Institution: Newcastle University		
Unit of Assessment: 12		
Title of case study: Natural Flood Management using Runoff Attenuation Features		
Period when the underpinning research was undertaken: 2010-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dr Paul Quinn	Senior lecturer	1996- to date
Dr Jennine Jonczyk	PDRA	2003- to date
Dr Mark Wilkinson	PDRA	2000- 2015
Dr Eleanor Starkey	PDRA	2015- to date
Dr Caspar Hewett	PDRA and then Lecturer	2008-date
Period when the claimed impact occurred: 2013-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Over 5.2 million homes and businesses in England are currently at risk from flooding, according to the Environment Agency (EA), and more will become threatened in the future. Newcastle's research into Natural Flood Management (NFM) and the use of Runoff Attenuation Features (RAFs) has directly led to changes in policy and practice, and at least £15 million investment on NFM projects that protect people/towns. RAFs are cost effective 'soft-engineered' interventions, slowing and storing flood waters in rural landscapes. The innovative soft engineering designs for RAFs pioneered by Newcastle to address flooding means that lives and businesses are now better protected from floods, and numerous projects both nationally and internationally now use the RAF approach.

2. Underpinning research (indicative maximum 500 words)

More people than ever are at risk of flooding. The risks are increasing as climate change affects weather patterns. Rainfall is predicted to become more frequent and more intense with peak river flows being more than twice-current levels in some English catchments by 2070 [E1].

Newcastle's body of research has identified a range of interventions that can be used to reduce the risk of flooding across catchments. From sites upstream close to the source of rivers, through to floodplain storage schemes, soft-engineered structures can divert, store, and slow the flow of water during large flood events. NFM is the broad term that includes planting forest, improving soil health, and engineering structures such as ponds and woody 'leaky' dams. The RAFs pioneered by Newcastle are a specific type of NFM that uses modified ponds and barriers to reduce flood flow, and through our research have proven them to be especially effective.

Runoff Attenuation Features

Newcastle has pioneered the design of RAFs and gathered the first evidence of their engineering and hydrological performance in space and time through detailed laboratory, fieldwork and full-scale modelling. The term was first pioneered by Newcastle in 2010 [P1] and is now in common use in NFM literature [E2-E7]. RAFs are a specific design that modifies the function of traditional ponds and barriers to control flood flow. Often referred to as 'leaky dams', soil bunds and woody dams can temporarily store flood flow, but crucially can operate during dangerous high flows. Wider NFM measures like tree planting and soil improvement can reduce smaller flood event impacts but are deemed to be less effective in larger flood events [P2, E2]. Our RAFs can therefore target flood flow and have been shown to be particularly effective in smaller catchments [P2, E2 and E3]. As RAFs are relatively small, they fit well into farmed landscape without negatively

impacting on farm production and revenues.

Belford NFM Flood Project

The Newcastle-led project in Belford, Northumberland was the first to demonstrate catchment scale impacts to support NFM [P1, P2, P4]. The measures comprising 50 RAFs across 6km^2 were constructed between 2010 and 2013 and studied until 2017. The project, costing £200,000 replaced a proposed traditional scheme using a large detention dam costing £2.1 million and has protected 30 properties and local inconvenience as the town has not flooded since 2010 despite numerous large, potential flood-causing events.

Through detailed instrumentation and observations of individual RAFs and flow gauging across the catchment, the RAF design has now been refined [P1, P2]. By studying observations of RAF function and by simulating the catchment, the impact of networks of RAFs has now been established to show significant reductions in peak flow in large flood causing events for catchments of ~10km^2 [P1, P2, E2, E3].

Scaling up NFM using RAFs

Following their successful implementation on a small catchment, more recent work (in partnership with the EA and ARUP) at Lustrum Beck, Stockton-on-Tees, and in Weardale, is demonstrating greater impacts by implementing RAFs on a larger scale. Newcastle, between 2017 and 2020, co-designed, instrumented, and evaluated the Lustrum scheme with Arup, which is now fully operational, and is expected to reduce flood peaks by 10%, at a cost of £300,000. The Weardale scheme, between 2019-to date, is the largest implementation of NFM in the UK (at a scale of 100km^2), featuring a network of over 100 larger scale RAFs co-designed by Newcastle and Arup to tackle flood flow. The estimated impact of the RAF network was based on the NFM Tool, a RAF network simulation toolkit developed by Newcastle and Arup [first published as the Pond Network Model in P2].

Underpinning partnerships with the EA, River Trusts, The National Trust, National Farmers Union (NFU), NGOs and industry [E10] is showing the benefits of community participation in delivering NFM [P3, P4]. RAF delivery by multiple organisations is now seen as the cornerstone of catchment-based partnership working, reflected in Newcastle using novel participatory processes, workshops, visualisation tools using decision support tools (such as the Flood Agricultural Floods Matrix, [P6]), and citizen science data collection [P3].

The Newcastle approach is now captured as a catchment-wide philosophy that includes nature-based solutions and engineering as part of a Catchment Systems Engineering approach [P4, P5].

3. References to the research (indicative maximum of six references)

[P1] Wilkinson, M.E., Quinn, P.F. and Welton, P. 2010. Runoff management during the September 2008 floods in the Belford catchment, Northumberland. *Journal of Flood Risk Management* 2010, **3**(4), 285-295. DOI:10.1111/j.1753-318X.2010.01078.x

[P2] Nicholson, A.R., O'Donnell, G.M., Wilkinson, M.E. and Quinn, P.F., 2020. The potential of runoff attenuation features as a Natural Flood Management approach. Journal of Flood Risk Management, 13, p.e12565. DOI: 10.1111/jfr3.12565

[P3] Starkey, E., Parkin, G., Birkinshaw, S., Large, A., Quinn, P. and Gibson, C., 2017. Demonstrating the value of community-based ('citizen science') observations for catchment modelling and characterisation. *Journal of Hydrology*, *548*, pp.801-817. DOI: 10.1016/j.jhydrol.2017.03.019

[P4] Wilkinson, M.E, Quinn, P.F., Barber, N.J and Jonczyk, J. 2014. A framework for managing runoff and pollution in the rural landscape using a Catchment Systems Engineering approach. Science of the Total Environment January 2014, Pages 1245–1254. DOI: 10.1016/j.scitotenv.2013.07.055

[P5] Hewett, C.J., Wilkinson, M.E., Jonczyk, J. and Quinn, P.F., 2020. Catchment systems engineering: An holistic approach to catchment management. "Wiley Interdisciplinary Reviews: Water", 7(3), p.e1417 DOI: 10.1002/wat2.1417

[P6] Wilkinson, M. E., Quinn, P. F. and Hewitt, C. J. M. 2013. The Floods and Agriculture Risk Matrix: a decision support tool for effectively communicating flood risk from farmed landscapes. International Journal of River Basin Management, 11, 237-252. DOI: 10.1080/15715124.2013.794145

4. Details of the impact (indicative maximum 750 words)

Newcastle has led on designing, implementing, monitoring and analysing Runoff Attenuation Features (RAFs) in rural catchments. Through workshops, media, journal papers, collaboration with industry and national policy makers our research has:

1. Provided rigorous data from observations and modelling that RAFs are a proven, localised, cost-effective innovation to slow and store fast runoff that can contribute to floods.
2. Demonstrated catchment scale reduction in flood flows in Belford and other sites across the North of England and shown additional co-benefits for water quality and carbon accumulation.
3. Played a central role in shaping national-level policy and informing future investment priorities (Quinn was a Special Advisor to the EFRA Committee).
4. Shown that NFM can provide greater benefits by implementing RAFs in larger catchments.
5. Led to national and international recognition and uptake.

Consequently, RAFs are now a significant part of natural flood management (NFM) in the UK. The 2021 Environment Food and Rural Affairs (EFRA) Flooding report states that *"The Government needs to explain how it will ensure a catchment-based approach to incentivising natural flood management (NFM)"* and that "*Working with natural processes is an important part of a holistic approach to flood risk management*".

1. The RAF. A typical RAF is a 'soft engineered' structure (e.g. a bund or swale) costing between £1,000-5,000 to build, using locally sourced materials. The Belford scheme included the invention and trial of a series of RAF designs, as a cost-effective and widely cited approach to flood management [E1, E2, E3]. It has demonstrated how to control discharge rates that can reduce a flood peak by working with farmers and the local community. RAFs are popular on intensive farms as they do not affect production and can be 'hidden' within the landscape. RAFs are now being constructed across the UK and are part of the NFM and nature-based solutions supported by many NGOs and government authorities [E2 contains a catalogue of case studies: the prevalence of RAF concepts and leaky dams are clear].

2. The Belford Catchment NFM Project was the first example of a catchment scale NFM scheme to gain evidence of both observational and modelled flood impacts. Belford had flooded 7 times in 8 years and the RAFs we designed and implemented generated a saving of £1.9 million over a hard engineering proposal, with the full support of local farmers. Consequently, the town has not flooded since 2010, despite many high river flow events. Over 2,000 visitors have and continue to visit the Belford site and Newcastle team, to replicate the design and to gain the confidence to build their own schemes. **The project was awarded the Institute of Civil Engineering North East, Robert Stephenson Prize 2015, with our partners the EA (funders) and AMCO (civil engineering contractors), for excellence in innovation and collaboration in civil engineering.**

Across England – Northumberland River Trust worked with us to deploy the Newcastle NFM design, in other villages such as Netherton. Similarly, based on our advice the Tyne Rivers Trust 4 RAF ponds and a 'Ker-Plunk' RAF (as seen on BBC Weather Watch), and specifically designed to trap debris and mange flows in forested catchments) were installed to protect Haltwhistle [P3]. In partnership with the National Trust at Wallington Estate (near Morpeth, Northumberland) we have demonstrated how flooding, poor water quality and carbon accumulation can be tackled simultaneously, using large-scale RAFs.

These successes have resulted in Newcastle providing advice, evidence and design guidance for NFM schemes across the UK, resulting in a rapid growth in the deployment and uptake of similar schemes across the country. One such example is in Greater Manchester, led by Dr David Brown, EA Senior Scientific Officer. David has studied the Newcastle approach and sums up the role and impact the Newcastle team's work has had over time and how it has influenced work in his area [E8]: "*Paul's advice significantly modified at least four of the projects and suggested focusing more*

on storage capacity to provide contingency for the 'really large' floods, and his input brought more attenuation storage, and resilience to large storm impacts, to those projects."

3. Special Advisor to EFRA Committee

In January 2016, Quinn was appointed as special advisor to the EFRA Select Committee, providing research and evidence for their 'Future Flood Prevention' report [E1]. This formed the basis of several recommendations on NFM and the catchment-based approach. The review concluded that as part of a new model for managing flood risk "*The Department for Environment, Food and Rural Affairs (Defra) should commission by July 2017 a large-catchment trial of the effectiveness of natural flood risk management approaches such as installation of leaky dams, tree planting and improved soil management, alongside other measures".*

As a direct consequence, the EA funded new national NFM Trials worth £15 million [E9]. Neil Parish MP (Chair of the EFRA Committee) summarises the input of Quinn's work [E9]: "*I would thank Paul for his valuable work in support of the Committee and the added impact his input had on the Future Flood Prevention Report. This will have helped to shape recent change in policy with the EA to adopt NFM methods."*

4. Using RAFs to Scale-up NFM in Larger Catchments

The successful implementation of our RAFs in Belford led to us working in partnership with Arup, the EA, Stockton Council and several NGOs to expand their scale. In Lustrum Beck (sub-catchment 17km^2) we advised on the design of a series of RAF storage ponds in Coatham Woods [E10] as part of a £5 million flood alleviation scheme in Stockton. The scheme, now fully operational, has been entered for The Robert Stephenson ICE Prize in 2021.

The largest of the EA national NFM Trials (see above), was in Weardale, targeting a 100km^2 catchment area. The NFM scheme was co-designed with partners Arup, and will be dominated by large-scale RAFs. Contracts worth £150,000-£200,000 have been released to construct over 100 of these in Middlehope and Killhope Burns in Weardale [E10].

The EA, Arup and the NFU are working on a smaller NFM trial in Kentmere (20km^2) upstream of Kendal. This uses large-scale RAFs, implemented across agricultural land, using networks of bunds and drains. This work was featured on the BBC's 'Costing the Earth' which focuses on the scaling-up potential of RAFs supported by Newcastle.

Existing collaboration with Arup's water team was accelerated in 2015 by Quinn being awarded a 6-month NERC industrial fellowship to address 'The uptake of NFM by Industry'. Newcastle design and principles are now used across Arup schemes nationally and internationally, including contributions to the award-winning Arup WATERUP project [E4]. Dr Alex Nicholson, senior consultant, sums up the partnership as: "*Newcastle University research into natural flood management (NFM), specifically runoff attenuation features (RAFs), has enabled Arup (and the wider industry) to incorporate NFM into standard flood risk management projects*" such that it has "*enabled [a] step-change [in] the current engineering practice behind flood risk management*". [E10]

5. Promotion of RAF Impacts Nationally and Internationally

Nationally – In addition to an ICE 2015 Prize, the Newcastle RAF study sites are cited as evidence of good practice in numerous documents in the UK [E5–E8]. Newcastle schemes have appeared on several news items, including BBC and ITV news, The One Show (BBC1, 5 Feb 2014), and a feature length film entitled 'High Water - Common Ground' aimed at schools and catchment communities.

The work underpins much of the evidence base in the EA document '*Working with Natural Processes Report*' (WWNP) [E2], which is used to guide EA policy on NFM uptake. Belford and several other Newcastle projects appear as case studies in this document. Two decision support tools, the FARM (Flood and Agricultural Risk Matrix [P6], funded originally by the EA) tool and the NFM tool (a RAF network impact calculator developed by Newcastle and Nicholson at Arup [published in P2 as the Pond Network Model]) are also included in the WWNP report. This tool was used by the EA on the Lustrum Beck and Weardale projects. '*The NFM Handbook'* produced by the Scottish Environment Protection Agency (SEPA) in 2015 [E3] also included RAFs, Belford

and the FARM tool. The work has been reported in numerous publications including The Institute of Civil Engineers, Royal Institute for Chartered Surveyors, Chartered Institute for Water Management, The NERC Magazine and NGO's such as the River Restoration Centre and The Green Alliance.

Internationally – Our work has been transferred internationally. For example, €1.5 million RAF features designed by Newcastle have been built by the EPA (Environment Protection Agency) and the Office of Public Works (OPW) and fully instrumented in Wexford and Cork [E6] leading to new Teagasc funding for the construction of more RAF features. Natural Water Retention Measures (NWRM) form part of a major EU project [E5]. Belford is listed in several places as an example of good practice. The US Corps of Engineers have visited Belford and list it in its '*World Atlas of Engineering with Nature'* [E4] as an example of "*advancing worldwide progress*" in the integration of natural and human systems. In Sweden [E7] Belford and Wallington are highlighted as exemplars that have informed their approach. The Flow Partnership and Arup's award winning WaterUp project used the Belford approach in India and Colombia. Furthermore, we were invited to join The Flow Partnership, led by Stockholm Water Prize winner Rajendra Singh, to disseminate best practice internationally.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[E1] **EFRA Committee Nov 2016. Future Food Prevention Report** https://publications.parliament.uk/pa/cm201617/cmselect/cmenvfru/115/115.pdf identifies Dr. Quinn as a special adviser for this influential report and confirms the need to change policy to incorporate NFM into catchment management.

[E2] **EA Working with Natural Processes – Evidence Directory, 2017** https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk extensively refers to the Belford scheme in the evidence base underpinning NFM to provide guidance to flood risk management practitioners and other responsible bodies and provide them with easy access to information.

[E3] **SEPA NFM Handbook, 2015** https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf provides the Belford scheme as a practical guide to local authorities and other practitioners for the delivery of NFM.

[E4] **Engineering with Nature. 2019 World ATLAS, US Corps of Engineers** – https://ewn.el.erdc.dren.mil/img/atlas/ERDC-EL_SR-18-8_Ebook_file.pdf highlights the Belford scheme as an example of worldwide progress in creating value by integrating natural and engineered systems.

[E5] **EU project on NWRM** providing details of Belford the NFM scheme as evidence of good practice http://nwrm.eu/.

[E6] '**Slowaters' Project Ireland** About the project – Natural Water Retention Measures detailing the implementation of NFM in Ireland. Our Team – Natural Water Retention Measures (wordpress.com)

[E7] **Swedish Catchment NFM report 2018 report**, link 2018-13.pdf (lansstyrelsen.se), [Swedish language: search for 'Belford']

[E8] **Testimonial Dr David Brown** – Senior Scientist EA Partnership & Strategic Overview Team, confirming Dr Quinn's inputs to the Working with Natural Processes (WWNP) guide commissioned by Defra providing the evidence base for NFM, and his oversight in the implementation of NFM projects.

[E9] **Testimonial Neil Parrish MP** – Head of EFRA committee, HM Government confirming Dr Quinn's role as special adviser and his impact on changes to NFM policy and practice.

[E10] **Testimonial Dr Alex Nicholson** – Arup Senior Engineer, Environment and Sustainability Team confirming how Newcastle's work has enabled Arup to incorporate NFM into standard flood risk management projects and has changed current engineering practice in flood risk management.