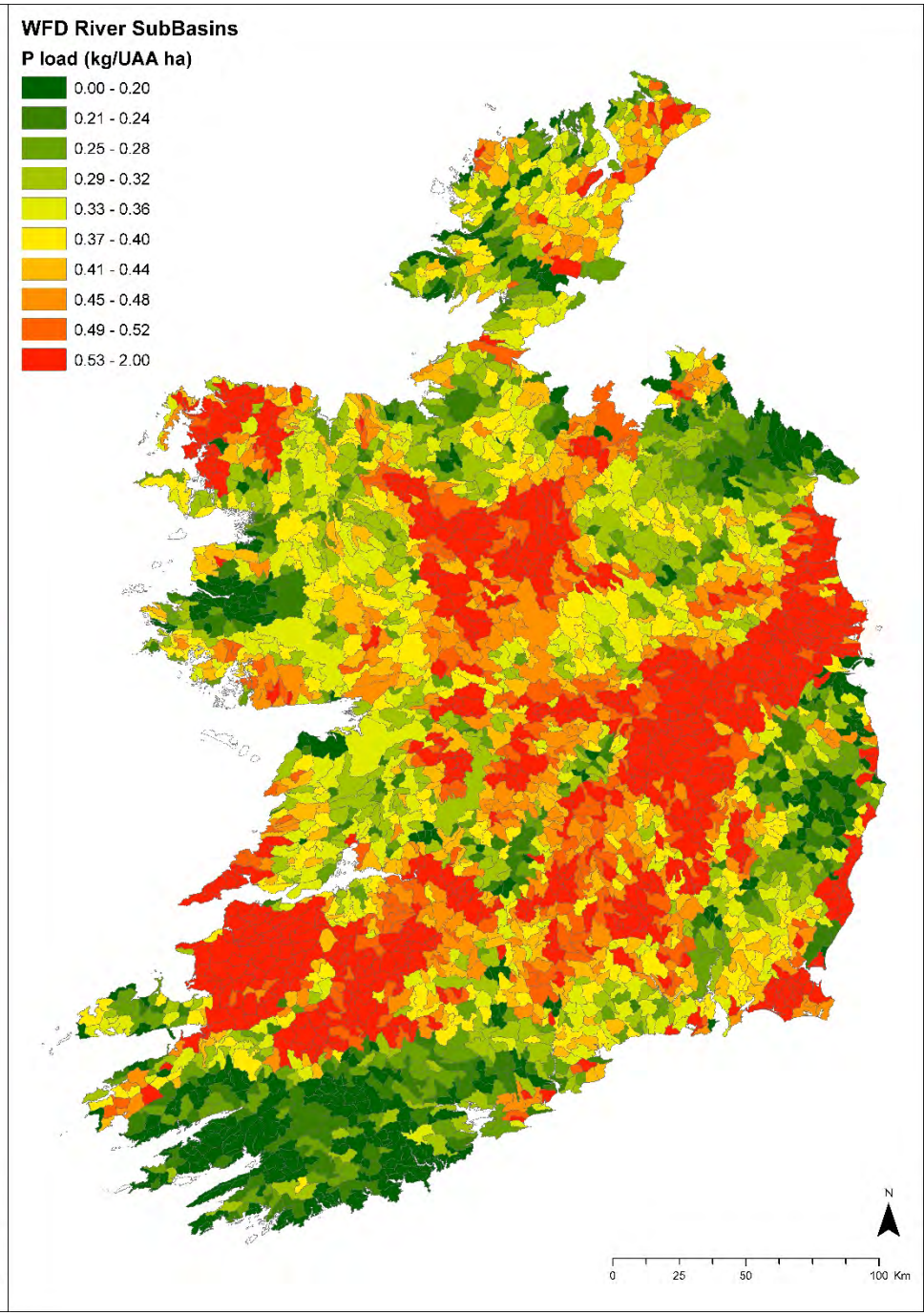

CSAs
N
0 0.075 0.15 0.3 Km

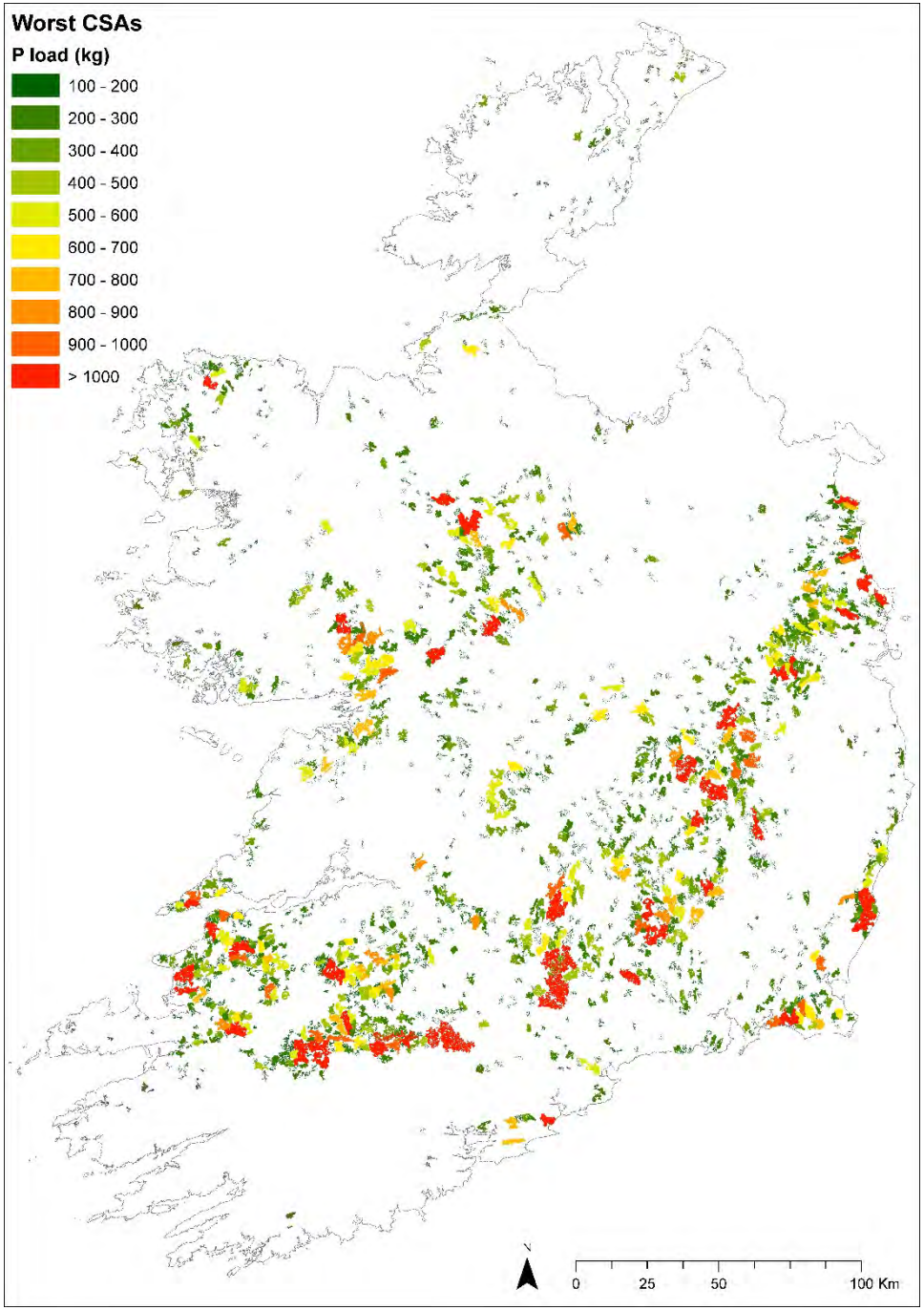

CSAs

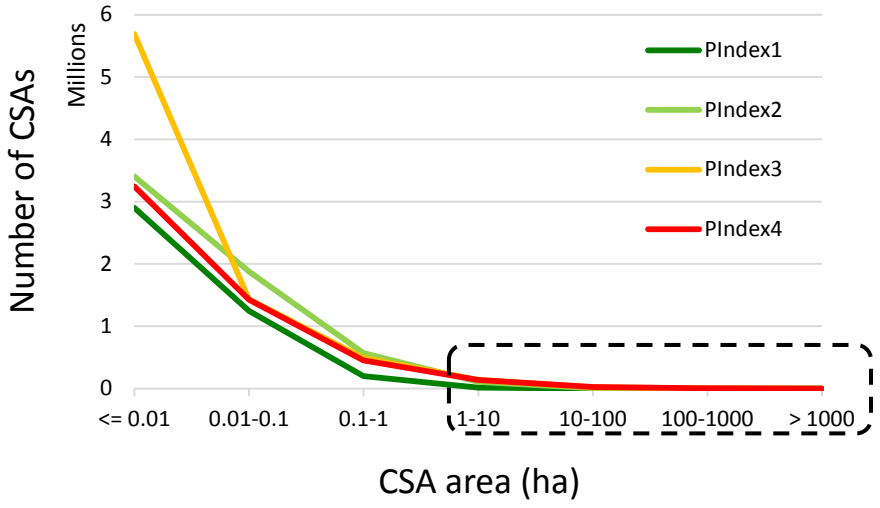

CSAs

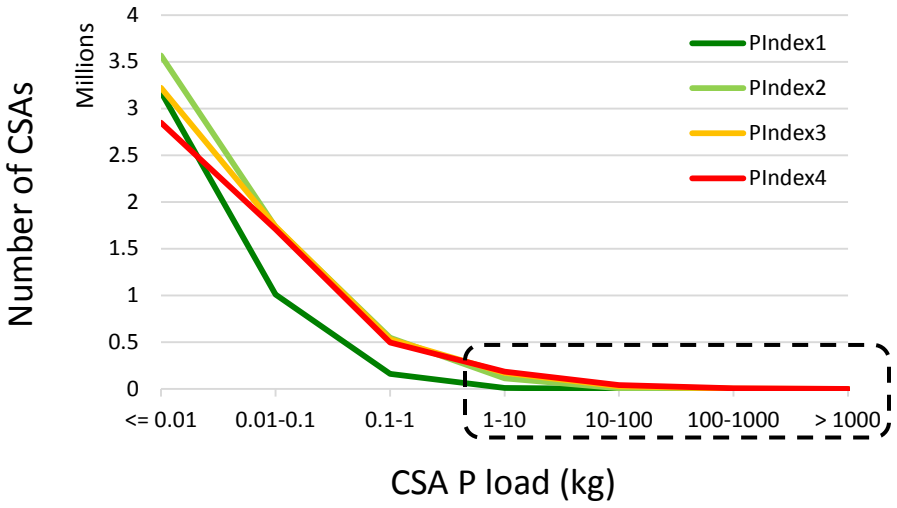

CSAs

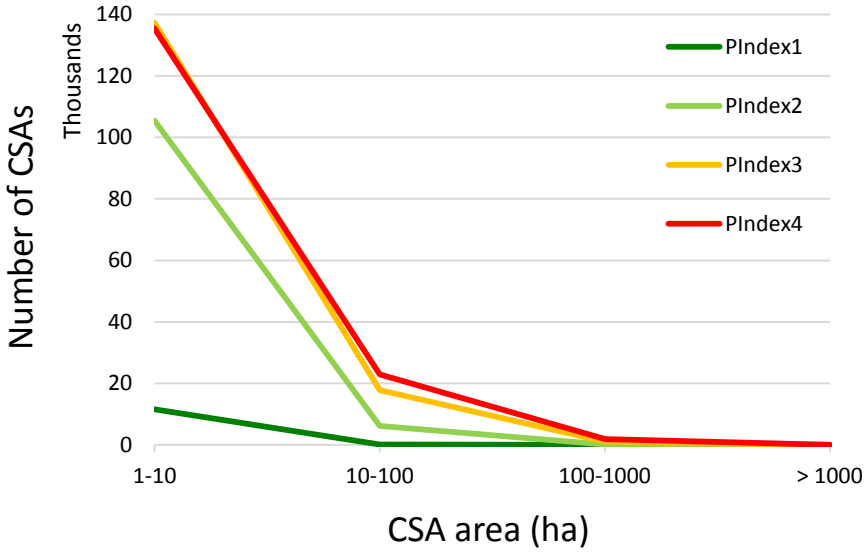

WFD River SubBasins
UAA % CSAs
0 - 10
11 - 14
15 - 18
19 - 22
23 - 26
27 - 30
31 - 34
35 - 38
39 - 42
> 42
N
0
25
50
100 Km

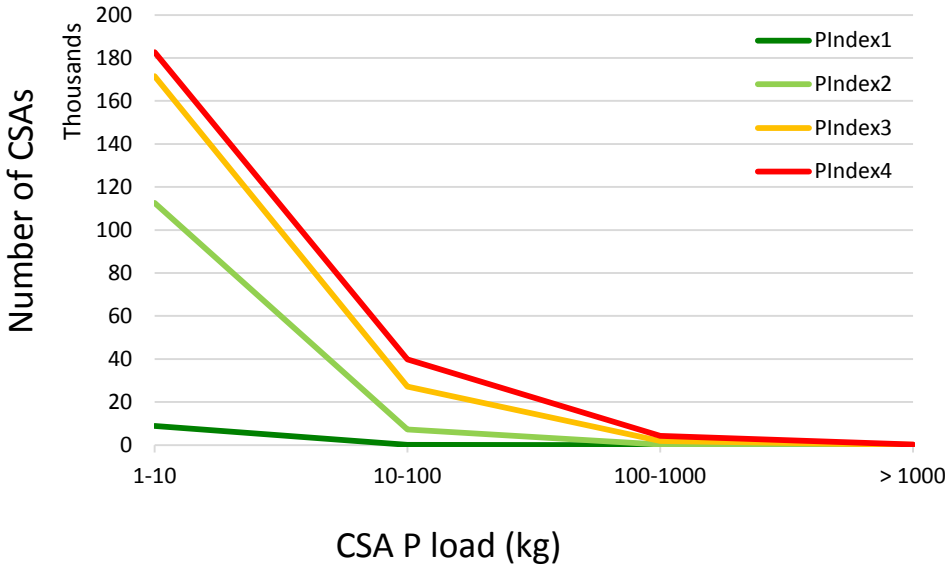

WFD River SubBasins
P load (kg/UAA ha)
0.00 - 0.20
0.21 - 0.24
0.25 - 0.28
0.29 - 0.32
0.33 - 0.36
0.37 - 0.40
0.41 - 0.44
0.45 - 0.48
0.49 - 0.52
0.53 - 2.00
N
0
25
50
100 Km


Worst CSAs
P load (kg)
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1000
> 1000
N
0
25
50
100 Km


Number of CSAs
Millions
6
5
4
3
2
1
0
PIndex1
PIndex2
PIndex3
PIndex4
<= 0.01
0.01-0.1
0.1-1
1-10
10-100
100-1000
> 1000
CSA area (ha)


Number of CSAs
Millions
4
3.5
3
2.5
2
1.5
1
0.5
0
PIndex1
PIndex2
PIndex3
PIndex4
<= 0.01
0.01-0.1
0.1-1
1-10
10-100
100-1000
> 1000
CSA P load (kg)


Number of CSAs
Thousands
140
120
100
80
60
40
20
0
PIndex1
PIndex2
PIndex3
PIndex4
1-10
10-100
100-1000
> 1000
CSA area (ha)

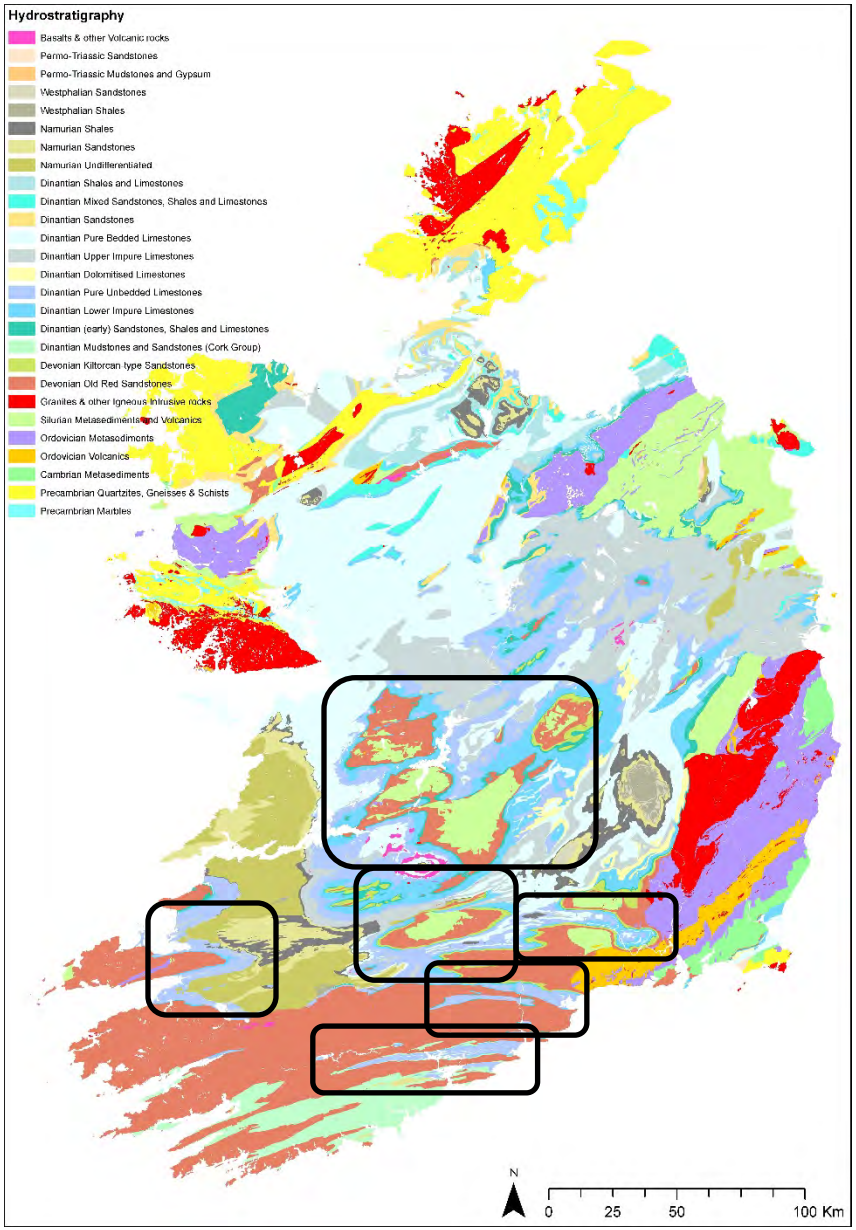

Number of CSAs
Thousands
200
180
160
140
120
100
80
60
40
20
0
PIndex1
PIndex2
PIndex3
PIndex4
1-10
10-100
100-1000
> 1000
CSA P load (kg)

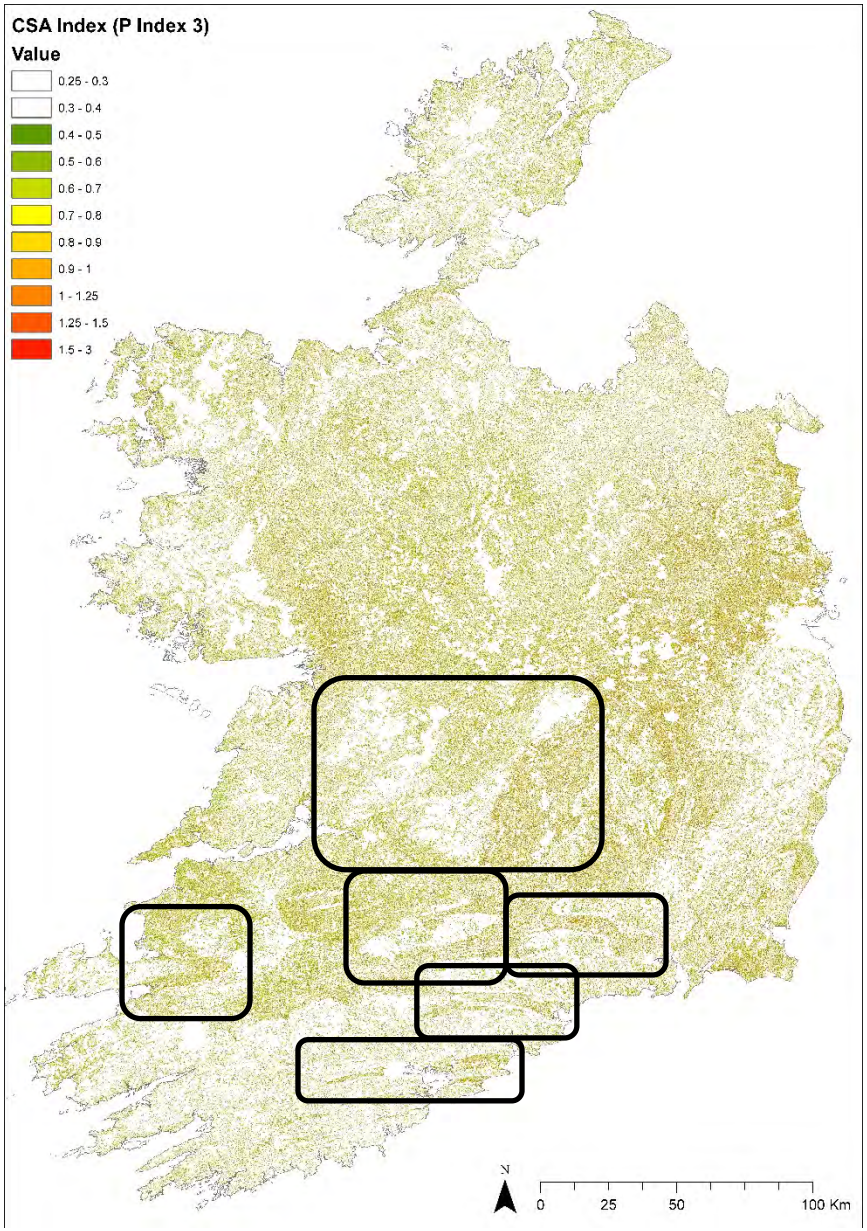
National CSA Summary Stats

		Mean	Min	Max	Sum	STD
CSA area (ha)	PIndex1	0.03	0.0025	60.4	123,390	0.17
	PIndex2	0.11	0.0025	494.9	663,056	1.24
	PIndex3	0.23	0.0025	3,332.2	1,315,532	4.77
	PIndex4	0.32	0.0025	4,711.2	1,664,545	7.33
CSA P load (kg)	PIndex1	0.02	0.0016	47.7	99,951	0.15
	PIndex2	0.12	0.0000	566.9	712,286	1.41
	PIndex3	0.34	0.0000	4,708.1	1,946,973	7.53
	PIndex4	0.60	0.0016	9,739.4	3,169,830	14.92
CSA P load (kg/ha)	PIndex1	0.76	0.6289	1.2	N/A	0.14
	PIndex2	0.97	0.0000	3.0	N/A	0.45
	PIndex3	1.26	0.0000	6.2	N/A	0.96
	PIndex4	1.58	0.6289	9.9	N/A	1.50
CSA Index (value)	PIndex1	0.30	0.2500	0.5	15,893,625	0.015 (mean)
	PIndex2	0.38	0.0000	1.2	113,263,589	0.040 (mean)
	PIndex3	0.50	0.0000	2.5	309,596,192	0.069 (mean)
	PIndex4	0.63	0.2500	3.9	504,047,710	0.098 (mean)

Total Ireland area (km²)								70,273
Total Ireland agricultural area (km²)								55,951
Total Ireland waterbody perimeter length (km)								496,670
	PIndex1	PIndex2	PIndex3	PIndex4	PIndex1	PIndex2	PIndex3	PIndex4
	All CSAs				CSAs >= 1kg P			
Total CSA area (km²)	1,234	6,631	13,155	16,645	214	4,219	11,217	15,100
Total delivery point length (km)	27,279	74,489	114,286	134,363	482	13,947	46,174	79,902
% of Ireland CSAs	1.8	9.4	18.7	23.7	0.3	6.0	16.0	21.5
% of Ireland agriculture area CSAs	2.2	11.9	23.5	29.8	0.4	7.5	20.0	27.0
% of Ireland waterbody perimeter length delivery points	5.5	15.0	23.0	27.1	0.1	2.8	9.3	16.1
Total runoff P loss over closed period (t; normalized by mean total rainfall of 337mm)	100	712	1,947	3,170	19	473	1,709	2,946

CSAs- Hydrogeology is King





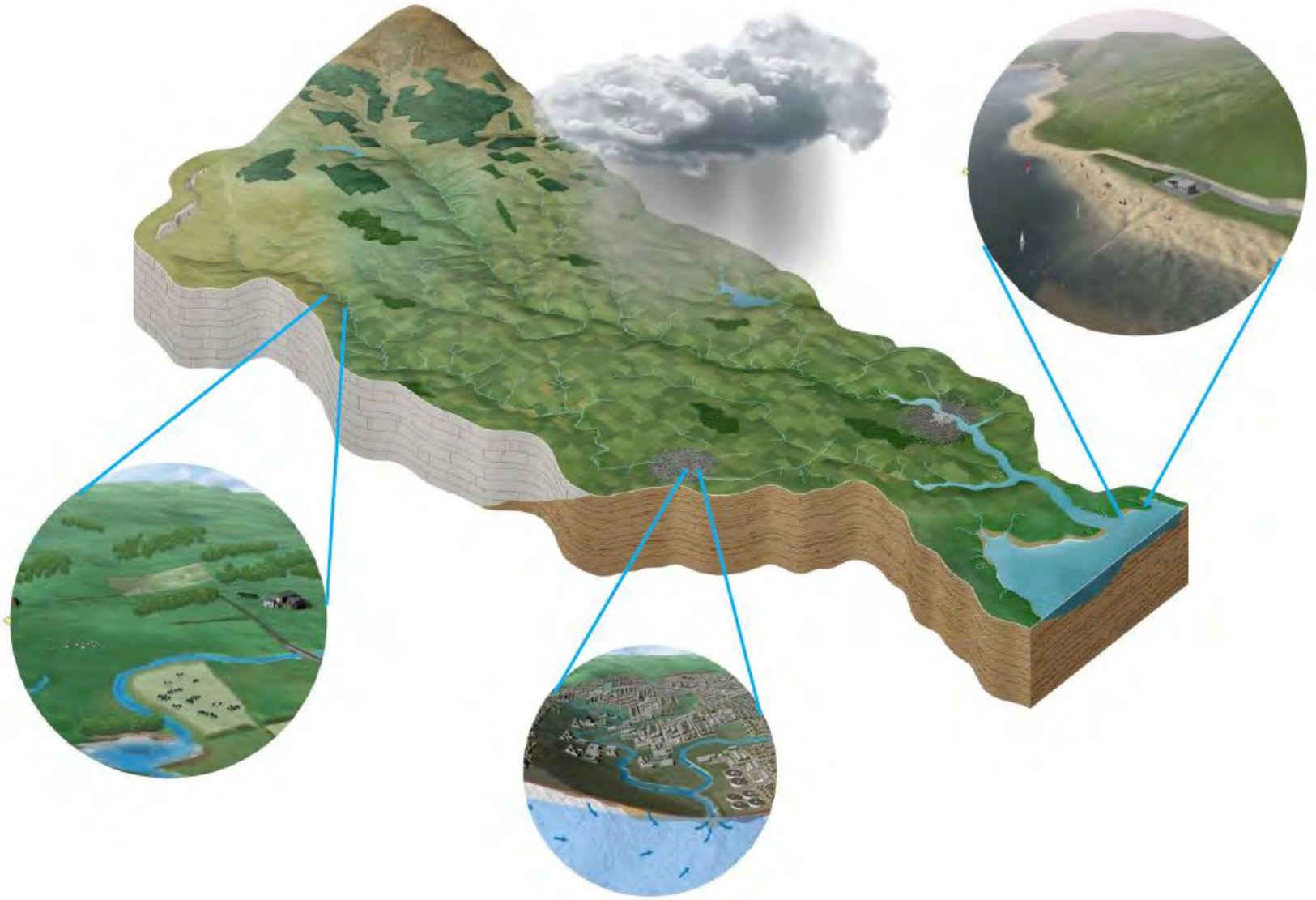
Further Model Development Needed to Account For:

- Subsurface and groundwater P losses (using the existing EPA CCT v2 model)
- SMD and rainfall variations across the country
- P mobilisation risk in peaty soils
- Low runoff risk in karst landscapes
- Redox-sensitive P mobilisation in waterlogged soils (e.g. drumlins)
- Subsurface drainage pipes

Conclusions

- New 5m resolution national CSA map for surface runoff P losses from soil P
- Model quantifies P losses (kg and kg/ha) and locates delivery points to waterbodies
- Results at 5m, CSA, river subbasin and national scales
- Policy implications:

- Target mitigation measures and BMPs cost-effectively (e.g. linking with SMARTER_BufferZ project)
- Smarter P applications and redistribution of excess P to non-CSAs (see Cassidy et al., Session 3)
- Implement CSA and delivery point maps into WFD RBMPs and agri-environment schemes



Acknowledgements
Project partners and collaborators
Steering Committee and EPA Catchments Unit
Data providers: EPA, UCD, Teagasc, DAFM, OPW, GSI, OSI, NEXTMap
This research is funded by the EPA (2016-W-MS-24)