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Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Calls, Final Report -

Lead Applicant Name	Jonathan Turner
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Host Organisation name	University College Dublin
Project Title	Reconstructing the late Quaternary history of the River Nore using OSL
Contract Number	2017-sc-023

Date: 14 Nov. 2018

This report covers the period November 1st 2017 to October 31st 2018

2. (a) Project information:

Final project report (*max **2500**words, excluding figures and headings*):

(i) *Progress* of objectives and scientific/engineering targets beyond the state of the art & *methods* used

This research investigates floodplain deposits in the River Nore catchment using cutting-edge geochemical and geochronological approaches. The methodological framework of this research investigates the *geomorphology*, *sedimentology* and *chronostratigraphy* of River Nore alluvium in a post-glacial context. Project components were sequenced as follows:

1. Planform morphology of floodplain sites
2. Sedimentology of floodplain sequences to establish sedimentary architecture
3. Chronology of alluviation/flood events

A combination of field and laboratory-based methods were employed:

1. Planform morphology:
    a) Geomorphological mapping
    b) Survey using an Unmanned Aerial Vehicle (UAV) and Structure from Motion (SfM) Photogrammetry
2. Floodplain architecture:
    a) Sediment coring using a percussion rig
    b) Conventional sediment logging
    c) Itrax core scanning
3. Chronology:
    a) Optically Stimulated Luminescence (OSL) dating
    b) Radiocarbon dating

1. PLANFORM MORPHOLOGY

Initial geomorphological mapping was completed using archival historical maps, aerial photography and satellite imagery in ArcGIS. The River Nore catchment is in the South East of Ireland, and the coverage comprised time-slices of various dating from the early nineteenth century (Table 1).

Table 1 Historical maps, aerial and satellite imagery available for the River Nore catchment

Image date	Raster type	Source
2015/2011/2010/2008	Satellite image	DigitialGlobe ESRI and Google Earth
2005/2000/1995	Orthophoto	OSi MapGenie through ArcGIS Server
1973	Original aerial photo	Geological Survey Ireland archives
1888-1913	Ordnance Survey map	OSi MapGenie through ArcGIS Server
Late 19th/early 20th Century	Ordnance Survey map	OSi MapGenie through ArcGIS Server
1829-1841	Ordnance Survey map	OSi MapGenie through ArcGIS Server

Using these raster layers, the river channel was digitised for the discrete time periods to establish planform changes and palaeochannel position along the floodplain of the middle Nore valley (Figure 1). Subsequently, topographic surveying using a drone and SfM photogrammetry was employed at targeted reaches to capture floodplain micromorphological elements (e.g. palaeochannels, scour features) that were not always evident in the planform maps and walkover surveys (Figure 2). These integrated data were used to inform the selection of coring sites.

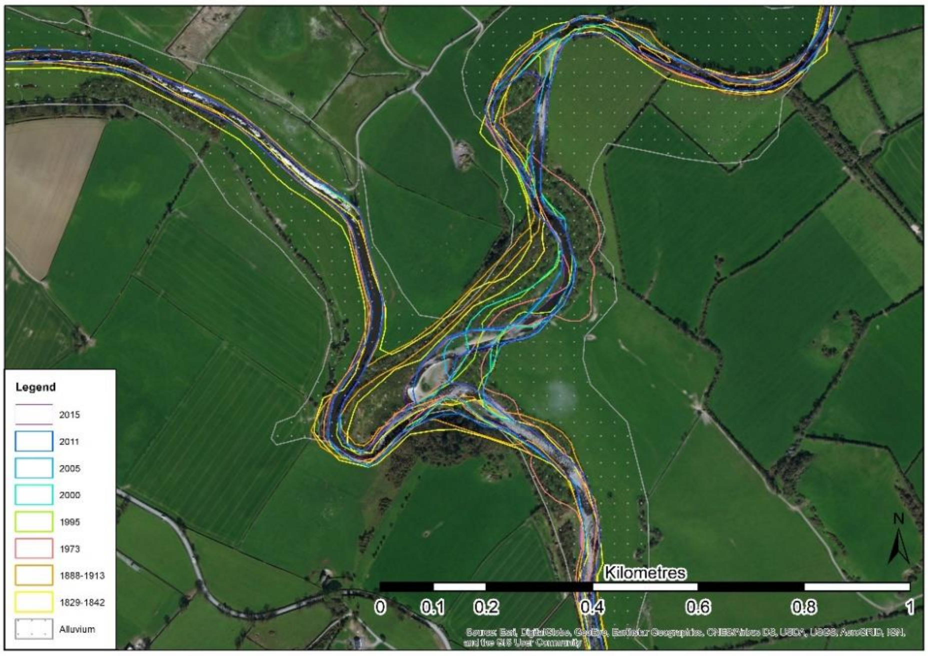

Figure 1 Map showing palaeochannels within the alluvial swathe at the NOR6 field site.

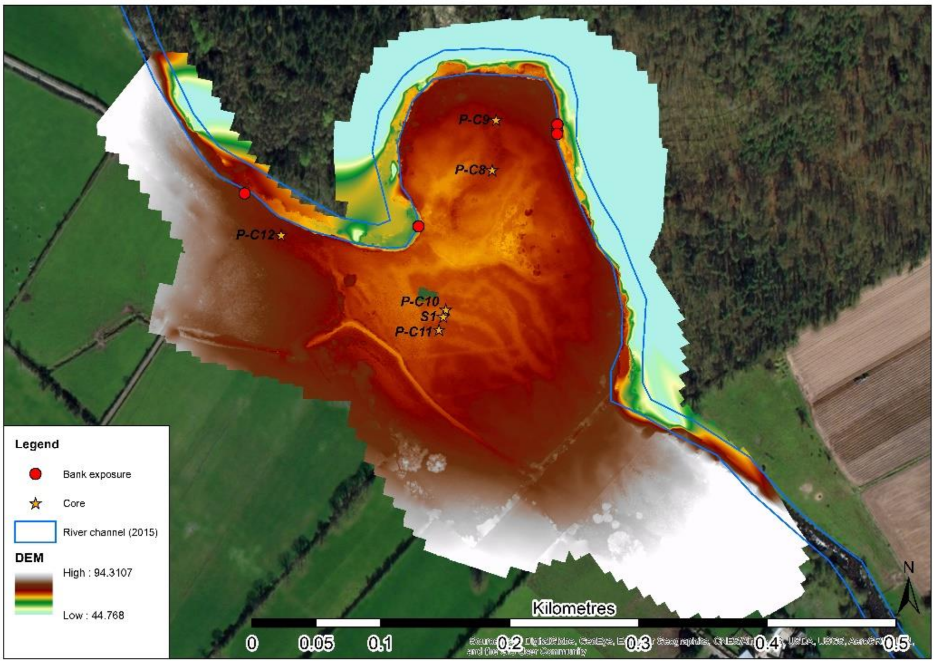

Figure 2 DEM at the NOR3 field site reveals microtopography.

2. FLOODPLAIN ARCHITECTURE

Floodplain bank exposures were characterised using conventional sedimentary logging techniques, when water levels were reduced to base flows (Figure 3). These investigations showed evidence of heterogeneous deposition within and between sites. Further upstream, sand dominates the lower profile of the floodplain with overlying silts and an underlying basal clay, whereas downstream the floodplain is dominated by silts overlying glacial gravels.

Figure 3 Examples of River Nore bank exposures.

Sediment cores were collected across two reaches, targeting morphological zones most likely to contain preserved palaeoflood deposits (e.g. palaeochannels, floodbasin, backswamp), and to identify locations suitable for retrieving samples for OSL dating. Following preliminary assessment using open window gouges, cores were extracted using a 1 m long closed gouge containing 50 mm diameter PVC tubes (Figure 4). Twelve cores were collected, totalling 30 m of closed core sections.

Figure 4 Sediment coring using a Van Walt percussion auger, gouge and extraction kit in the field.

Cores were split and logged following conventional procedures for sedimentary sequences (Nichols, 2009; Fryirs and Brierley, 2013). Thereafter, cores were scanned using the Itrax µXRF core scanner, located in the UCD School of Geography (Figure 5). This state-of-the-art analytical tool provides a non-destructive method for capturing high resolution (sub-mm) XRF-based chemostratigraphy, together with a high-resolution image, X-ray and magnetic susceptibility data for split core sections. To-date, 17 m (of the total 30 m) have been scanned with the core scanner.

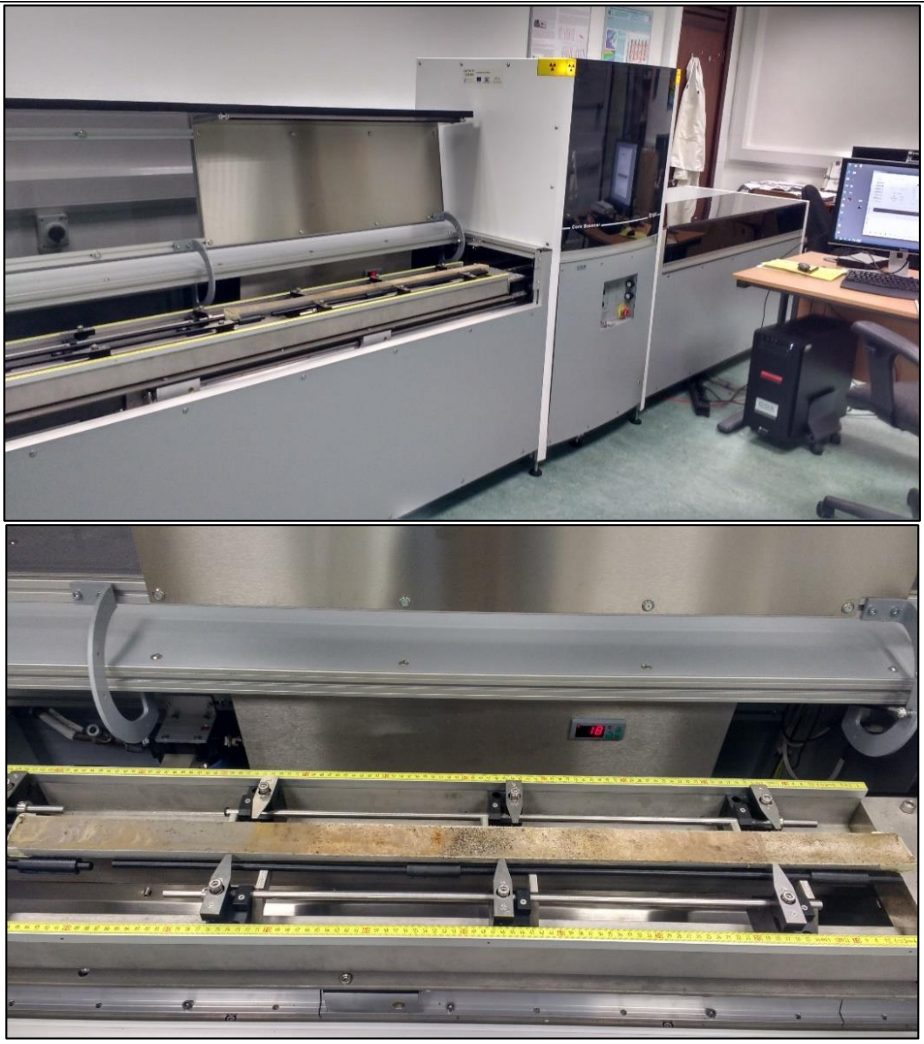

Figure 5 Sediment core in the Itrax core scanner, located in the UCD School of Geography.

Previous research has used geochemical element log ratios from Itrax scanning as proxies for grain size (Jones *et al.*, 2012; 2015; Fuller *et al.*, 2018). This approach was used to pick up high magnitude flood events, extending the instrument and historical flood record in the UK and New Zealand. In Ireland Itrax geochemical data have been used to discriminate floodplain composition related to degrees of pedogenesis and activity associated with redoximorphic processes (Turner *et al.*, 2015a). O'Shaughnessy (2012) has demonstrated that log(Si/Ti) is a suitable proxy for grain size variations in the Nore valley which has direct relevance to this project.

An example of the Itrax results from this project is shown for a sediment core taken on a raised part of the floodplain at site NOR3 (Figure 7). These data are reported as additive log-ratios (using Ti as the divisor). Covarying geochemical trends in the lower 2 m of the core, that corresponded to grey clay-rich sediments, suggest a detrital (rather than biological) origin for these sediments (Turner *et al*., 2015b). These are believed to have been deposited in a low energy system, possibly a standing waterbody. Although sand at the top of sections 3 and 4 is likely to represent material that had fallen in from the edges of the borehole during drilling, the peak in log(Si/Ti) in the middle of section 3 is indicative of an influx of coarser grained sediments into this low energy system – possibly a large flood or period of landscape instability. At 1.68 m there is a shift to coarse sands that subsequently transition to overlying silts. The combined lithology and geochemistry of these sediments indicates a change in the depositional environment from apparent lacustrine to fluvial sedimentation. Gross variations in the lithology and nested oscillations in geochemistry are indicative of changes in the energy environment and possibly sediment provenance as the floodplain evolved, while the marked shift in geochemistry at 0.6 m appears to correspond to an erosion surface. Further analysis and integration of lithological and geochemical datasets from cores across the floodplain, alongside the establishment of robust dating control, is needed to test emerging hypotheses. This this work is ongoing.

Given the complexity of this core, this location was investigated via trenching to establish a chronology for the sedimentary sequence.

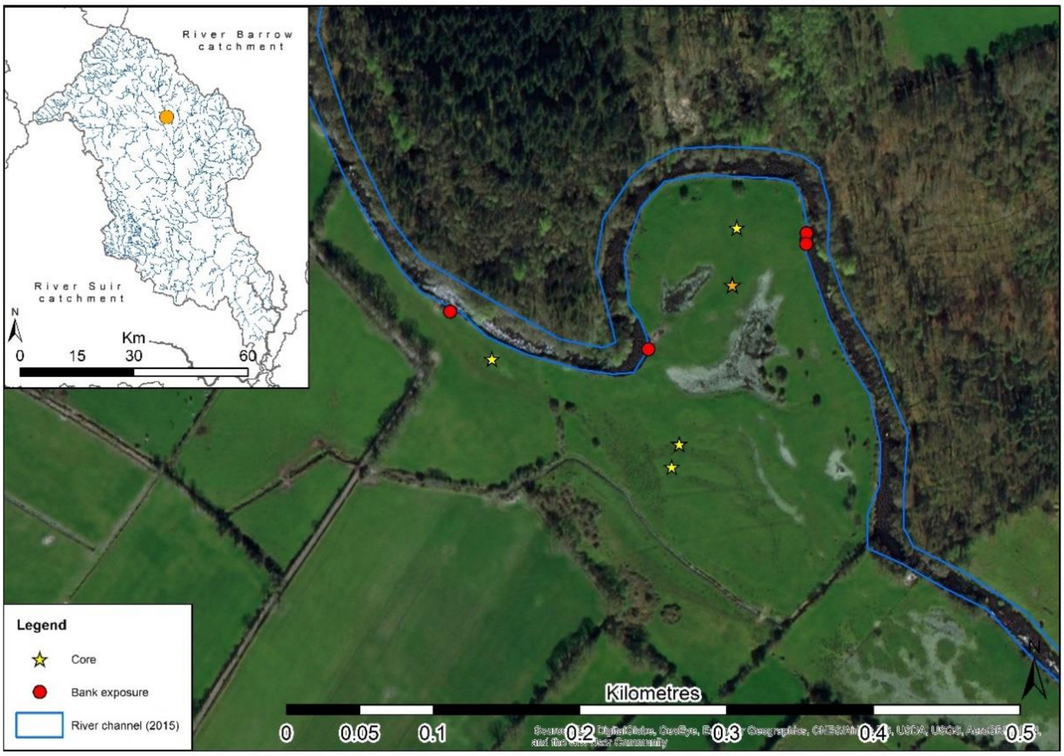

Figure 6 Map of field site showing location of sediment cores and bank exposures. Inset map shows field site location within the Nore catchment (reach NOR3).

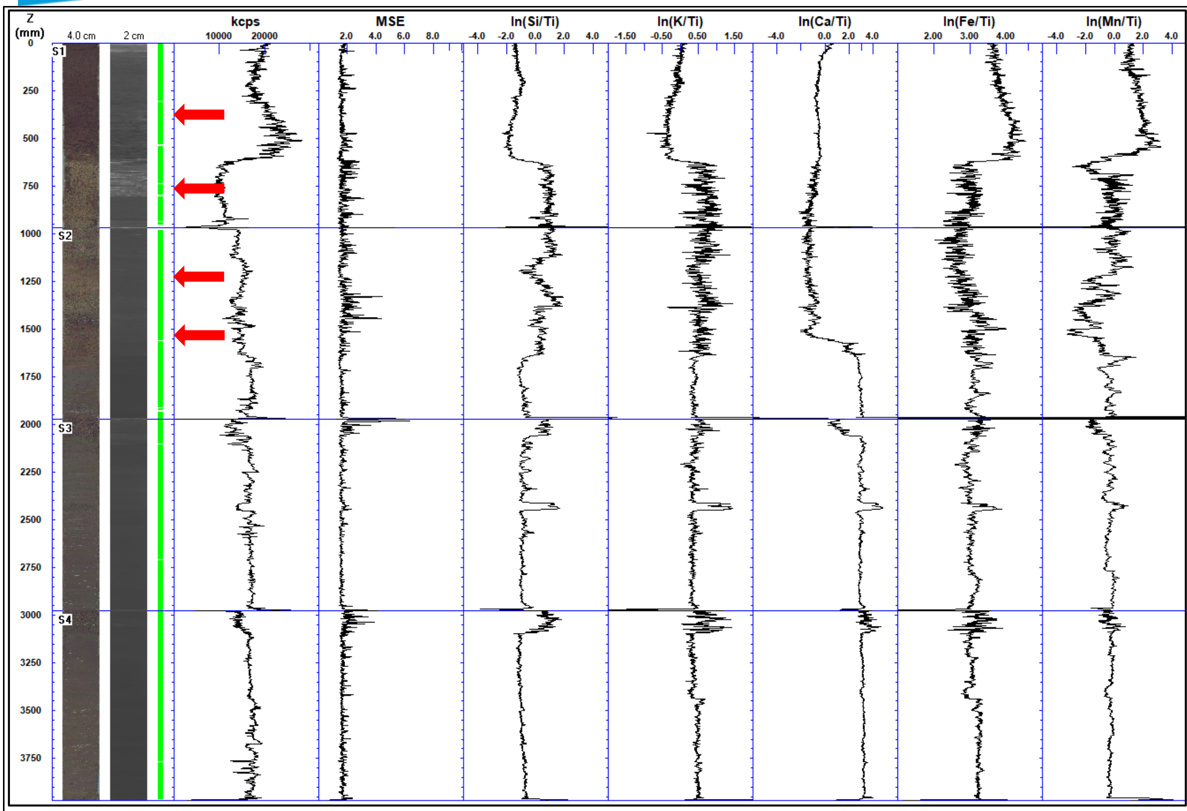

Figure 7 Itrax data includes high resolution image, x-ray & geochemical element profiles from Core 8 (orange star in Figure 6 marks core location). Red arrows mark location of OSL samples (Table 4).

3. CHRONOLOGY

Optically stimulated luminescence (OSL) dating is a technique used to measure burial ages in geology. It relies on a natural dosimetric property of quartz and feldspar minerals, both abundantly present in sediment. Its latent luminescence signal is easily reset to zero when these minerals are exposed to a sufficient amount of sunlight during their last sedimentary cycle (erosion, transport, deposition). A few seconds to a few minutes is usually sufficient, for quartz minerals, under direct sunlight. After deposition, these minerals will absorb a fresh dose of radiation, from the surrounding (up to 30 cm) natural background radiation in sediment (Aitken, 1998). The OSL age is obtained by measuring the total amount of radiation dose absorbed by these minerals (i.e. the equivalent dose) and dividing it by the annual rate of dose accumulation (i.e. the dose rate).

The single aliquot regenerative (SAR) dose protocol enables dating of single grains of quartz or feldspar (Murray and Wintle, 2000, 2003) and provides effective solutions to some previous limitations of applying OSL to date fluvial sediments including low quartz sensitivity and incomplete zeroing of the signal found in mixed-grain populations (Rhodes, 2011). In Irish sedimentary environments, there has been limited use of this method in dune systems (Wintle *et al.*, 1998; Wilson *et al.*, 2004) and coastal zones (Gallagher *et al.*, 2015). The SAR dose protocol (Murray and Wintle, 2000, 2003) has been applied successfully to a variety of fluvial settings internationally (Wallinga, 2002; Preusser *et al.*, 2008; Rhodes, 2011). Thermoluminescence dating was attempted in Irish fluvial sediments in the late 1990s without success (Gallagher, 2017, *pers. comm.*). This research presents the first findings of OSL dating in an Irish fluvial setting.

Preliminary investigations on sediments included a dose recovery ratio, recuperation test, recycling tests and comparison with a quartz calibration standard. All parameters on the Nore sediment were within the acceptable margin of error. During these initial stages of testing, the low amount of OSL light intensity or 'dim' quartz presented an issue, though it was not unexpected (S. Huot, 2018, *pers. comm.*). Recently glaciated landscapes tend to deliver 'dim' quartz, with poor luminescence characteristics (Preusser *et al.*, 2008) whereas landscapes with more sedimentary cycles tend to generate minerals with better luminescence characteristics.

Figure 8 Photo inside trench showing equivalent dose samples for OSL analysis captured in PVC and steel tubes.

In the Nore floodplain, manganese nodules present in sand unit are associated with redox cycles and changes in the water table. These nodules have a different radiometric properties than the host matrix. In the preliminary testing, this material accounted for 4% by dry weight so the overall amount in the host sediment is small.

Following investigations of the sediment cores, specific locations were targeted for OSL analysis. Two rectangular trenches (1.5 m x 2 m) were dug to the water table depth. Sedimentary logs were drawn in the field and specific horizons chosen for sample locations. Sediment was taken for the 'equivalent dose' sample in circular 50 mm PVC tubes and 19 mm diameter steel tubes, and thereafter sealed in light-proof bags (Figure 8)Figure 1. A 20-30 cm radius around the 'equivalent dose' locations was sampled for bulk sediments, to determine the 'dose rate'. Samples were sent to the US Geological Survey laboratory in Illinois for analysis using the standard SAR protocol (Table 2), which was completed with the following parameters for each sample (Table 3).

Table 2 Measurement steps for the SAR dose protocol (Murray and Wintle, 2000; 2003)

Step	Procedure
1	Regeneration[1]/natural dose
2	Preheat (160°C), hold for 10 seconds
3	OSL stimulation with blue LEDs at 100°C for 40 seconds (Lx)
4	Test dose beta irradiation (3.4 Gy)
5	Cut heat (160°C) for 0 seconds
6	OSL stimulation with blue LEDs at 100°C for 40 seconds (Tx)
7	Repeat Steps 1–6 with further regeneration doses

[1]For equivalent dose measurements, we gave a range of laboratory-induced doses that would properly encompass the variability of the observed natural luminescence.

Table 3 Parameters used in OSL analysis of Nore samples

Site	Sample name	Mineral	Grain size (µm)	Equivalent dose (Gy)	Dose rate (Gy/ka)	n (accepted /total)
NOR3, Trench 8	NOR3_T8_OSL4	Quartz	150-200	0.41 ± 0.05	1.42 ± 0.05	72/291
	NOR3_T8_OSL3	Quartz	150-200			
	NOR3_T8_OSL2	Quartz	150-200	13.49 ± 0.73	1.40 ± 0.06	24/144
	NOR3_T8_OSL1	Quartz	150-200	9.44 ± 0.63	1.09 ± 0.04	21/240
Bank exposure - Log 4	NOR3_L4_OSL	Quartz	150-200			
Bank exposure - Log 5	NOR3_L5_OSLb	Quartz	150-200			
	NOR3_L5_OSLa	Quartz	150-200			
NOR6, Trench 2	NOR6_T2_OSL2	Quartz	150-200			
	NOR6_T2_OSL2	Quartz	150-200			

The OSL age results thus far are presented in Table 4 (note: some pending). Nine samples in total have been targeted for OSL dating. Four samples were taken from one trench at site NOR3, along with 3 samples from exposed bank sections. Two more samples from a trench at site NOR6 are to be determined. Dating of the sequence in one trench is almost complete. A basal coarse sand at 155 cm depth was dated to 8.66 ± 0.68 ka using a minimum age model. An overlying sand at 120 cm depth was dated to 9.66 ± 0.70 ka using a weighted mean. The OSL date from next unit in the sequence is still pending and the uppermost fine sand at a depth of 36-40 cm yielded an OSL date of 0.29 ± 0.03 ka, also using a minimum age model.

Table 4 OSL results

Site	Sample name	Depth	Sediment type	Minimum Age (ka)	Weighted mean (ka)	Comment
NOR3, Trench 8	NOR3_T8_ OSL4	36-40cm	Fine sand	0.29 ± 0.03	0.99 ± 0.08	Partially-bleached
	NOR3_T8_ OSL3	77-86cm	Fine-med grey sand			
	NOR3_T8_ OSL2	120cm	Fine-med sand		9.66 ± 0.70	Well-bleached
	NOR3_T8_ OSL1	155cm	Coarse sand	8.66 ± 0.68	11.0 ± 1.1	Partially-bleached
Bank exposure - Log 4	NOR3_L4_ OSL	190-195cm	Fine-med grey sand			
Bank exposure - Log 5	NOR3_L5_ OSLb	160cm	Sand with Mn			
	NOR3_L5_ OSLa	200cm	clay			
NOR6, Trench 2	NOR6_T2_ OSL2	To be determined				
	NOR6_T2_ OSL2	To be determined				

Discussion & Lessons Learned

The results indicate the coarse sand present at the base of the trench (155 cm depth) is from the early Holocene. Radiometric ratios (e.g. $^{232}Th/^{40}K$) suggest a different provenance for sediment in this basal sample. The overlying unit (NOR3_T8_OSL2) was given an apparent older age (9.66 ± 0.70 Ka), but when looking at the margin of error on both these ages it can be seen that they overlap within the 2 sigma uncertainty bands. It can therefore be concluded that both of these sedimentary units are from the early Holocene. The uppermost unit at 36-40 cm depth is recent and yielded an age of 0.29 ± 0.03 ka.

The age for two samples (NOR3_T8_OSL1 and NOR3_T8_OSL4) were generated using a minimum age model (Galbraith *et al.*, 1999). Over-dispersion is a parameter used to discriminate between samples requiring calculation of a minimum age model and those where a weighted mean will suffice. Over-dispersion is calculated from the observed age distribution (including uncertainties) and it quantifies the amount of scatter in the distribution. When predicted distributions fall below a given threshold, minimum age models are used to identify a young age population, hidden inside a positively skewed distribution.

Bleaching is identified in age distributions (Figure 9). A well-bleached single-age population of aliquots should return a normal distribution. Meanwhile, a sedimentary unit affected by partial bleaching will demonstrate a positively-skewed distribution.

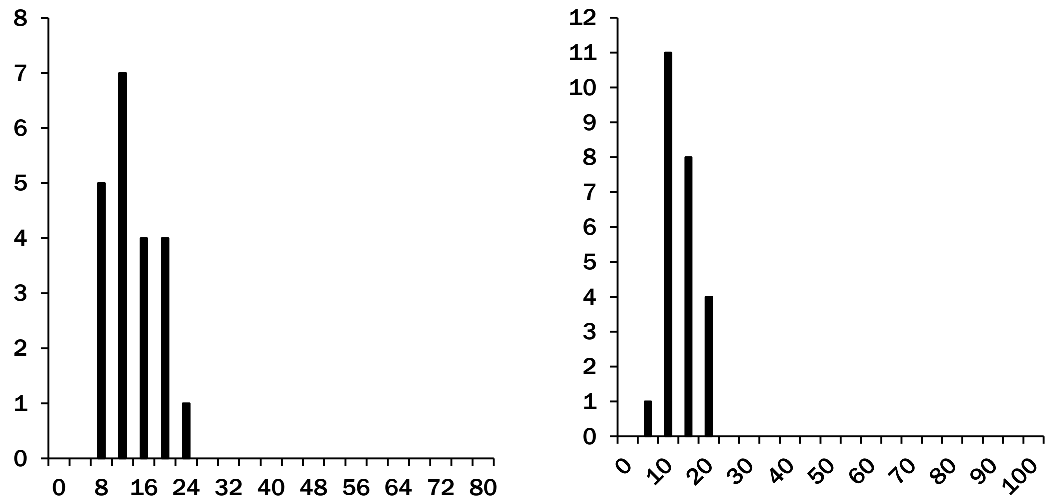

Figure 9 Age distribution examples. Sample NOR3_T8_OSL1 (left) was partially bleached, during its last sedimentary cycle. Sample NOR3_T8_OSL2 (right) appears to be have been well bleached.

The nuances of partially- vs well-bleached sediments can also be visualised in radial plots, where age is plotted on the radial arc against the uncertainties (X-axis), with 2 sigma standard deviation axes (Figure 10). The first radial plot is typical of a well-bleached sample (Huot, 2018, pers. comm.). The aliquots are well-distributed within the 2 sigma axes, from which the weighted mean can be calculated. In contrast the partially-bleached sample shows many aliquots falling outside the 2 sigma axes and well-distributed number of aliquots within the axes.

Another issue which complicated the dating of these sediments was the luminescence properties of the quartz. For example, the aliquots for NOR3_T8_OSL2 were extremely dim, and this impacts on the random uncertainties included in the age produced. Water content is an important parameter affecting random uncertainty in the OSL age equation, which can only be estimated as it reflects moisture throughout the burial length of the sediments. The period prior to sampling in this study was exceptionally dry, and measurements taken reflected moisture related to these recent weather patterns and seasonal trends. Water content was measured in the laboratory and conservative estimates applied in the age modelling.

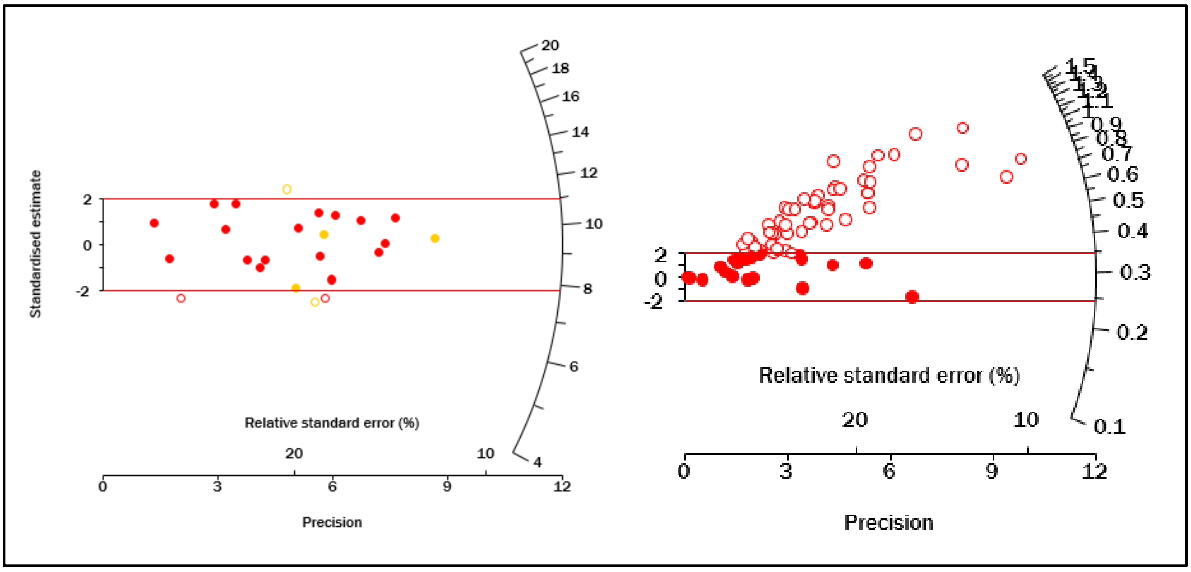

Figure 10 Radial plots for a well-bleached sample (left, NOR3_T8_OSL1) partially-bleached sample (right, NOR3_T8_OSL4).

Conclusion & further work

The first phase of OSL dating at a site in reach NOR3 suggests that only the uppermost 1.5 m of alluvium are of definitively Holocene age at this floodplain location. The underlying clays with interspersed sands observed in the core (Figure 7) could also be from the early Holocene but our working hypothesis is that that these were laid down in a Late Glacial lake system. Given that the log Ca/Ti profile covaries with other minerogenic indicators (log K/Ti, Fe/Ti, Si/Ti), these geochemical data suggest a dominant detrital rather than biological origin for these sediments, inferring low productivity consistent with a cooler period such as the Younger Dryas (Turner *et al*. 2015b). Pollen analysis on these sediments will be used to test this hypothesis. A Late Glacial lake at this site may be a localised feature, as this lithology was not observed in all sediment cores across this reach, or in any of the cores retrieved from the downstream study area. Relatively shallow depths of Holocene sediment may infer low sedimentation rates, but evidence for a non-conformity at the site, together with the close age of the OSL dates towards the base of the Holocene sequence may indicate floodplain stripping and/or an absence of sedimentation during the evolution of the floodplain.

The chronology of floodplain development on the Nore will be constrained further using pending OSL dates. Radiocarbon dating is commonly used to validate OSL results, but no organic macrofossil material was found in samples from the sediment cores or trenches. During the summer, when water levels were at their lowest in the Nore, the project team were able to sample large wood fragments that had become exposed at the base of floodplain cut banks. These samples have been identified by Dr. Rob Sands of UCD Archaeology as diffuse hardwood, which were interpreted as *Salix* species (Willow) and are likely to be *in situ*. Samples of the outer hardwood rings have been submitted to the SUERC radiocarbon laboratory in the UK for radiocarbon dating. OSL samples were taken from the matrix sands hosting these wood samples so that the results of the two dating methods can be directly compared.

This project is the first attempt to use OSL dating in an Irish fluvial setting and the first three OSL dates show promise given the floodplain sedimentary context. Although the errors on the dates may appear large (5-10%), they reflect the systematic and random uncertainties (e.g. calibration, water content, partial bleaching) which have to be accounted for when using the OSL method. Further results for both OSL and radiocarbon dating will provide additional age constraints on the floodplain evolution in the middle Nore, as well as an opportunity to test the accuracy of the OSL ages in this context. Issues identified with the OSL dating in this study, such as very dim quartz and partial bleaching, were not unexpected and have been overcome by the Illinois laboratory using appropriate age modelling techniques. The preliminary results indicate that in minerogenic, sand-rich floodplain sites such as those constituting much of the middle Nore valley, where organic matter for radiocarbon dating is limited, OSL dating presents a viable, albeit somewhat costly and labour-intensive, alternative dating method for reconstructing Holocene alluviation.

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(ii) Implementation (please include any issues with timelines, milestones, management etc. or deviations from the original implementation plan)

As outlined in the interim report there were some issues with timing and implementation of the initial project plan, specifically related to the method of OSL dating.

Scoping at the grant proposal stage with a laboratory in Denmark indicated the chosen method of analysis could be completed within the project timeframe. Initial sediment samples were collected in February and sent thereafter. Follow-up communication with the lab in March and April did not reveal any progress. In early May it became clear that the lab had closed for a period of time due to safety concerns. At this stage other possibilities were being investigated by the project team with laboratory managers at Aberystwyth University, Sheffield University, Oxford University and USGS Denver. The most timely and efficient of these was found to be the US Geological Survey laboratory in Illinois. Sediments for initial testing were re-sampled and sent to the USGS lab. These initial tests were positive, and the laboratory manager indicated a sample turnaround time of November.

(iii) Outputs (please provide a short description *and* complete the table below)

- Geomorphological maps: GIS vector and raster files derived for two floodplain sites on the River Nore showing micro-topography (DEMs), planform channel change and landform-scale geomorphology
- Floodplain sedimentology: 30 m of core sections from 12 core locations across two sites. 17 m of core sections have scanned to-date using the Itrax core scanner.
- Dating: 9 OSL dates (some results pending) and 2 radiocarbon dates (pending)
- Conferences/dissemination: One national and one international conference presentation showcasing this research. Poster for GSI annual conference.

Task No.	Deliverable description	Planned delivery (as per proposal)	Date of delivery
1	Sampling and analysis of River Nore sand samples for OSL dating	Month 5	Months 3-10
2	National conference presentation outlining project	Month 1	Month 1
3	International conference presentation showing preliminary project results	Month 6	Month 6
4	Manuscript for peer-reviewed international journal	Month 11	Delayed
5	Geomorphological maps of field sites	Month 6	Month 6
6	Final project report for the GSI	Month 12	Month 12

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Publications to date:

[Poster] Fleming, C.; Turner, J.N.; Bourke, M., Huot, S. (2018) Optically Stimulated Luminescence Dating of Lowland Floodplain Sediments in Ireland, *Geoscience 2018 – Meeting the Challenges*, Dublin, 6-NOV-18.

[Conference Publication] Fleming, C.; Turner, J.N.; Bourke, M. (2018**)** The dating game: palaeoflood reconstruction in an Irish catchment, *EGU General Assembly 2018 – Geophysical Research Abstracts* 20, EGU2018-15314-1, Vienna, 13-APR-18

[Conference Publication] Fleming, C.; Turner, J.N.; Bourke, M. (2017) The dating game: Optically Stimulated Luminescence in Irish fluvial sediments *5th Annual Irish Geomorphology Group Scientific Workshop*, Dublin, 23-NOV-17

4. Data/outputs submitted with final report *(please list the documents, presentations, datasets etc. submitted with this report)*

a. [Poster] Fleming, C.; Turner, J.N.; Huot, S.; Bourke, M. (2018) Optically Stimulated Luminescence Dating of Lowland Floodplain Sediments in Ireland, *Geoscience 2018 – Meeting the Challenges*, Dublin, 6-NOV-18.
b. [Conference Publication] Fleming, C.; Turner, J.N.; Bourke, M. (2018**)** The dating game: palaeoflood reconstruction in an Irish catchment, *EGU General Assembly 2018 – Geophysical Research Abstracts* 20, EGU2018-15314-1, Vienna, 13-APR-18
c. [Conference Publication] Fleming, C.; Turner, J.N.; Bourke, M. (2017) The dating game: Optically Stimulated Luminescence in Irish fluvial sediments *5th Annual Irish Geomorphology Group Scientific Workshop*, Dublin, 23-NOV-17