NRA South West 188

ENVIRONMENTAL PROTECTION

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National Rivers Authority
South West Region

IMPACT ASSESSMENT OF MELDON QUARRY ON WATER QUALITY IN THE WEST OKEMENT RIVER

March 1991

FWI/91/002

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EXETER

This work has been produced as the result of co-operative effort between the Freshwater Investigation Team and the Hydrometrics Section of the National Rivers Authority South West Region.

SUMMARY.

A study was carried out between July & October 1990 to assess the impact of Meldon Quarry on water quality in the West Okement River. The study is part of an overall project to identify and control intermittent acidic and metalliferous discharges in the River Okement catchment. Acidic pollution events are of particular concern because they can lead to a significant loss of salmon and trout from the River Torridge catchment.

Surveys carried out during rainfall demonstrate that Meldon Quarry has a significant impact on water quality in the West Okement catchment. River pH and metal concentrations exceeded relevant Environmental Quality Standards in the West Okement River.

During a detailed survey in July 1990, flow in the West Okement River was low and upstream of the Red-a-Ven Brook confluence was restricted to the compensation flow from Meldon Reservoir. During a second detailed survey in October flows were higher as a result of Meldon Reservoir over-topping the dam allowing greater dilution for the discharges from Meldon Quarry.

Poor quality drainage from Meldon Quarry is comparable to acid mine drainage. Although natural acidic and metalliferous drainage occurs within the catchment as a result of normal weathering of mineral sulphides, quarrying activities have "greatly" enhanced the acidification process by exposing mineral sulphides to air. Where mineral sulphides have been exposed by quarrying, acid mine drainage is likely to continue even if further quarrying is discontinued.

The study has identified further acid and metalliferous problems within the catchment. These require investigation to identify the causes of poor water quality.

It is recommended that discharges from Meldon Quarry are controlled by consent to ensure water quality objectives and standards in receiving water courses are met and identified water uses are protected.

Aerial photograph of Meldon Quarry

1. West Okement River.
2. Reservoir Stream.
3. Meldon Quarry Stream.
4. Wigney Stream.
5. Railway Stream

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IMPACT ASSESSMENT OF MELDON QUARRY ON WATER QUALITY IN THE WEST OKEMENT RIVER

1. INTRODUCTION.

The West Okement River is a tributary of the River Okement in the River Torridge catchment (see Fig. 1). It is known to suffer from occasional acid and metalliferous pollution particularly during heavy rainfall after droughts.

Acidic polluting events in 1976, 1978, 1984 & 1989 resulted in fish mortalities. Fishery surveys have estimated that 100,000 salmon and trout were lost during the 1989 event (Ref. 1). This represented 50% of the salmonid fish stock of the River Torridge. The continuing fish mortalities are of major concern because of the substantial effort that is being undertaken to rehabilitate the fishery. The Okement catchment is regarded as a important area for salmon recruitment in the River Torridge catchment.

Water quality data associated with these fish mortalities have been inadequate to determine the source of pollution. This is due to the sporadic and sudden nature of the acidic events. A water quality survey undertaken during a heavy rainfall in October 1989, which produced similar conditions to that of the fish kill which had occurred shortly before, provided an indication that discharges from Meldon Quarry were a significant contributor to poor water quality (Ref. 2).

Data from the routine river water quality monitoring programme provide further indication that discharges from Meldon Quarry have an impact on the West Okement River. In the West Okement River downstream of Meldon Quarry there has been non-compliance with quality standards for pH and certain metals. The precise cause of non-compliance can not be identified because there were a number of inputs that were not monitored.

This study sets out to determine the impact of discharges from Meldon Quarry on water quality in the West Okement River and investigates the causes of non-compliance with water quality standards.

The study is part of an overall project to identify and control acidic and metalliferous pollution in the River Okement Catchment. Other work includes a pollution control exercise in the Brightley Stream (Ref. 3)

2. THE STUDY AREA.

2.1. River Quality Objectives.

The West Okement River is a moorland watercourse that rises on Dartmoor and has a River Quality Objective (RQO) of National Water Council (NWC) Class 1A.

Tributaries in the West Okement catchment that have been assigned RQO's include the Red-a-Ven Brook (RQO = Class 1A) and the Meldon Quarry Stream (RQO = Class 3).

2.2. River Uses.

The NRA SW have adopted the following use related Environmental Quality Objectives (EQO) for the West Okement River and Red-a-Ven Brook.

* Protection of Aesthetic Quality
* Abstraction for Potable Supply
* Protection of Salmonid Fish
* Protection of Other Aquatic Life
* Protection for Livestock Watering
* Protection for Irrigation of Crops

2.3. Routine Monitoring.

Water quality is routinely monitored at 6 sites in the West Okement catchment. Physical details and recent classifications using the NWC water quality classification system are given in Table 1.

TABLE 1. Routine monitoring in the West Okement catchment.

Location	NGR	Length from source	Flow (cumecs) ADF	Q95	Annual Classification 1985	86	87	88	89
West Okement River									
A. D/S Meldon Dam	SX 564919	10.7km	0.895	0.151	-	3	2	2	2
B. Meldon Viaduct	SX 565924	11.2km	1.176	0.193	-	-	1A	1A	1A
C. Meldon Quarry Bridge	SX 568935	12.5km	1.241	0.196	-	1A	1A	1A	2
D. Okehampton Hospital	SX 586947	15.0km	1.562	0.123	1A	1A	1A	1A	1A
E. Red-a-Ven Brook	SX 565919	4.3km	0.220	0.019	-	3	2	2	2
F. Meldon Quarry Stream	SX 566930	0.5km	-	-	-	-	-	3	3

N.B. Annual classification is based on three years of data.

The NRA SW have adopted EIFAC criteria for pH, copper and zinc concentrations recommended in the NWC annual classification system (Ref. 4). Total copper concentrations exceed the standard (=5 ug/l) at two sites upstream of Meldon Quarry (Below Meldon Dam and the Red-a-Ven Brook). Downstream of Meldon Quarry standards for total copper (=22 mg/l) and total zinc (=200 ug/l) were exceeded.

The West Okement River has been designated a salmonid river between its source and its confluence with the East Okement River under the EC Freshwater Fish Directive (Ref. 5). pH, aluminium and copper concentrations exceed Environmental Quality Standards (EQS's) specified in the directive both upstream and downstream of the Meldon Quarry (see Table 2). However, water quality is poorer at sites downstream of Meldon Quarry. The standard for zinc is exceeded only at sites downstream of Meldon Quarry. Iron, nickel and cadmium concentrations are within the EQS's at all sites.

Metal standards relating to the EC Freshwater Fish Directive are not applicable to the Red-a-Ven Brook because this watercourse is not designated. However, standards apply in principle because the river supports fish life. Copper concentrations in the Red-a-Ven Brook marginally exceed the copper standard. These Directive metal standards are not applicable to the Meldon Quarry Stream because it does not support fish life and has not been designated.

Metal standards (except iron) specified in the EC Freshwater Fish Directive are stringent enough to protect other uses designated for West Okement River. The iron standard specified in the EC Dangerous Substances Directive has been adopted for the protection for the irrigation of crops (see Ref. 6).

At the break of an extreme drought in 1989 water quality significantly deteriorated in the West Okement River particularly at sites downstream of Meldon Quarry (see Table 3).

3. MELDON QUARRY.

Meldon Quarry is situated on the northern edge of Dartmoor near Okehampton and is worked by Meldon Quarry Ltd. The quarry is approximately 1 km square and spans a succession of Lower Carboniferous rocks including cherts, shales and slates. The granite intrusion that formed Dartmoor, has folded and metamorphosed deposits into calc-silicate hornfelses. Mineral sulphides are common within the rocks and include pyrite (FeS_2), chalcopyrite ($CuFeS_2$) and sphalerite (ZnS).

Hornfelses are quarried at Meldon Quarry primarily for use as ballast along railway lines.

3.1. Drainage of Meldon Quarry.

Meldon Quarry has cut into the catchment of the Wigney Stream which is a minor tributary of the West Okement River (see Fig. 1).

Flow in the Wigney Stream is minimal during the summer because groundwater that would normally feed this stream has been intercepted and now drains from the quarry face into the Meldon Quarry Stream.

During 1990 the Meldon Quarry Stream was diverted into the Locomotive Reservoir as part of an interim treatment measure adopted by the quarry management to control the quality of drainage from the quarry. Lime was added to increase pH and precipitate metals. The discharge was then piped to the Wigney Stream and to the Railway Stream. Under very high flows some of the flow overspilled the system into the original course of the Meldon Quarry Stream which then flowed directly to the West Okement

TABLE 2. Water quality in the West Okement River (1983-1989) in relation to different standards.

	Below Meldon Dam	Meldon Viaduct	Meldon Quarry Bridge	Okehampton Hospital	Red-a-Ven Brook	EC Directive (<50mg/l CaCO3)
pH	5.1	5.6	5.5	5.9	5.4	6.0 (5%-ile)+
Diss. copper (ug/l Cu)	6	<5	17	8	6	5 (95%-ile)+
Tot. zinc (ug/l Zn)	23	39	211	124	24	30 (95%-ile)+
Tot. iron (ug/l Fe)	355	285	600	299	61	1,000 (annual mean)•
Tot. cadmium (ug/l Cd)	<0.7	<0.7	0.8	0.7	0.7	5 (annual mean)+
Diss. aluminium (ug/l Al)	202	272	439	350	213	100 (95%-ile)*
Diss. nickel (ug/l Ni)	6	8	44	33	0.6	50 (annual mean)+

TABLE 3. Water quality in the West Okement River on 18 September 1989 in relation to different standards.

	Below Meldon Dam	Meldon Viaduct	Meldon Quarry Bridge	Okehampton Hospital	Red-a-Ven Brook	EC Directive (<50mg/l CaCO3)
pH	6.8	-	5.0	5.0	5.8	6.0 (5%-ile)+
Diss. copper (ug/l Cu)	<5	-	45	48	<5	5 (95%-ile)+
Tot. zinc (ug/l Zn)	9	-	310	358	12	30 (95%-ile)+
Tot. iron (ug/l Fe)	1,050	-	1,050	580	70	1,000 (annual mean)•
Tot. cadmium (ug/l Cd)	<0.7	-	<0.7	2	<0.7	5 (annual mean)+
Diss. aluminium (ug/l Al)	20	-	970	1,090	160	100 (95%-ile)*
Diss. nickel (ug/l Ni)	<5	-	161	223	<5	50 (annual mean)+

+Standards from the EC Freshwater Fish Directive (Ref. 5).
•Standards from the EC Dangerous Substances Directive (Ref. 6).
*Tentative EQS adopted by NRA SW.
Diss. = Dissolved.
Tot. = Total.

River.

The Reservoir Stream is culverted under spoil heaps and drains to the West Okement River downstream of the confluence with the Red-a-Ven Brook.

A drainage adit has been tunnelled beneath Meldon Quarry to drain surface water directly to the West Okement River. During 1990 the entrance to the drainage adit was blocked as an interim pollution control measure.

3.2. Quality of the Meldon Quarry Stream.

Typically water quality of the Meldon Quarry Stream is poor with very high metal concentrations and low pH (see Table 4).

TABLE 4. Water quality of the Meldon Quarry Stream.

Determinand	Concentration (Mean, 1985-1989)
pH	4.3
Dissolved copper (ug/l Cu)	250
Total zinc (ug/l Zn)	2,540
Total cadmium (ug/l Cd)	15
Dissolved aluminium (ug/l Al)	12,200
Dissolved nickel (ug/l Ni)	1,540
Total iron (ug/l Fe)	8,500

4. METHODS.

4.1. Water quality monitoring.

Detailed water quality surveys were carried out during high rainfall events on 4-5 July 1990 and 28-29 October 1990.

Continuous pH monitoring.

pH was monitored at 30 minute intervals in the West Okement River upstream and downstream of the discharges from Meldon Quarry using pHOX 100 DPM monitors. Monitoring was carried out over two survey periods (4-22 July 1990 and 18 September - 19 November 1990).

Validation of monitors was carried out during the second period using a WTW pH meter and monitors were recalibrated where necessary. pH data collected during the first period was not validated.

Continuous automatic sampling (4-5 July 1990).

Hourly water samples were collected by automatic water quality samplers from the West Okement River upstream and downstream of the discharges from Meldon Quarry, and downstream of the confluence with the Meldon Quarry Stream. Samples were analysed for total and dissolved metals. Dissolved metal samples were not filtered immediately on-site but later in the laboratory. This delay might result in a difference between the actual dissolved concentrations of metals in the river water at the time of sampling.

Continuous manual sampling (28-29 October 1990).

During the survey on 28-29 October water samples were collected manually every three hours upstream and downstream of Meldon Quarry. Samples were collected manually so they could be immediately filtered on site to improve accuracy (see above).

Spot sampling.

A series of spot samples were collected during both surveys at 30 sites in the vicinity of Meldon Quarry (see Fig. 1). During the survey on 4-5 July 1990 samples were taken at sites where autosamplers were located in order to validate samples obtained by this method.

4.2. Sediment sampling.

During summer 1990 it was noticed that fine sediment had deposited on the bed of the West Okement River downstream of the drainage adit. Samples of this sediment were collected on 9 August 1990 from different sites along the river between Meldon Reservoir and Okehampton and analysed for metal content.

4.3. Flow gauging.

A stage logger was installed in the West Okement River upstream of the discharges from Meldon Quarry during August 1990. The site was rated so that flow could be calculated from the continuous stage height data.

5. RESULTS.

5.1. Rainfall & flow gauging.

Rainfall recorded at Okehampton Pleasure Gardens during the first survey ranged from 8.1mm on 3 July 1990 to 11.9mm on 4 July 1990 (see Fig. 2). Although this rainfall event was not particularly notable during the summer of 1990, it produced a surge of drainage water from Meldon Quarry.

It was not considered necessary in the early stages of the investigation to record flow in the West Okement River during the survey on 4-5 July. However, flows at this time are likely to have been similar to flows recorded during August 1990 when Meldon Dam was not over-topping (= 0.1 to 0.4 cumecs - see Fig. 3). Rainfall during July 1990 and August 1990 was similar (see Fig. 2).

During the end of October 1990 rainfall was more continuous reaching a maximum of 20.5mm on 25 October 1990. Flow in the West Okement River on 28 October peaked at 5.6 cumecs (see Fig. 3).

5.2. Water quality: Survey 1 (4-5 July 1990).

pH monitoring.

Following rainfall on 4 July, pH in the West Okement River upstream of Meldon Quarry became more acidic, changing from pH 6.2 to pH 5.5 and exceeded the lower limit of the EQS (see Fig. 4). The river's acidity decreased as flows receded and a maximum of pH 6.7 was recorded. There was a marked diurnal pH variation during low flows with pH exceeding the lower limit of the EQS during the evening.

pH monitored downstream of Meldon Quarry appeared to be incorrect (see Fig. 4). The data was too consistent and did not conform to expected diurnal variations (except 18-23 July 1990). Consequently the pH data was not used.

Automatic water quality sampling (Autosampling).

All metal concentrations (except aluminium) were higher downstream of Meldon Quarry and the Meldon Quarry Stream compared to those found upstream (see Fig. 5).

Concentrations of zinc, nickel and copper downstream of Meldon Quarry exceeded the relevant EQS's. Metal concentrations upstream of Meldon Quarry were within the relevant EQS's.

Spot sampling in the tributaries of the West Okement River.

Water quality in the Railway Stream deteriorated significantly downstream of the discharge from Locomotive Reservoir at Meldon Quarry (see Appendix I).

The impact of the discharge from the Locomotive Reservoir on water quality in the Wigney Stream could not be assessed because water quality was already impacted upstream (see Appendix I). At the time of sampling it was noticed that run-off from spoil heaps was entering the Wigney Stream upstream of the discharge from the Locomotive Reservoir. This probably accounted for the poor water quality in the Wigney Stream. Water quality in the Wigney Stream upstream of the influence of Meldon Quarry was poor but not to the same degree as that further downstream of the spoil heaps. The woodland marsh within the Wigney Stream system improved water quality in the stream prior to its discharge into the West Okement River (see Appendix I).

Water quality in the Reservoir Stream deteriorated significantly downstream of the spoil heaps at Meldon Quarry (see Appendix I).

Metal concentrations were particularly high in the Meldon Quarry Stream (see Appendix I).

Tributaries that were not impacted by discharges from Meldon Quarry (the Red-a-Ven Brook, Golf-course Stream and East Okement River) had good water quality (see Appendix I). The Fowley Stream and Youlditch Brook were exceptions.

Water quality in the Fowley Stream was acidic (pH 4.4) and metal concentrations were high. Iron and aluminium concentrations were similar in magnitude to concentrations found downstream of discharges from Meldon Quarry in the Wigney and Railway Streams.

Although the Youlditch Brook had a high zinc concentration (≈52 ug/l), it was much lower than zinc concentrations found in streams affected by Meldon Quarry.

Spot sampling in the West Okement River.

At the time of sampling pH values did not change significantly at sites along the West Okement River (see Appendix I) during 4 July 1990 and did not fall below the lower EQS limit.

Metal concentrations (except aluminium and cadmium) in the West Okement River exceeded the relevant EQS's downstream of the Meldon Quarry Stream and downstream of the confluence of the Wigney/Railway Streams (see Fig. 6).

Aluminium concentrations exceeded the tentative EQS adopted by NRA SW in the West Okement River above Meldon Reservoir. Downstream of Meldon Reservoir aluminium concentrations remained below the EQS.

The discharge from the drainage adit only increased iron concentrations in the West Okement River to levels above the EQS.

Iron concentrations in the West Okement River exceeded the EQS downstream of the Fowley Stream. The cause of this increase was almost certainly due to the poor water quality found in the Fowley Stream (see above). Poor water quality in the Fowley Stream did not increase nickel, copper, aluminium or cadmium concentrations in the West Okement River above their relevant EQS's. The effect of the Fowley Stream on zinc concentrations in the West Okement River is unknown because the water quality in the West Okement River was already impacted upstream. Further investigation is needed to assess the cause of poor water quality in the Fowley Stream and its impact on water quality in the West Okement River.

5.3. Water quality: Survey 2 (28-29 October 1990).

pH monitoring.

During rainfall at the end of October 1990, the automatic water quality monitor recorded a pH change from pH 6.7 to pH 5.9 upstream of Meldon Quarry (see Fig. 7). pH values downstream of Meldon Quarry did not change but remained around pH 6.5.

High pH peaks (up to pH 9.3) occurred in the West Okement River downstream of the discharges from Meldon Quarry. These exceeded the upper EQS (=pH 9.0) during October and November. Similar peaks did not occur upstream of the discharges from Meldon Quarry.

Continuous sampling.

Metal concentrations in the West Okement River were much lower downstream of discharges from Meldon Quarry during the survey on 28-29 October 1990 compared to the survey on 4-5 July 1990 (see Fig. 8 compared to Fig. 5).

Samples collected in the West Okement River downstream of discharges from Meldon Quarry were higher in metal concentrations than those upstream by an insignificant amount.

Concentrations of metals in the West Okement River were within the relevant EQS's both upstream and downstream of the discharges from Meldon Quarry on most occasions (except aluminium).

Spot sampling.

Water quality during 28-29 October 1990 was poorer in streams affected by discharges from Meldon Quarry compared with the survey on 4 July 1990 (cf. Appendix II and III with Appendix I). However, the impact of inputs on the West Okement River during 28-29 October 1990 was not as great.

Metal concentrations (except iron and cadmium) in the West Okement River marginally exceeded the relevant EQS's downstream of the discharges from Meldon Quarry.

5.4. Sediment survey.

A significant increase in iron concentration was found in river sediments collected from the West Okement River downstream of the drainage adit from Meldon Quarry compared with the upstream control site (see Fig. 9). Copper concentrations were higher in river sediments in the West Okement River downstream of the Meldon Quarry Stream compared with the upstream control site.

There was no identified increase in concentration of other metals in river sediments in the West Okement River downstream of discharges from Meldon Quarry.

6. DISCUSSION.

This study has demonstrated that Meldon Quarry has a significant impact on water quality in the catchment of West Okement River.

Adequate dilution of the discharges from Meldon Quarry by the West Okement River is a key factor determining the degree of pollution occurring in the West Okement River.

Flow from Meldon Reservoir largely controls the amount of dilution available. Flow in the West Okement River during the survey on 28-29 October 1990 was much greater than the July survey mainly because the flow from Meldon Reservoir after the drought was not restricted to the compensation flow (see Fig. 3).

6.1. Cause of poor quality drainage from Meldon Quarry.

The Meldon Quarry Stream has very poor water quality and is comparable to acid mine drainage often associated with underground metalliferous mines in Devon and Cornwall.

The Meldon Quarry Stream is known to originate from groundwater that seeps from the quarry face. It is likely that this groundwater is acidic and metalliferous due to oxidation of mineral sulphides present within the geological deposits. Thiobacillus soil bacteria are responsible for catalysing and augmenting the acidification process.

Natural acidic drainage probably occurs from soils within the catchment of the quarry as a result of normal oxidation and weathering of mineral sulphides. Indeed the Wigney Stream upstream of discharges from Meldon Quarry had relatively high concentrations of zinc, iron and copper (see Appendix I and II).

Quarrying activities have increased metal concentrations substantially in drainage waters from Meldon Quarry. This is probably because large working areas where mineral sulphides occur, become exposed to air when blasting creates fractures within the ground.

Similar oxidation of mineral sulphides occurs within the soils of the Brightley Stream catchment (Ref. 3). Mineral sulphides have been exposed to air during a land drainage improvement scheme. During drought conditions it is thought that metal salts are drawn into the peat overlaying the mineral deposits where they are concentrated due to the lack of rainfall. At the break of the drought it is thought that rainfall leaches exceptionally high metal concentrations from the soil surface (Ref. 3).

At Meldon Quarry a precipitated layer of metal salts may accumulate on some of the rock faces and the quarry floor where groundwater collects and evaporates during droughts. It is unknown whether exceptionally high metal concentrations will accumulate in these areas or whether there is a surge of exceptionally high metal concentrations during the first rainfall after drought. Results from this study suggest that metal concentrations in the Meldon Quarry Stream vary little even during periods of high rainfall (cf. Table 4 with Appendix I).

The large volume of contaminated water draining Meldon Quarry following certain rainfall events can have potentially a major impact on the quality of the West Okement River. This is particulary the case when minimal dilution is available in the West Okement River because flow is mainly restricted to the compensation flow from Meldon reservoir.

In addition to acidic discharges from Meldon Quarry, these discharges can have high concentrations of suspended solids as a result of erosion and disturbance of rocks within the quarry. These are likely to pose a pollution hazard because metals can be transported by adsorption onto suspensions of iron and aluminium hydroxides. These metals are likely to dissolve in drainage waters that are acidic.

Large deposits of iron hydroxide have accumulated within the drainage adit from Meldon Quarry and in river sediments downstream of the drainage adit (see Fig. 9).

Iron biofouling commonly occurs when air comes in contact with non-acidic goundwater that is rich in soluble iron. Iron precipitating bacteria thrive in these conditions and promote the oxidation of iron-organic complexes and the precipitation of iron hydroxide.

The precise source of iron is unknown but is probably derived from non-acidic groundwater entering within the drainage adit. Surface water from the quarry is an additional source of iron. Iron biofouling should be prevented from occurring within the drainage adit in order to prevent pollution of the West Okement River.

6.2. Variations in water quality results.

There were marked differences between samples collected by autosamplers and those collected as spot samples at the same site and at approximately the same time (see Fig. 5). It had been noticed that a layer of metals could adsorb onto the sides of the autosample bottles. This layer accumulates during the autosampling period and may explain why spot samples have higher concentrations than those found in samples from the autosampler.

Chemical reactions are also likely to occur in the autosample bottles over the autosampling period. Indeed dissolved aluminium concentrations collected by autosamplers were higher than concentrations found in spot samples. It is therefore important that dissolved metals are filtered immediately when sampling.

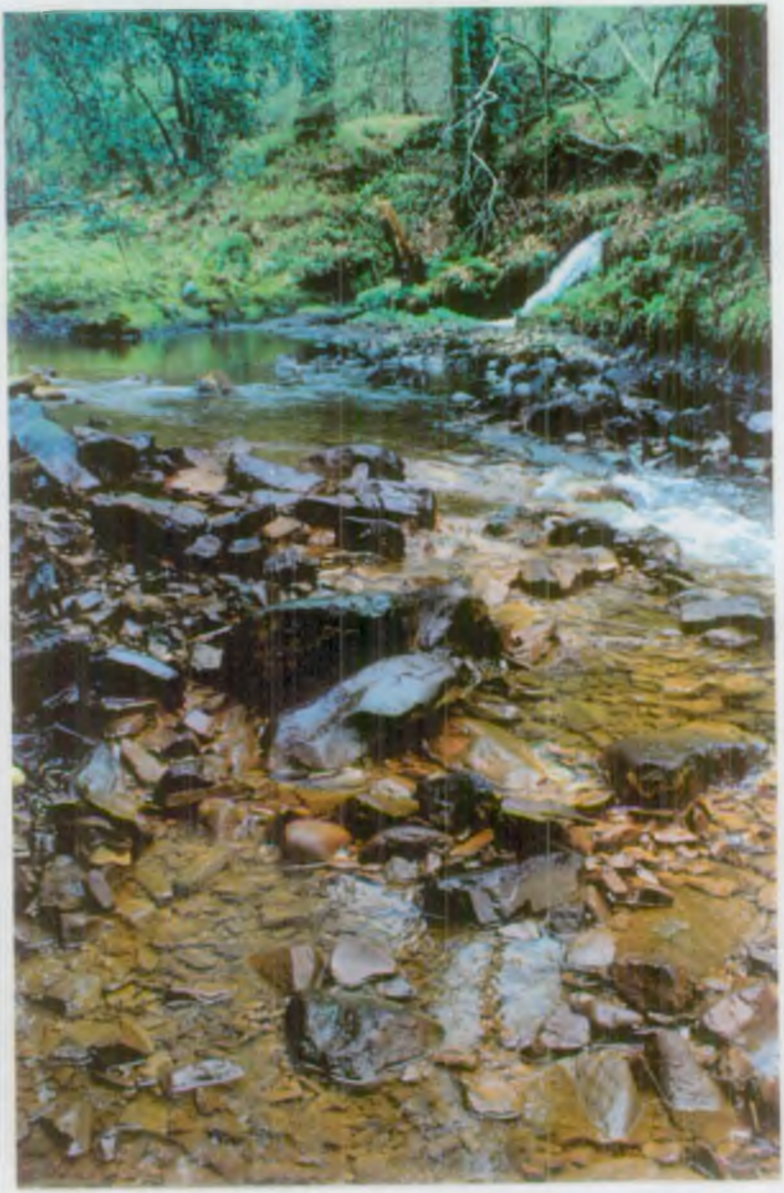
During the survey on 28-29 October 1990, pH in spot samples were approximately 0.5-1.0 pH units lower than pH recorded by the pH monitors both upstream and downstream of Meldon Quarry. Since the pH monitors were regularly validated it is thought that spot samples were more likely to be inaccurate because of the lag between sampling and the subsequent laboratory analysis. If poorly buffered water such as that of the West Okement River is left standing before analysis, changes in the concentration of carbon dioxide in solution can lead to marked changes in pH.

6.3. Other water quality problems.

It is clear from the results in this study and from routine water quality data that acidification occurs in the West Okement River upstream of Meldon Quarry. Similar acidification occurs in the East Okement River and other Dartmoor rivers (Ref. 7).

Drainage waters on Dartmoor are poorly buffered and are likely to be naturally acidic during rainfall. Increased acidity also leads to a greater mobility of aluminium in drainage waters.

Iron hydroxide deposits in the drainage adit from Meldon Quarry and in the West Okement River downstream of the drainage adit.



Natural acidity is caused by:-

1. Presence of organic acids in peat.
2. Drying out of anaerobic peat leading to the oxidation of sulphur and nitrogen compounds.
3. Weathering of mineral sulphides present in geological formations.
4. Displacement of hydrogen ions from naturally acidic soils by sea-salts in rainfall.

Photosynthetic activity by algae in the West Okement River leads to marked diurnal fluctuations in pH (see Fig. 4). River water is more acidic during the evening when there is an increased production of carbon dioxide.

The cause of the acidic and metalliferous pollution in the Fowley Stream is unknown but may be due drainage waters from an abandoned mine in the headwaters of this stream.

Copper concentrations in the West Okement River obtained from routine water quality monitoring upstream of Meldon Quarry marginally exceed the EQS (see Table 2). Drainage from two abandoned copper mines on the West Okement River and one on the Red-a-Ven Brook is likely to be the cause of copper present in river water upstream of Meldon Quarry.

It must be noted that the maximum copper concentration recorded upstream of Meldon Quarry is 6 ug/l and that the limit of detection for copper in river water during routine monitoring is 5 ug/l. If the limit of detection were lower it is questionable whether the 95%-ile concentration would exceed the EQS. There is a requirement for an improved analytical technique which can detected lower concentrations of copper.

7. POLLUTION CONTROL OPTIONS.

Acid mine drainage is notoriously difficult to stop once oxidation of mineral sulphides has been initiated. Poor quality drainage is likely to continue even if quarrying were discontinued at Meldon Quarry. In order to control pollution in the West Okement River, drainage water from Meldon Quarry could be collected and treated to neutralize pH and remove metals.

During the three surveys carried out in this study interim treatment of drainage waters adopted by Meldon Quarry was not effective in preventing non-compliance with quality standards for certain metals in the West Okement River. However, the continuous pH monitoring data downstream of Meldon Quarry revealed that there was not a surge of acidic water at the end of the drought in 1990 that was significant enough to cause a fish kill. This was confirmed by a detailed search of the river for dead fish. It is unknown whether the interim treatment measures adopted by Meldon Quarry prevented significant acidic pollution from occurring in the West Okement River.

Ad hoc lime treatment of discharges by Meldon Quarry was the cause of high pH peaks that occurred in the West Okement River downstream of Meldon Quarry (see Fig. 7). This was brought to the attention of the quarry management. The effects of high pH peaks on the flora and fauna of the West Okement River are unknown. Further high pH peaks should be prevented from occurring in the West Okement River.

Run-off from spoil heaps and working areas should be prevented from gaining access to the Reservoir Stream and Wigney Stream.

8. CONCLUSIONS.

1. Meldon Quarry has a significant impact on water quality in the West Okement catchment, and causes non-compliance with objectives and standards.

2. A principle cause of poor water quality is due to a form of acid mine drainage. Quarrying activities have exposed large quantities of mineral sulphides to air leading to acidic and metalliferous drainage.

3. Acid mine drainage from Meldon Quarry is likely to continue even in the event of quarrying being discontinued at this site.

4. Dilution of discharges from Meldon Quarry by the West Okement River is a key factor in determining the degree of pollution in the West Okement.

   Dilution is likely to be minimal during heavy rainfall following extensive periods of dry weather when flow in the West Okement River is restricted to the compensation flow from Meldon Reservoir.

5. There are a number of other water quality problems in the West Okement catchment that cause non-compliance with objectives and standards. These include natural acidification on Dartmoor, and acidic and metalliferous pollution in the Fowley Stream.

9. RECOMMENDATIONS.

1. Discharges from Meldon Quarry must be controlled so that water quality objectives and standards in receiving water courses are achieved.

   - Action by Quality Regulation Officer.

2. The causes of other water quality problems in the West Okement catchment identified in this report should be investigated.

   - Action by Catchment Planner.

3. Particular care is needed in future investigations involving pH and metal analysis from poorly buffered waters. The existing automatic water quality samplers used in this investigation are not suitable for collecting samples for metals analysis. Future continuous monitoring should be done manually.

   - Action by Catchment Planner.

4. Improved routine analytical method capable of detecting copper concentrations to 1 ug/l.

   - Action by Laboratory Controller.

10. REFERENCES.

1. MILFORD, B.L. (1990). Torridge Catchment Management Plan, stage 1. NRA SW Report 1990.

2. NEWTON, M.R.N. (1990). Assessment of the impact of discharges from Meldon Quarry on the water quality of the West Okement River. NRA SW Report, FWI/90/001.

3. SMITH, R.P. (1991). Pollution control of acidic water in the Brightley Stream. NRA SW Report, FWI/91/001.

4. Water Quality for European Freshwater Fish.
EIFAC/T27 Report on copper and freshwater fish (1976).
EIFAC/T21 Report on zinc and freshwater fish (1973).
EIFAC/T4 report on extreme pH values and inland fisheries (1968).

5. COUNCIL OF THE EUROPEAN COMMUNITIES. Directive concerning the quality of freshwaters needing protection or improvement in order to support fish life, 18 July 1978 (78/659/EEC. Official Journal (1978), L222, 14 August.

6. COUNCIL OF THE EUROPEAN COMMUNITIES. Directive on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community, 4 May 1976 (7/464/EEC. Official Journal (1976), L129, 18 May.

7. MILFORD, B.L. (1984). An assessment of acidic river waters in the East Area. South West Water Report SSE/ENV/84/19.

Fig. 1. Map of the West Okement River Catchment

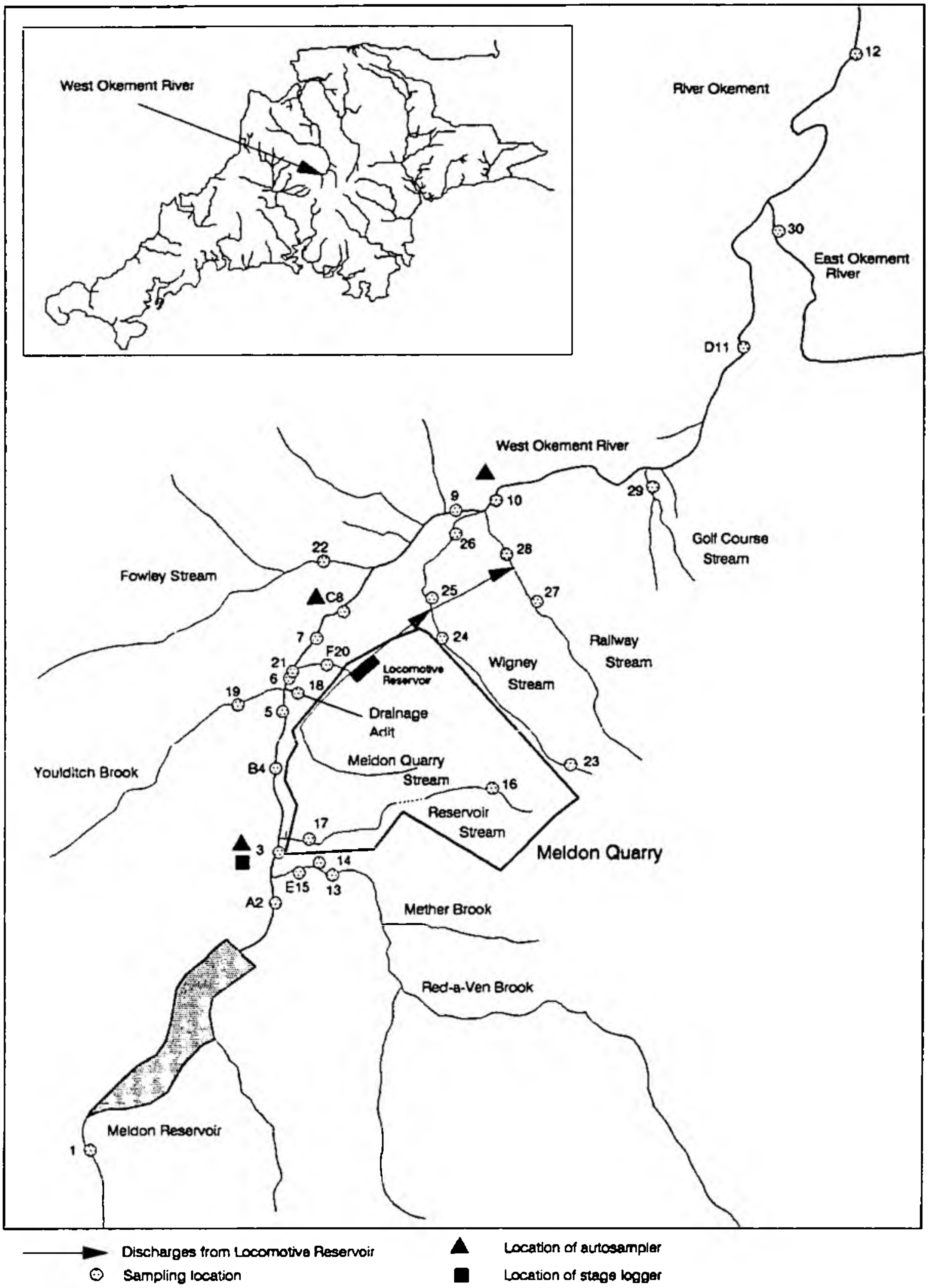


Fig. 2. Daily & monthly rainfall at Okehampton Pleasure Gardens during 1990

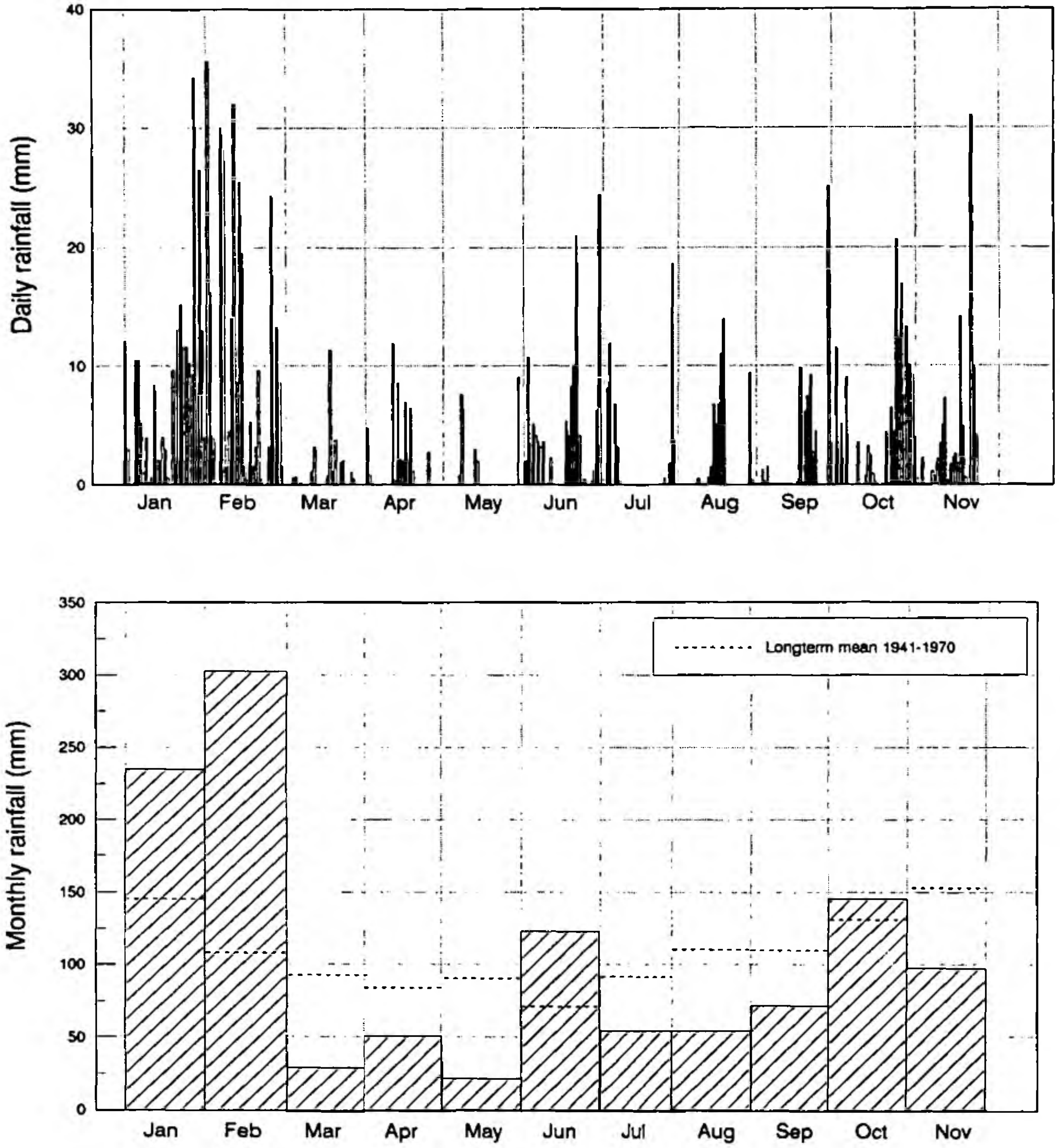


Fig. 3. Flow in the West Okement River upstream of Meldon Quarry During August to November 1990.

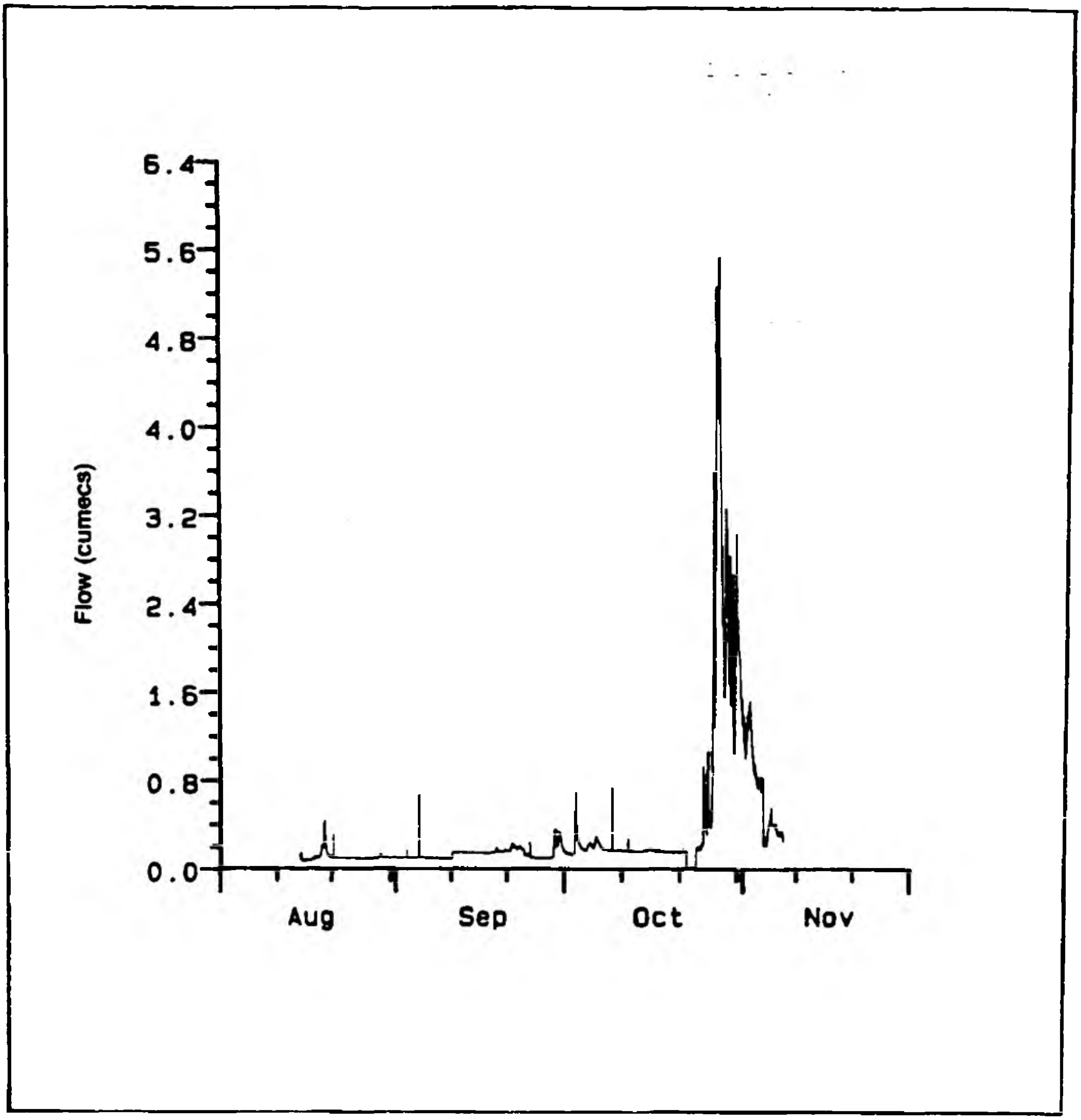


Fig. 4. pH recorded in the West Okement River during July 1990.

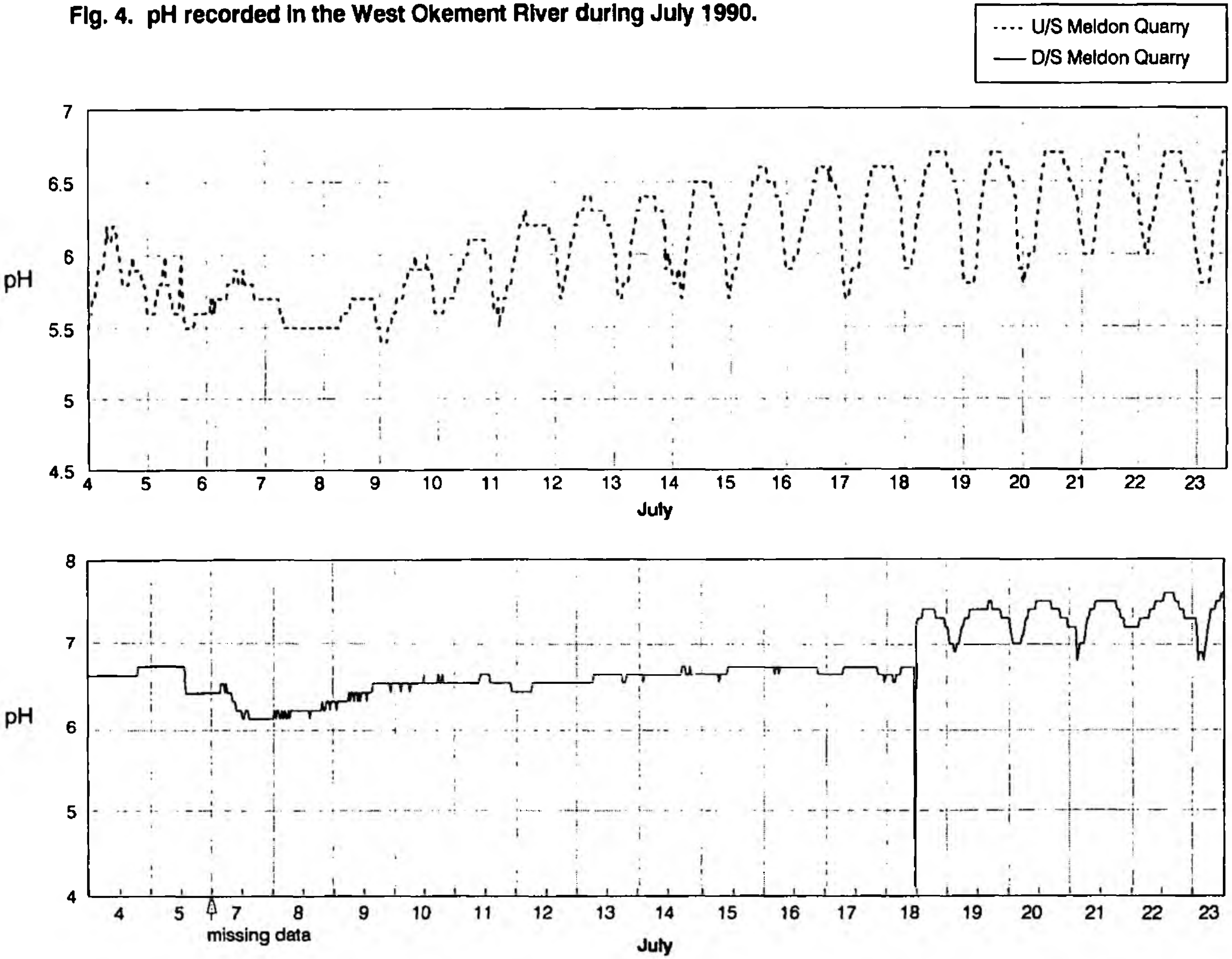


Fig. 5. Water quality in the West Okement River on 4-5 July 1990.

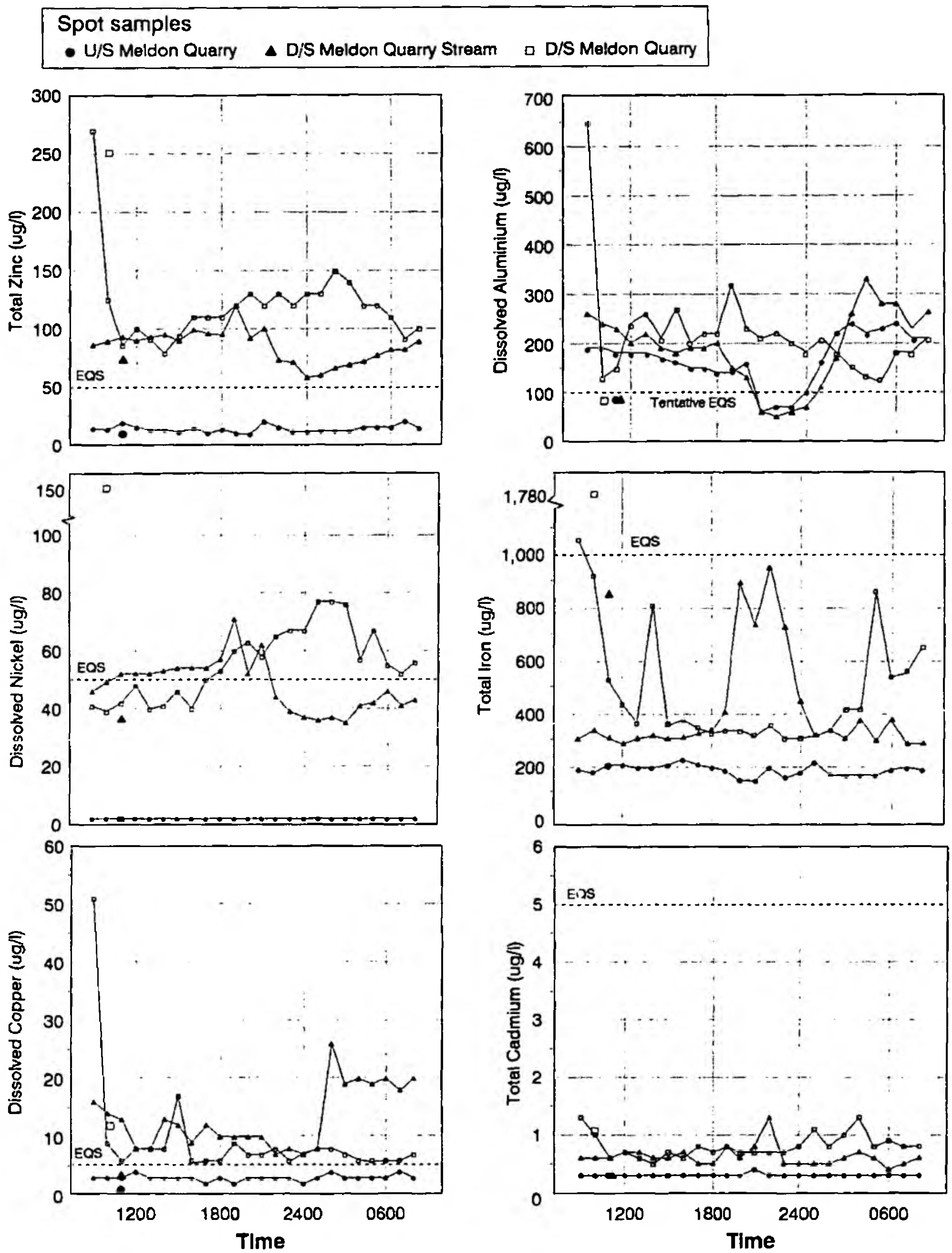


Fig. 6. Water quality at sites along the West Okement River during 4 July 1990

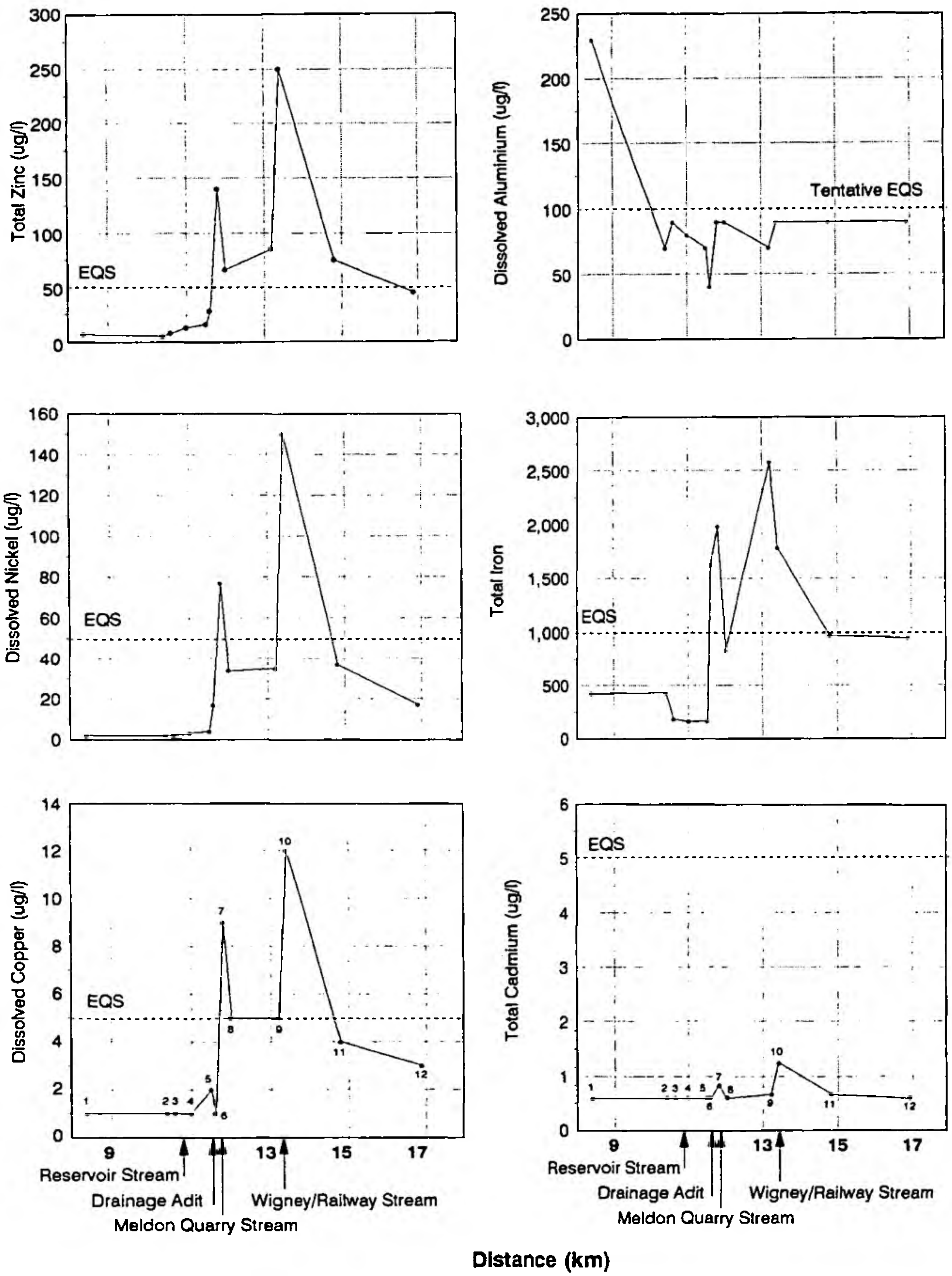


Fig. 7. pH recorded in the West Okement River during September to November 1990.

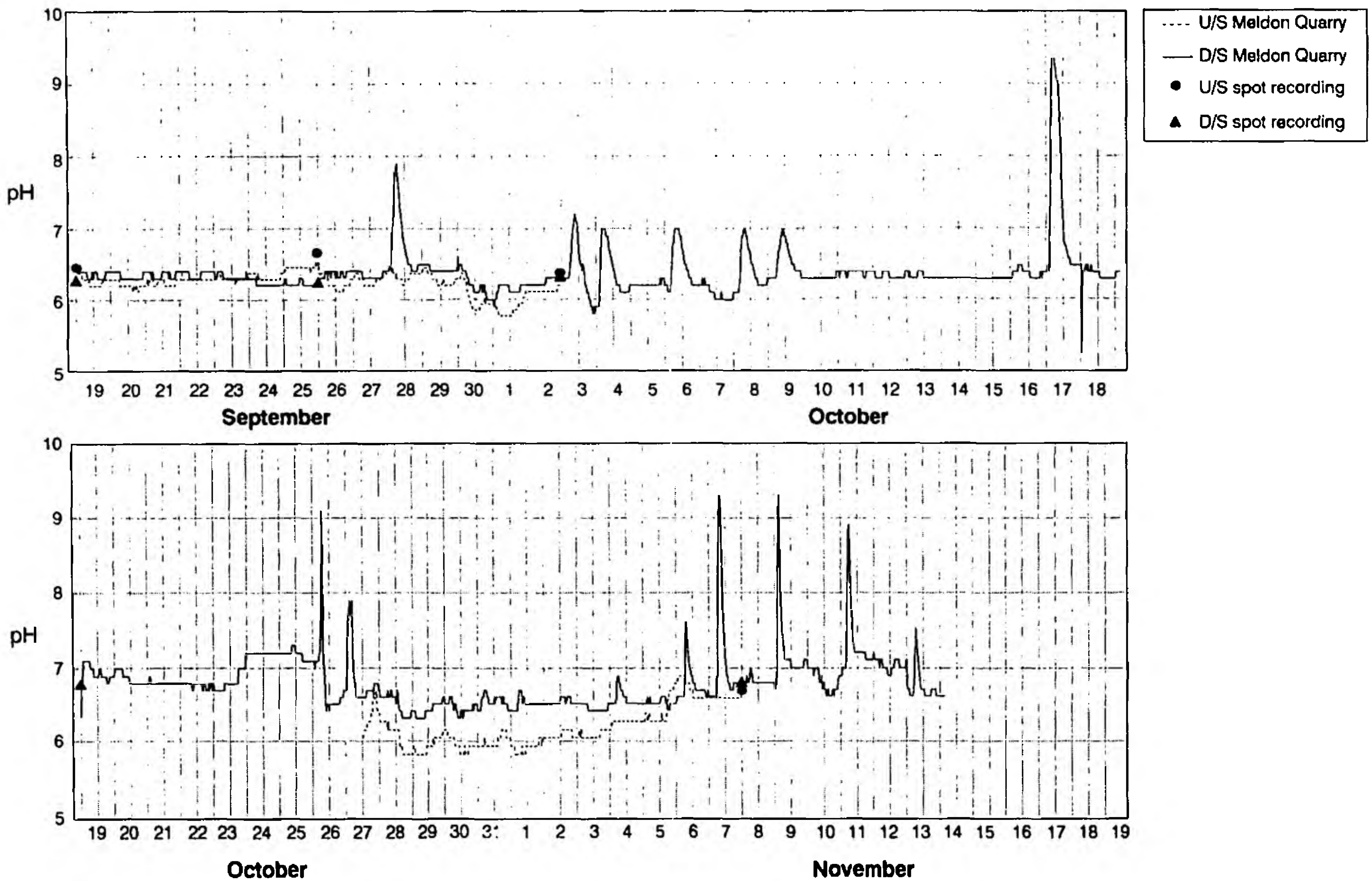
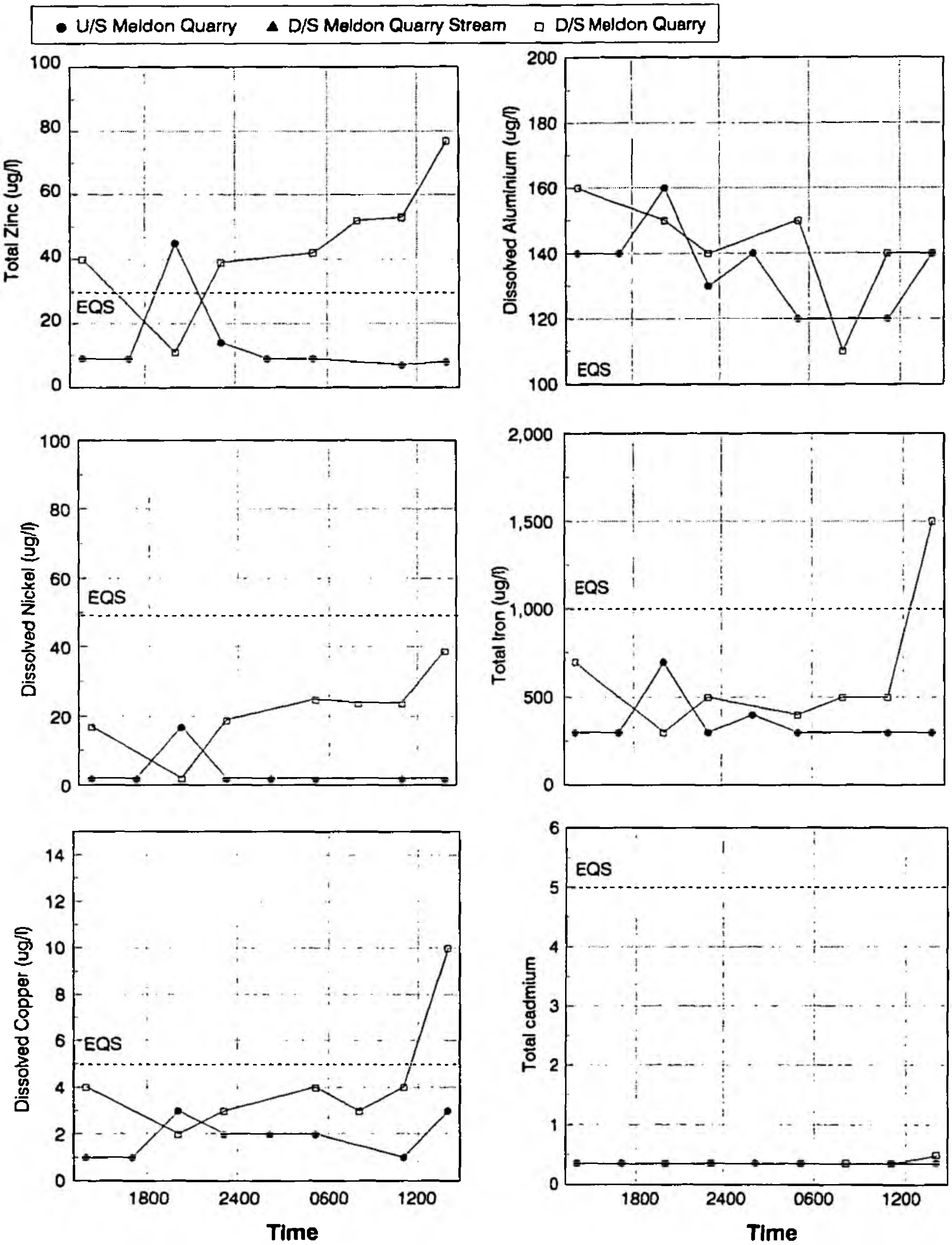
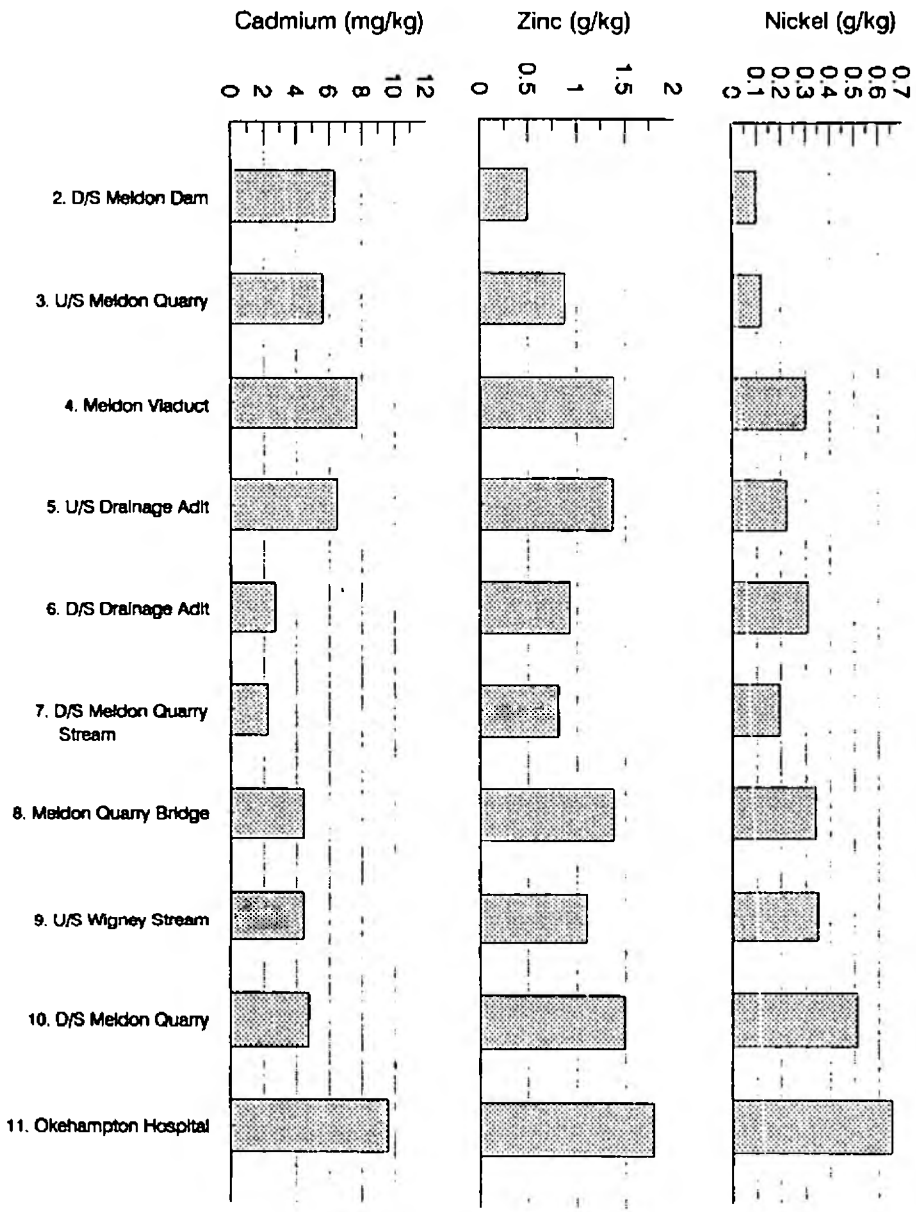


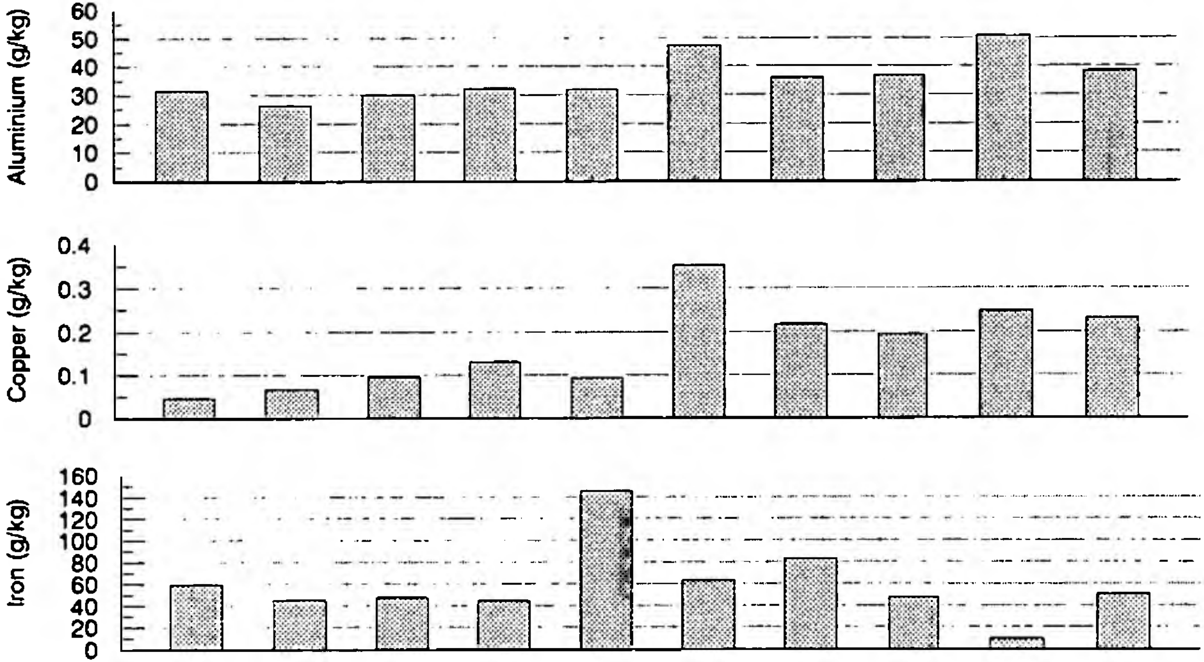
Fig. 8. Water quality in the West Okement River on 28-29 October 1990





Cadmium (mg/kg)
Zinc (g/kg)
Nickel (g/kg)
0
2
4
6
8
10
12
0
0.5
1
1.5
2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2. D/S Meldon Dam
3. U/S Meldon Quarry
4. Meldon Viaduct
5. U/S Drainage Adit
6. D/S Drainage Adit
7. D/S Meldon Quarry Stream
8. Meldon Quarry Bridge
9. U/S Wigney Stream
10. D/S Meldon Quarry
11. Okehampton Hospital

Fig. 9. Metal concentrations in river sediments collected from the West Okement River on 9 August 1990.



Appendix I. Water quality in the West Okement River Catchment 4 July 1990.

WEST OKEMENT RIVER	pH	Total zinc	Total iron	Diss. Nickel	Diss. copper	Diss. Alumin	Total Cadmium
1. U/S Meldon Reservoir	6.3	7	420	2	1	230	0.3
2. D/S Meldon Reservoir	6.7	5	430	2	1	70	0.3
3. U/S Meldon Quarry	6.8	8	180	2	1	90	0.3
4. Meldon Viaduct	6.7	13	160	3	1	80	0.3
5. U/S Meldon Quarry adit	6.8	16	160	4	2	70	0.3
6. D/S Meldon Quarry adit	6.5	28	1,650	17	1	40	0.3
7. D/S Meldon Quarry Stream	6.0	140	1,980	77	9	90	0.6
8. Meldon Quarry Bridge	6.7	66	830	34	5	90	0.3
9. U/S Wigney Stream	6.6	85	2,580	35	5	70	0.4
10. D/S Meldon Quarry	6.2	250	1,780	150	12	90	1.1
11. Okehampton Hospital	6.5	75	970	37	4	90	0.4
12. R. Okement at Knowle Bridge	6.6	45	950	17	3	90	0.3
TRIBUTARIES							
13. Red-a-Ven U/S aplite quarry	5.9	9	150	2	2	160	0.3
14. Stream from aplite quarry	6.8	26	50	5	2	20	0.3
15. Red-a-Ven D/S aplite quarry	6.4	12	90	2	2	110	0.3
16. Reservoir Stream U/S M. Quarry	6.9	13	860	2	2	60	0.3
17. Reservoir Stream D/S M. Quarry	6.6	290	100	140	9	60	1.9
18. Meldon Quarry drainage adit	6.0	480	10,800	650	13	20	2.4
19. Youlditch Brook	7.0	52	710	7	4	100	0.3
20. Meldon Quarry Stream.	4.2	2,100	9,800	1,000	160	7,300	8.0
21. Meldon Quarry Stream Outfall	4.3	2,100	4,800	1,200	190	9,200	9.0
22. Fowley Stream	4.4	150	3,260	40	13	1,700	2.4
23. Wigney Stream U/S M. Quarry	6.9	63	4,400	2	18	50	0.3
24. Wigney Stream U/S discharge	4.5	1,200	5,600	720	95	3,100	7.6
25. Wigney Stream D/S discharge	5.0	1,200	1,690	770	93	2,100	5.8
26. Wigney Stream D/S marsh	6.2	160	690	88	5	100	0.9
27. Railway Stream U/S discharge	7.2	5	300	2	2	80	0.3
28. Railway Stream D/S discharge	4.9	1,150	1,190	720	100	2,500	4.8
29. Golf-course Stream	7.3	13	210	8	3	90	0.3
30. East Okement River	7.0	12	450	2	2	100	0.3

Appendix II. Water quality in the West Okement River Catchment 28 October 1990

WEST OKEMENT RIVER	pH	Total zinc	Total iron	Diss. Nickel	Diss. copper	Diss. Alumin	Total Cadmium
1. U/S Meldon Reservoir	4.5	8	400	2	2	310	0.3
2. D/S Meldon Reservoir	5.6	11	400	2	2	100	0.3
3. U/S Meldon Quarry	5.4	9	300	2	2	140	0.3
4. Meldon Viaduct	5.6	18	300	5	1	160	0.3
5. U/S Meldon Quarry adit	5.6	16	300	4	1	150	0.4
6. D/S Meldon Quarry adit	5.5	25	400	13	2	160	0.3
7. D/S Meldon Quarry Stream	5.8	31	500	12	2	140	0.3
8. Meldon Quarry Bridge	5.7	36	500	15	2	150	0.3
9. U/S Wigney Stream	5.7	38	800	13	2	150	0.3
10. D/S Meldon Quarry	5.5	97	800	52	7	230	0.6
11. Okehampton Hospital	5.8	48	900	17	3	160	0.5
12. R. Okement at Knowle Bridge	6.0	48	1,000	14	4	160	0.4
TRIBUTARIES							
13. Red-a-Ven U/S aplite quarry	4.8	16	200	2	2	300	0.3
14. Stream from aplite quarry	6.6	27	300	3	2	90	0.4
15. Red-a-Ven D/S aplite quarry	5.3	24	800	2	3	300	0.3
16. Reservoir Stream U/S M. Quarry	6.6	7	800	2	1	20	0.3
17. Reservoir Stream D/S M. Quarry	4.6	1,370	140	620	51	4,900	7.0
18. Meldon Quarry drainage adit							
19. Youlditch Brook	6.6	160	700	16	6	110	1.0
20. Meldon Quarry Stream.	3.6	3,120	3,900	1,900	410	14,000	17.0
21. Meldon Quarry Stream Outfall	3.8	3,360	3,700	1,800	410	13,300	14.0
22. Fowley Stream	4.8	110	5,400	23	9	1,010	1.7
23. Wigney Stream U/S M. Quarry	7.1	64	5,200	2	8	40	0.3
24. Wigney Stream U/S discharge	4.2	1,070	73,000	400	47	2,000	5.0
25. Wigney Stream D/S discharge	4.7	1,130	5,000	62	78	1,280	6.0
26. Wigney Stream D/S marsh	5.9	140	300	83	3	120	1.1
27. Railway Stream U/S discharge	-	-	-	-	-	-	-
28. Railway Stream D/S discharge	4.8	1,020	1,800	680	120	3,300	14.0
29. Golf-course Stream	6.6	8	200	2	2	50	0.3
30. East Okement River	6.1	26	600	2	3	170	0.9

Appendix III. Water quality in the West Okement River Catchment 29 October 1990

WEST OKEMENT RIVER	pH	Total zinc	Total iron	Diss. Nickel	Diss. copper	Diss. Alumin	Total Cadmium
1. U/S Meldon Reservoir	4.6	10	300	2	1	250	0.3
2. D/S Meldon Reservoir	5.2	13	90	2	2	190	0.3
3. U/S Meldon Quarry	4.8	7	300	2	1	120	0.3
4. Meldon Viaduct	5.8	16	300	5	1	140	0.3
5. U/S Meldon Quarry adit	5.2	29	300	4	2	130	0.3
6. D/S Meldon Quarry adit	5.0	59	400	45	2	170	0.3
7. D/S Meldon Quarry Stream	6.0	36	300	14	3	130	0.3
8. Meldon Quarry Bridge	5.9	38	300	18	2	130	0.3
9. U/S Wigney Stream	5.0	43	400	18	2	130	0.3
10. D/S Meldon Quarry	5.8	60	500	31	4	160	0.3
11. Okehampton Hospital	5.9	60	600	27	3	140	0.8
12. R. Okement at Knowle Bridge	6.2	58	500	21	3	140	0.4
TRIBUTARIES							
13. Red-a-Ven U/S aplite quarry	5.2	13	90	2	2	190	0.3
14. Stream from aplite quarry	6.7	21	90	5	1	20	0.3
15. Red-a-Ven D/S aplite quarry	5.4	12	100	2	2	180	0.3
16. Reservoir Stream U/S M. Quarry	6.7	14	800	2	1	20	0.3
17. Reservoir Stream D/S M. Quarry	4.5	1,120	170	460	42	3,300	7.0
18. Meldon Quarry drainage adit							
19. Youlditch Brook	6.7	85	400	11	4	100	0.3
20. Meldon Quarry Stream.	3.6	2,850	3,600	1,600	260	11,800	15.0
21. Meldon Quarry Stream Outfall	3.8	2,100	8,700	1,200	200	8,400	12.0
22. Fowley Stream	5.3	59	2,700	12	3	100	0.8
23. Wigney Stream U/S M. Quarry	7.0	20	1,500	2	4	20	0.3
24. Wigney Stream U/S discharge	4.3	1,100	23,000	50	45	2,150	8.0
25. Wigney Stream D/S discharge	4.8	1,150	2,700	700	120	2,600	6.0
26. Wigney Stream D/S marsh	6.1	115	200	6	3	80	0.6
27. Railway Stream U/S discharge	8.0	5	200	2	2	40	0.3
28. Railway Stream D/S discharge	4.4	1,670	3,700	1,050	230	7,600	10.0
29. Golf-course Stream	6.6	31	200	22	6	170	0.3
30. East Okement River	6.4	25	300	3	6	140	0.3