Project number: 6124
Funding source: Teagasc
Date: September 2019
Project dates: Jan 2011 – Nov 2018

Sediment: Flux, provenance and ecological impact

Key external stakeholders:

Policy-makers, land-owners, water-managers, stakeholders involved in water quality.

Practical implications for stakeholders:

Greater focus on reductions in sediment inputs to rivers is required. Management strategies need to reduce the magnitude and duration of fine sediment delivery to aquatic ecosystems. Maintenance of existing landscape features is a priority to prevent acceleration of soil losses from agricultural catchments. Additional management strategies include soil conservation practices, stabilising structures and buffer zones. Arable land on low permeability soils is a high soil loss risk. In-field mitigation measures such as rapid establishment of crop cover after drilling are practical approaches to reduce the space and time soils are bare.
Sediment has the potential to interact synergistically with nutrients resulting in greater negative ecological effects in downstream river reaches, thus a holistic approach to river management should be taken.

Main results:

- Suspended sediment exports from Irish catchments are low compared to values for the UK and mainland Europe.
- Field topsoils, channel banks/sub-surface soils and roads were the dominant contributors to suspended sediments in this study and contrasted between catchments e.g. grassland catchments dominated by low permeability soils with extensive sub-surface and surface drainage primarily exported sediment originating from channel banks due to delivery of high velocity flows from up-catchment drained hillslopes
- Both drainage type and season have a significant influence in structuring macroinvertebrate communities. Poorly-drained catchments were most impacted, with communities dominated by pollution-tolerant taxa
- Sediment was found to be a more pervasive stressor on freshwater ecosystems than nitrogen or phosphorus, with high sediment cover levels having the greatest negative impact on macroinvertebrate communities.

Opportunity / Benefit:

This study highlights the need for targeted management practices to reduce inputs of sediment to freshwater ecosystems. Arable land on high permeability soils could benefit from temporary sediment control measures, (e.g., sediment fences) only when rainfall amount, duration and intensity are sufficient to saturate soils and when groundcover is low. Grassland dominated low-permeability catchments require channel mitigation measures. Creation of riparian wetlands, widening channels, and re-vegetation with deep rooted tree species will dissipate flow energy, decrease of banks erosion risk and nutrient inputs to streams
Further work is needed to determine ecologically relevant thresholds which also take into account length of exposure.

Collaborating Institutions:

University of Dundee
University of Ulster
University College Dublin

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1. Project background:

Sediment is a naturally occurring material, derived from the weathering and erosion of underlying bedrock and steam banks, which is then subsequently transported downstream by mass movement. However, excessive delivery of fine sediment (for example from agricultural catchments) to aquatic ecosystems can impact chemical water quality and degrade ecological habitat. Sediment dynamics in intensive agricultural catchments are under-researched in Ireland; therefore, this project aimed to quantify sediment export, determine the processes responsible for soil erosion and sediment transport and identify sediment contributions from multiple sources in different agricultural systems to evaluate approaches to fine sediment management. Additionally, the impact of sediment on freshwater ecology was also assessed.

2. Questions addressed by the project:

This project aimed to quantify sediment export, determine the processes responsible for soil erosion and sediment transport and identify sediment contributions from multiple sources in different agricultural systems. Additionally, the project aimed to assess the influence of chronic and acute inputs of sediment, relative to other agricultural stressors including nitrogen and phosphorous, on freshwater ecology. The specific objectives were to:

- Quantify suspended sediment fluxes from Irish agricultural catchments over a gradient of land uses
- Investigate event-scale suspended sediment delivery in relation to land use and hydrological controls in intensive agricultural catchments
- Identify suspended sediment sources over time in multiple intensive agricultural catchments
- Characterise the effect of drainage type in structuring macroinvertebrate communities.
- Investigate the effect of chronic and acute pressures across drainage types during the ecologically sensitive summer period to identify times of greatest ecological risk.
- Investigate the singular and combined effects of chronic and acute inputs of sediment. Nitrogen and phosphorus a multiple-stressor context.

3. The experimental studies:

- To estimate sediment flux and concentration, e*x-situ* and *in-situ* suspended sediment monitoring methodologies were used in five study catchments (see Agricultural Catchments Programme for greater information on study sites),
- A storm event scale metric, was applied to all storm events in three of the five study catchments (over two years) to investigate the seasonality of sediment dynamics. Seasonal trends were interpreted according to the connectivity (from source to receptor) resulting from catchment soil type and ground cover attributes and storm specific rainfall.
- Sediment fingerprinting was undertaken in three study catchments to investigate the provenance (source) of sediments collected at respective catchment outlets. This novel approach involved using natural tracers (radio-nuclides, magnetics, particle-size) in soil, to determine and quantify relative contribution of sediment source material.
- Medium-term field-scale soil erosion rates in an intensively cultivated catchment with high-permeability were quantified using caesium dating.
- Macroinvertebrate data were assessed for four study catchments over four years. Stream hydrochemical data were also assessed.
- High-frequency monitoring of macroinvertebrate communities was undertaken from March and October 2016 to assess changes in community structure and related metrics during this period in seven catchments. High-frequency chemical monitoring data were used to assess the effect of chronic versus acute pressures. Two high-status control catchments were also used to allow for the effects of natural seasonal variation to be disentangled from effects of chronic and acute inputs across drainage types and months.

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- To assess the impact of sediment, phosphorus and nitrogen on macroinvertebrate communities, a 112-channel streamside mesocosm facility was established. This facilitated that addition of acute and chronic concentrations of sediment, phosphorus and nitrogen. Stressors were manipulated for two weeks and the response of the macroinvertebrate community was assessed.

4. Main results:

- Suspended sediment export from five intensive agricultural Irish catchments were low compared to values for the UK and mainland Europe. This was attributed to greater density of landscape features such as hedgerows and drainage ditches which reduced field sizes, and act as natural mitigation measures.
- Catchments with low permeability exported larger suspended sediment yields than those with high permeability. Where arable land occurred on low permeability soils, the highest sediment export was recorded. High inter-annual variability resulted from rainfall fluctuations. The results indicate that catchment soil erosion risk can be classified according to soil drainage characteristics and land use type.
- Analysis of sediment response following rainfall-runoff events over time revealed the impact of sediment source location and availability. Catchments with reduced drainage and, therefore, good surface connectivity had contrasting sediment responses due to the location of available sediment sources (hillslope versus channel bank). Channel erosion was likely accelerated by high flow resulting from extensive artificial drainage (surface ditches and sub-surface drains). Sediment export was elevated in arable catchments when low groundcover was coupled with high connectivity. The results indicate the variability of sediment source availability, hydrological transport pathways, and subsequent sediment exports are variable in time.
- Assessment of the provenance of suspended sediments highlighted that field topsoils, channel banks/sub-surface soils and roads were the dominant contributors, and contrasted between catchments. Overall, dominant sources in Grassland B, Arable A and Arable B were channel banks, channel banks/sub-surface soils and field topsoils respectively. Contributions from road sources, including farm tracks, were low in all catchments.
- Field-scale assessment of medium-term soil erosion and deposition in a long-term predominantly arable catchment, showed net soil erosion was high and exceeded tolerable soil erosion rates. Net erosion was greater from cultivated soils than those under permanent pasture. Erosion from cultivated land was primarily attributed to soil loss from harvesting of root crops, namely sugar beet up until 2005..
- Freshwater ecosystems are under pressure from multiple-stressors at any one time.
- Both drainage type and season can have a significant influence in structuring macroinvertebrate communities. Poorly-drained catchments were most impacted, with communities dominated by pollution-tolerant taxa such as *Gammarus* sp., Simuliidae, Chironomidae and *Asellus* sp. Both well- and poorly-drained agricultural catchments were impacted compared to reference conditions, with poorly-drained catchments having the lowest ecological quality. Poorly-drained catchments were subject to chronic P pollution over the summer months, particularly in July and August.
- In mesocosm experiments sediment was found to be the most pervasive stressor with high sediment cover levels (90%) having the greatest negative impact on macroinvertebrate communities.
- Nutrient effects were weak compared to those of sediment and negative effects of nutrient enrichment were as a result of chronic inputs, with acute inputs having no additional effect.
- Effects of nitrogen enrichment were generally more negative than those of phosphorus, while the effects of both phosphorus and nitrogen enrichment also became increasingly negative the longer the community was exposed.

3. Opportunity/Benefit:

This study highlights the need for targeted management practices to reduce inputs of sediment to freshwater ecosystems. Effective catchment sediment management strategies must consider both the frequency and magnitude of all catchment sediment pathways.Arable land on high permeability soils could benefit from temporary sediment control measures, (e.g., sediment fences) only when rainfall amount, duration and intensity are sufficient to saturate soils and when groundcover is low. Grassland dominated low-permeability catchments require channel mitigation measures. Creation of riparian wetlands, widening channels, and re-vegetation with deep rooted tree species will dissipate flow energy, decrease of banks erosion risk and nutrient inputs to streams

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4. Dissemination:

The methodology, results and outputs from this project were presented to various stakeholders through a variety of dissemination techniques, including conference presentations, popular articles, and scientific publications.

5. Main publications:

Sherriff, S.C., Rowan, J.S., Fenton, O., Jordan, P. & Ó hUallacháin, D. (2019) Influence of land management on soil erosion, connectivity and sediment delivery in agricultural catchments. *Land Degradation and Development* In press

Davis, S.J., Ó hUallacháin, D., Mellander, P.-E., Kelly, A.-M., Matthaei, C.D., Piggott, J.J., Kelly-Quinn, M. (2019) Chronic nutrient inputs affect stream macroinvertebrate communities more than acute inputs: an experiment manipulating phosphorus, nitrogen and sediment. *Science of the Total Environment*, 683, 9-20

Sherriff, S.C., Rowan, J.S., Fenton, O., Jordan, P. & Ó hUallacháin, D. (2018) Sediment fingerprinting as a tool to identify temporal and spatial variability of sediment sources and transport pathways in agricultural catchments. *Agriculture, Ecosystems and Environment* 267, 188-200

Davis, S.J., Ó hUallacháin, D., Mellander, P.-E., Kelly, A.-M., Matthaei, C.D., Piggott, J.J., Kelly-Quinn, M. (2018) Multiple-stressor effects of sediment, phosphorus and nitrogen on stream macroinvertebrate communities. *Science of the Total Environment*, 637-638, 577-587.

Sherriff, S., Rowan, J.S., Fenton, O., Jordan, P., Melland, A., Mellander, P.-E., & Ó hUallacháin, D. (2016) Storm event suspended sediment-discharge hysteresis and controls in agricultural watersheds: implications for watershed scale sediment management. *Environmental Science and Technology*, 50, 1769-1778.

Sherriff, S.C., Rowan, J.S., Melland, A.R., Jordan, P., Fenton, O. and Ó hUallacháin, D. (2015) Identifying the controls of soil loss in agricultural catchments using ex-situ turbidity-based suspended sediment monitoring. *Journal of Hydrology and Earth System Sciences*, 19, 3349-3363.

Sherriff, S., Franks, S., Rowan, J.S., Fenton, O. and Ó hUallacháin, D. (2015) Uncertainty-based assessment of tracer selection, tracer non-conservativeness and multiple solutions in sediment fingerprinting using synthetic and field data. *Journal of Soils and Sediment*, 15, 2101-2116.

Popular publications:

Davis, S., Ó hUallacháin, D., Piggott, J., Mellander, P.-E., Kelly-Quinn, M. (2017). Multiple stressors in Irish agricultural streams: a mesocosm study on macroinvertebrate response to nutrients and sediment. *Symposium for European Freshwater Sciences*, Olomouc, Czech Rep. July 2017.

Davis, S., Kelly-Quinn, E. Hannigan M., Shore, M., Mellander, P._E., & Ó hUallacháin, D. (2016) Seasonal variation of macroinvertebrate communities in agricultural catchments: implications for water quality assessments. *1st Ecology and Evolution Ireland Conference,* Institute of Technology, Sligo, November 2016.

Sherriff, S., Rowan, J.S., Melland, A., Jordan, P., Fenton, O. & Ó hUallacháin, D. (2016) Targeting sediment management strategies using sediment quantification and fingerprinting methods. *European Geosciences Union General Assembly 2016*, Vienna, April 2016

Sherriff, S., Rowan, J., Fenton, O., Jordan, P. & Ó hUallacháin, D. (2015) Combining sediment flux and fingerprinting to target soil erosion and sediment management strategies in agricultural catchments. *Catchment Science 2015*, Wexford, September 2015.

Sherriff, S., Rowan, J.S., Franks, S., Walden, J., Melland, A., Jordan, P., Fenton, O. and Ó hUallacháin, D. (2014) Sediment Fingerprinting, *TResearch* vol 12, pg 40-41.

6. Compiled by: Daire Ó hUallacháin

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