

FACTORS INFLUENCING THE DOWNSTREAM TRANSPORT OF SEDIMENT IN THE LOUGH FEEAGH CATCHMENT, BURRISHOOLE, CO. MAYO, IRELAND

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Introduction

A fundamental requirement of salmonid fish is an abundant supply of cool, clear and well-oxygenated water. High levels of suspended silt in streams have a negative impact on salmonids at all stages of their lifecycle. Silt deposits in spawning beds have a negative impact by reducing the flow of water, and therefore of oxygen also, around incubating eggs (Bruton 1985). The fry and adult stages are impacted by the clogging of gills and lower light penetration which affects food production and also reduces the ability of fish to forage for food (Alabaster 1972). An understanding of the factors that give rise to high silt loads in salmonid-bearing waters is therefore of fundamental importance.

Research laboratories in the Burrishoole catchment, now owned and operated by the Irish Marine Institute, have been the focus of salmonid research since 1955. The Institute also operates a salmon and sea trout hatchery as well as a smolt production unit which supports a range of research activities and a salmon ranching programme. One aspect of the research has been to monitor the number of salmon and sea trout migrating to sea as smolts and returning to the catchment as adults. In the early 1990s it became clear that the smolt output from the catchment had declined over the previous two decades (Annual Reports of the Salmon Research Agency 1975–1992). At about the same time the presence of fine particles of peat silt in the hatchery became increasingly apparent and led to a higher incidence of mortality of young fry (D. Cotter, personal communication). These observations and management difficulties led to a study of silt transport in the surface waters of the catchment, which we describe in this article. The implementation of an erosion model for the Burrishoole catchment is described elsewhere within this volume (May et al. 2005).

Burrishoole is located at 53°57'N 9°35'W in Co. Mayo, western Ireland. The upland sections of Burrishoole are part of the Nephin Beg Range and

these drain to the south through a typical glaciated landscape to Clew Bay (Fig. 1). The highest peak is Nephin Beg (627 m). The catchment of Lough Feeagh forms the greater part of the Burrishoole area and has an area of 100.3 km² (Irvine et al. 2001). Lough Feeagh itself has an area of 4.1 km². The principal sub-catchments of the Lough Feeagh catchment, which are the main focus of this article, are Glenamong (17.8 km²), Maumaratta (6.4 km²), Altahoney (10.7 km²), Gaulaun (9.4 km²) and Rough (4.5 km²) (Fig. 2). The locations of monitoring equipment used in the study are also shown in Fig. 2.

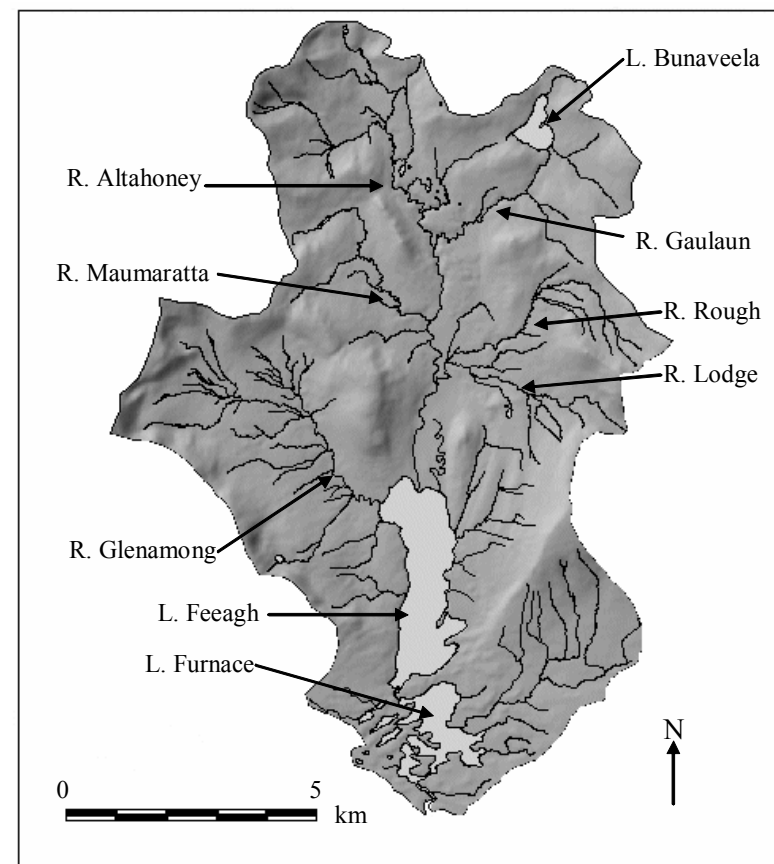


FIG. 1. The Burrishoole catchment showing relief and surface waters.

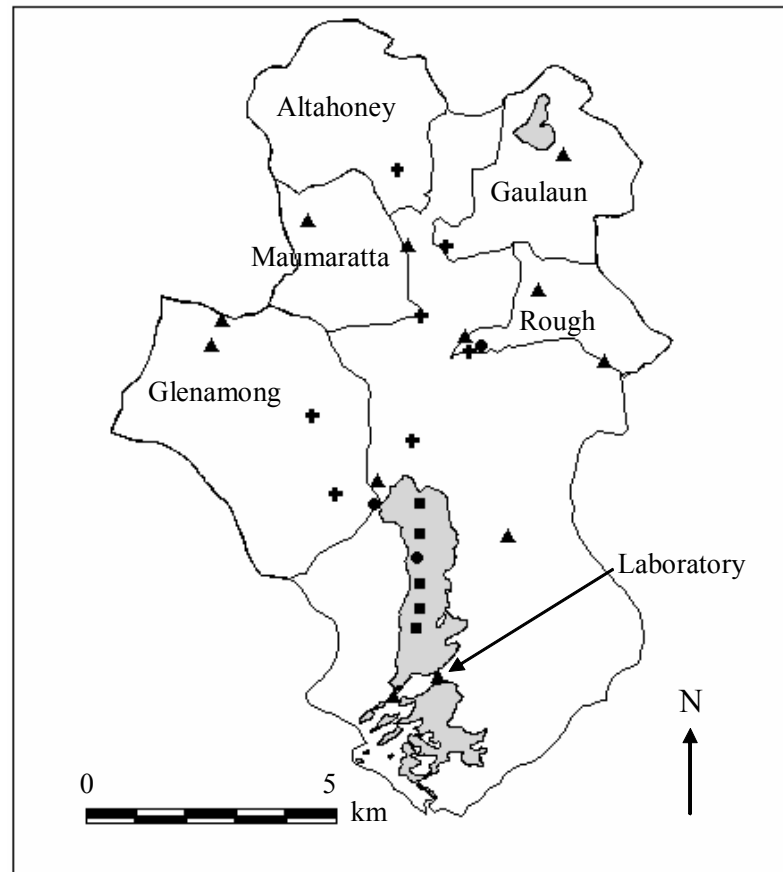


FIG. 2. Location of monitoring equipment in L. Feeagh sub-catchments. Monitoring equipment includes rain gauges (triangles), water level recorders and automatic water samplers (crosses), automatic monitoring stations (circles), and sediment traps in lake (squares).

Geology

The bedrock geology of the catchment is dominated by metamorphic rocks of the Dalradian Series which are probably of late Precambrian age (Long et al. 1992). The western sub-catchments are quartzite, as in the Maumaratta and Altahoney, or a mixture of quartzite, schist and gneiss as in Glenamong. Quartzite, schist and gneiss also predominate in the eastern sub-catchments but in addition there are dolomite bands up to 200 m wide

which run approximately north-south from midway along the east shore of L. Feeagh to the Gaulaun sub-catchment (Long et al. 1992). The presence of dolomite has a marked effect on the buffering capacity of the eastern sub-catchments.

Soils, vegetation and land-use

The main soil types are blanket peat, hill peat and peaty podsoles, though there are deposits of alluvium in the valleys of the Black River, to the north of Lough Feeagh, and Glenamong River to the north-west of Lough Feeagh (Kieley et al. 1974). Blanket peats are widespread on the lower slopes of the western side of the catchment and are characterised by vegetation with *Molinia caerulea* (purple moor grass), *Schoenus nigricans* (black bog rush) and *Scirpus caespitosus* (deergrass) (O'Sullivan 1993). This vegetation is important as a source of grazing for sheep. However, the soil is water-saturated for much of the year, especially in winter, and is therefore very prone to damage by poaching.

Extensive sheep farming is the primary land-use in the catchment. Sheep numbers increased dramatically during the 1980s from about 0.5 ha⁻¹ in 1980 to about 1.3 ha⁻¹ in 1991 (Weir 1996) as a result of EU subsidies which were paid on a headage basis. By comparing aerial photographs from the 1970s with those from the 1990s, Weir (1996) concluded that there had been a dramatic increase in the area of the catchment that was devoid of vegetation and was being actively eroded. The second most important land-use in the region is plantation coniferous forestry which covers approximately 18% of the catchment. Forestry operations at the planting stage and during harvesting are liable to produce high silt loads in surface waters. Harvesting operations on the east side of the catchment have also been a source of silt from time to time over the last decade.

Climate and weather

The average annual rainfall at Furnace (site of the laboratory of the Marine Institute in Burrishoole) was 1567 mm over the period 1970–2001. Average monthly rainfall figures (1970–2001; Fig. 3) show that the driest months at Burrishoole are April to June after which there is a gradual increase over the period July to September. The late autumn and winter (October to January) is the wettest of the year. Rainfall in February and March is intermediate between January and April but, somewhat anomalously, rainfall is lower on average in February than in March. However, the monthly rainfall figures can vary dramatically from year to year and wet weather can predominate at Burrishoole at any time of year. The most variable month in the recording period was December, which had 64.4 mm in 1995 but 367.1 mm in 1999.

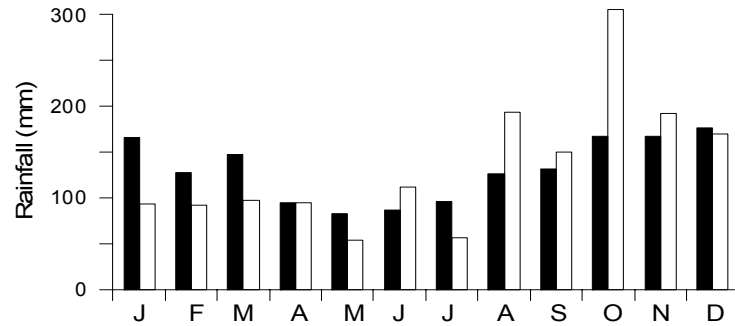


FIG. 3. Average monthly rainfall 1970–2001 (black bars) and monthly rainfall between July 2000 and June 2001 (open bars) at Furnace in the Burrishoole catchment.

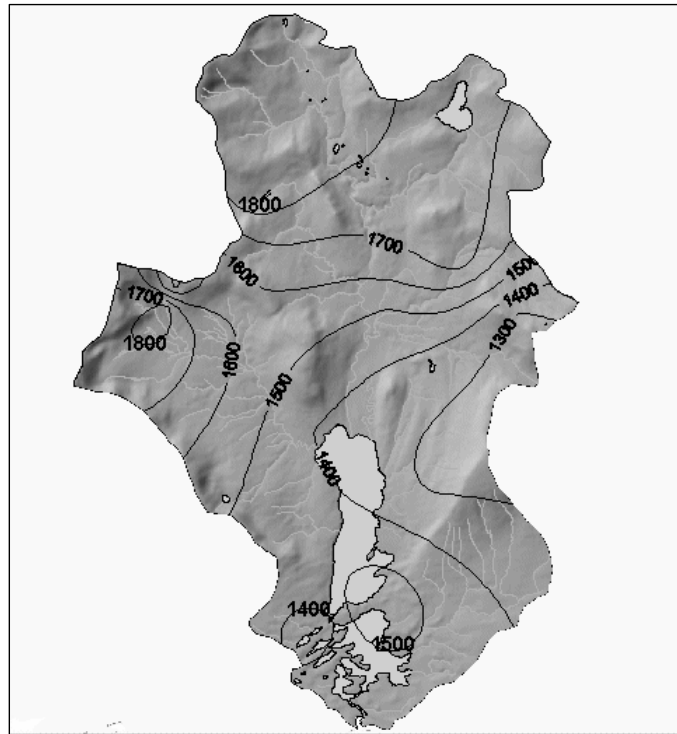


FIG. 4. Distribution of rainfall (mm) in the Burrishoole catchment, July 2000 – June 2001.

Detailed monitoring of rainfall was carried out over the period July 2000 to June 2001 at 12 sites in Burrishoole (Fig. 2). Results of this monitoring show that there was measurable precipitation (≥ 0.2 mm) at one or more of the sites on 346 days of that year while there was more than 10 mm of rain at one or more sites on 65 days. These results illustrate the high frequency of rainfall at Burrishoole. The total rainfall at the Furnace site (July 2000 to June 2001) was 1609 mm, which was close to the long term average of 1567 mm but its distribution through the year was atypical. August and October were much wetter than normal in 2001 whereas July 2000 and January to March 2001 were drier than normal (Fig. 3).

The spatial distribution of rainfall (July 2000 to June 2001) at Burrishoole (Fig. 4) shows a marked gradient from about 1800 mm in the north-west of the catchment (Glenamong and Maumaratta valleys) to less than 1300 mm in the hills on the east side of L. Feeagh. Rainfall increased again to between 1400 mm and 1600 mm towards the south-east of the catchment. It is also notable that the highest rainfall was recorded at medium altitude in both the west side (Glenamong) and east side (Buckoogh) of the catchment.

Hydrology and sediment in streams

The flow regimes of the five most important tributaries in the Burrishoole catchment, for the period March–September 2001, are shown in Fig. 5. Stream stage rather than discharge is used because the rating curves are not yet sufficiently comprehensive for all streams to allow calculation of discharge over the full range of their flow. It is clear that the flow regime in these streams is characterised by a high frequency of spate events interrupted from time to time (particularly in May 2001) by periods of base flow. The large number of spate events in both spring and summer suggests a lack of seasonality in the flow regime of these streams as has also been noted by Muller (1997). The rising limb of the flood peaks is invariably very steep in all of the streams, which strongly suggests the rapid transfer of rainfall to streams by quickflow processes. Overland flow, pipe flow and macropore flow are likely to be important. The falling limb of flood peaks is also very steep, particularly so in the Glenamong and Rough tributaries which return to base flow conditions very quickly unless a further flood follows immediately. Some flattening out towards the base of the falling limb of flood peaks is evident in the Maumaratta, Altahoney and Gaulaun tributaries which indicates greater storage capacity in these sub-catchments compared to the Glenamong or the Rough. The presence of upstream lakes and the somewhat lower relief of Maumaratta, Altahoney and Gaulaun sub-catchments are factors that would increase storage capacity. Such storage capacity is, however, very limited and all these

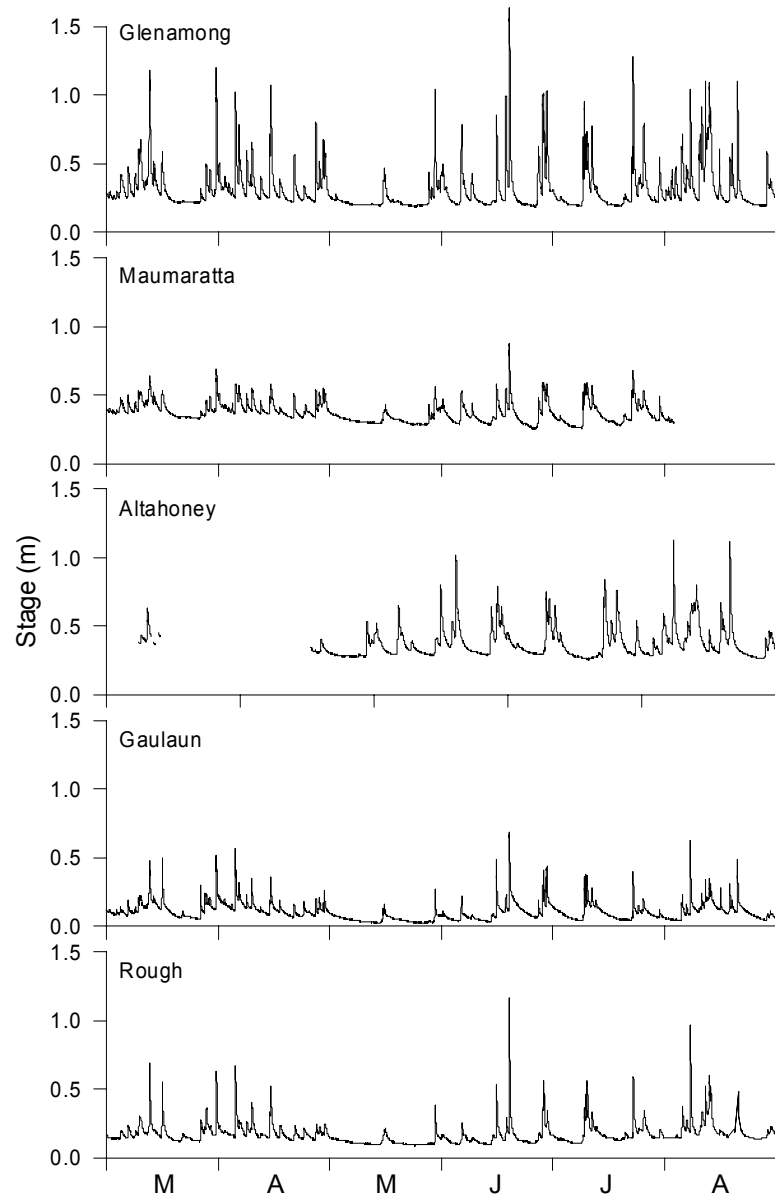


FIG. 5. Flow regimes of the five main tributaries to L. Feeagh, March 2001 – August 2001.

streams would be described in hydrological terms as 'flashy'. The principle features of the catchment that give rise such a flow regime are impermeable rock types, high relief and relatively impermeable peats and peat-podsols. Similar catchments in North Wales give rise to flow regimes like those at Burrishoole (Bird et al. 1990).

Details of three spate events in the Rough River, showing rainfall and suspended sediment concentration in addition to river stage, are displayed in Figures 6–8. River stage was recorded at 15-minute intervals. Rainfall was recorded in 0.2 mm increments, then summed over the same 15-minute intervals for which river stage was recorded and averaged across the three gauges in the sub-catchment. Suspended sediment concentration was measured with a nephelometer in samples that were taken with an automatic sampler at 8-hour intervals and converted to mg l^{-1} using a calibration curve that was developed for the Rough River.

The three spate events in Figures 6 to 8 vary from small (23 July 2001) to large (19 June 2001) and are typical of the range of spate events that occur in the Rough River. All three events arose from periods where rainfall intensity was greater than $1 \text{ mm } 15 \text{ min}^{-1}$ ($> 4 \text{ mm h}^{-1}$). Rainfall intensities less than this did not produce a discernible change in river stage.

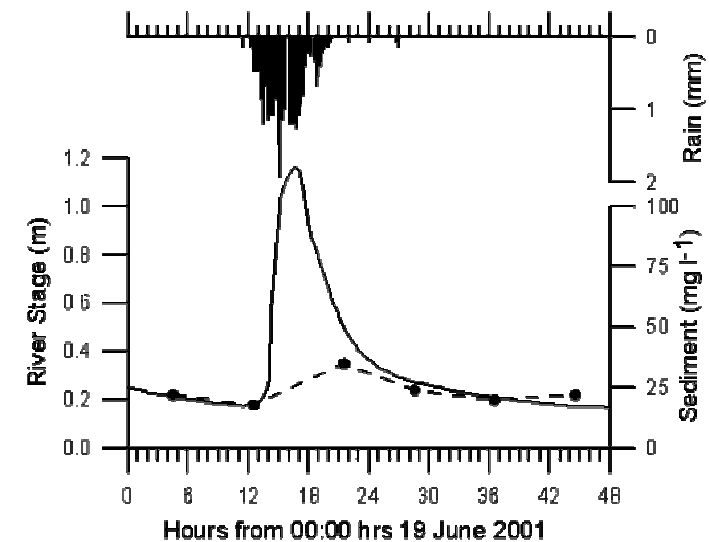


FIG. 6. Large flood event on the R. Rough (solid line), showing contemporaneous rainfall in its sub-catchment and stream sediment concentration (dotted line).

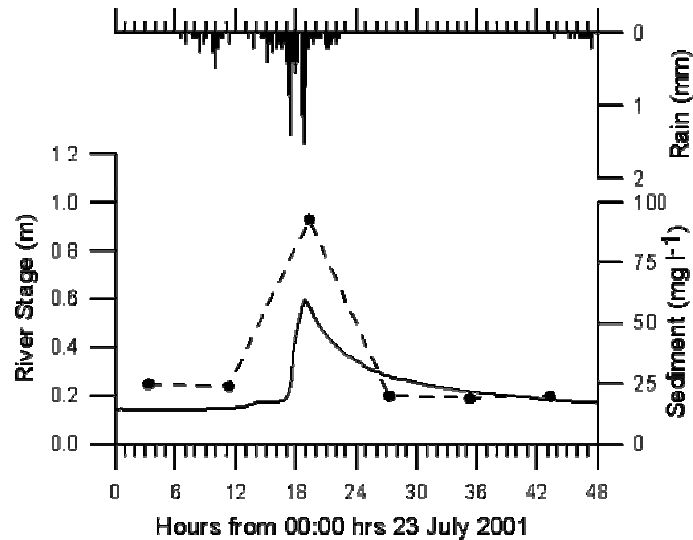


FIG. 7. Small flood event on the R. Rough, showing contemporaneous rainfall in its sub-catchment and stream sediment concentration.

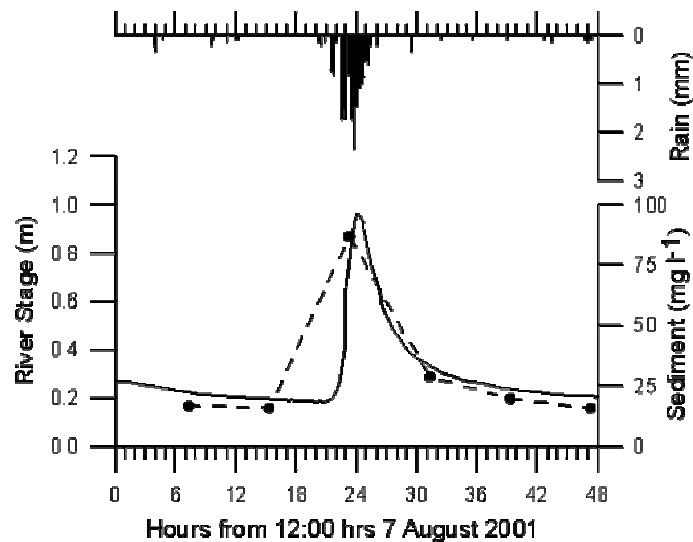


FIG. 8. Medium-sized flood event on the R. Rough, showing contemporaneous rainfall in its sub-catchment and stream sediment concentration.

It is clear from Figures 6 to 8 that the Rough River responds very rapidly to rainfall in the sub-catchment. Fig. 6 (19 June 2001) gives the clearest comparison between rainfall and river stage and indicates a lag time of about one hour. The concentration of suspended sediment also increased during the spate events but the detailed nature of the response is unclear because of the long (8 h) interval between samples. During the smallest spate (Fig. 7), when the sediment sample was taken at about the same time as the peak of the spate, the concentration of suspended sediment increased from 24 to 93 mg l^{-1} . The medium-sized spate (Fig. 8) produced a similar increase in sediment concentration (16 to 87 mg l^{-1}) but this time the sample was taken on the rising limb of the event and it is quite probable that the peak was missed. The smallest increase in sediment concentration (18 to 35 mg l^{-1}) occurred in the largest spate event (19 June 2001) but on this occasion the sample was taken well after the flood crest and almost certainly missed the peak sediment concentration.

An important point that emerges from a consideration of the sediment data presented in Figs 6 to 8 is the inadequacy of the 8-hour sampling interval for suspended sediment measurements. This underlines the importance of automatic equipment for taking high resolution measurements that is described elsewhere in this volume (Rouen et al. 2005). It should also be noted that, since sediment load is the product of sediment concentration and discharge volume, rating curves must include measurements at very high as well as very low flows. As this was not possible in the Rough sub-catchment and stage measurements had to be used instead, the true impact of the events depicted in Figs 6 to 8 cannot be assessed. However, the existing measurements indicate that the sediment load at peak flow during the small flood event was 13.4 kg min^{-1} (0.8 t h^{-1}) while the medium-sized event (7 August 2001) was at least 40 kg min^{-1} (2.7 t h^{-1}).

Sediment deposition in Lough Feeagh

Sediment from most of the L. Feeagh catchment enters the lake at the northern end through the Glenamong and Black rivers (Fig. 2). The relatively large size of L. Feeagh in relation to its catchment indicates that it would be expected to be the primary depositional zone for sediment in the catchment. Since the outflows from L. Feeagh are at the extreme southern end (about 4 km from the inflows), it is clear that all but the finest particles are likely to be deposited as sediment in the lake.

Sediment traps were installed at 10 m and 20 m depth at five locations along the length of Lough Feeagh in order to study the pattern and extent of sediment deposition. Fig. 9 shows sediment deposition ($\text{g m}^{-2} \text{ d}^{-1}$) over

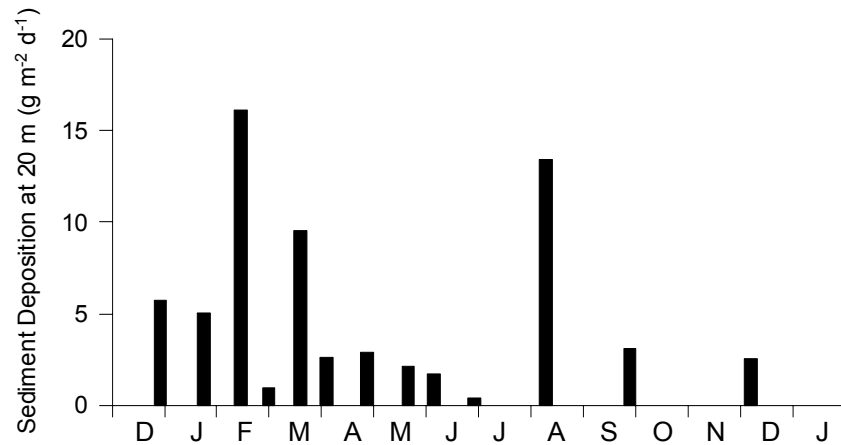


FIG. 9. Sediment deposition at 20 m depth in L. Feeagh (northern site), December 2000 – January 2002.

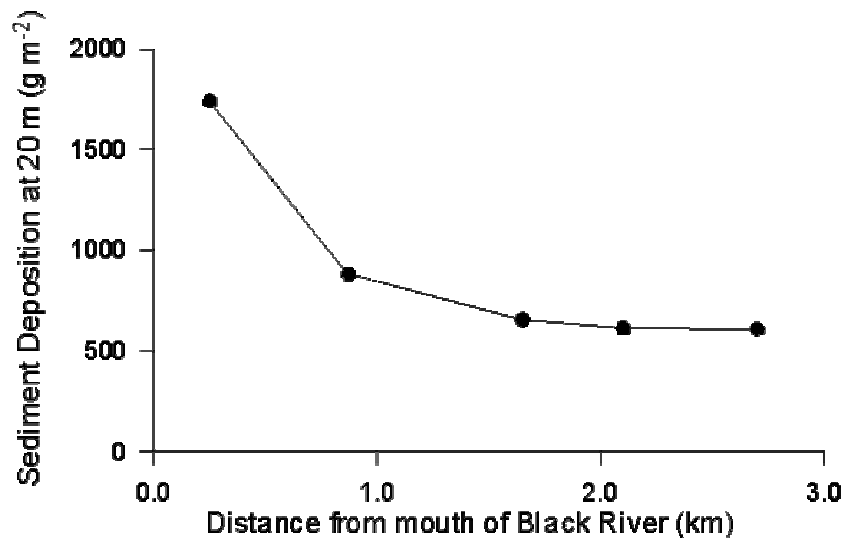


FIG. 10. Sediment deposition at 20 m depth from north to south in L. Feeagh, December 2000 – January 2002.

time (December 2000 to January 2002) at the northern-most site. The trends in sediment deposition were similar at the other sites along the transect. The highest rate of sediment deposition occurred in February 2002 ($16.1 \text{ g m}^{-2} \text{ d}^{-1}$) and the second highest was in August 2002 ($13.4 \text{ g m}^{-2} \text{ d}^{-1}$), while the lowest rate was in late June/early July ($0.4 \text{ g m}^{-2} \text{ d}^{-1}$) and the second lowest was late February/early March ($1.0 \text{ g m}^{-2} \text{ d}^{-1}$). It is clear, therefore, that there was no seasonal pattern in the deposition of sediment in Lough Feeagh but that large sediment loads are delivered to the lake following periods of intense rainfall in the catchment which, as outlined above, can occur at any time of year.

The total amount of sediment deposited at each of the locations along the lake between December 2000 and January 2002 is presented in Fig. 10. The high rate of deposition at the north end of the lake is largely due to the rapid settling of the dense mineral fraction of sediment. The rate of sediment deposition declined further along the transect of sediment traps but the rate of decline was very low between the three southern-most sites.

Conclusions

Intensive monitoring of rainfall at Burrishoole between July 2000 and June 2001 showed that there was a marked gradient from 1800 mm in the NW of the catchment to about 1300 mm in the SE of the catchment. Rainfall intensity in the R. Rough sub-catchment was up to 8 mm h^{-1} . The main feature of the streams in Burrishoole is the high frequency of short-lived spates. The lag time between peak rainfall and peak flow in streams was very short (1–2 hours) and implies a predominance of quickflow processes. These features predispose the catchment to episodes of soil erosion.

Episodes of soil erosion were detected in streams but the sampling interval of eight hours was insufficient to fully characterise the episodes. Deposition of sediment in L. Feeagh (December 2000 to January 2002) varied from 1741 g m^{-2} at the north end of the lake (close to the main inflows) to 610 g m^{-2} at south end of the lake.

Acknowledgements

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