Regional variations of fluvial sediment yield in eastern Scotland

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Abstract Analysis of the first nine years of data (1975-1983) from the Harmonized Monitoring Programme of river water quality, for the 33 gauged rivers of eastern Scotland, has enabled the recognition of six related catchment groupings on the basis of sediment yield. In each group there is an increase in yield with catchment area. The regional variations indicate that soil losses are least in the Southern Uplands and are marginally greater in the catchments of the Moray Firth area and the northeast Grampian Highlands. Substantially greater yields occur in the Forth basin and the Tay basin-central Grampian Highlands area. There appear to be two major catchment associations, related to mean annual precipitation, one with low rates of sediment yield (4-20 t km^{-2} $year^{-1}$) and the other with rates five to seven times greater (20-200 t km^{-2} $year^{-1}$) for comparable catchment areas. The analyses indicate sediment yields within the ranges of values derived from short term, intensive sampling investigations on nine of the rivers, which lends some credence to the dataset.

INTRODUCTION

Sediment yield from a catchment may be evaluated by means of three quite separate approaches. These involve the measurement of how much material has gone from a particular location, how much has been deposited elsewhere, or the determination of the quantity of debris in transit between source and sink. The latter method forms the subject of this regional overview of regional variations of fluvial sediment yield in catchments of eastern Scotland.

Estimation of fluvial sediment transport may be attempted by direct or indirect methods. In practice, the direct measurement of sediment loads in rivers is fraught with pitfalls, and estimates are seldom thought to be better than +/-25% of the actual total load (Ferguson, 1987). The indirect methods are notoriously difficult to apply, and results within one order of magnitude of directly estimated loads are normally accepted as being of good quality (Walling, 1978; Walling & Webb, 1981).

Direct estimation of sediment transport in rivers acknowledges that the suspended sediment, which often accounts for 90-95% of the particulate load, increases with water discharge. Thus, during low flows little material moves downstream, whereas in floods very heavy charges of suspended material may be carried. Most studies of fluvial sediment transport in Scotland have been relatively short-term exercises, typically spread over periods of three to a maximum of five years (e.g. Kirkby, 1967; Fleming 1970; Al-Ansari & McManus, 1979; Al-Jabbari *et al.*, 1980; Al-Bayati & McManus, 1984; Asaad & McManus, 1986). However, one major project, the Harmonized Monitoring Programme of river water quality has continued over a longer period of time. Instead of frequent determination of suspended sediment concentrations to permit the establishment of rating curves, this programme has involved sampling at monthly intervals, or less frequently, but from all the gauged rivers in Great Britain.

The database for Scotland, held by the Scottish Development Department, permits direct comparison of analogous information levels throughout the country. From a knowledge of the long term flow duration curves for the rivers, monitored in most cases by the relevant River Purification Board, and using rating curves constructed albeit with sparse information, it is possible to provide directly comparable estimates of annual fluvial sediment transport. In this way the relative rates of sediment yield in different parts of the country, averaged over entire drainage basins, may be assessed and compared.

RESULTS

The first nine years of data from the Harmonized Monitoring Programme (1975-1983), for rivers of eastern Scotland have been analysed and the results are presented in Table 1. Also tabulated for comparison are the ranges of sediment yield derived on the basis of 3-5 year studies of nine rivers in the Forth-Tay catchments of east-central Scotland. The latter ranges are broad and relate to the total annual river discharge in specific years, rather than averages over a nine year period as provided by the long term flow duration curves used for load estimation from the Harmonized Monitoring Programme data.

Although much criticism has been levelled at the use of rating curve-based estimates of sediment transport, the application here is for the purposes of intercomparability of catchment behaviour. The values in Table 1 are therefore presented to identify *relative* levels of suspended sediment discharge, rather than the absolute loads carried by the rivers during the period concerned. Some of the computed data have already been presented for rivers of the Forth and Tay basins (McManus, 1986) but the analysis has now been broadened to extend from the River Shin in the north to the River Tweed, some 300 km distant, in the south. The catchments examined thus exhibit considerable contrasts of physiography, climatic conditions and land use.

When the estimates of total solids yield per unit area (t km^{-2} $year^{-1}$) are plotted against catchment area (Fig. 1) a wide spread of points results. However, the yields from adjacent or analogous catchments form discrete groupings which are apparently distributed along regular linear paths on log-log plots. By this means, six related catchment groupings are recognized (Fig. 1):

1. **Southern Uplands**: The catchments of the Rivers Tweed and Whiteadder are dominated by grazing country, moorland and forestry mainly on sedimentary rocks of mixed type.
2. **Forth basin**: The Rivers Almond, Esk, Tyne, Allan Water, Carron, Water of Leith and the Ardoch Burn are tributaries largely in agricultural areas with admixtures of

Table 1 Sediment yields of river catchments of eastern Scotland listed geographically from north to south.

River	Catchment area (km^2)	Sediment yield ($t\ km^{-2}\ year^{-1}$) 1975-1983 data	Sediment yield ($t\ km^{-2}\ year^{-1}$) 3-5 year studies
Shin	575	9.06	
Conon	962	6.30	
Ness	1839	11.97	
Nairn	313	31.05	
Findhorn	782	48.37	
Lossie	216	4.44	
Spey	2861	11.83	
Deveron	955	10.87	
Ugie	325	8.90	
Ythan	448	9.64	
Don	1273	18.40	
Dee	1844	17.83	
North Esk	732	88.50	
South Esk	575	14.26	
Dighty Water	503	4.16	
Isla	367	66.0	39.3-106.9
Tay	3212	100	43.1-201.7
Almond (Tay basin)	175	34	17.3- 64.9
Earn	782	78	67.3-128.8
Eden	307	88	23.8-315.6
Leven	800	37	
Allan Water	161	14.5	10.6- 19.7
Ardoch Burn	48	14.0	11.0- 18.3
Teith	518	10.5	8.9- 12.3
Forth	397	210	163.8-296.1
Carron	122	26.8	
Avon	145	47.14	
Almond (Forth basin)	369	25.45	
Water of Leith	107	14.53	
Esk (Forth basin)	330	23.61	
North Tyne	307	19.39	
Whiteadder	503	5.51	
Tweed	4390	14.62	

urbanization and local uplands of low relief. All have catchments largely based on sedimentary rocks. Exceptions to the trend are the River Forth, which carries an exceptionally high sediment load from its agricultural catchment, and the River Teith, which derives its waters from the Grampian Highlands.

3. **Tay basin and Central Grampian Highlands**: The Rivers Tay, Isla, Almond and Earn have catchments which straddle the Highland Boundary Fault so that their headwaters are in highland moors, whereas their lower reaches and valley floors are intensively cultivated. The River Eden in northeast Fife, with a similar mixture of upland and agricultural land use conforms to the same pattern, as does the River North Esk, draining the Howe of the Mearns.
4. **Northeast Grampian Highlands**: The Rivers Dee, Don, Ugie and Ythan drain largely metamorphic and igneous rocks in highland terrain supporting principally moorland and pastures. The River South Esk, whose catchment is highland-dominated, also falls into this grouping.

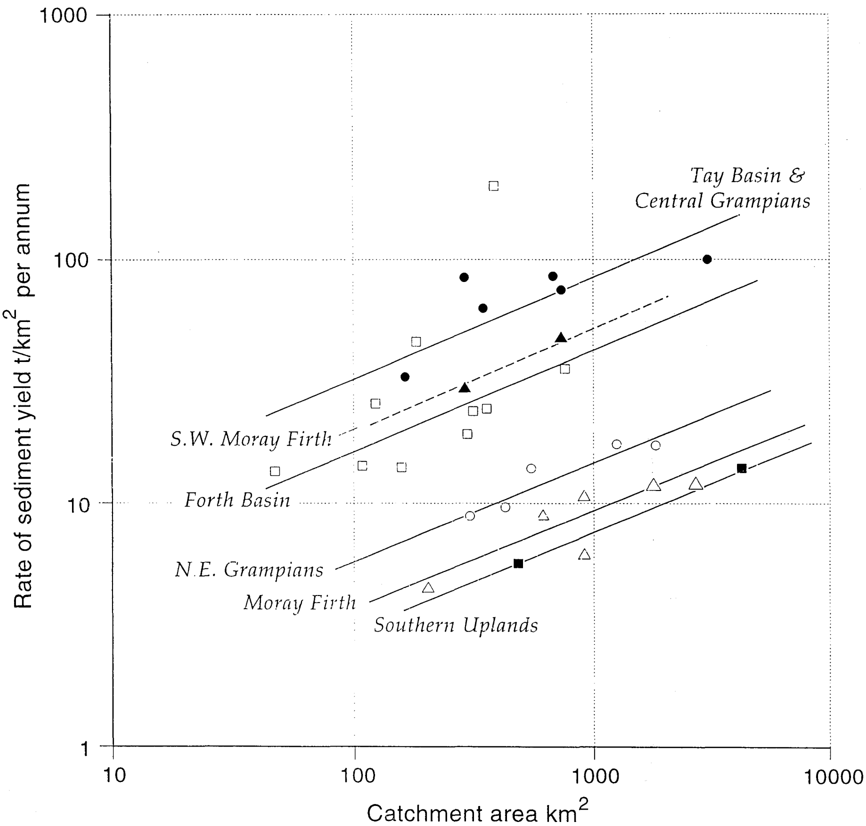

Fig. 1 The sediment yields of river catchments in eastern Scotland plotted against catchment area. Trend lines link associated river groups; see text for details. (1) Southern Uplands – solid squares, (2) Forth basin – open squares, (3) Tay basin and Central Grampian Highlands – solid circles, (4) Northeast Grampian Highlands – open circles, (5) Moray Firth (excluding the Southwest Moray Firth) – open triangles, (6) Southwest Moray Firth (solid triangles).

5. **Moray Firth (excluding the Southwest Moray Firth)**: The Rivers Lossie, Deveron, Shin, Conon, Spey and Ness, which largely drain highland moors on metamorphic rocks, form a plot which is closely related to that of the rivers of the northeast Grampian Highlands.
6. **Southwest Moray Firth**: The Nairn and Findhorn form a separate grouping of rivers with high sediment yields. Although farming and forestry are important in the catchments, it is by no means clear why these two rivers stand apart from their neighbours in terms of high sediment yields.

DISCUSSION

In all cases, the trend lines of Fig. 1 indicate an increase of sediment yield with increasing catchment area. A similar trend was observed for sediment yields derived on the basis of reservoir surveys in the Midland Valley of Scotland (Duck & McManus, 1987). It is suggested that the reason for sediment yields being higher for large catchments than they are for small ones is due to the larger number of First Order streams developed in the drainage networks of the former, thus exposing greater lengths of stream banks and channels to fluvial erosion.

The regional variations (Table 1 and Fig. 1) suggest that sediment yields and soil erosion rates are least in the Southern Uplands and are marginally greater in the Moray Firth and northeast Grampian Highlands catchments. However, substantially greater yields occur in the catchments of the Forth basin, the Tay basin and central Grampian Highlands and the southwest Moray Firth streams, all of which are underlain by substantial areas of sedimentary rocks, often with a thick cover of glacial drift.

It may be an artefact of summarizing the data, but there appear to be two major catchment associations, one with low rates of sediment yield (4-20 t km^{-2} $year^{-1}$) and the other with rates five to seven times greater (20-200 t km^{-2} $year^{-1}$) for comparable catchment areas. A detailed appraisal of the grouping has not been undertaken but it would appear to be directly related to the mean annual precipitation. Reference to Table 1 shows that the analyses derived from the Harmonized Monitoring Programme indicate sediment yields which lie within the ranges of values derived from short term (3-5 year studies) intensive sampling investigations of nine of the featured rivers. This lends some credence to the newly presented dataset.

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