Appendices

Appendix 1

Definition of Aquifer Classifications (Geological Survey of Ireland)

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Regionally Important Bedrock Aquifers:
Bedrock aquifer unit is capable of supplying regionally important abstractions (e.g. large public water supplies), or '*excellent*' yields (>400 m^3/d). The continuous aquifer unit generally has an area of >25 km^2. Groundwater flow predominantly occurs through fractures, fissures and joints.

Rf Regionally Important Fissured Bedrock Aquifer:
Aquifer in which the network of fractures, fissures and joints, through which groundwater flows, is well connected and widely dispersed, resulting in a relatively even distribution of highly permeable zones. There is good aquifer storage and groundwater flow paths can be up to several kilometres in length. There is likely to be substantial groundwater discharge to surface waters ('baseflow') and large (>2000 m^3/d), dependable springs may be associated with these aquifers.

Rk Regionally Important Karstified Bedrock Aquifer:
'Karstification' is the process whereby limestone is slowly dissolved away by percolating waters. It most often occurs in the upper bedrock layers and along certain fractures, fissures and joints, at the expense of others. Karstification frequently results in the uneven distribution of permeability through the rock, and the development of distinctive karst landforms at the surface (e.g. swallow holes, caves, dry valleys), some of which provide direct access for recharge/surface water to enter the aquifer. The landscape is characterised by largely underground drainage, with most flow occurring through the more permeable, solutionally-enlarged, interconnected fissure/conduit zones, which may be several kilometres long. Groundwater velocities through fissures/conduits may be high and aquifer storage is frequently low. Groundwater often discharges as large springs (>2000 m^3/d), which range from regular and dependable to highly variable ('flashy'). There is strong interconnection between surface water and groundwater.
The degree of karstification ranges from slight to intense. GSI recognises two types of karst aquifer: those dominated by diffuse flow (Rk^d) and those dominated by conduit flow (Rk^c).

Rg Regionally Important Sand/Gravel Aquifer:
A sand/gravel aquifer is classed as **regionally important** if it can supply regionally important abstractions (e.g. large public water supplies), or '*excellent*' yields (>400 m^3/d). It is highly permeable, more than 10 m thick or has a saturated thickness of at least 5 m, and normally extends over *at least* 10 km^2.

Groundwater flows through the pore spaces between sand/gravel grains, and the permeability is mainly determined by the grain size (larger grains give larger pore spaces), and the 'sorting' of the material (the more uniform, the higher the permeability). There is a relatively uniform distribution of groundwater, good aquifer storage and long groundwater flow paths, typically limited by the aquifer's extent.

Groundwater gradients are typically low ('flatter' water tables), giving relatively low groundwater velocities. There is generally a strong interaction between surface water and groundwater, with groundwater discharging into streams if the water table is high, or conversely, the surface water moving into the aquifer, if the surface water level is high. Large, dependable springs (>2000 m^3/d) are often associated with sand/gravel aquifers, especially in low-lying areas or at the periphery of the aquifer.

Locally Important Bedrock Aquifer:
Bedrock aquifer unit capable of supplying locally important abstractions (e.g. smaller public water supplies, group schemes), or '*good*' yields (100-400 m^3/d). Groundwater flow occurs predominantly through fractures, fissures and joints.

Lm Locally Important Bedrock Aquifer, Generally Moderately Productive:
Aquifer in which the network of fractures, fissures and joints, through which groundwater flows, is reasonably well connected and dispersed throughout the rock, giving a *moderate* permeability and groundwater throughput. Aquifer storage is moderate and groundwater flow paths can be up to several kilometres in length. There is likely to be a substantial groundwater contribution to surface waters ('baseflow') and large (>2000 m^3/d), dependable springs may be associated with these aquifers.
This classification also includes aquifers similar to the ***Regionally Important Fractured Bedrock Aquifer (Rf)***, but with a smaller continuous area (<c.25 km^2). Although the aquifer may supply *'excellent'* yields, the small size limits the amount of recharge available to meet abstractions.

Ll Locally Important Bedrock Aquifer, Moderately Productive only in Local Zones:
Aquifer with a limited and relatively poorly connected network of fractures, fissures and joints, giving a *low* fissure permeability which tends to decrease further with depth. A shallow zone of higher permeability may exist within the top few metres of more fractured/weathered rock, and higher permeability may also occur along fault zones. These zones may be able to provide larger 'locally important' supplies of water. In general, the lack of connection between the limited fissures results in relatively poor aquifer storage and flow paths that may only extend a few hundred metres.

Due to the low permeability and poor storage capacity, the aquifer has a low 'recharge acceptance'. Some recharge in the upper, more fractured/weathered zone is likely to flow along the relatively short flow paths and rapidly discharge to streams, small springs and seeps. Groundwater discharge to streams ('baseflow') can significantly decrease in the drier summer months.

Lk Locally Important Karstified Bedrock Aquifer:
Essentially similar to the ***Regionally Important Karstified Bedrock Aquifer (Rk)***, but with a smaller continuous area (<c.25 km^2). Although the properties imply that this aquifer can supply *'excellent'* yields, the smaller size limits the amount of recharge available to meet abstractions.

Lg Locally Important Sand/Gravel Aquifer:
Similar to a ***Regionally Important Sand/Gravel Aquifer (Rg)***, but with a smaller continuous area (c.1-10 km^2) and/or less consistent permeability. Although the aquifer may supply *'excellent'* yields, the smaller size limits the amount of recharge available to meet abstractions.

Poor Bedrock Aquifer:
Bedrock aquifer capable of supplying small abstractions (e.g. domestic supplies, small group schemes), or *'moderate'* to *'low'* yields (<100 m^3/d). Groundwater flow occurs predominantly through a limited and poorly-connected network of fractures, fissures and joints.

Pl Poor Bedrock Aquifer, Moderately Productive only in Local Zones:
Similar to a ***Locally Important Bedrock Aquifer, Moderately Productive only in Local Zones (Ll)***, but with fewer and more poorly-connected fractures, fissures and joints, and with less permeable and/or more limited zones of higher permeability. Overall permeability, storage capacity, recharge acceptance, length of flow path and baseflow are likely to be less than in ***Ll*** aquifers.

Pu Poor Bedrock Aquifer, Generally Unproductive:
Aquifer with generally few and poorly connected fractures, fissures and joints. This *low* fissure permeability tends to decrease further with depth. A shallow zone of slightly higher permeability may exist within the top few metres of more fractured/weathered rock, and higher permability may rarely occur along large fault zones. In general, the poor fissure network results in poor aquifer storage, short flow paths (tens of metres) and low 'recharge acceptance'. Groundwater discharge to streams ('baseflow') is very limited.

Appendix 2

Pilot Catchments Descriptions

Pilot Catchments Descriptions

Owenduff

The Owenduff catchment is located in the west of Ireland, in County Mayo. It has steep slopes in the upper part of the catchment (up to 1.02 i.e. 102 m vertically for every 1 m horizontally) with an average slope of 0.15 across the catchment. The topography of the catchment is presented in Figure 1. The catchment is dominated by a poorly productive Pl aquifer (almost 100%), consisting of Precambrian Quartzites, Gneisses and Schists (Figures 2 and 3).

The flow pathway lengths in the poorly productive aquifer would be expected to be in the order of tens or hundreds of metres, but probably less than 300m. There is 38% extreme vulnerability in the catchment and the subsoils are dominated by blanket peat (59% greater than 3m thick) which cover the rest of the catchment (Figure 4). The catchment is also dominated by poorly drained soils (Figure 5). These characteristics suggest that the Owenduff is a flashy catchment and that the components of flow contributing to the streams would be expected to be overland, interflow (from peat), shallow and deep groundwater.

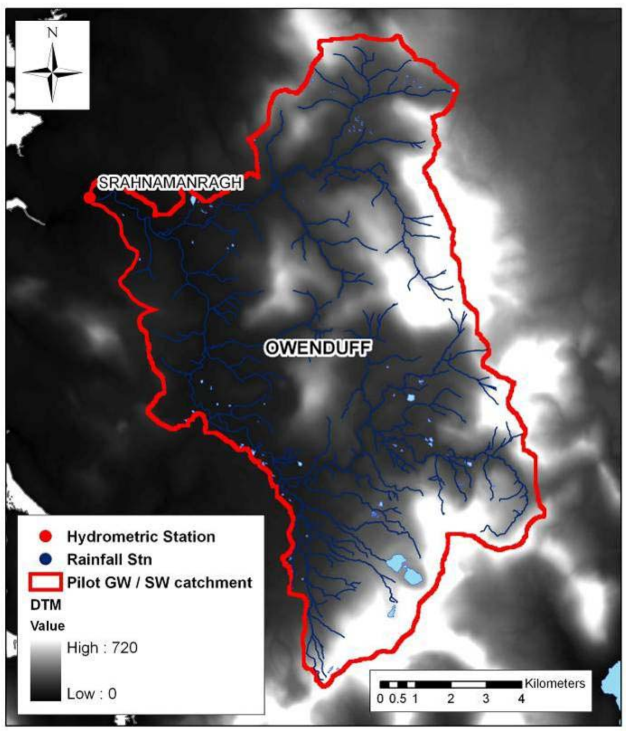


Figure 1. The topography (Digital Terrain Model DTM in metres) of the Owenduff catchment.

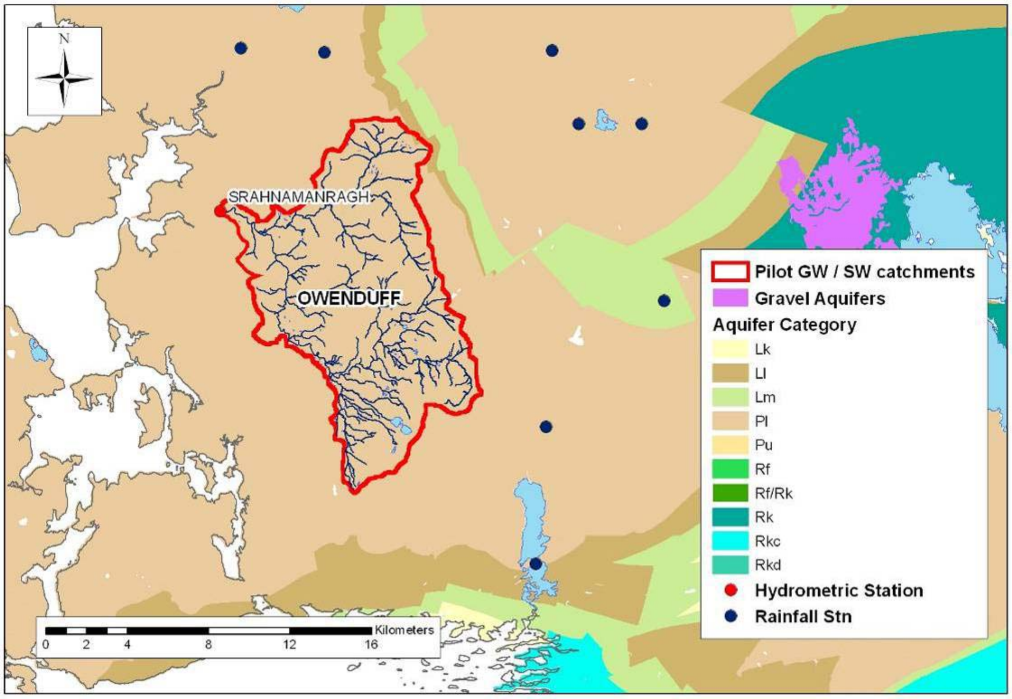


Figure 2. The aquifer categories within the Owenduff catchment and the rainfall stations used for the mathematical modelling.

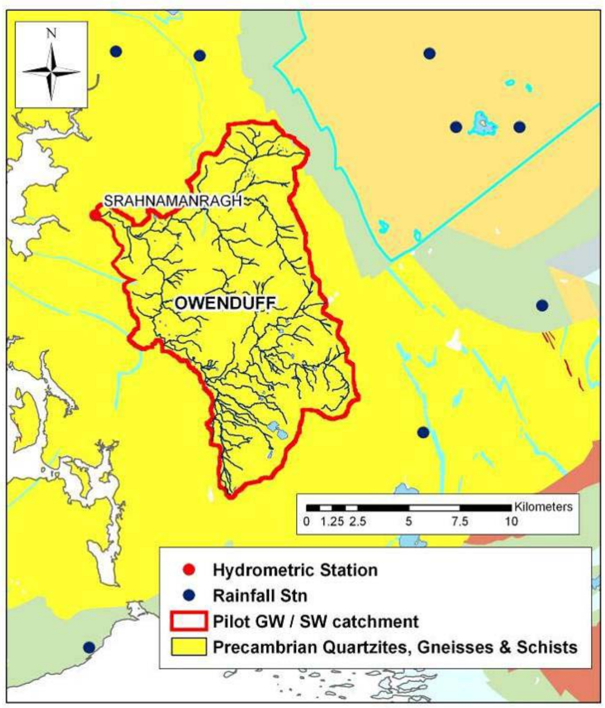


Figure 3. The rock units within the Owenduff catchment.

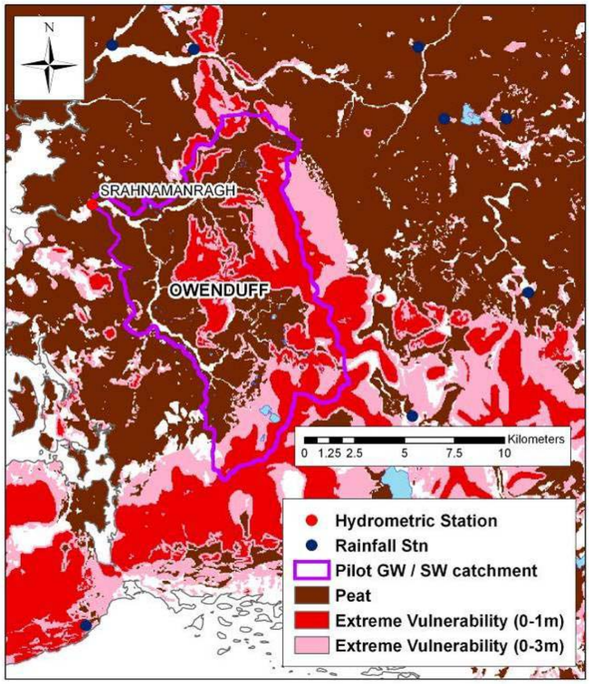


Figure 4. The vulnerability and subsoils within the Owenduff catchment.

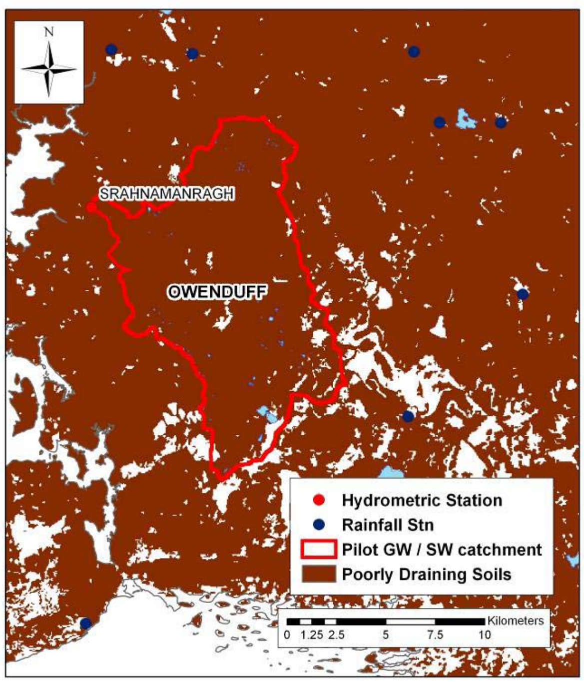


Figure 6. Poorly drained soils in the Owenduff catchment.

Shournagh

The Shournagh catchment is located in the southwest of Ireland, in County Cork. It has relatively steep slopes in the catchment with an average slope of 0.06. The topography of the catchment is presented in Figure 7. The dominant aquifer type is poorly productive Ll aquifer (99%), consisting mainly of Devonian Old Red Sandstones (Figures 8 and 9).

The flow pathway lengths in the poorly productive aquifer would be expected to be in the order of tens or hundreds of metres, but probably less than 300m, and the upper part of the aquifer is possibly fractured allowing shallow groundwater flow. The subsoils in the catchment are dominantly of moderate permeability (91% of Devonian sandstone tills) and there is 34% extreme vulnerability (Figure 10). There is very little peat in the catchment (<1%). There are also few poorly draining soils in the catchment (Figure 11). The contributions to stream flow that would be expected for this hydrogeological scenario are components of deep and shallow groundwater, tills and overland flow.

Bride

The Bride catchment represents the ‘Southern Synclines’ Scenario which represents the steep slopes of the Old Red Sandstone (poorly productive Ll aquifer, 86.5%) that drain into the Dinantian Pure Unbedded Limestones (karst Rkd aquifer 13%) (Figures 8 and 9). There is also a small amount of poorly productive Pl aquifer (1%) that is located at the periphery of the karst aquifer in places. The average slope of the catchment is relatively steep (0.06 across the catchment). The topography of the catchment is presented in Figure 7). The extreme vulnerability area in the catchment (25%) is mainly in the poorly productive aquifer areas (Figure 10). There is little to no low permeability subsoils in the catchment (~2%). There is only a small percentage of poorly drained soils in the catchment (Figure 11). The main flow pathways in the catchment would be expected to be overland flow and interflow on the steep slopes, with a small proportion of flow from the shallow groundwater (in the poorly productive bedrock aquifers) and deep groundwater. In the valley it is expected that there will be a greater contribution of groundwater to river flow. There is a clear reduction in drainage density over the limestone suggesting higher recharge and lower overland flow in the karst areas.

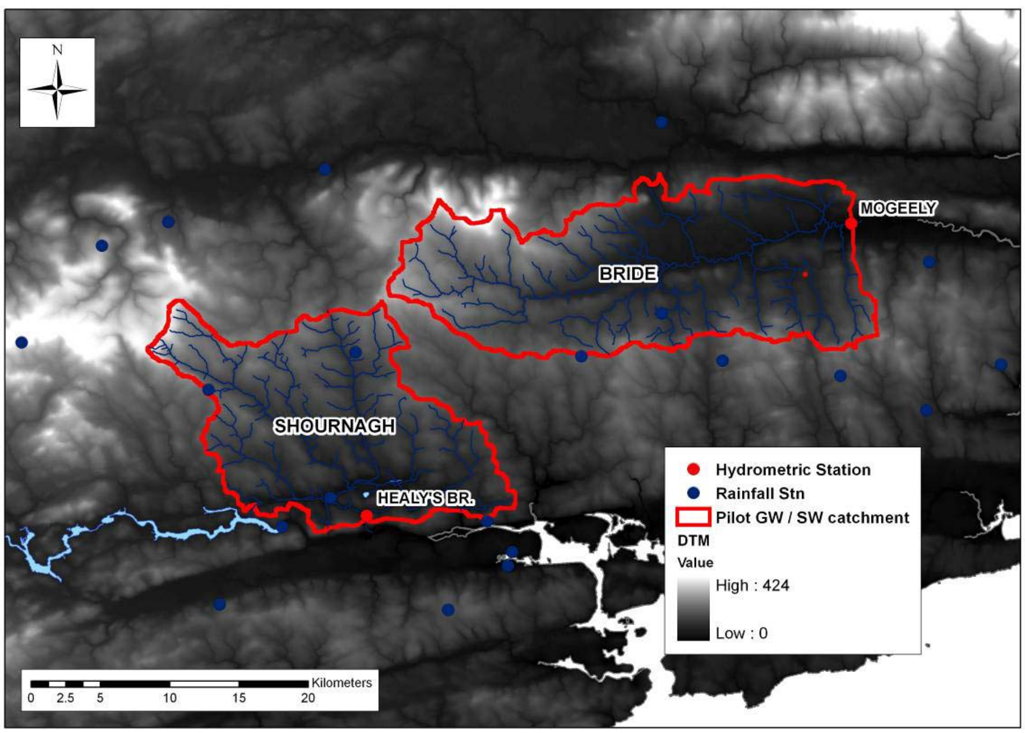


Figure 7. The topography (Digital Terrain Model DTM in metres) of the Bride and Shournagh catchments.

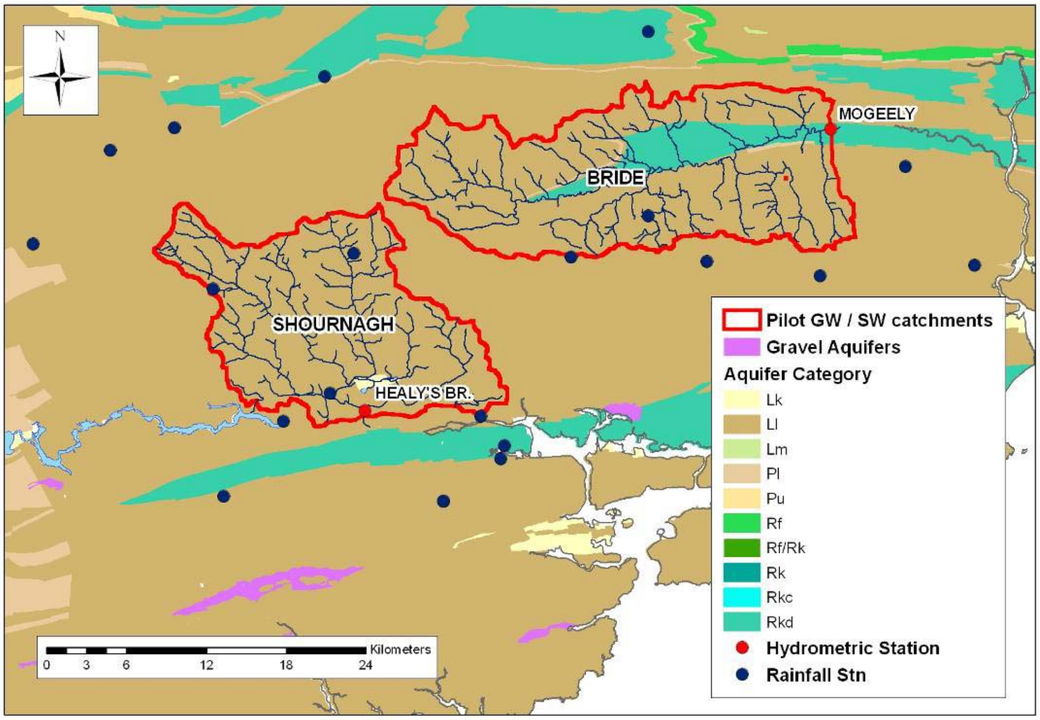


Figure 8. The aquifer catagories within the Shournagh and the Bride catchment areas long with the rainfall stations used for the mathematical modelling.

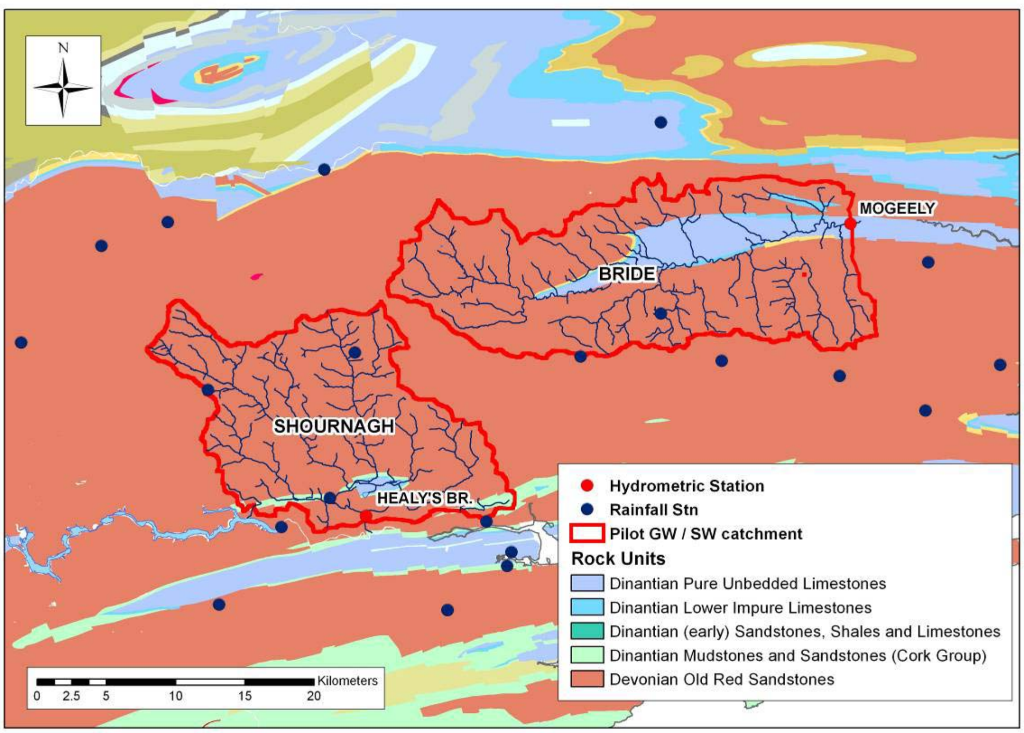


Figure 9. Rock units within the Shournagh and the Bride catchments.

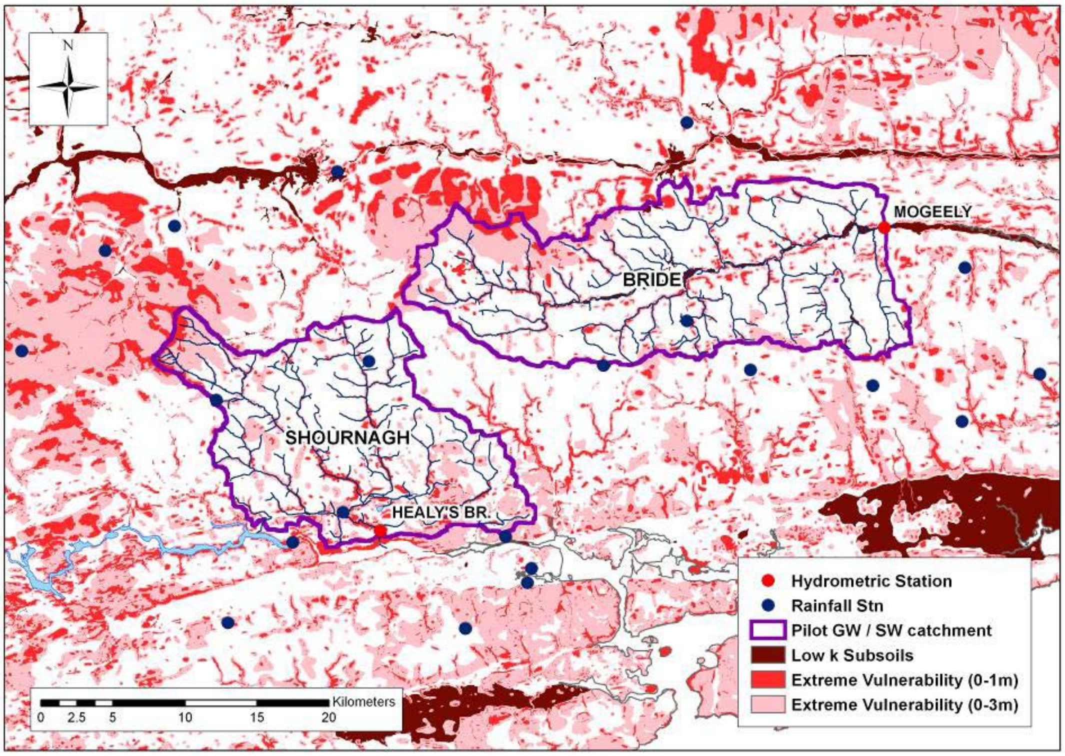


Figure 10. The vulnerability and subsoils within the Bride and Shournagh catchments.

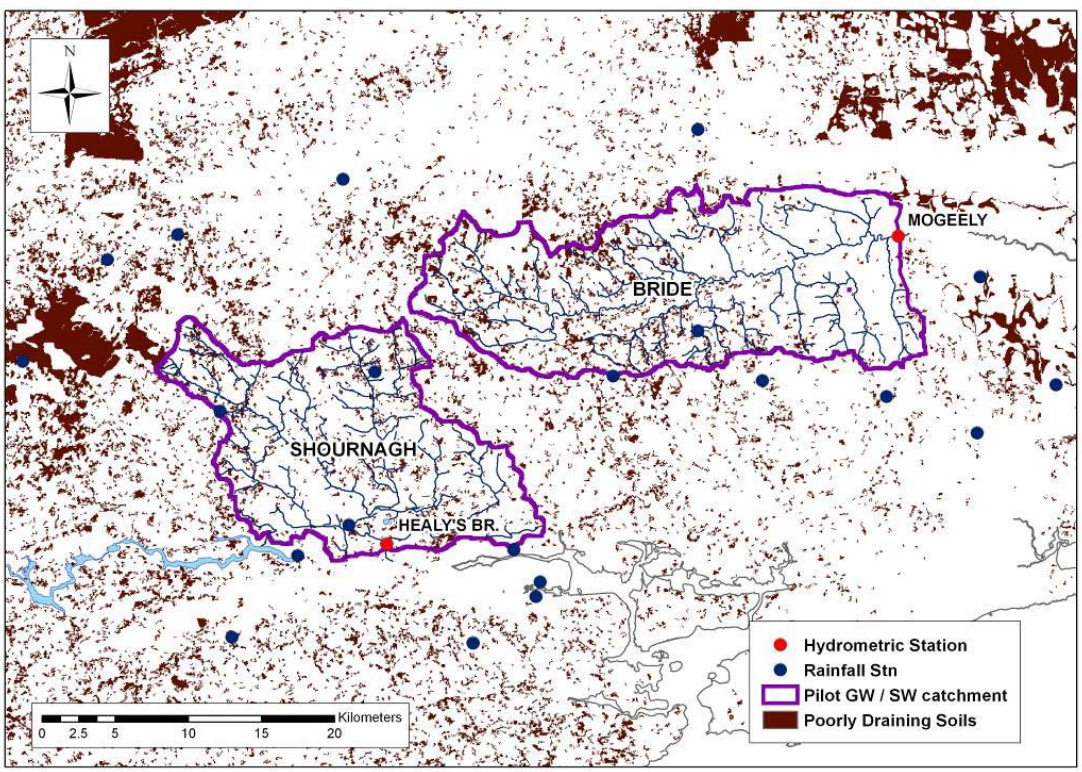


Figure 11. Poorly drained soils in the Bride and Shournagh catchments.

Deel
The Deel catchment is located in the midlands of Ireland, mainly in County Westmeath although the outlet is in County Meath. The topography of the catchment is presented in Figure 12. It is a shallow catchment with an average slope of 0.02. The dominant aquifer type is poorly productive Ll aquifer (88%), consisting mainly of Dinantian Upper Impure Limestones and Dinantian Pure Unbedded Limestones (Figures 13 and 14a).

The remaining 14% of the catchment consists mainly of Lk (in the upper reaches of the catchment) and Pl aquifer types. There is a large lake at the top of the catchment (Lough Lene, 416 hectares) which may act as surface storage in the catchment. The flow pathway lengths in the poorly productive aquifer would be expected to be in the order of tens or hundreds of metres, but probably less than 300m, and the upper part of the aquifer is possibly fractured allowing shallow groundwater flow. There is a small amount of extreme vulnerability in the catchment (12.5% with no low permeability subsoil above the bedrock) and the subsoils mainly have moderate or high permeability (76%). The remaining subsoils consist of cut peat (23% with a thickness greater than 3m) (Figure 15a). The catchment also contains 32.5% poorly drained soils (Figure 16a). Consequently, the contribution of flow to streams will consist of components of flow from deep and shallow groundwater, till, peat and overland flow.

Ryewater
The Ryewater catchment is located in the east of Ireland, in Meath and Kildare and it has the same hydrogeological setting as the Deel. It has a shallower topographic gradient than the Deel catchment (average slope of 0.015). The topography of the catchment is presented in Figure 12. The Ryewater's dominant aquifer type is also Ll, poorly productive (79%) (Figure 13). It contains 19% Pl aquifer and 2% productive fissured Lm aquifer as well. The main rock types are Dinantian limestones in the catchment, as well as Namurian sandstones (Figure 14b).

Like the Deel catchment there is a small amount of extreme vulnerability in the catchment (16%). There is a large percentage of low permeability subsoils (77.5%). The main difference is that there is little peat in the catchment (< 1%) (Figure 15b). There is a higher percentage of poorly drained soils in the Ryewater catchment (72.5%) compared to the Deel (32.5%) (Figure 16b). The flow pathways in the aquifer are likely to be less than 300m and there would be a shallow groundwater component to stream flow, as well as an interflow component from the till subsoils.

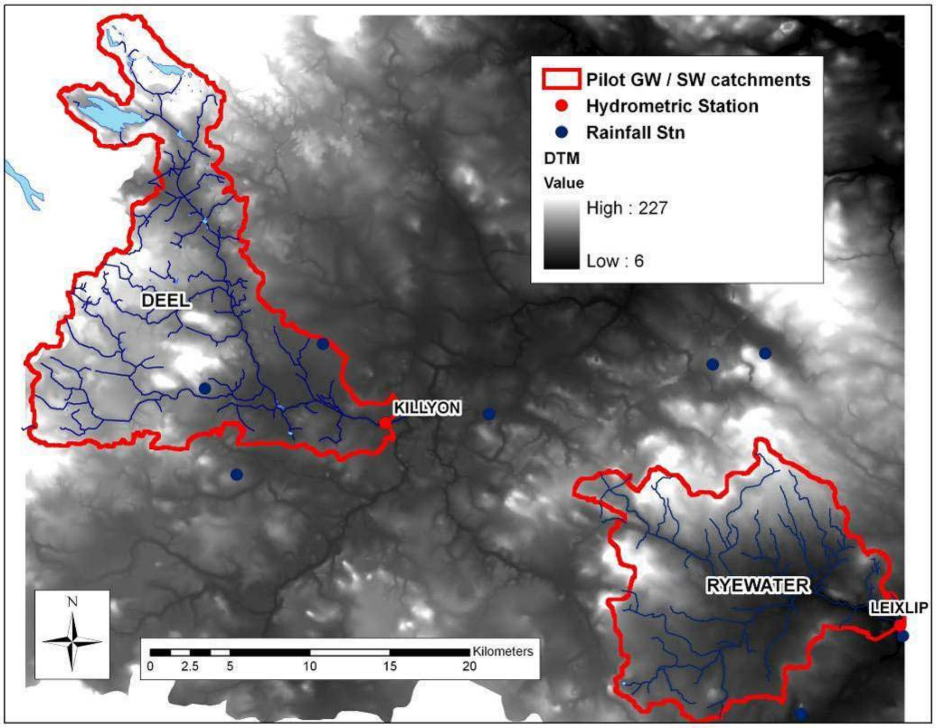


Figure 12. The topography (Digital Terrain Model DTM in metres) of the Deel and Ryewater catchments.

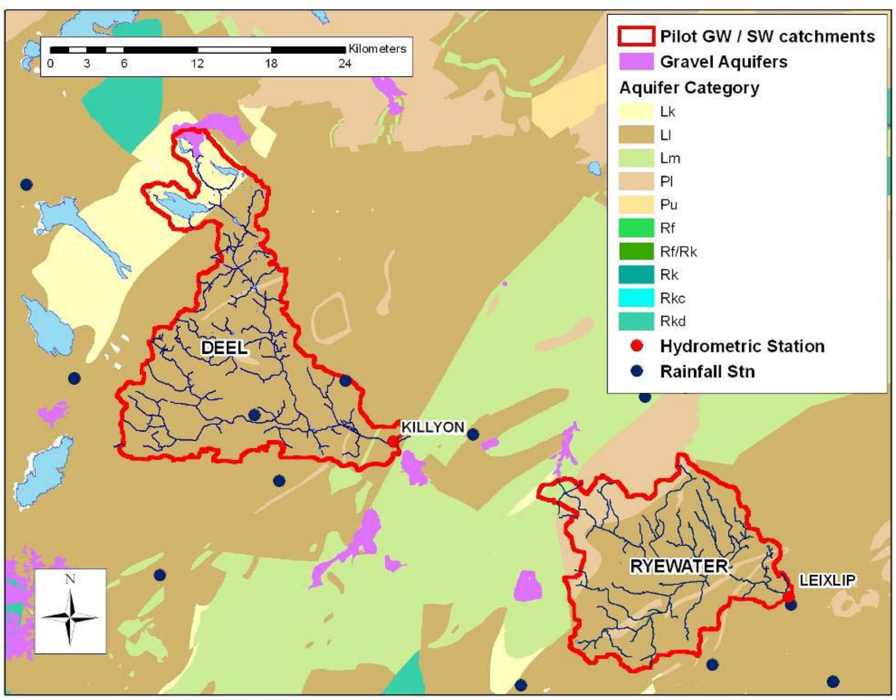
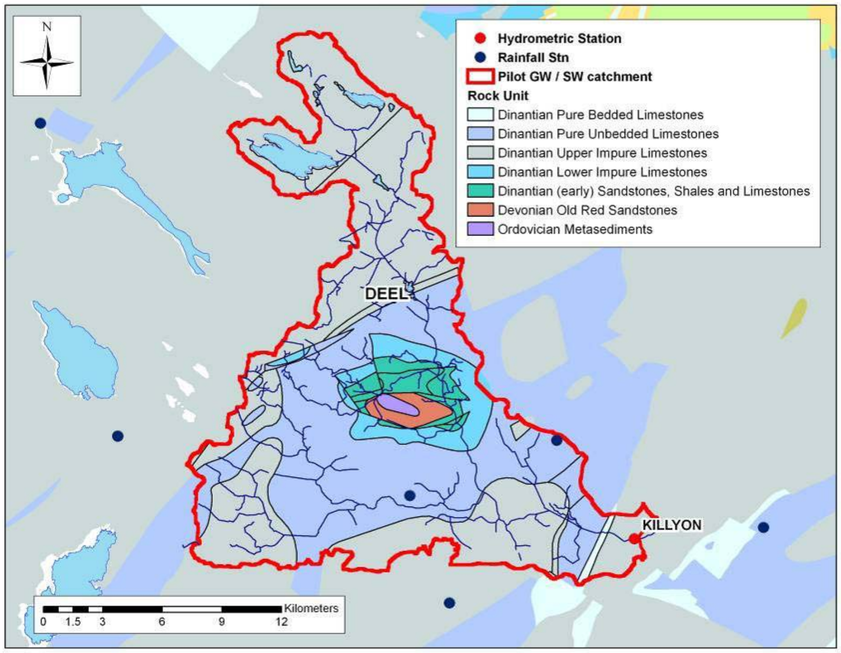
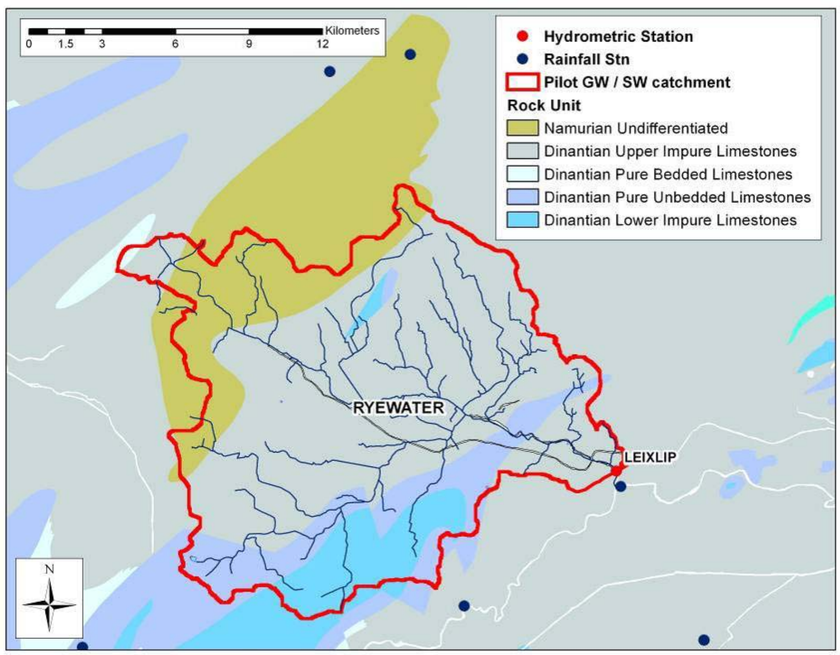


Figure 13. Aquifer categories within the Deel and Ryewater catchments and the rainfall stations used for the mathematical modelling

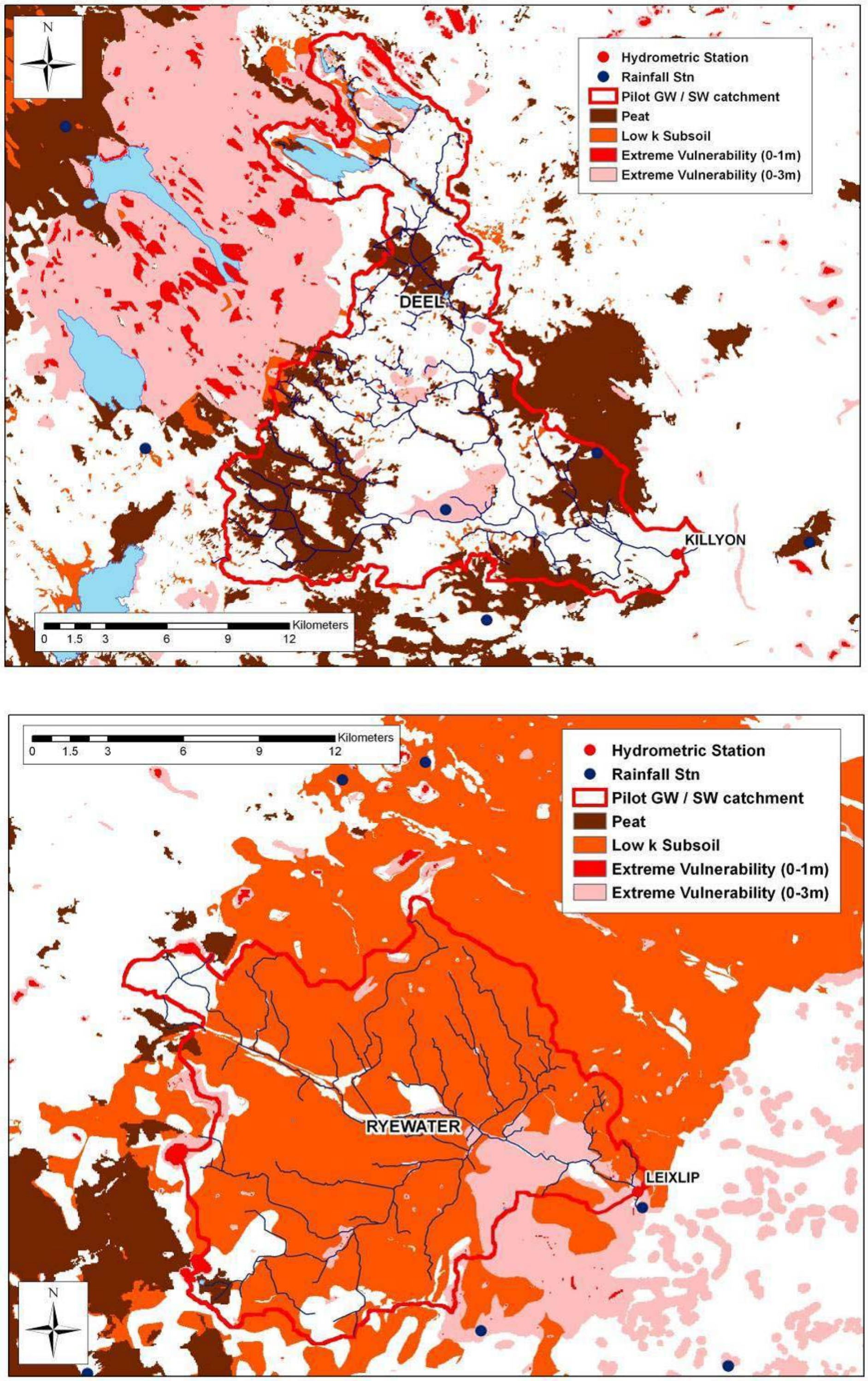


(a)



(b)

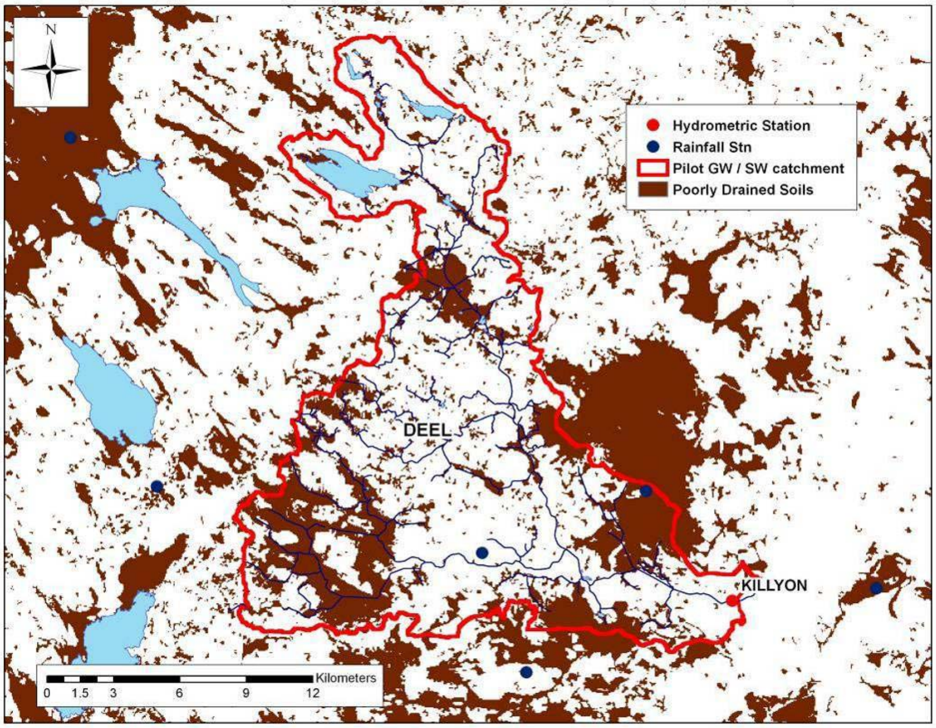
Figure 14. Rock units within the (a) Deel catchment and (b) Ryewater catchment.



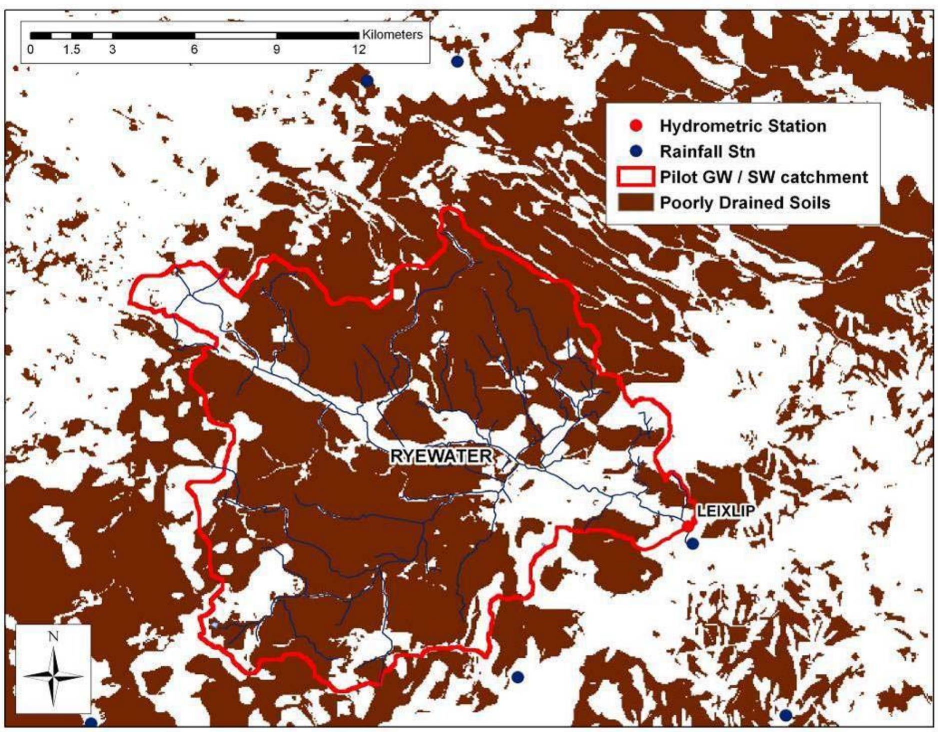
(a)

(b)

Figure 15. The vulnerability and subsoils within the (a) Deel catchment and (b) Ryewater catchment.



(a)



(b)

Figure 11. Poorly drained soils in the (a) Deel catchment and (b) Ryewater catchment.

Suck

The Suck catchment is a tributary of the Shannon River and is located within Roscommon and Galway. The conceptual model for the Suck catchment is fundamentally different to those scenarios that include poorly productive and productive fissured bedrock aquifers. In addition to the deep groundwater flow, there is a shallow karst aquifer component that will allow a quick flow of water into the streams (through the epikarst), with pathway lengths possibly up to 2km. The karst aquifer comprises 87% of the Suck catchment, with a relatively small percentage of poorly productive Ll (12%) and productive fissured Lm (2%) aquifers (Figures 17 and 18).

The catchment has shallow slopes (average slope of 0.02). The topography of the catchment is presented in Figure 19. Above the karst aquifer the subsoils are dominated by peat (35%). The distribution of low permeability subsoils is presented in Figure 20. The presence of a large proportion of peat will allow a significant proportion of the effective rainfall drain to the streams by overland flow. There is 23% extreme vulnerability in the catchment.

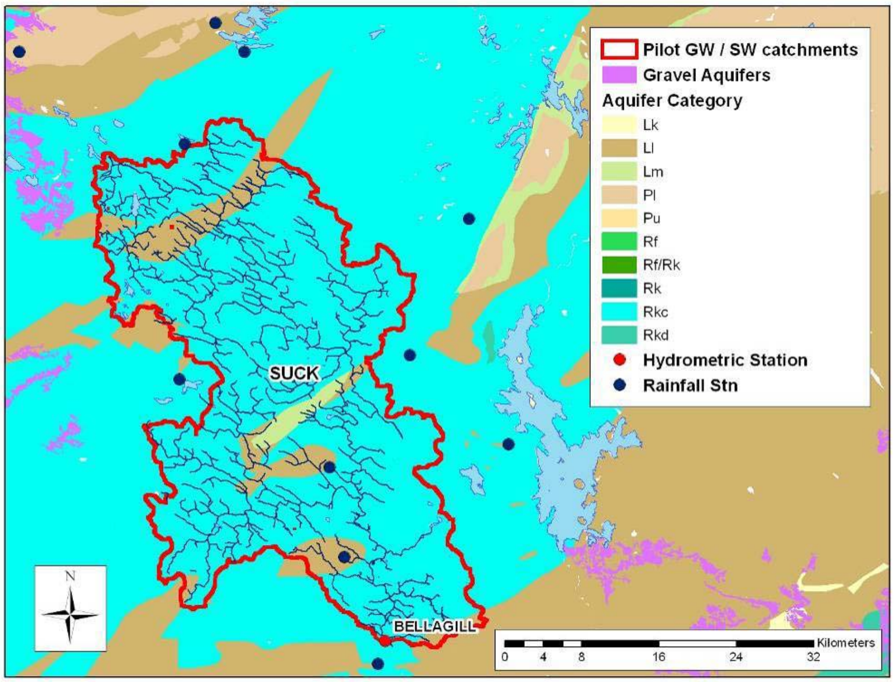


Figure 17. Aquifer categories in the Suck catchment and rainfall stations used for the mathematical modelling.

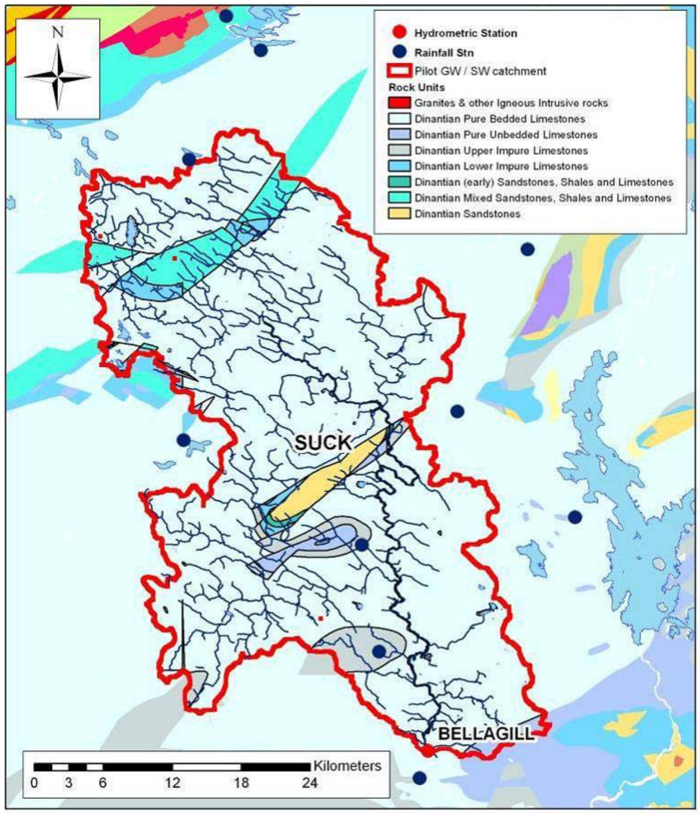


Figure 18. Rock units in the Suck catchment.

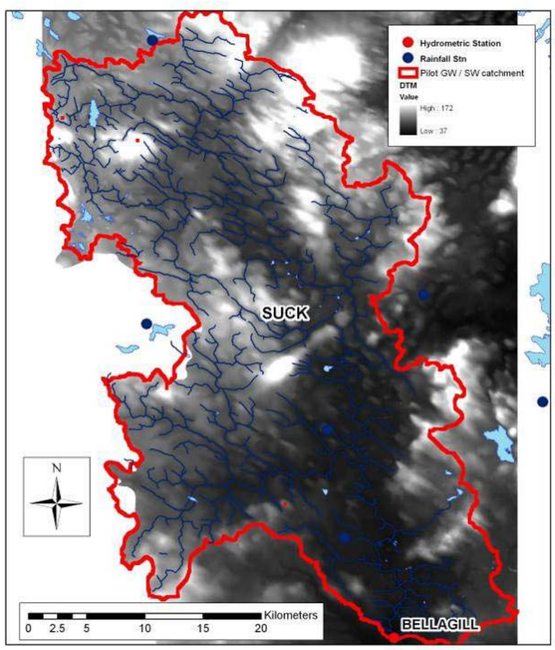


Figure 19. The topography (Digital Terrain Model DTM in metres) of the Suck catchment.

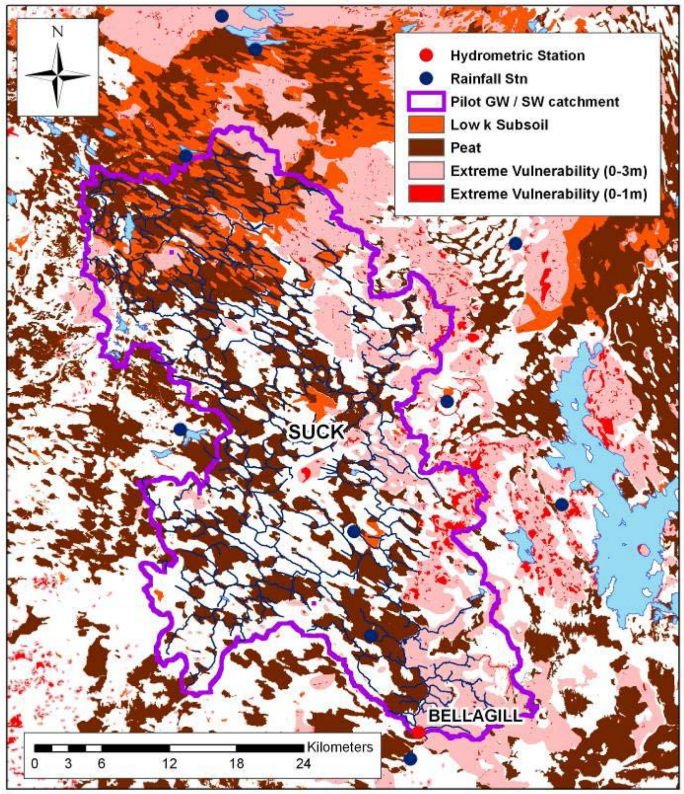


Figure 20. The vulnerability and subsoils within the Suck catchment.

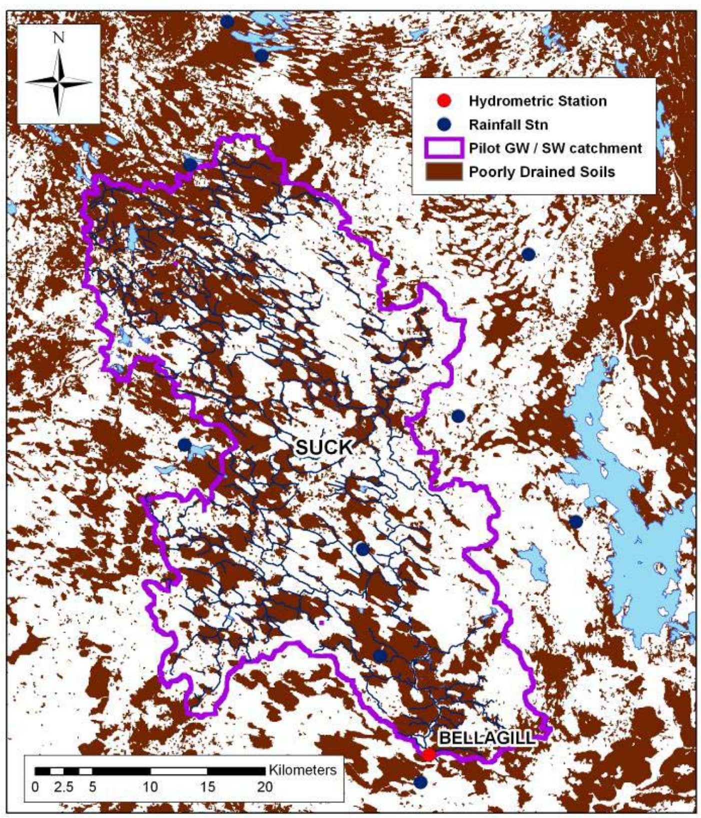


Figure 21. Poorly drained soils in the Suck catchment.

Boro

The Boro catchment is located in the southeast of Ireland in Wexford. It is a relatively steep catchment with an average slope of 0.06. The topography of the catchment is presented in Figure 22. The catchment was selected to consider productive fissured aquifers with free-draining soils. However, there are no catchments that can be studied that contain a dominantly productive fissured aquifer, and meet all of the data modeling requirements. The Boro is a mixed aquifer scenario and contains 36% productive fissured aquifer (Rf) and 64% poorly productive aquifer (46% Ll and 18% Pl, Figure 23). The productive fissured aquifer is in the lower reaches of the catchment and consists of Ordovician volcanics whilst the poorly productive aquifer is in the upper part of the catchment and consists of Ordovician metasediments (Figure 24).

There is 18% extreme vulnerability in the catchment, none of which is not overlain by low permeability subsoils (Figure 25). However, there is a large proportion of low permeability subsoils in the catchment (47% mainly Paleozoic Sandstone tills). There is no peat in the catchment. There are 21% poorly drained soils in the catchment (Figure 26). The flow paths in the productive fissured aquifers will be high, possible up to 2km, whereas they will be a lot shorter in the poorly productive aquifers. The result is that the contribution from deep groundwater flow will be less than expected for a wholly Rf aquifer. There will also be contributions to flow from shallow groundwater from the poorly productive aquifers and interflow from the tills, as well as overland flow.

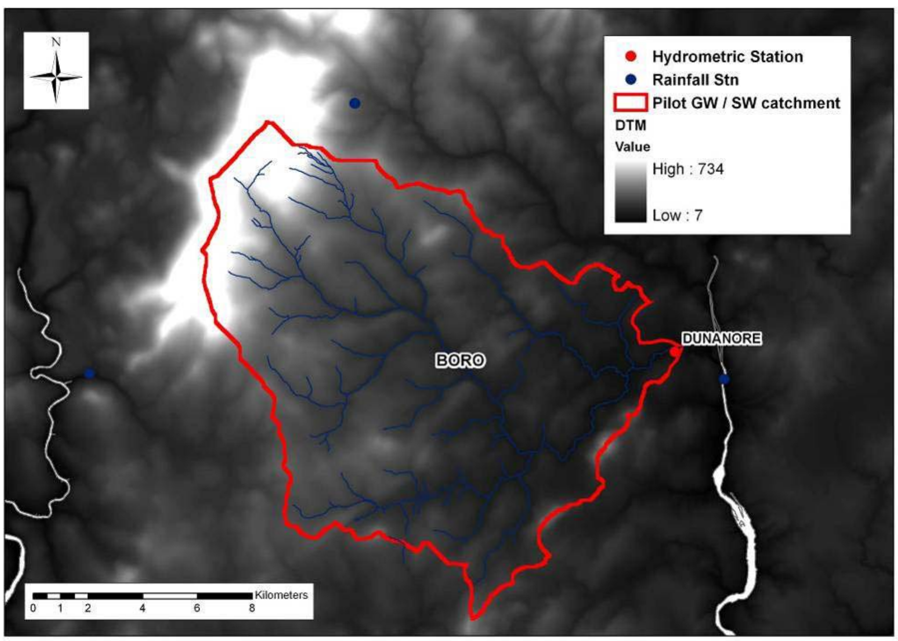


Figure 22. The topography (Digital Terrain Model DTM in metres) of the Boro catchment.

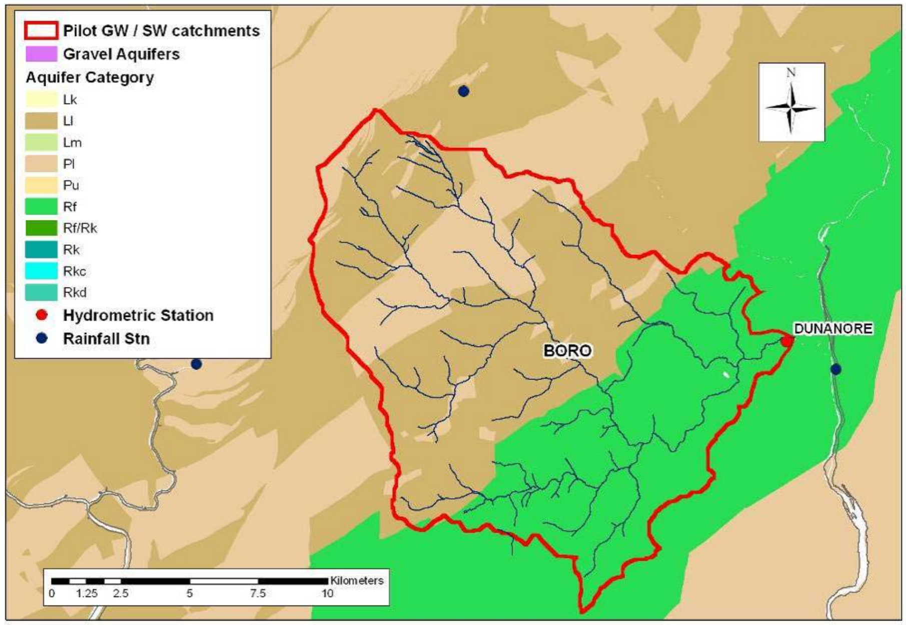


Figure 23. Aquifer categories in the Boro catchment and the rainfall stations used for the mathematical modeling.

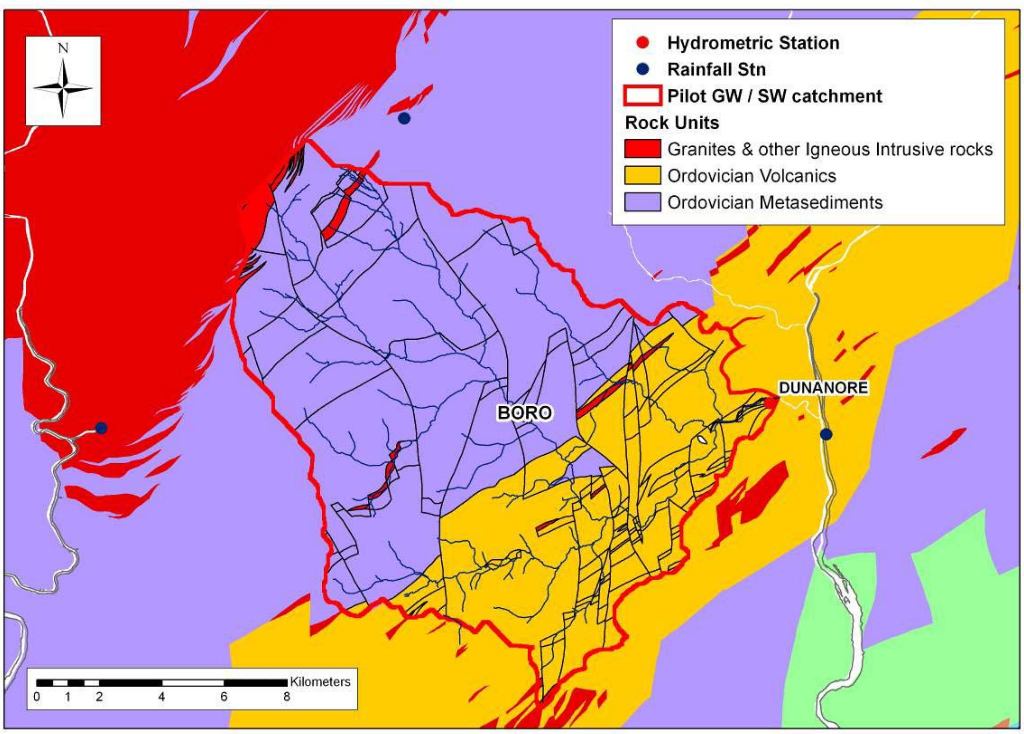


Figure 24. Rock units within the Boro catchment.

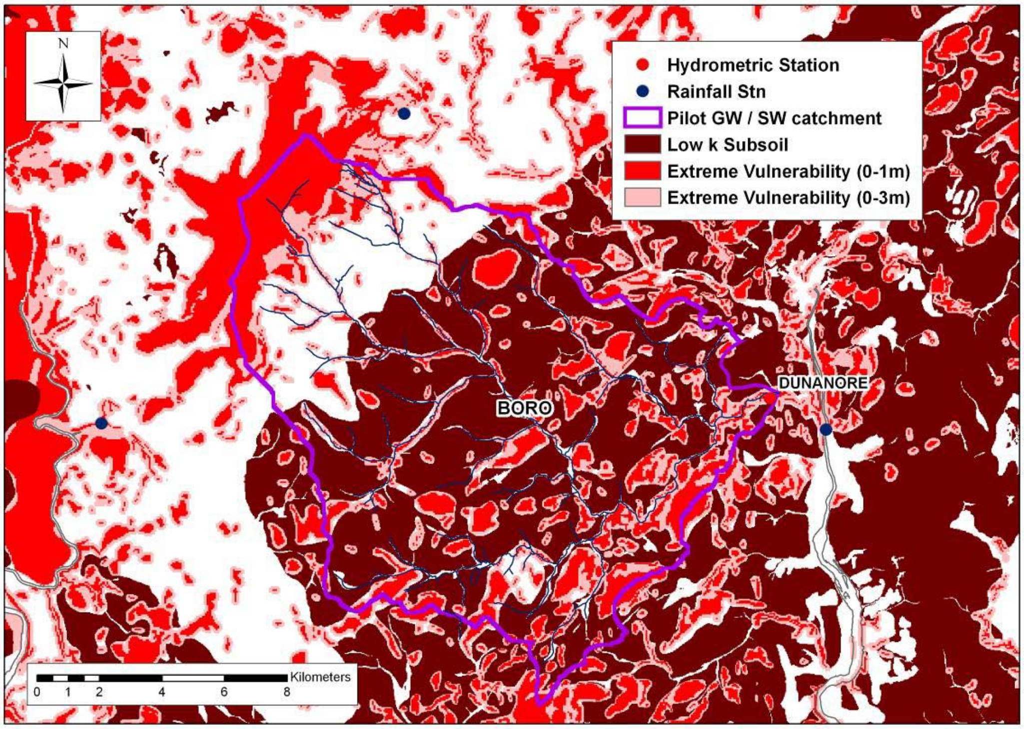


Figure 25. The vulnerability and subsoils within the Boro catchment.

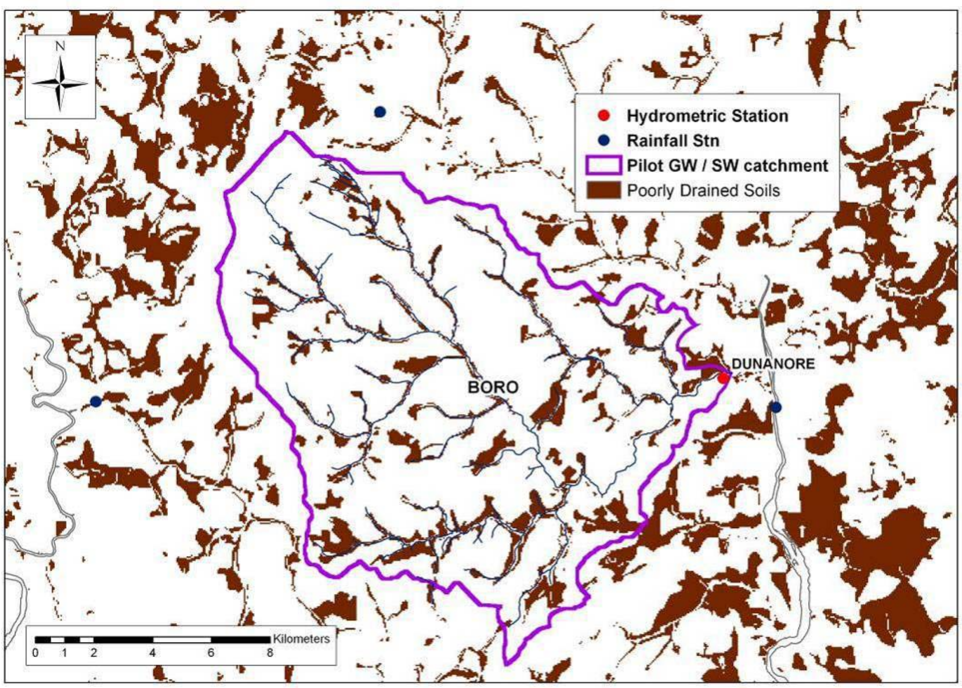


Figure 26. Poorly drained soils in the Suck catchment.

Appendix 3

Table of hydrometric stations that discharge data has been used for modelling.

Table of hydrometric stations that discharge data has been used for modelling.

Waterbody	Station Location	Station Number	Responsible Body	Easting	Northing	Modelling Catchment
Bride	Mogeely	18001	OPW	195610	94146	Pilot
Boro	Dunanore	12016	WEX	296008	136463	Pilot
Owenduff	Srahnamanragh	33006	MAY	81213	315429	Pilot
Deel	Killyon	7002	OPW	268401	249139	Pilot
Ryewater	Leixlip	9001	OPW	300516	236430	Pilot/ Regional
Shournagh	Healy's Bridge	19015	ESB	160310	73266	Pilot
Suck	Bellagill	26007	OPW	184100	234600	Pilot / Regional
Anner	Anner	16010	OPW	225300	125600	Regional
Aughrim	Knocknamohill	10028	WIC	317400	178200	Regional
Avonmore	Rathdrum	10002	WIC	319700	188300	Regional
Bandon	Curranure	20002	OPW	152900	57100	Regional
Bann	Ferns	12015	WEX	303000	149300	Regional
Barrow	Royal Oak	14018	OPW	268900	161400	Regional
Blackwater	Ballyduff	18002	OPW	196400	99100	Regional
Bonet	Dromahair	35011	OPW	180500	330800	Regional
Boyle	Tinacarra	26012	OPW	177000	301800	Regional
Boyne	Slane Castle	07012	OPW	294900	273900	Regional
Camlin	Mullagh	26019	OPW	211600	275900	Regional
Clare	Corrofin	30004	OPW	142600	243000	Regional
Clodiagh	Rahan	25016	OPW	225600	225600	Regional
Deel (Munster)	Rathkeale	24013	LIM	134500	149000	Regional
Erne	Belturbet	36019	OPW	235900	316600	Regional
Feale	Listowel	23002	OPW	99700	133300	Regional
Fergus	Ballycorey	27002	OPW	134400	180300	Regional
Finn	Ballybofey	01043	OPW	213400	394600	Regional
Flesk(Laune)	Flesk	22006	OPW	97200	89400	Regional
Graney	Scarriff	25030	OPW	164100	184200	Regional
Inny	Ballymahon	26021	OPW	216000	257000	Regional
Little Brosna	Croghan	25021	OPW	205300	205600	Regional
Maigue	Islandmore	24082	OPW	151400	139900	Regional
Moy	Rahans	34001	OPW	124300	317800	Regional
Mulkear	Annacotty	25001	OPW	164200	157600	Regional
Nenagh	Clarianna	25029	OPW	186000	182200	Regional
Nore	Brownsbarn	15006	OPW	261700	139100	Regional
Rinn	Johnston's Br.	26008	OPW	209000	286400	Regional
Robe	Foxhill	30005	OPW	123700	268100	Regional
Ryewater	Leixlip	09001	OPW	300500	236400	Regional
Suir	Caher Park	16009	OPW	205200	122800	Regional
Sullane	Macroom	19031	ESB	133700	72600	Regional
Woodford	Bellaheady	36027	OPW	225000	315600	Regional