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PILOT DESCRIPTION AND ASSESSMENT

Gort Lowlands, Ireland

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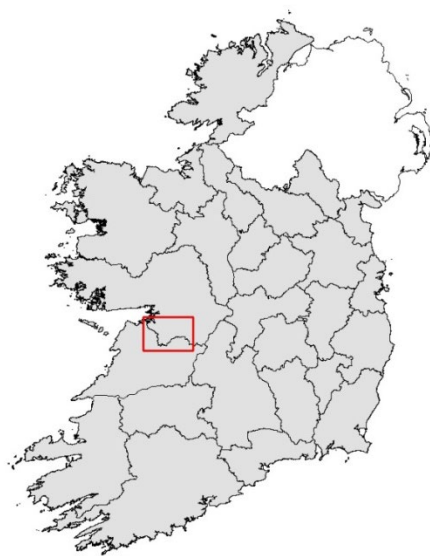
LIST OF ABBREVIATIONS & ACRONYMS

SAR	Synthetic Aperture Radar
API	Antecedent Precipitation Index
SMD	Soil Moisture Deficit

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1 EXECUTIVE SUMMARY

Pilot name	Gort Lowlands	
Country	Ireland	
EU-region	Western Ireland	
Area (km ²)	480km ²	
Aquifer geology and type classification	Sedimentary. Porous and karstified Aquifer System	
Primary water usage	Drinking Water	
Main climate change issues	Increased risk of flooding	
Models and methods used	Earth Observation and Hydrological Modelling	
Key stakeholders	Local Authorities, Office of Public Works (Ireland)	
Contact person	Ted McCormack (Ted.McCormack@gsi.ie)	

This pilot describes the novel approach developed to produce historic and predictive groundwater flood maps for Ireland in line with the 2nd implementation cycle of the EU Floods Directive. A monitoring network of over 50 sites was established during the winter of 2016/2017 to improve our understanding of groundwater flood regimes and provide baseline model calibration data. A methodology for delineating flood extents and water elevations from multi-temporal Synthetic Aperture Radar (SAR) imagery was developed to provide flood data from the 2015/2016 extreme flood event at gauged and ungauged sites. Maximum flood extents derived from SAR imagery from this event were combined with limited field observations to produce historic groundwater flood maps.

Identifying and mapping areas vulnerable to flooding is a key step in the management of flood risks. However, the nature of groundwater flooding on the lowland karst limestone plains of Ireland pose significant technical challenges in this respect. These areas are susceptible to groundwater flooding due to the combination of low soil and aquifer storage, high diffusivity and limited surface drainage. Unprecedented groundwater flooding in Ireland during winter

2015/2016 reinforced the need for a greater understanding of groundwater flooding as a geohazard and improve our ability to quantify the location and likelihood of flood occurrence.

Hydrological models capable of reproducing groundwater flooding time series from antecedent rainfall and soil moisture conditions were developed. Models for viable groundwater flooding locations were calibrated on a combination of observed and SAR hydrographs. Using long-term observational and stochastic meteorological series as input, the models have been used to construct long-term hydrological series suitable for extreme value analysis and the generation of predictive groundwater flood extents and maps.

Predictions of the future groundwater flood conditions are not clear in terms of the direction change. The impacts to groundwater flooding differ depending on the TACTIC scenario being applied. The dry scenarios indicate minor mean annual change in water levels and minor change in peak flood levels but with an increase in dry conditions during summer. The wet scenarios indicate an increase in mean water levels, an increase in peak levels and a reduction in dry conditions during the summer.

2 INTRODUCTION

Climate change (CC) already have widespread and significant impacts in Europe, which is expected to increase in the future. Groundwater plays a vital role for the land phase of the freshwater cycle and have the capability of buffering or enhancing the impact from extreme climate events causing droughts or floods, depending on the subsurface properties and the status of the system (dry/wet) prior to the climate event. Understanding and taking the hydrogeology into account is therefore essential in the assessment of climate change impacts. Providing harmonised results and products across Europe is further vital for supporting stakeholders, decision makers and EU policies makers.

The Geological Survey Organisations (GSOs) in Europe compile the necessary data and knowledge of the groundwater systems across Europe. In order to enhance the utilisation of these data and knowledge of the subsurface system in CC impact assessments the GSOs, in the framework of GeoERA, has established the project “Tools for Assessment of Climate change Impact on Groundwater and Adaptation Strategies – TACTIC”. By collaboration among the involved partners, TACTIC aims to enhance and harmonise CC impact assessments and identification and analyses of potential adaptation strategies.

TACTIC is centred around 40 pilot studies covering a variety of CC challenges as well as different hydrogeological settings and different management systems found in Europe. Knowledge and experiences from the pilots will be synthesised and provide a basis for the development of an infra structure on CC impact assessments and adaptation strategies. The final projects results will be made available through the common GeoERA Information Platform (<http://www.europe-geology.eu>).

The Gort Lowlands pilot represents a local scale study where the impacts of Climate Change on groundwater flooding is assessed. The winter of 2015/2016 saw unprecedented levels of rainfall across the Republic of Ireland. Over 600mm of rainfall fell across the island of Ireland between December and February, representing 190% of the long-term average and making it the wettest winter on record in a rainfall time series stretching back to 1850 (McCarthy et al., 2016; Noone et al., 2016). The sustained heavy rainfall caused exceptional and widespread flooding, with rivers across the country bursting their banks and registering some of the highest levels on record. The winter also saw the most extensive groundwater flooding ever witnessed on the karstic limestone plains in the west of Ireland (Naughton et al., 2017b). Here homes were flooded or cut off, roads submerged, and agriculture disrupted, with some affected areas remaining inundated for months after flooding had subsided elsewhere.

Groundwater flooding in Ireland is primarily associated with the lowland limestone areas of western Ireland. The prevalence of groundwater flooding in this region is fundamentally linked to bedrock geology. Groundwater flow systems in these areas are characterised by high spatial heterogeneity, low storage, high diffusivity, and extensive interactions between ground and surface waters, which leaves them susceptible to groundwater flooding (Naughton et al., 2017a). During intense or prolonged rainfall, the solutionally-enlarged flow paths are unable to drain recharge and available sub-surface storage rapidly reaches capacity. Consequently, surface flooding occurs in low-lying topographic depressions known as turloughs, which represent the

principal form of extensive, recurrent groundwater flooding in Ireland (Mott MacDonald, 2010; Naughton et al., 2012). There are over 400 recorded examples of turloughs across the country, with the majority located in the limestone lowlands in counties Roscommon, Galway, Mayo and Clare.

Unlike fluvial flooding (or fluvially derived groundwater flooding due to seepage through permeable deposit riverbanks), where the flood is typically caused by high intensity rainfall, groundwater flooding in karst regions is primarily driven by cumulative rainfall over a prolonged period. It is this accumulation of water over a period of weeks or months that determines flood severity and duration.

In response to serious flooding during winter 2015, Geological Survey Ireland, in collaboration with Trinity College Dublin and Institute of Technology Carlow have developed a monitoring, mapping and modelling programme to address the knowledge gap regarding groundwater flooding in karst systems. The study is providing the requisite data to address the gap in groundwater hydrometric data by establishing a permanent telemetric network, as well as developing modelling tools to help address issues surrounding groundwater flood mapping and flood frequency estimation. A key output from this project is to devise and implement a novel approach to produce historic and predictive groundwater flood maps for Ireland in line with the 2nd implementation cycle of the EU Floods Directive.

The EU Floods Directive (Directive 2007/60/EC) requires all Member States including Ireland to reduce and manage the risks that all forms of flooding pose through the mapping of probabilistic flood extents and the establishment of flood risk management plans. For flooding from groundwater sources, the Floods Directive stipulates that Member States may decide that the preparation of flood hazard maps shall be limited to the scenario floods with a low probability, or extreme event scenarios. This was the approach taken for groundwater flood mapping during the first implementation phase of the Floods Directive, where an evidence-based method was used to map areas vulnerable to groundwater flooding (Mott Mc Donald, 2010). After the extensive flooding of the winter of 2015/2016 there was a requirement to incorporate this new information into updated historic groundwater flood maps. Furthermore, considering the increased frequency of groundwater flooding in recent decades, methodologies for the estimation of flood frequency would also provide a valuable tool for groundwater flood management.

It is in this context that Geological Survey Ireland has developed a groundwater flood mapping methodology for gauged and ungauged sites, which includes the first approach to groundwater flood frequency estimation undertaken in the State.

3 PILOT AREA

The Gort Lowlands is an extensively karstified lowland limestone catchment located in Co. Galway, on the western coast of Ireland. The hydrogeomorphological history of the Gort Lowlands is complex; recurrent karstification and glaciation of the Carboniferous limestone formations has created an extensive conduit and cave system that dominates groundwater flow. Variations in the lithology, stratigraphy, fracturing and faulting of the limestone bedrock have all played a role in shaping this subterranean system. So too has the nature of catchment recharge, with just over half of annual recharge supplied by rivers from adjacent non-carbonate mountains. Surface flow in the lowlands is intermittent and drainage is via the karst network which discharges at a series of intertidal and submarine springs along the coast.

3.1 Site description and data

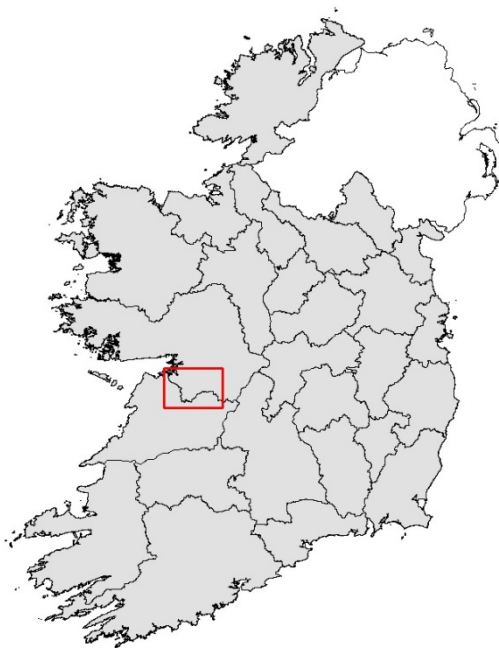


Figure 1: Location of Pilot Area

The Gort Lowlands is a 480 km² catchment located in County Galway in the west of Ireland. The eastern portion of the catchment is dominated by the mountains underlain by Devonian Old Red Sandstone. The western portion of the catchment is mostly flat and underlain by pure carboniferous limestone. Similar to the majority of karstic regions found within Ireland, the catchment is primarily lowland (rarely rising above 30 m), and, as such, the region is subject to considerable interaction between ground and surface waters.

Average annual rainfall (1981–2010) across the region area ranges from more than 1500mm on the high ground, to approximately 1100mm in low-lying areas (Walsh 2012). The lowest monthly average rainfall generally occurs in April (60 to 80mm), followed by a gradual rise in average



rainfall to the highest values between October and January (110 to 150mm). Recharge can be divided into those sources which originate within the karst body (autogenic) and those that originate from outside the karst aquifer (allogenic). Recent studies estimate that the discharge from the catchment is split approximately 55% allogenic to 45% autogenic in origin (McCormack et al. 2014).

The presence of ephemeral lakes known as turloughs is a key characteristic of Irish lowland karst regions. These lakes are described as topographic depressions in karst, which are intermittently flooded on an annual cycle via groundwater sources and have substrate and/or ecological communities characteristic of wetlands (Environmental Protection Agency, 2004). These seasonal lakes provide storage for excess recharge in the Gort Lowlands that cannot be accommodated by the groundwater system.

3.2 Climate change challenge

Regionally downscaled climate models indicate that future climate conditions in the pilot area will consist of reduced summer precipitation and increased winter precipitation (Nolan, 2015). These changes will result in an amplification of the seasonal flooding pattern already occurring within the catchment. This change in seasonal precipitation patterns, as well as the predicted increased frequency of storm events, will likely cause an increased risk of river, coastal and groundwater flooding.

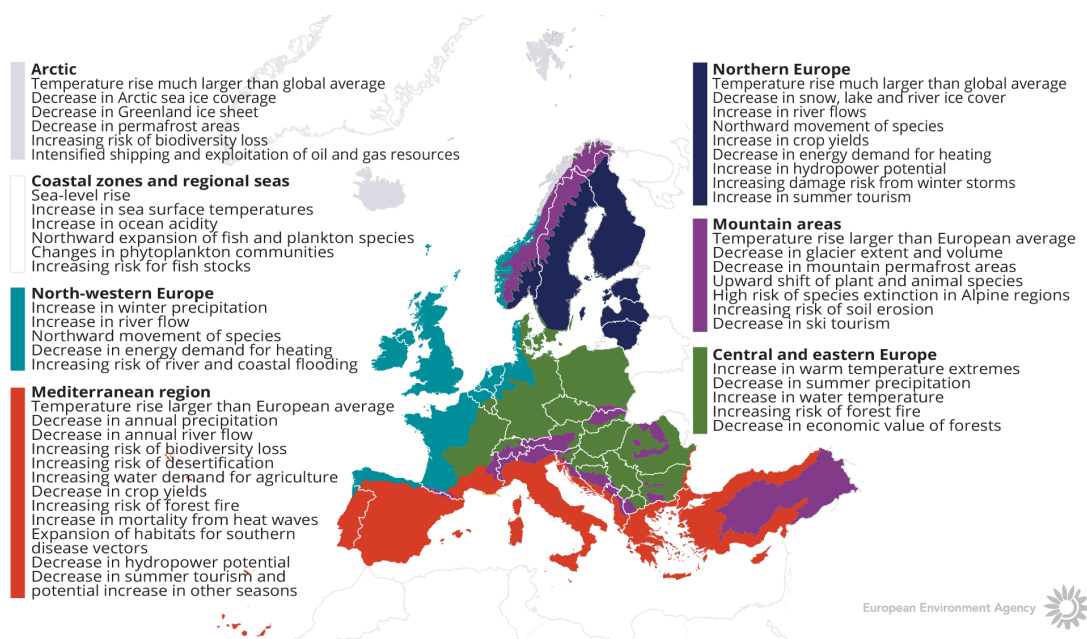


Figure 2: Observed and projected climate change and impacts for the main biogeographical regions in Europe (European Environmental Agency).



4 METHODOLOGY

Hydrological models capable of reproducing groundwater flooding time series from antecedent rainfall and soil moisture conditions were developed. Models for viable groundwater flooding locations were calibrated on a combination of observed and SAR hydrographs. Using long-term observational and stochastic meteorological series as input, the models have been used to construct long-term hydrological series suitable for extreme value analysis and the generation of predictive groundwater flood extents and maps. The modelling technique consists of two broad steps:

- Generation of hydrometric data using earth observation techniques.
- Hydrogeological modelling of flood sites based on

4.1 Climate data

Hydrogeological models require daily rainfall and evapotranspiration data from nearby weather stations. This data is obtained from the Irish National weather agency, Met Eireann.

The present study relies on the TACTIC standard climate change dataset to reflect future climate conditions, which include a “wet” and a “dry” climate for a +1 and +3 degree global warming scenario. The study has further used an ensemble of climate change scenarios based on the Euro-CORDEX dataset.

4.1.1 TACTIC standard Climate Change scenarios

The TACTIC standard scenarios are developed based on the ISIMIP (Inter Sectoral Impact Model Intercomparison Project, see www.isimip.org) datasets. The resolution of the data is 0.5°x0.5° global grid and at daily time steps. As part of ISIMIP, much effort has been made to standardise the climate data (a.o. bias correction). Data selection and preparation included the following steps:

1. Fifteen combinations of RCPs and GCMs from the ISIMIP data set were selected. RCPs are the Representative Concentration Pathways determining the development in greenhouse gas concentrations, while GCMs are the Global Circulation Models used to simulate the future climate at the global scale. Three RCPs (RCP4.5, RCP6.0, RCP8.5) were combined with five GCMs (noresm1-m, miroc-esm-chem, ipsl-cm5a-lr, hadgem2-es, gfdl-esm2m).
2. A reference period was selected as 1981 – 2010 and an annual mean temperature was calculated for the reference period.
3. For each combination of RCP-GCM, 30-years moving average of the annual mean temperature were calculated and two time slices identified in which the global annual mean temperature had increased by +1 and +3 degree compared to the reference period, respectively. Hence, the selection of the future periods was made to honour a specific temperature increase instead of using a fixed time-slice. This means that the temperature changes are the same for all scenarios, while the period in which this occurs varies between the scenarios.
4. To represent conditions of low/high precipitation, the RCP-GCM combinations with the second lowest and second highest precipitation were selected among the 15 combinations for the +1 and +3 degree scenario. This selection was made on a pilot-by-



- pilot basis to accommodate that the different scenarios have different impact in the various parts of Europe. The scenarios showing the lowest/highest precipitation were avoided, as these endmembers often reflect outliers.
5. Delta change values were calculated on a monthly basis for the four selected scenarios, based on the climate data from the reference period and the selected future period. The delta change values express the changes between the current and future climates, either as a relative factor (precipitation and evapotranspiration) or by an additive factor (temperature).
 6. Delta change factors were applied to local climate data by which the local particularities are reflected also for future conditions.

For the analysis in the present pilot the following RCP-GCM combinations were employed:

Table 4.4.1-1. Combinations of RCPs-GCMs used to assess future climate

		RCP	GCM
1-degree	"Dry"	4.5	noresm1-m
	"Wet"	6.0	miroc-esm-chem
3-degree	"Dry"	6.0	hadgem2-es
	"Wet"	8.5	miroc-esm-chem

4.2 Hydrological Modelling based on Earth Observation data

4.2.1 Generation of hydrometric data using earth observation techniques

While traditional monitoring is an effective tool for hydrometric data collection at priority sites, the distributed nature of groundwater flooding in karst lowlands hampers any systematic mapping efforts. Groundwater flooding occurs in isolated basins across the landscape. The large number and wide distribution of these basins makes them impractical to monitor using field instrumentation. Earth Observation and Geographical Information System (GIS) approaches offer significant advantages in this respect. The ability to describe and map how floods develop and recede accurately and at a large spatial scale is a prerequisite for effective flood risk management

Active systems, such as synthetic aperture radar (SAR), are particularly useful for flood mapping as they have a day-and-night capability and are not impacted by cloud cover. SAR systems emit radar pulses and record the return signal at the satellite. Flat surfaces such as water operate as specular reflectors for the radar pulses resulting in minimal backscatter signal returning to the satellite thus providing a contrast between dry and flooded areas. While interpretation of SAR images involves a degree of ambiguity due to factors such as speckle effects and dielectric properties, overall SAR systems offer a powerful tool for water delineation (see Figure 3).

The information gained from SAR imagery can be further enhanced by adding contextual information from high-resolution topographic mapping. The flood boundary can be cross-referenced against the topographic data to calculate the elevation of the land-water interface and thus the depth of water in the turlough. This methodology benefits from the fact that

turlough flooding typically occurs in enclosed, isolated basins. As a result, and unlike river flooding scenarios, the water surface can be assumed to have a uniform elevation value.

An additional benefit of Sentinel-1 is the frequency of image capture; the satellites have been collecting imagery over Ireland at a 1 to 3 day revisit time since late 2014. While this revisit time may be inadequate for observing flash floods, which appear and dissipate within hours, it is suitable for monitoring groundwater flooding which occurs at a much slower rate (weeks to months). The considerable catalogue of Sentinel-1 imagery available has allowed us to track groundwater flood development through time. For sites with suitable size and topography characteristics the depth calculation process can be repeated for every satellite orbit enabling the generation of dynamic flood mapping and hydrographs.

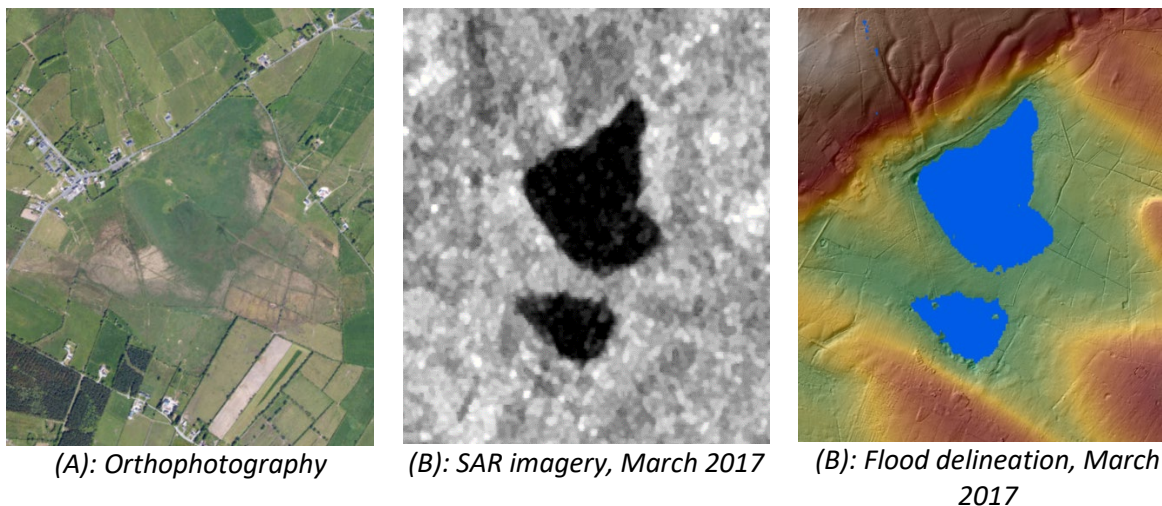


Figure 3: Imagery of Castleplunket turlough showing (A) orthophotography of it empty, (B) pre-processed SAR flood image and (C) flood delineation overlaid on LiDAR data

Image processing techniques have been developed by the GSI in-house to optimise detection of groundwater flood extents from SAR data. By combining satellite derived flood extents with high resolution topographic mapping, it is possible to extract water level information from each satellite image. This methodology enhances the accuracy of once-off flood extent maps as well as enabling the generation of historic flood hydrographs for previously unmonitored sites. The flood monitoring methodology consists of five broad stages (for more information, see McCormack et al. (2020)):

1. Data acquisition and pre-processing
2. Flood delineation using an automated, repeatable image thresholding algorithm
3. Image filtering & correction
4. Application of topography to establish the most probable land-flood interface elevation value.
5. Map and hydrograph generation

Hydrographs were generated for the 12 sites shown in Figure 4. Once complete, the hydrographs were then used as inputs to the hydrological models.

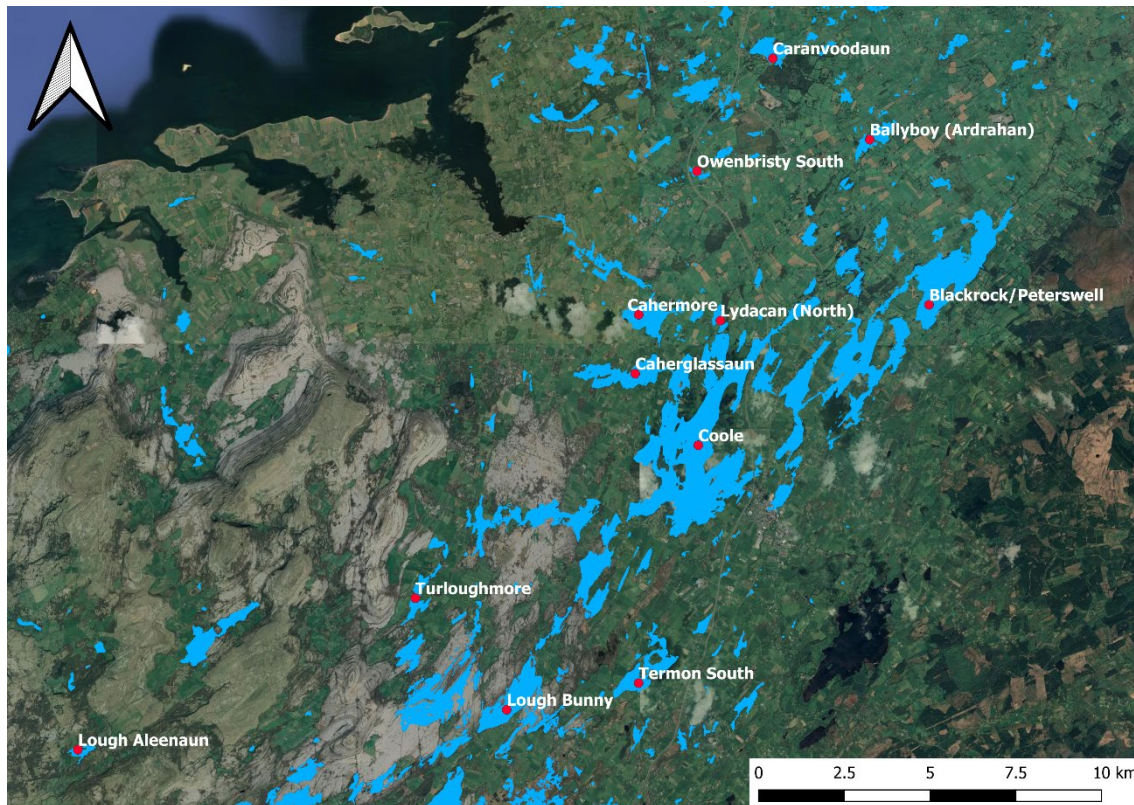


Figure 4: Locations of sites chosen for hydrograph generation and climate change modelling

4.2.2 Hydrological Modelling

Geological Survey Ireland developed a hydrological modelling methodology to quantify the relationship between rainfall and turlough flooding to reconstruct the requisite long-term hydrological series from observed and stochastic rainfall data.

There are two fundamental approaches to the mathematical modelling of karst hydrogeological systems; distributive models and global models. Given the limited data availability in Irish karst groundwater flow systems, and the required broad application of the methodology, a global modelling approach was deemed the most appropriate approach. Global (or lumped parameter) models concentrate on mathematically deriving a relationship between input and output; they consider the karst aquifer as a transfer function, transforming the rainfall input signal into the output hydrograph signal. The transfer function is taken to represent the overall (or global) hydrogeological response of the karst aquifer to recharge events (Kovacs and Sauter, 2007).

The primary objective of the global modelling approach was to develop predictive relationships between antecedent rainfall and flooding within individual turlough basins. Once established, this would allow the reconstruction of hydrological series sufficiently long for flood frequency analysis to be carried out and predictive flood levels to be estimated.



A version of the Antecedent Precipitation Index (API) (Kohler and Linsley, 1951; Smakhtin and Masse, 2000) was used to model flood behavior. The API assumes the effect of antecedent precipitation can be represented by catchment or site-specific recession coefficient (Beschta, 1998). A modified version of the API, the Current Precipitation Index (CPI) (Smakhtin and Masse, 2000), has been used to model turlough flood volumes and is given by:

$$CPI = \sum_{t=-1}^{-i} R_t k^{-t}$$

Where i is the number of antecedent days, k is a decay constant and R_t is recharge on day t . The coefficient k represents the percentage water that remains after a specified time interval; a large k leads to a slow recession after the cessation of rainfall while a small k indicates a quick recession (Lee and Huang, 2013). To ensure convergence and remove the influence of initial conditions on analysis, effective rainfall series beginning at least one year before the corresponding hydrological series were used in the calculation of the CPI. CPI series using a range of k values were generated, with the k value showing the highest correlation with observed volume selected. The model then took the form of a simple linear regression between the CPI (predictor) and flood volume (response) where:

$$V = S + C * CPI$$

where S is the intercept C is the slope. Conceptually the intercept S represents a groundwater storage term, or the volume of water required to have built up in the karst groundwater flow system before flooding occurs. The slope term C represents a notional contributing area, defining the minimum zone of contribution required to supply the recorded water volume.

A soil moisture deficit (SMD) model was used to estimate recharge based on the SMD model developed for Irish grasslands by Schulte et al. (2005). The soil and unsaturated zone were represented as a single reservoir with the flux in the reservoir dependent on the inputs and outputs, namely rainfall (R) as input and actual evapotranspiration (ET_A) and recharge (R_E) as output.

4.2.3 Calibration

Accuracy for both remote sensing data generation and hydrological modelling was calibrated and validated a network of water level monitoring stations installed at flood hazard areas throughout the Gort Lowlands. Goodness of fit for the SAR hydrograph process was assessed using Nash-Sutcliffe Efficiency (NSE) for flood volume (volume is preferred to stage as it prioritises model efficiency at high flood conditions).

Observed water level data were compared to SAR derived hydrographs at a subset of sites and the hydrograph generation variables were tweaked to achieve maximum efficiencies. Nash Sutcliffe efficiency coefficients of between 0.95 and 0.7 were achieved at the test sites. See Figures 5-7 for examples.

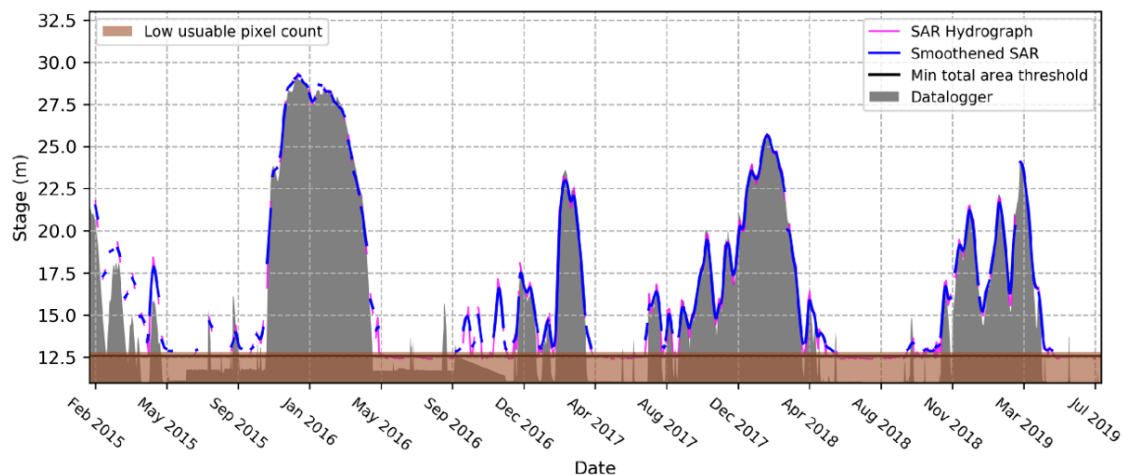


Figure 5: SAR Derived hydrograph for Blackrock Turlough.

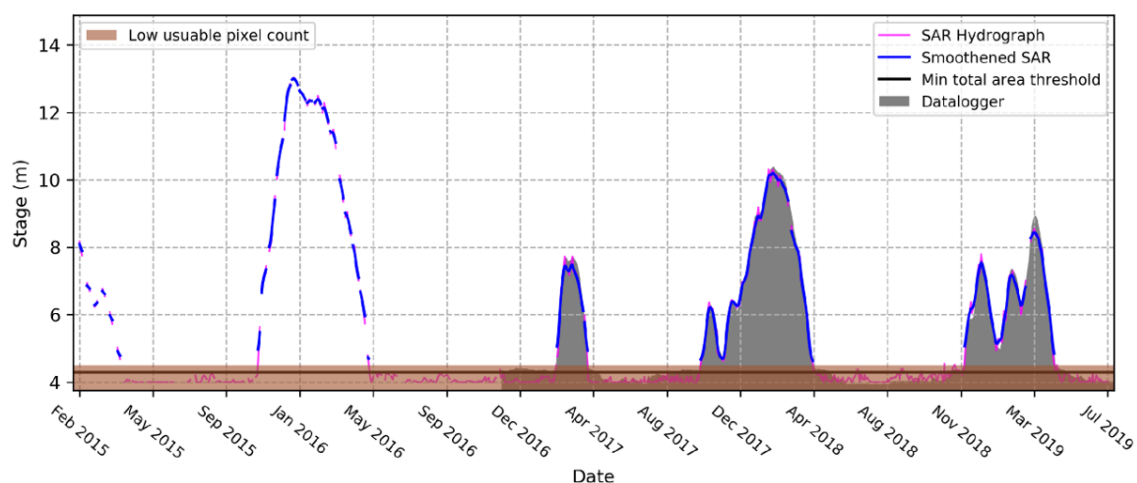


Figure 6: SAR Derived hydrograph for Cahermore Turlough

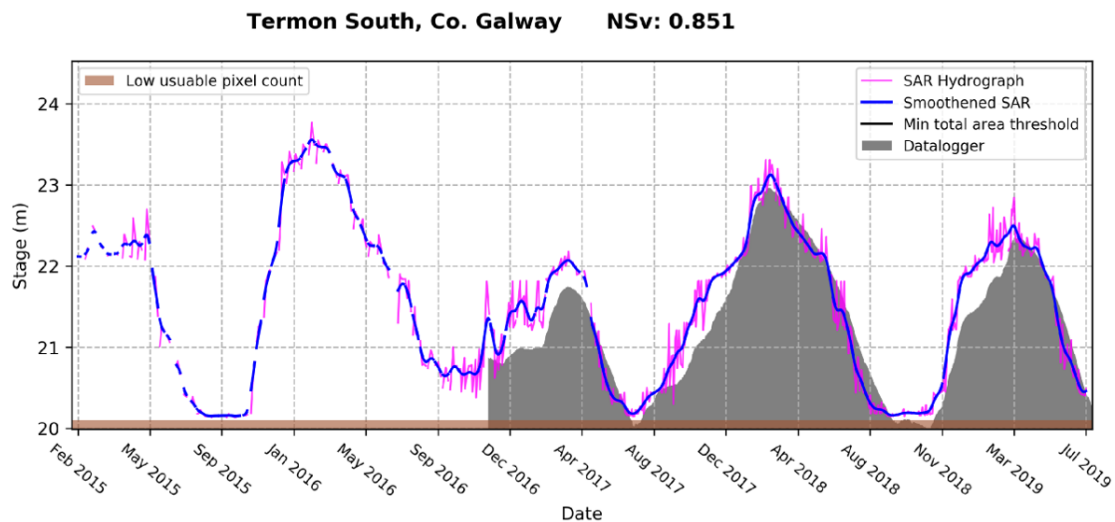


Figure 7: SAR Derived hydrograph for Termon South

Models were calibrated using a combination of observed and SAR hydrographic data (see Figure 8 and Figure 9 for examples). Goodness of fit was assessed using the NSE, percentage bias (PBIAS), and annual maxima error (AmaxE) criteria for volume. The average NSE value for all accepted models was 0.80.

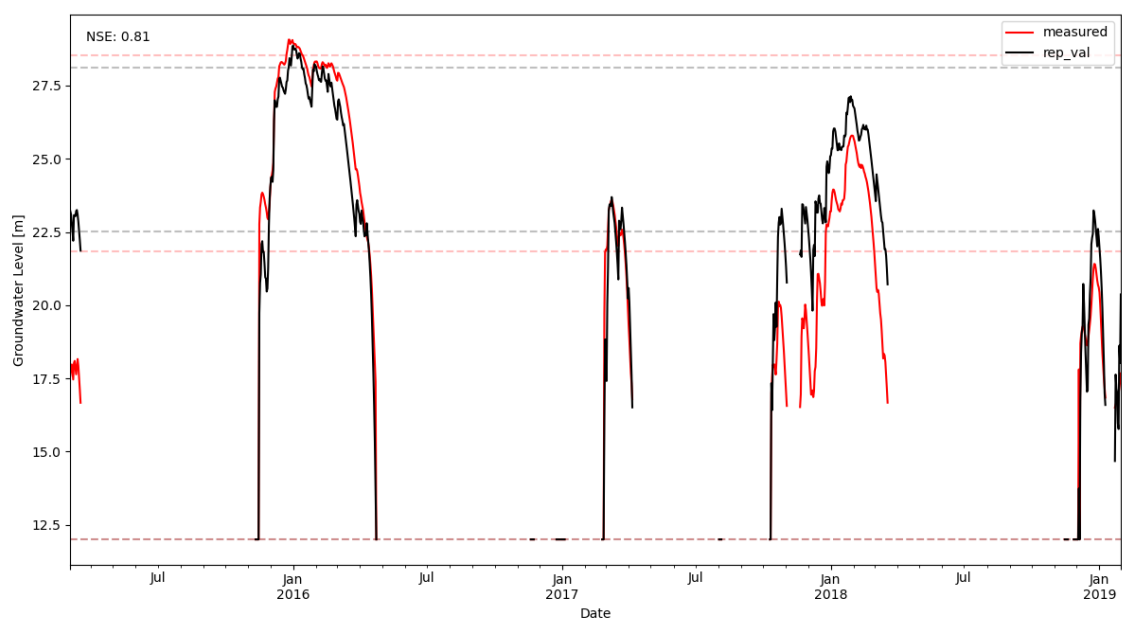


Figure 8: Observed (red) and modelled (black) hydrograph. Blackrock Turlough, Co. Galway.

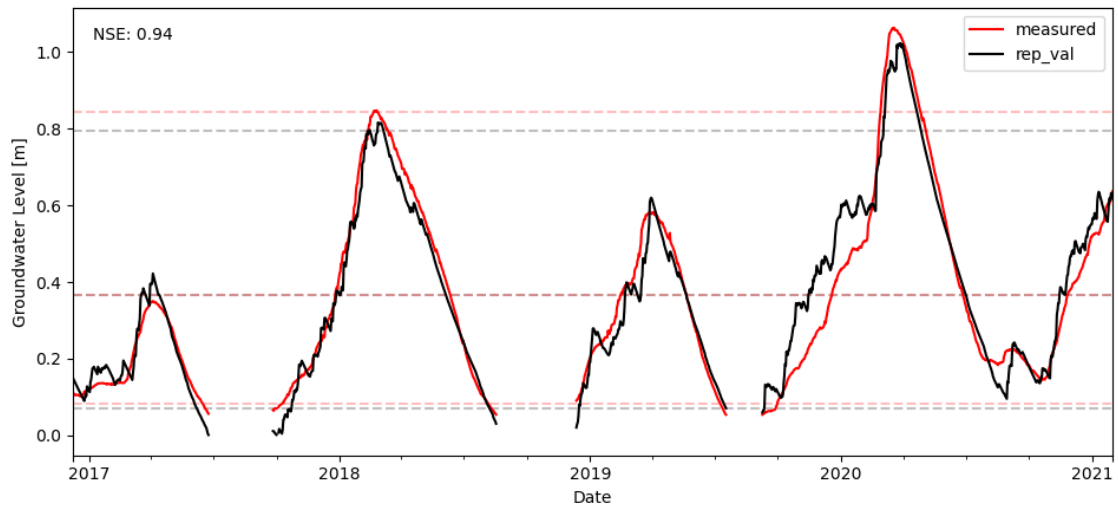


Figure 9: Observed (red) and modelled (black) hydrograph. Termon South, Co. Clare.

5 RESULTS AND CONCLUSIONS

5.1 Hydrological Modelling based on Earth Observation data

Once calibrated, the models were run for the reference period as well as for the TACTIC standard scenarios. Modelling the TACTIC scenarios consisted of applying the delta change factors to precipitation and reference evapotranspiration (the models do not require temperature). In the Gort Lowlands, the delta change factors for precipitation varied between 1.3 and 0.77 (see Figure 10) whilst evapotranspiration only varied between 1.07 and 0.993.

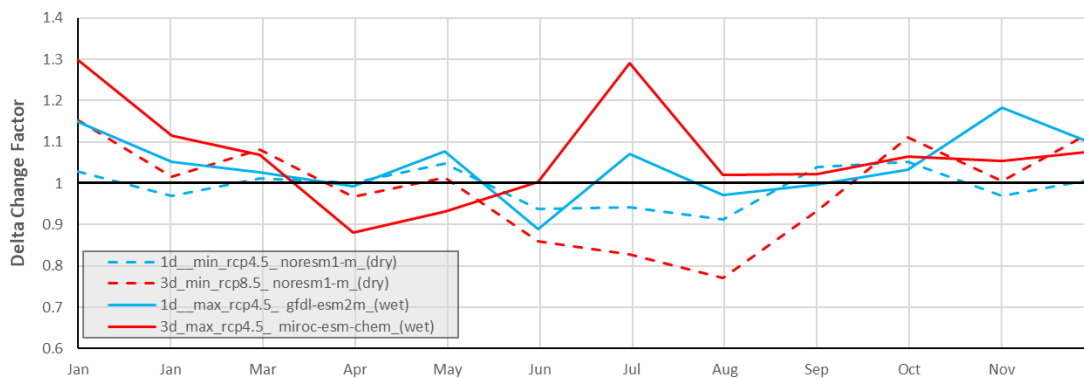


Figure 10: Delta Change Factors for precipitation in the Gort Lowlands. Factors for 1 and 3 degree change are shown in blue and red respectively. “Wet” scenarios are shown as unbroken lines and “Dry” scenarios are shown as solid lines.

Outputs from the 12 models was produced in the format of daily timeseries of water levels over the specified time period. For the purposes of consistency and comparison with other TACTIC pilot studies, the model results are presented here as mean water levels over the analysis period and changes to mean water levels due to climate change. The mean water levels for the reference period and for the TACTIC scenarios are presented in Table 5.1-1 and the relative changes in mean levels are shown in Table 5.1-2.

Table 5.1-1: Mean Water levels for individual sites over the reference period and TACTIC scenarios

Site Name	Reference Period	1d min (dry) rcp4.5 noresm1-m	1d max (wet) rcp4.5 gfdl-esm2m	3d min (dry) rcp8.5 noresm1-m	3d max (wet) rcp4.5 miroc-esm-chem
Termon South	21.15	21.07	21.29	21.12	21.41
Lough Aleenaun	72.70	72.65	72.78	72.66	72.82
Blackrock	14.57	14.53	14.98	14.82	15.43
Coole Lough	5.35	5.19	5.56	5.25	5.80
Caherglassaun	4.74	4.64	4.93	4.72	5.13
Caranavoodaun	23.52	23.48	23.58	23.49	23.63
Turloughmore	27.60	27.57	27.67	27.57	27.69
Lough Bunny	16.91	16.89	16.94	16.89	16.97
Cahermore	5.47	5.47	5.62	5.61	5.83
Ballyboy	29.90	29.89	29.96	29.95	30.04
Owenbristy	18.04	18.03	18.09	18.06	18.14
Lydican	13.92	13.89	13.99	13.92	14.06

Table 5.1-2 Relative changes in mean water levels between the reference period and TACTIC scenarios

Site Name	1d min (dry) rcp4.5 noresm1-m	1d max (wet) rcp4.5 gfdl-esm2m	3d min (dry) rcp8.5 noresm1-m	3d max (wet) rcp4.5 miroc-esm-chem
Termon South	-0.07	0.14	-0.02	0.27
Lough Aleenaun	-0.05	0.08	-0.04	0.12
Blackrock	-0.05	0.41	0.25	0.86
Coole Lough	-0.16	0.22	-0.10	0.45
Caherglassaun	-0.10	0.19	-0.02	0.39
Caranavoodaun	-0.04	0.06	-0.02	0.11
Turloughmore	-0.03	0.07	-0.03	0.09
Lough Bunny	-0.02	0.03	-0.02	0.05
Cahermore	0.00	0.15	0.14	0.36
Ballyboy	-0.01	0.07	0.05	0.14
Owenbristy	-0.01	0.05	0.02	0.10
Lydican	-0.03	0.07	0.00	0.14
Average	-0.05	0.13	0.02	0.26

Further summary statistics are presented in Table 5.1-3 and Table 5.1-4 which show the change in maximum water levels and number of dry days (i.e. the number of days the turlough is empty, typically in summer) respectively.

Table 5.1-3: Relative changes in maximum water levels between the reference period and TACTIC scenarios

Site Name	1d min (dry)	1d max (wet)	3d min (dry)	3d max (wet)
	rcp4.5 noresm1-m	rcp4.5 gfdl-esm2m	rcp8.5 noresm1-m	rcp4.5 miroc-esm-chem
Termon South	-0.01	0.31	0.27	0.54
Lough Aleenaun	-0.15	-0.01	-0.08	0.31
Blackrock	-0.09	-0.01	-0.22	0.50
Coole Lough	-0.12	0.06	0.17	0.43
Caherglassaun	-0.15	0.02	0.26	0.52
Caranavoodaun	-0.06	0.03	0.08	0.20
Turloughmore	-0.06	-0.03	-0.04	0.11
Lough Bunny	-0.03	0.00	0.05	0.12
Cahermore	-0.01	0.33	0.59	0.99
Ballyboy	-0.03	-0.01	-0.07	0.13
Owenbristly	-0.06	0.01	0.09	0.21
Lydican	-0.09	0.14	0.18	0.33
Average	-0.07	0.07	0.11	0.37

Table 5.1-4: Relative changes in number of annual dry days (i.e. the turlough is empty) between the reference period and TACTIC scenarios

Site Name	1d min (dry)	1d max (wet)	3d min (dry)	3d max (wet)
	rcp4.5 noresm1-m	rcp4.5 gfdl-esm2m	rcp8.5 noresm1-m	rcp4.5 miroc-esm-chem
Termon South	7.21	-8.28	5.89	-12.80
Lough Aleenaun	6.51	-1.04	8.91	-0.64
Blackrock	1.83	-3.14	0.77	-6.24
Coole Lough	4.66	-2.23	5.74	-4.42
Caherglassaun	3.92	-2.91	5.05	-4.96
Caranavoodaun	6.02	-3.65	7.72	-3.47
Turloughmore	4.58	-5.93	5.67	-3.53
Lough Bunny	5.18	-3.03	8.27	-1.67
Cahermore	0.65	-2.42	-1.22	-5.87
Ballyboy	0.75	-2.60	-0.77	-5.59
Owenbristly	3.31	-3.11	2.79	-6.73
Lydican	0.03	-0.03	0.03	-0.07
Average	3.72	-3.20	4.07	-4.66

From Table 5.1-2 it can be seen that average water levels in the turloughs show consistent reductions under the 1 degree dry scenario and mixed impacts under the 3 degree dry scenario. However, the impacts of these dry scenarios are relatively minor with most sites presenting changes of less than 5cm. For the wet scenarios the impacts are more significant. The average change in the 1 degree wet scenario is a 0.13m increase while the 3 degree wet scenario shows a 0.26m increase (with one site, Blackrock, increasing by 0.86m).

The seasonal effects of the TACTIC delta change factors are presents in Table 5.1-3 and Table 5.1-4. From these tables it can be seen that the dry scenarios show mixed changes in peak water levels (7cm drop for 1 degree and 11cm rise for 3 degree) but a consistent increase in dry days per year (+3.7% and +4.1%). This indicates that the winter levels are not dramatically changed but the summer is significantly dryer resulting in longer periods of without groundwater flooding. These findings broadly follow the dry scenario delta change factors as shows in Figure 10 which show mixed winter impacts but consistent dryer summer months. In contrast, the wet scenarios show consistent impacts from increased rainfall throughout the year. The maximum flood level is increased and the number of dry days is reduced.

5.1.1 Conclusions

Predictions of the future groundwater flood conditions are not clear in terms of the direction change. The impacts to groundwater flooding differ depending on the TACTIC scenario being applied. The dry scenarios indicate minor mean annual change in water levels and minor change in peak flood levels but with an increase in dry conditions during summer. The wet scenarios indicate an increase in mean water levels, an increase in peak levels and a reduction in dry conditions during the summer.

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