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Impacts of, and possible improvements to, discharges of metalliferous wastewaters from the Lisheen Mine, Co Tipperary, Ireland

Final Report

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IMPORTANT NOTE

This report has been prepared by the authors drawing on numerous sources of information provided both by staff at the Lisheen mine and from the reports of other independent consultants. Some of the most important data from these various sources is reproduced in tabular and graphical form in this report. However, the data in these tables and graphs should not be interpreted in isolation from the accompanying text, which contains vital information regarding the context and implications of these data. As far as possible the authors of this report have checked that the data collected by third parties is reliable and accurate. Where there are uncertainties about the sampling or analytical methods employed these are highlighted in the text.

EXECUTIVE SUMMARY

The catalyst for this report was the outcome of an investigation into sediment-metal concentrations in the Rivers Drish and Rossestown, downstream of the points at which the Lisheen mine discharges water from its operation in Tipperary, Ireland. Sediment zinc and lead concentrations as high as 88,200 mg/kg and 6,179 mg/kg respectively were reported in the aforementioned investigation. In April 2006 the authors of this report were commissioned by Lisheen mine to evaluate the problem, with specific reference to 3 key issues:

1. An assessment of the precise nature and severity of sediment contamination in the Rivers Drish and Rossestown, and in particular an assessment of the potential impact on the health of higher animals.
2. An investigation of the most appropriate approach to remediating the problem.
3. Identification of methods of minimising the possibility of a recurrence of the problem over the remaining life of the mine (currently projected as 6-8 years from 2006).

To address these issues the report is divided into 4 technical sections: Water quality and quantity (Section 2), River sediment-metal concentrations (Section 3), Ecological impacts of sedimentation / elevated metal concentrations (Section 4), and Review of the Lisheen mine water treatment system (Section 5). The objective of the report is to advise Lisheen mine on the source of the problem (s.2), the nature of the problem and its resolution (s.3), the impacts of the problem (s.4), and future minimisation of the problem (s.5).

In terms of water quality and quantity, the Lisheen mine meets its Integrated Pollution Control Licence for the vast majority of the time, and typically discharges water with concentrations of lead and zinc well below consent conditions. However, the mine discharges a very large volume of water (approximately 60 ML/d) and, consequently, the metal *load* to the rivers is approximately 13 kg/d zinc and 1 kg/d lead. Approximately 70% of the zinc load, and 40% of the lead load, discharging to the conditioning pond (the final stage of treatment prior to discharge to the Rivers Drish and Rossestown) in fact arises from the combination of the F2/F3 Fissure water and Canal water. The conditioning pond currently has a limited impact in terms of further reducing zinc and lead concentrations. Suspended solids concentration in the waters discharged to the two rivers is also well within IPC licence limits. To ensure that representative samples of water are being collected for suspended solids concentration determination it is recommended that grab samples of final discharge water are collected for analysis, since reducing suspended solids concentrations may be an important part of minimising sediment-metal contamination problems in the future.

Subsequent to the initial analysis of sediment-metal concentrations in the Rivers Drish and Rossestown two additional surveys have been conducted to supplement the preliminary dataset. The results show very substantial variation between investigations. Possible reasons for such variation include spatial and temporal heterogeneity of metal distribution in river sediments, and differences in the precise sampling and analytical techniques used in determining metal concentrations. In order to clarify this issue it is recommended that a precise methodology for sampling and analysis of river sediment is agreed between Lisheen mine, the EPA, and external experts, prior to any further surveys. Notwithstanding these comments, determination of sediment-metal concentrations using a laboratory procedure that more closely indicates 'bioavailable' metals has shown concentrations approximately an order of magnitude lower than more aggressive techniques designed to extract all metals from sediments.

There is no doubt that accumulation of sediment in the rivers immediately adjacent to, and downstream from, Lisheen mine are due to deposition of particulates from the mine discharges. Selective removal, and appropriate disposal, of these sediments is recommended, and appropriate methods are outlined.

In order to assess how river sediment contamination can be minimised in the future, current mine water treatment at Lisheen has been reviewed. Historic data from the Mine Water Treatment Plant (MWTP) and Reclaim Water Treatment Plant (RWTP) illustrate that the optimum pH for zinc removal is 9.0 – 9.5. Optimisation of the treatment system may provide scope for partial treatment of water from the F2/F3 Fissure and Canal in the existing plant. An additional measure for improved reduction of metal concentrations in these waters is lime dosing prior to the conditioning pond. It is recommended that performance of the holding and conditioning ponds, in terms of metal removal, are investigated further by detailed monitoring. Installation of settlement facilities at the mine water outfalls may help to reduce the mass of suspended solids discharged to the two rivers. Pilot trials are recommended to determine the size and effectiveness of units required (costing approximately €15,000). If successful, full-scale gravity-fed lamella plate clarification units at each of the outfalls have a budget cost estimate of €965,000.

A programme of measures for implementation at the mine is provided. These principally relate to:

1. Immediate actions to address the current problems of sedimentation in the Rivers Drish and Rossestown
2. Additional monitoring, to clarify issues relating to the nature of suspended solids in the two discharges and possible improvements to mine water treatment
3. Monitoring of river water quality, both chemical and biological

It is proposed that these actions should be implemented over the next 18 months.

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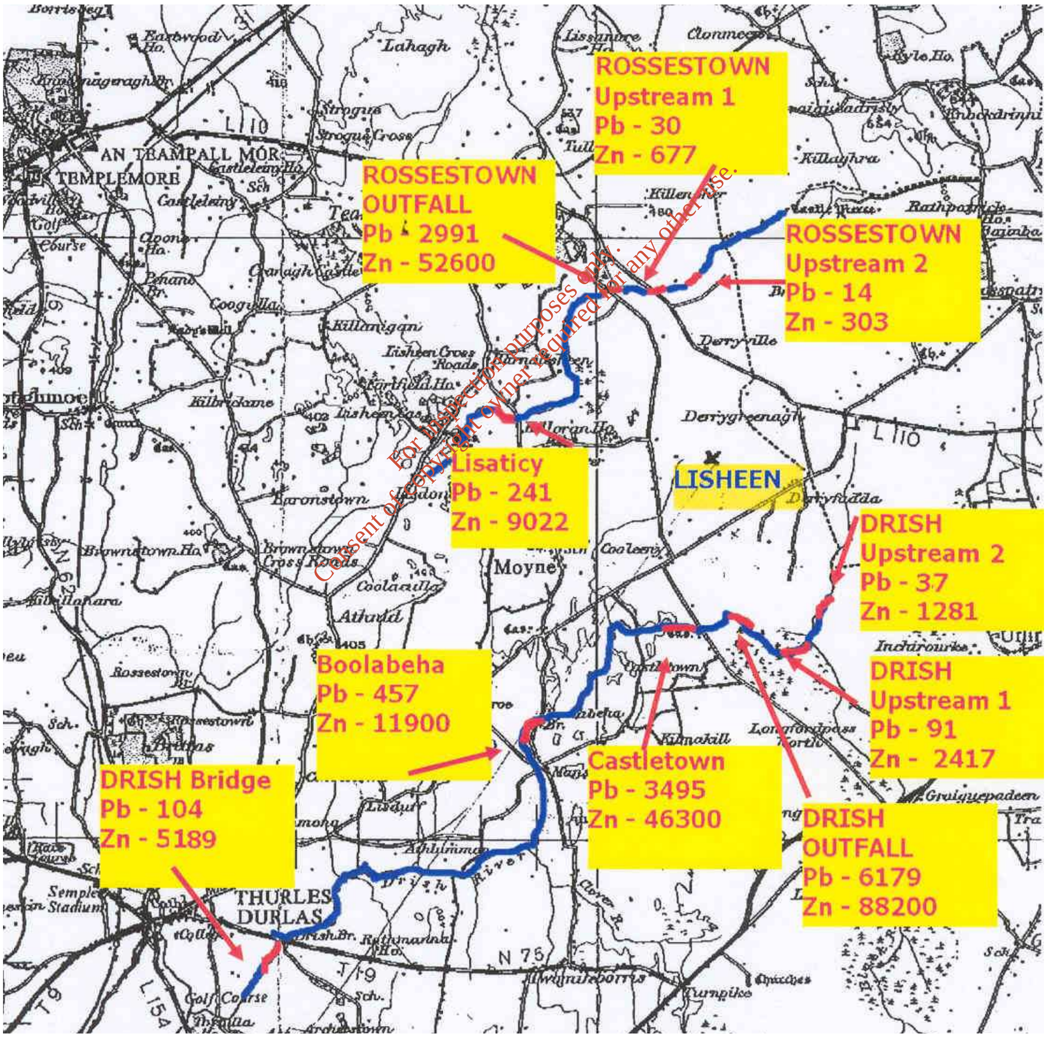
1. INTRODUCTION

On 25 April 2006 Professor Paul Younger at Newcastle University was contacted by Lisheen mine with a view to obtaining technical advice on how to address a potential problem with elevated sediment-metal concentrations in the Rivers Drish and Rossestown, to both of which the Lisheen mine discharges treated mine water. The analytical results which were the immediate cause of concern are those illustrated in Figure 1.

Figure 1. Results of sediment-metal analyses along the Rivers Drish and Rossestown, indicating concentrations both upstream and downstream of Lisheen mine outfalls



On 28 April 2006 Dr Adam Jarvis (Deputy Head of the Newcastle team) visited the Lisheen mine to conduct initial meetings, and gain an overview of the problem. Following that meeting the Newcastle team drew together a small team (the authors of

this report) to address the issues for the Lisheen mine. Three key issues required addressing and resolving:

1. An assessment of the precise nature and severity of sediment contamination in the Rivers Drish and Rossestown, and in particular an assessment of the potential impact on the health of higher animals (principally fish and dairy farm livestock).
2. An investigation of the most appropriate approach to remediating the problem.
3. Identification of methods of minimising the possibility of a recurrence of the problem over the remaining life of the mine (currently projected as 8 years from 2006).

From these broad objectives a scope of works was drawn up, which is reiterated here as originally written:

1. <u>Nature and impact of sediment contamination</u>

- Review existing data (including analytical methods used in determination of recent sediment-metal concentrations and historic concentrations), collate and review new data (Zn and Pb concentrations in Gammarus, fish, dairy milk and cattle blood are currently being analysed)[1], and relate to regulatory standards in force in Ireland and elsewhere.
- Investigate other possible sources of the contaminated sediment (e.g. remobilisation of historically dredged materials deposited on riparian zones).
- Advise The Lisheen Mine on requirements for further data collection to assess compliance with current and future regulatory targets, and to support the following tasks.
- In light of these data, and previous investigations, report on the possible impacts of the contaminated sediments on the ecology of the stream and health impacts on higher organisms.
- If impacts are likely, advise on mitigating measures to prevent these impacts [at the time of writing The Lisheen mine have fenced off the affected river reaches to prevent access to cattle, and angling activity has been suspended].

2. <u>Remediation of sediment contamination:</u>

- The EPA has advised The Lisheen Mine that acceptable concentrations of Zn and Pb in sediment are <5,000 mg/kg and <1,000 mg/kg respectively (presumed to be concentrations determined by Aqua Regia digestion).
- Notwithstanding the above, options for remediation will be investigated. Dredging and disposal has been proposed as an option. The feasibility, potential impact on downstream water quality and amenity, methods, and costs, will be reviewed in light of international precedents (to the extent valid analogues exist).
- The sediment transport regimes of the two rivers will be investigated on a hydrological basis, to assess whether monitored natural attenuation would in fact be the preferable option (with cognisance for the outcomes of objective 1, above).

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[1] These results were available by the time this report was prepared, and are discussed in this document

- Advise The Lisheen Mine on requirements for further data collection to assist in meeting the above deliverables.

3. Minimisation of future sediment contamination:

- The Lisheen Mine discharges a large volume of water with low Zn and Pb concentrations. If the sediment contamination of the rivers is a result of these discharges it will be necessary to establish what reduction in effluent metal concentrations will be required to prevent (or minimise) future elevation of sediment metal concentrations (in light of the hydrology and sediment dynamics).
- The Lisheen mine already operates an effective mine water treatment system that meets consent conditions the majority of the time. Nevertheless, a thorough review of the existing system will be undertaken to identify whether further reductions in effluent metal concentrations can be achieved cost-effectively. Possibilities such as re-routing of F2/F3 water in the treatment train have already been identified during Dr Jarvis' visit, and other options include air-sparging simultaneously to lime dosing, alternative flocculants, and addition of suspended solids removal units.
- Alternative long-term options will be investigated. For example, if the effluent metal concentrations required to prevent future increase in sediment contamination are not attainable (for technical and / or economic reasons), best options for the long-term management of river sediment will be provided e.g. installation of, and periodic dredging from, sediment traps in the rivers.

This is the final report of the team that has conducted the investigation. For clarity the report is not arranged in the order in which the scope of works is outlined above. Rather, the report is divided into 5 sections, as follows:

Section 2: Water quality and quantity
Section 3: River sediment-metal concentrations
Section 4: Ecological impacts of sedimentation / elevated metal concentrations
Section 5: Review of the Lisheen mine water treatment system
Section 6: Conclusions and recommendations

Each section reviews the quality, and implications, of historical data relating to the relevant issue, and also considers additional data collected by Lisheen mine staff, typically following discussions between mine staff and the authors of this report. There is a large volume of data relating to the issues discussed in this report. The intention here is not to simply reproduce and review all of the data available, but to focus on key elements in order to produce a clear picture that can be used to inform future management decisions.

Each individual chapter also contains conclusions and recommendations. These are broadly split into suggestions either for remedial action / system improvements, or for additional monitoring in key areas in cases where it is not possible to make evidence-based judgements on the most appropriate course of action. In all instances, justification for the proposed course of action is provided. All conclusions and recommendations arising from the investigation are reiterated in Chapter 6 of this report, together with a recommended approach to the future management and monitoring of discharges from the Lisheen mine to the Rivers Rossestown and Drish.

2. WATER QUALITY AND QUANTITY

2.1 Zinc and lead concentration and load

Figures 2 and 3 illustrate that the discharges to the Rivers Drish (Figure 2) and Rossestown (Figure 3) are within the mine's IPC licence conditions for Zn and Pb the vast majority of the time.

Figure 2. Zn and Pb concentrations of the discharge to the River Drish for the period 01/01/2005 to 06/06/2006

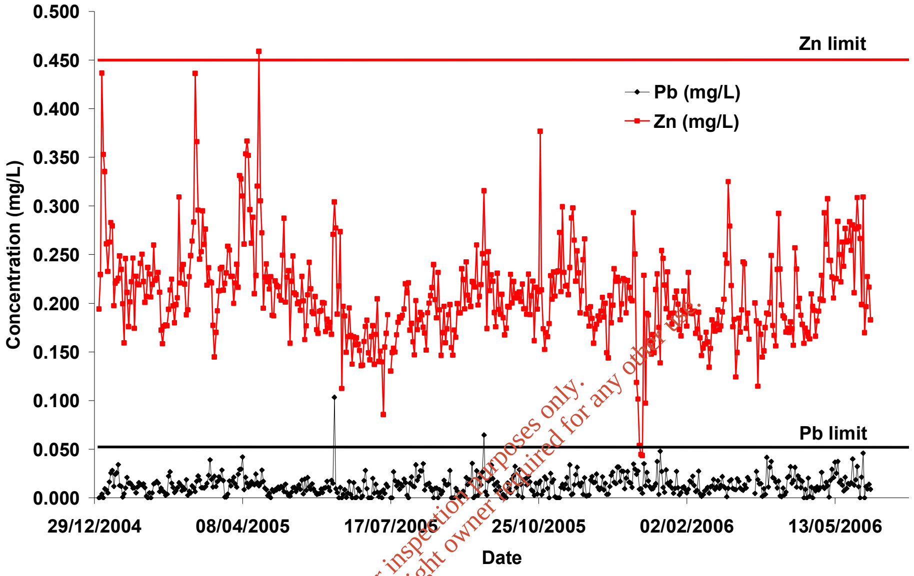
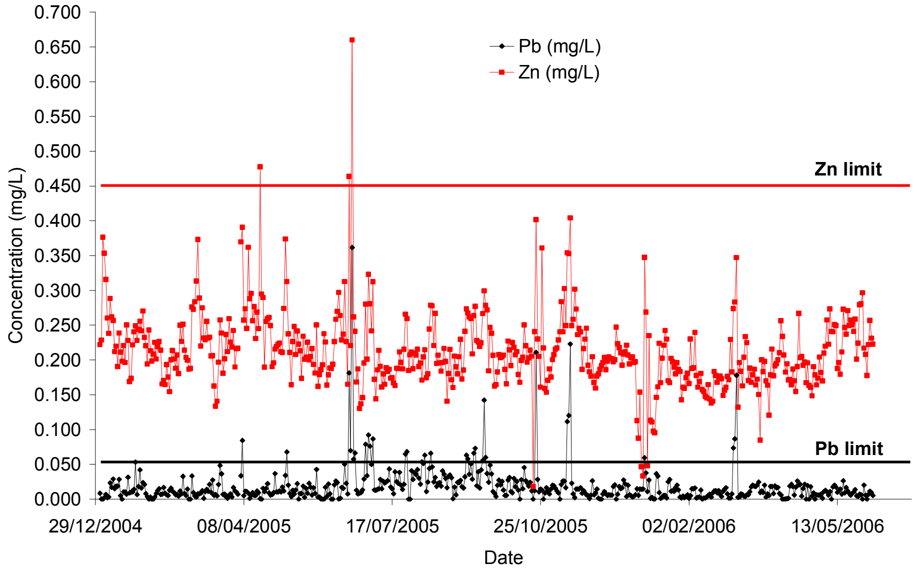


Figure 3. Zn and Pb concentrations of the discharge to the River Rossestown for the period 01/01/2005 to 06/06/2006



However, Lisheen mine discharges a high volume of water – currently around 60 MLD. This is well within the limit of 120 MLD. Although concentrations of Pb and Zn are low, and within licence conditions, the mean total metal *loading* to the Rivers for 2005 are 10.73 kg/d Zn and 0.71 kg/d Pb for the Drish and 2.60 kg/d and 0.27 kg/d for the Rossestown, despite both discharge volume and Zn and Pb concentrations being well within limit conditions the majority of the time. It is worth noting that, prior to any treatment, the total collective loadings[2] of Zn and Pb in waters pumped from the Lisheen mine (for 2005) were 121 kg/d and 103 kg/d respectively. Therefore, as an annual mean for 2005, 89% of Zn, and 99% of Pb, were removed from the waters discharged from the mine to the Rivers Drish and Rossestown.

In order to evaluate areas within the mine in which improvements to water treatment could assist in minimising the absolute mass of metals discharged to the Rivers Drish and Rossestown, Table 1 summarises the sources of Zn and Pb within the mine site. Over 70% of the total zinc load discharging to the conditioning pond arises from the F2/F3 water (28.7%) and canal water (46.9%), and receives no other treatment other than what little (see below) is afforded by the conditioning pond. The situation with lead load is only a little less serious in this respect; over 60% of the total Pb load arises from the F2/F3 and canal water.

Table 1. Sources of zinc and lead loads to the conditioning pond at Lisheen mine (calculated from mean values for 2005)

	Zinc		Lead	
	Load (kg/d)	% of total	Load (kg/d)	% of total
MWTP	2.93	17.6	0.32	18.1
RWTP	1.14	6.8	0.37	20.9
F2/F3	4.79	28.7	0.22	12.4
Canal @ Killoran	7.82	46.9	0.86	48.6
TOTAL	16.68	100.0	1.77	100.0

It was noted above that the total Zn loads discharged to the Drish and Rossestown were 10.73 kg/d and 2.60 kg/d respectively. Comparing this total (13.33 kg/d) with that entering the conditioning pond (16.68 kg/d; Table 1) illustrates that the conditioning pond has little impact in terms of improvement in water quality with respect to zinc. The pattern for Pb is somewhat more encouraging; 1.77 kg/d enters the conditioning pond and 0.98 kg/d leaves it, probably reflecting the lower mobility of this metal.

In order to assess the reasons for the poor Zn and Pb removal in the conditioning pond, and the form of these two metals entering the two rivers, daily samples of the discharges to the Drish and Rossestown were taken for a 2 week period from 09/05/06 to 23/05/06, and a further sampling exercise was conducted over the period 09/06/06 to 18/07/06. Analysis of these samples for both total and dissolved Zn and Pb show that, for zinc in

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[2] Calculated from the sum of (1) the Reclaim Water Treatment Plant raw water (2) the Mine Water Treatment Plant raw water (3) the F_2/F_3 water and (4) the Canal water at Killoran.

particular, the majority of the metal is in the dissolved phase (Table 2 and Table 3). Given the high mobility of dissolved zinc, and the high pH required to effect its removal from solution, there is little chance of preventing dissolved zinc associated with the F2/F3 and canal water entering the Rivers Drish and Rossestown without chemical treatment of these two waters. Raising the height of the outfall from the conditioning pond is unlikely to reduce the problem given that zinc is principally in the dissolved phase. However, if zinc can be converted to a particulate form prior to it discharging from the conditioning pond then elevation of the outfall point is likely to assist in minimising zinc load discharged to the Rivers Drish and Rossestown. Options for reducing the concentrations of zinc and lead in the final discharges to the Rivers Drish and Rossestown are discussed in Section 5 of this report, below.

Table 2. Summary statistics for total and filtered zinc and lead concentrations discharging to the Rivers Drish and Rossestown (mean values based on daily sampling for the period 09/05/06 – 23/05/06)

	Zinc (mg/L)				Lead (mg/L)			
	Drish		Rossestown		Drish		Rossestown	
	Total	Filt.	Total	Filt.	Total	Filt.	Total	Filt.
Mean	0.248	0.198	0.236	0.205	0.019	0.008	0.013	0.007
Min	0.206	0.124	0.180	0.147	< 0.001	< 0.001	< 0.001	< 0.001
Max	0.284	0.234	0.272	0.239	0.037	0.017	0.027	0.018

Table 3. Mean total and filtered zinc and lead concentrations through the Lisheen treatment plant and at the oufalls to the Rivers Drish and Rossestown for the period 09/06/06 to 18/07/06 (n = total number of samples analysed)

	Zinc (mg/L)		Lead (mg/L)		n
	Total	Filtered	Total	Filtered	
MWTP1	0.13	0.03	0.06	0.02	12
MWTP2	6.55	1.30	6.12	0.30	12
MWTP3	0.12	0.09	0.01	0.01	12
MWTP4	8.18	1.50	7.22	0.04	12
MWTP5	0.18	0.14	0.03	0.01	12
TMF Reclaim	3.41	2.92	0.14	0.11	4
Concentrator discharge	0.58	0.48	0.23	0.10	5
F2/F3	0.18	0.16	0.01	0.01	5
Canal @ FAS	0.40	0.33	0.04	0.01	12
Canal @ Killoran	0.28	0.24	0.02	0.01	12
Conditioning pond	0.22	0.19	0.01	0.01	12
Drish discharge	0.19	0.16	0.01	0.01	12
Rossestown discharge	0.18	0.16	0.01	0.01	12

2.2 Suspended solids concentrations

Lisheen mine’s Integrated Pollution Control Revised Licence (Register Number 550) stipulates that suspended solids concentration of discharges to rivers must be < 25 mg/L.

This requirement is met by Lisheen the vast majority of the time, as Table 4 illustrates. The mine has installed autosamplers at the outfalls to the Rivers Drish and Rossestown, to facilitate regular water quality monitoring at these points. Observations of the discharge points during a site visit by these authors (06/06/06) revealed that the water visibly contains particulates. It is thought by mine staff that these particulates may be due to sloughing of 'biofilm' from the walls of the pipes that carry water from the conditioning pond to the two outfalls. The particulates appear to be similar in nature to the large volumes of sediment that accumulate immediately adjacent to the two outfalls. We recommend that large grab samples (10 – 20 litres) of outfall water are collected and filtered, in order that these particulates can be isolated by filtration and analysed for total metal concentrations. We also recommend that suspended solids concentrations of the two outfalls are also checked by this method. Table 4 suggests there is some variation in suspended solids concentrations between the water leaving the conditioning pond and that discharging from the two outfalls. This may well be due to sloughing of 'biofilm' as noted above, but it would also be beneficial to check whether the autosamplers take a representative sample; the high water velocity at the outfalls may result in poor recovery of particulates.

Table 4. Suspended solids concentrations (in units of mg/L) at the conditioning pond outlet and Drish and Rossestown outfalls

Date	Conditioning pond outlet	Drish outfall	Rossestown outfall
09/06/06	3.7	5.4	1.6
13/06/06	4.5	5.9	4.7
15/06/06	3.6	13.3	4.3
20/06/06	3.1	4.2	2.1
22/06/06	5.2	4.4	7.2
27/06/06	3.1	2.1	2.5
30/06/06	3.0	3.8	6.9
04/07/06	4.7	5.5	2.4
06/07/06	1.4	0.9	2.1
11/07/06	4.1	4.8	2.8
13/07/06	2.9	2.8	3.1
18/07/06	2.2	2.2	2.0
Mean	3.63	4.61	3.48
Minimum	1.4	0.9	1.6
Maximum	5.2	13.3	7.2

2.3 Sulphate concentrations

As with the vast majority of mining operations that extract sulphide minerals, sulphate concentrations are elevated in pumped mine waters at Lisheen. The EPA has imposed a limit of 250 mg/L for discharge to rivers, which is based on European Union drinking water guidelines. There is also a limit within the mine site of 370 mg/L (at the effluent from the holding pond). In order to meet the internal limit Lisheen mine dilutes treated water from the Mine Water Treatment Plant and Reclaim Water Treatment Plant (which each have mean sulphate concentration of approximately 500 – 600 mg/L) with F2/F3 water. Further dilution with Canal water (in the Conditioning pond) allows the limit of 250 mg/L for the discharge to rivers to be met (the F2/F3 and Canal waters do not have intimate contact with sulphide minerals, and therefore sulphate concentrations are typically < 50 mg/L).

This need to dilute mine water to meet limit values for sulphate restricts the potential options for re-routing waters to improve the overall efficiency of the water treatment plant. It is not clear to these authors why it has been necessary for the EPA to impose such stringent limits, to drinking water standards (there are no potable abstractions on either the River Drish or Rossestown). Sulphate concentration in the two rivers downstream of the mine discharge points are typically < 200 mg/L. For comparative purposes, the Canadian Water Quality Guidelines for Livestock recommend a maximum recommended limit of 1,000 mg/L sulphate. We recommend that discussions are held with the EPA regarding relaxation of the sulphate limit, since there is no evidence that higher concentrations of sulphate would have a deleterious impact on the ecology of the two rivers. However, a limit that is set in the context of the current uses of the Rivers Drish and Rossestown may well allow other issues (especially elevated metals concentrations) to be addressed much more satisfactorily.

2.4 River water quality

During 2006 monthly water samples have been collected from the Rivers Drish and Rossestown, and results for Zn, Pb and suspended solids are presented in Table 5. Zinc and lead concentrations downstream of the discharges do not appear to be entirely a function of discharge water quality (i.e. high metal concentration in the discharge is not necessarily reflected in high concentration in the rivers downstream). Dilution effects are almost certainly important (due to high / low upstream river flows and / or high / low discharge volume).

The key point to draw from Table 5 is that lead concentration in the water column of the two rivers is low, even immediately downstream of the discharge point, and zinc concentration is also typically low at these locations. The data in Table 5 therefore suggest that Zn and Pb concentrations in the water column of the Rivers Drish and Rossestown are not, in their own right, a cause for concern. As detailed in Section 4 of this report, analyses of cattle milk and blood are also well within acceptable limits for zinc and lead concentration, suggesting that ingestion by cattle of water from the Rivers Drish and Rossestown is having no deleterious effects upon them.

2.5 Conclusions and recommendations

- Zinc and lead concentrations in the discharges to the Rivers Drish and Rossestown are within Integrated Pollution Control limits set by the Environmental Protection Agency for the vast majority of the time (based on data from the start of 2005).
- However, as a result of the very high volumes of water that it is necessary for the mine to discharge, metal loads to the rivers are approximately 13 kg/d Zn and 1 kg/d

Pb (though it is worth noting than in 2005 water treatment at the mine resulted in mean removal of 90% of the total Zn load and 99% of the total Pb load).

- Inspection of flows and metal concentrations around the mine reveals that in excess of 70% of the total Zn load entering the holding and conditioning ponds actually arises from the F2/F3 water and the Canal.
- The conditioning pond does very little to attenuate metal loadings, and this appears to be because Zn in particular is present largely in a dissolved (filterable) phase i.e. it will remain in solution at the current pH of the conditioning pond, and will therefore be carried over to the outfalls, rather than settle out.

Table 5. Zinc and lead concentrations in the Rivers Drish and Rossestown compared to outfall concentrations

(a) Zinc in River Drish

	19/01/06	16/02/06	15/03/06	20/04/06	18/05/06
Discharge	0.194	0.160	0.190	0.188	0.263
Upstream discharge	< 0.001	0.007	< 0.001	< 0.001	0.015
Downstream discharge	0.106	0.050	0.058	0.120	0.181
Castletown Bridge	0.103	-	-	0.117	-
Boolabeha Bridge	0.095	-	-	0.125	-

(b) Lead in River Drish

	19/01/06	16/02/06	15/03/06	20/04/06	18/05/06
Discharge	0.029	0.011	0.021	0.011	0.013
Upstream discharge	0.002	0.002	0.011	0.002	< 0.001
Downstream discharge	0.010	0.004	0.013	0.016	< 0.001
Castletown Bridge	0.007	-	-	0.011	-
Boolabeha Bridge	0.007	-	-	0.004	-

(c) Zinc in Rossestown

	19/01/06	16/02/06	15/03/06	20/04/06	18/05/06
Discharge	0.170	0.144	0.188	0.192	0.247
Upstream discharge	< 0.001	0.004	0.003	< 0.001	0.007
Downstream discharge	0.072	0.045	0.061	0.121	0.104

(d) Lead in Rossestown

	19/01/06	16/02/06	15/03/06	20/04/06	18/05/06
Discharge	0.025	0.007	0.011	0.015	0.009
Upstream discharge	< 0.001	0.004	< 0.001	0.007	< 0.001
Downstream discharge	0.005	0.003	0.004	0.012	< 0.001

- Suspended solids concentrations of the two outfalls are well within IPC limits. However, we recommend that suspended solids concentrations at the outfalls are checked by the collection of large (10 – 20 L) grab samples, since it is possible that the velocity of water at the outfalls prevents representative uptake of particulates by the autosamplers at these locations. We also recommend that these particulates are analysed for metals content, to assess whether they are in fact a major contributor to the elevated sediment-metal concentrations in the two rivers.

- Metal concentrations in the water column of the rivers below the discharges to the Rivers Drish and Rossestown are in fact low and are therefore not, in themselves, a cause for concern. However, we would recommend that the Lisheen mine commences routine sampling and analysis of the river waters at points both upstream and downstream of the two outfalls. In particular it is important that both total and dissolved concentrations of metals are determined on a routine basis. This will assist in evaluating improvements accruing from the recommended actions outlined later in this report.

3. METALS IN RIVER SEDIMENTS

3.1 Sediment-metal concentrations

The results of sediment metal analyses shown in Figure 1 were the catalyst for this report, and many of the additional sampling and exercises that the Lisheen Mine has undertaken during 2006. These data were reported by Aquens Ltd in a report by Lyons *et al.* (2006). Subsequent analysis of sediment has been undertaken by Bord na Móna, and by Macaulay Enterprises (part of the Macaulay Institute), Aberdeen. Results of lead and zinc analyses for all three sampling exercises are shown in Tables 6 (River Drish) and 7 (River Rossestown).

Table 6. Results of sediment-metal analyses, by 3 laboratories, for the River Drish (all results in mg/kg)

Sampling location or I.D. (from upstream to downstream)	Pb			Zn		
	Lyons	BnM	Mac.	Lyons	BnM	Mac.
Upstream		789			4078	
Upstream 2	37			1281		
Upstream 1	91			2417		
Drish outfall / D7	6179	5	5366	88200	10	23144
D8			5796			23928
Castletown / D9	3495	56	4547	46300	419	17917
D11			316			991
D10			850			3713
D6			183			755
D5			50			221
Boolabeha / D4	457	24	35	11900	80	136
D3			45			386
Drish Bridge	104			5189		
D2			21			170

Notes:
Lyons: Aquens report authored by Lyons *et al.* (2006)
BnM: Bord na Móna
Mac.: Minerex report; analysis by Macaulay Enterprises (Macaulay Institute, Aberdeen)

Table 6 in particular illustrates the substantial differences between the results of the sampling and analysis exercises. The two most obvious explanations for these differences are (1) substantial spatial and temporal heterogeneity of metal concentration within the river bed sediments and / or (2) differences in sampling and analytical methods.

The most recent sampling exercise was conducted by Minerex (with analysis by Macaulay Enterprises). The Minerex report indicates that 7 samples were taken from a single location below the outfall to the Rossestown, but individual analyses are not available to allow an assessment of possible heterogeneity in sediment-metal concentrations. It will only be possible to assess such heterogeneity when the results of multiple samples, collected from the same locations, and analysed in exactly the same manner, become available. It is certainly the case, however, that previous workers have found spatial and temporal heterogeneity in the distribution of metals in river sediments (e.g. Hudson-Edwards *et al.*, 2006).

Table 7. Results of sediment-metal analyses, by 2 laboratories (plus one off sample by Unipure), for the River Rossestown (all results in mg/kg)

Sampling location or I.D. (from upstream to downstream)	Pb		Zn		
	Lyons	Mac.	Lyons	Mac	Unipure
Upstream 2	14		303		
Upstream 1 / L3	30	15	677	102	
Rossestown outfall / L1	2991	5020	52600	20267	22900
R9		155		471	
R10		10		52	
R13		9		56	
R8		27		153	
R12		59		237	
R11		70		238	
Lisaticy / R7	241	101	9022	502	
R6		34		181	
R5		33		181	
R4		22		165	

Notes:

Lyons:	Aquens report authored by Lyons *et al.* (2006)
Mac.:	Minerex report; analysis by Macaulay Enterprises
Unipure:	Unipure Europe Ltd., Monmouth, Wales; note this result from a single grab sample.

3.2 Procedures for sediment-metals analysis

There are many methods available for the sampling and analysis of river sediments. In particular, there are numerous 'operationally defined' extraction procedures for metals analysis, ranging from methods which extract only the very weakly bound metals, through methods designed to determine metals that are 'bioavailable', to those very aggressive procedures that determine total metal concentration (irrespective of the particular metals' mobility). Unfortunately the lack of uniformity in the methods often makes direct comparison difficult, and this is an issue here also, since the methods used to acquire the results shown in Tables 6 and 7 are slightly different. Bord na Móna and Macaulay have used an Aqua Regia digestion, which essentially entails extraction of metals using a combination of nitric and hydrochloric acid. This is an aggressive method, designed to maximise extraction. The methods differed in the size fraction of sediment analysed; Bord na Móna sieved to analyse sediment < 0.15 mm, whereas Macaulay sieved to determine sediment-metal concentration on the < 2 mm fraction. Since higher concentrations of Zn are usually associated with the finer sediment fraction, the results in Table 6 are all the more confounding, since the Macaulay's results are up to several orders of magnitude higher than those of Bord na Móna. Aquens Ltd used a slightly different method, entailing digestion in a microwave at 180°C with nitric acid. However, this is also an aggressive method and, like the Aqua Regia method, would be expected to recover all metals from the sediment. Aquens Ltd sieved samples to obtain the 0.15 mm or 0.063 mm fraction as required. For all sampling and analysis exercises, detailed clarification is required from the laboratories regarding the method of laboratory drying of sediment samples, as it is not currently clear whether the results reported in Tables 6 and 7 are wet weight or dry weight.

Lisheen mine initially used Aquens Ltd to undertake sampling of sediments, with subsequent analysis by a laboratory of Aquens' selection. This was at the recommendation of the EPA. However, further precise clarification regarding the method is advised in light of the comments above.

3.3 Guideline values for Pb and Zn in sediments

The Irish Environmental Protection Agency has suggested to Lisheen mine that sediment-metal concentrations should be < 1,000 mg/kg Pb, and < 5,000 mg/kg Zn (both dry weight) in the Rivers Drish and Rossestown, based on reports from previous studies of mining districts in Ireland (EPA, 2003, 2004).

3.4 Alternative extraction procedures

Both of the guideline values cited above appear to be based on an Aqua Regia, or equivalent, extraction. Such a procedure does not necessarily represent that fraction of the bound metal which is 'bioavailable' however. Less aggressive procedures are more suited to assessing whether sediment-bound metals may be available to aquatic flora and fauna, and higher animals. For this reason Macaulay Enterprises conducted both Aqua Regia digestion and acetic acid digestion on samples provided by Minerex. The results for the Rivers Drish and Rossestown are presented in Tables 8 and 9 respectively.

Table 8. Comparison of extraction using Aqua Regia and acetic acid for sediment-metal concentrations in the River Drish

Sample ID	Distance from outfall	Pb		Zn	
		Aqua Regia	Acetic acid	Aqua Regia	Acetic acid
D7	10	5366	909	23144	2850
D8	260	5796	986	23928	2481
D9	583	4547	463	17917	1918
D11	1062	316	114	991	293
D10	1490	850	157	3713	1055
D6	1843	183	58	755	190
D5	4719	50	15	221	68
D4	5270	35	11	136	47
D3	9463	45	7	386	123
D2	15594	21	2	170	78

In the most contaminated sediments (sites D7-D9 and RL1 and RL2) Pb concentrations are > 70% lower, and Zn concentrations > 85% lower, when the acetic acid procedure is used. Caution must always be taken when interpreting such results, principally because different organisms' capacities for uptake of metals varies, and therefore no single operationally defined extraction procedure has the capability to accurately represent the full range of ecological conditions in the environment. Nevertheless, the data in Tables 8 and 9 strongly suggest that a substantial proportion of the metals in the sediments of the Rivers Drish and Rossestown are strongly bound, and may not therefore be available for uptake by flora and fauna. Results and interpretation of metal analysis of tissues from such organisms is the subject of the following section of this report, and Section 4.3 in particular suggests that accumulation of metals in benthic macroinvertebrates is in fact occurring, irrespective of the results above.

Table 9. Comparison of extraction using Aqua Regia and acetic acid for sediment-metal concentrations in the River Rossestown

Sample ID	Distance from outfall	Pb		Zn	
		Aqua Regia	Acetic acid	Aqua Regia	Acetic acid
RL3	-20	15	0.9	102	21
RL1	0	4979	1443	20267	2478
RL2	0	5020	479	20289	2238
R9	244	155	29	471	68
R10	1420	10	1.4	52	13
R13	1741	9	1.3	56	16
R8(L)	2144	27	3.0	153	44
R8(H)	2144	21	1.7	94	20
R12(L)	2650	59	12.8	237	77
R12(H)	2650	26	5.8	121	53
R11	3182	70	13.6	238	97
R7	3529	101	18.0	502	158
R6	5087	34	6.5	181	60
R5	6645	33	6.6	181	78
R4(L)	10640	22	4.9	165	67
R4(H)	10640	22	3.5	151	55

3.5 Management options for metal-contaminated river sediments

Notwithstanding the very substantial variations in results of river sediment-metals analyses, illustrated in Tables 6 and 7, visual observation alone is sufficient to show that there is a build up of sediment immediately adjacent to, and downstream from, the outfalls to the Rivers Drish and Rossestown. Sediment-metal analyses conducted by Lyons *et al.* (2006) and Macaulay Enterprises (and, in the case of the River Rossestown, corroborated by recent analysis by Unipure Europe Ltd), further suggest that these sediments are indeed heavily contaminated with lead and zinc, albeit only a fraction of the metal content appears to be 'bioavailable' (Table 8).

It is therefore recommended that targeted removal of sediments, in the vicinity of the two outfalls, is undertaken (i.e. targeting those areas where Zn and Pb concentrations exceed

5,000 mg/kg and 1,000 mg/kg respectively). Such an exercise must be conducted with great caution, since there is a very real risk of causing downstream sediment pollution due to disturbance of the material. We have consulted with co-workers at the Bureau of Land Management, USA, and the Canadian Centre for Mineral and Energy Technology (CANMET) regarding this matter. The conclusion of these discussions is that some short-term downstream effects are almost inevitable. In an effort to minimise such problems we advise removal of the material by some form of hydraulic suction, rather than more conventional dredging (the UK Coal Authority has experience of such approaches for sludge removal from mine water treatment systems, and we could provide contact details if required). The temporary installation of silt curtains or fences in downstream locations is also recommended, as it is inevitable that some material will be washed downstream. Clearly there will be a need to closely monitor downstream water quality before, during, and after sediment removal and, if such a course of action is followed, close liaison with the Irish EPA will of course be required. The precise details of the approach to sediment removal is the preserve of specialist contractors (the exact means by which it is most effectively undertaken depending on issues such as river flow volume, velocity and depth, as well as the nature of the sediment). Contact with appropriate companies can be made if required.

The results of sediment-metal analyses to date would suggest that there may be ‘hotspots’ of pollution along the course of the Rivers Drish and Rossestown, and selective removal of sediment in these locations may also be advisable (following discussions with the EPA). Minerex (2006) calculated that the total volumes of sediment in the Drish and Rossestown are 13,511 m^3 and 3,267 m^3 respectively. However, some major assumptions were made in deriving these values. In particular it was assumed that the volume of sediment between sample points remained the same. In the vicinity of the outfalls it seems most unlikely that this is the case, since visual observation alone is sufficient to suggest that sediment volume rapidly decreases with distance from the outfall. Coupled with the dynamic nature of sediment behaviour in riverine environments, it is therefore recommended that whilst the results of Minerex (2006) can be used as a guide to locations for selective sediment removal, visual observations of sediment ‘hotspots’, identified by walkover surveys, will be important to ensure the sediment removal exercise is conducted as effectively as possible.

Disposal of sediment removed will clearly need to be to a contained facility, and the existing Tailings Management Facility (TMF) on the Lisheen mine site is the obvious choice.

3.6 Conclusions and recommendations

- Three independent sampling and analysis exercises have been undertaken to establish sediment-metal concentrations in the Rivers Drish and Rossestown. The first of these exercises indicated highly elevated concentrations of zinc and lead in the sediments, and were the catalyst to this, and many other investigations, commissioned by Lisheen mine. However, subsequent sampling and analysis exercises (undertaken by Bord na Móna and Minerex / Macaulay Enterprises), have shown highly varied results, even for samples taken from the same locations. There are a number of possible reasons for this, most notably:

  - spatial and temporal heterogeneity in distribution of metals in river sediments
  - variation in the sampling procedures used
  - variation in the precise method of analysis of sediments

- There is clearly a need to clarify this matter, and as a first step we would recommend reaching firm agreement with the EPA on the precise sampling and analytical methodology to be used, and one which will provide the Lisheen mine, the EPA, and external experts, with confidence in the results of the analysis.
- The EPA has suggested to the Lisheen mine that appropriate limits for Pb and Zn in sediments are < 1,000 mg/kg and < 5,000 mg/kg respectively.
- A related matter is that of the extraction procedure used for the determination of sediment-metal concentrations. Aqua Regia (or equivalent) extraction has been used by all 3 laboratories to date. However, this is an aggressive extraction procedure, which is not necessarily representative of that portion of metals that may be 'bioavailable'. Therefore Macaulay Enterprises recently conducted a parallel extraction using acetic acid, which gives a far better indication of the likely bioavailability of metals. The results (Tables 8 and 9) indicate that the acetic acid procedure extracts approximately 70% less Pb, and 85% less Zn, implying that a large proportion of the sediment-metals may in fact not be 'bioavailable'. Again, we recommend that clarification from the Irish EPA is sought on this matter.
- Notwithstanding the comments above, visual inspection alone reveals accumulation of sediment adjacent to, and immediately downstream from, the two mine outfalls. In these areas, and potentially other 'hotspots' of contamination downstream (following confirmation by agreed sampling and analysis), we recommend selective removal and disposal of sediment. There is a serious risk of causing pollution if such an exercise is undertaken, however, and therefore close attention will need to be paid to addressing this risk, and consulting fully with the EPA.

4. ECOLOGICAL IMPACTS OF SEDIMENTATION / ELEVATED METALS CONCENTRATIONS

4.1 Background

Biological assessment of water quality in Ireland is based on the Q-system. This involves collection of a 'kick sample' of river substratum, subsequent analysis of which allows the type and diversity of invertebrate families present to be quantified, which in turn gives an insight into the extent of pollution at that site. Each invertebrate family is placed into one of five 'indicator groups', depending upon its sensitivity to pollution and the relative abundance of each of these groups is used to compute a Q-value, ranging from Q5, associated with unpolluted water, to Q1, associated with heavily polluted water. When assessing Q values in the Drish, the following points need to be remembered:

- The Q-system was designed primarily with organic pollution, rather than toxic pollution, in mind.
- A toxic effect is indicated, separately, by the suffix '/0' after the Q-value (i.e. Q3/0) whilst an asterisk indicates something worthy of special attention (typically heavy siltation of the substratum; McGarrigle *et al*., 2002).
- The relationship between the Q-system and the EU Water Framework Directive (WFD) has still not been finalised, but $Q \geq 4$ is likely to indicate good ecological status or better (John Lucey, pers. comm.). Anything less is likely to indicate moderate ecological status or lower and, therefore, to necessitate a 'programme of measures' to affect improvements.
- The WFD will necessitate assessment of not just benthic invertebrates but also macrophytes (aquatic plants), algae and fish.

4.2 Results

4.2.1 Benthic invertebrates

The results of surveys of benthic invertebrates in the Drish River by the EPA, along with surveys commissioned by Lisheen Mine itself, are given in Table 10, along with their likely assessments of ecological status. The points that stand out from Table 10 are:

- All sites, whether upstream or downstream of the discharge, are likely to be classified as no better than moderate status, according to the WFD;
- The observed impact immediately downstream of the Drish outfall is of sediment, not toxic effects;
- Toxic effects are observed further downstream (NE Castletown).

Analyses of numbers of individuals and taxa largely confirm these data (Figures 4 and 5). Site 4 (NE Castletown), the only site where a toxic impact was recorded, also has the lowest number of individuals overall and the joint lowest number of taxa, despite a mixed substratum (cobbles, gravel, pebbles, sand). However, there is a relatively rich macrophyte flora (Sweeney, 2005) at site 4 (see below), and trout were observed during the site visit by this author in June 2006 (note that macrophyte results should be interpreted with caution as these are the observations made to support interpretation of invertebrate data, and are not the results of a comprehensive macrophyte survey).

Table 10. Biological survey results from Drish and Longetown Rivers, 1992 – 2006 (1992 – 2002 surveys by EPA; 2004 - 2006 surveys by Pascal Sweeney)

EPA code	Present code	Location	1992	1996	1999	2002	2004	2005	2006
40	1	U/s Longfordpass			3-4	3-4	3	2-3	3-4
	2	100 m u/s discharge					2-3	2-3	3
	3	100 m d/s discharge					3*	2-3*	2*
70	4	Br., NE Castletown	4-5	3-4	2/0	2-3/0	3/0*	2-3/0*	2-3/0*
	5	Br., NW Castletown					3*	3	3*
100	6	Boolabeha Bridge	4	4	3-4	3	3	3	3

Blue = likely to be classified as ‘good ecological status’
Green = likely to be classified as ‘moderate ecological status’
Yellow= likely to be classified as ‘poor ecological status’

N.B. A toxic effect is indicated, separately, by the suffix ‘/0’ after the Q-value (i.e. Q3/0) whilst an asterisk indicates something worthy of special attention (typically heavy siltation of the substratum

Figure 4. Total number of individuals recorded at biological sampling sites on the River Drish in 2004, 2005 and 2006

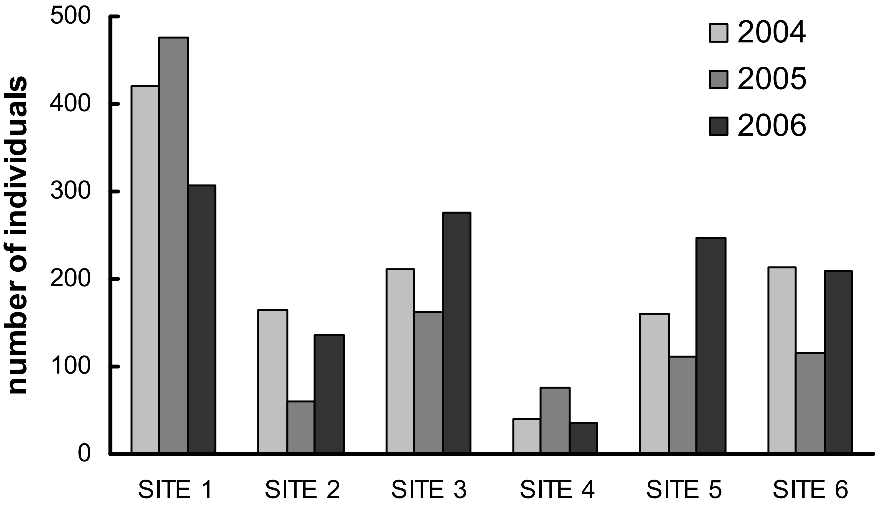
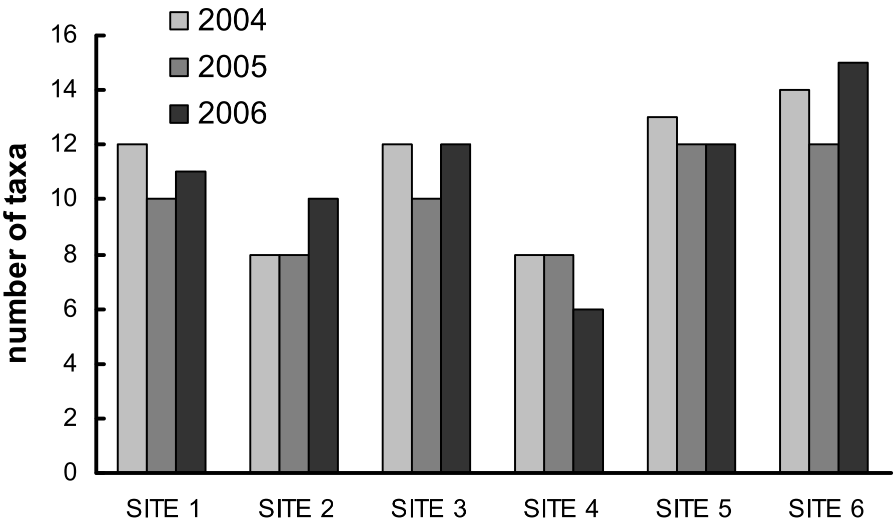


Figure 5. Number of taxa recorded at biological sampling sites on the River Drish in 2004, 2005 and 2006



However, it is difficult to disentangle the various factors that govern the biota in the Drish River. The Q values upstream of the discharge suggest a significant nutrient / organic input to the river. Notes in Sweeney (2004, 2005, 2006) suggest a change in physical habitat between sites 1 and 2 that may be responsible for the observed differences between these sites upstream of the discharge.

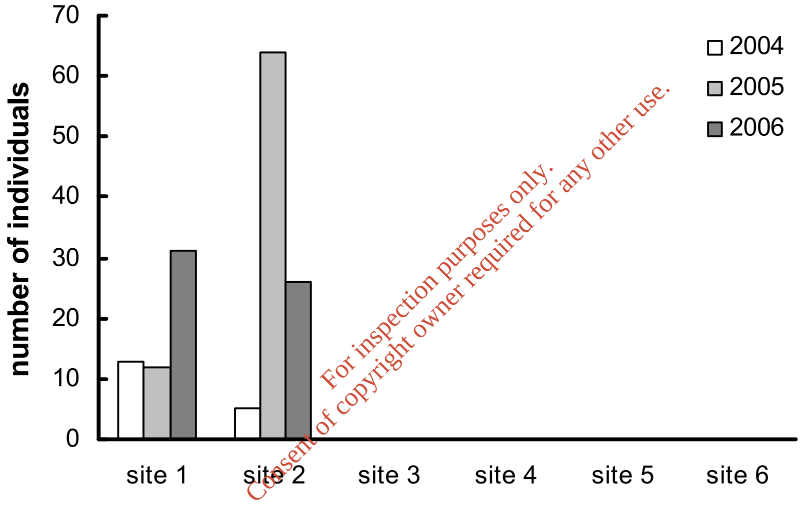
The increase in both number of individuals and taxonomic richness between sites 2 and 3 may reflect the change in habitat – the nature of site 2 is such that many of the invertebrate taxa may be associated with the vegetation rather than the substratum, and may therefore have been missed by the sampling method. Another possibility is that the river, at this point, is incompletely mixed, allowing metal-sensitive taxa to survive.

In terms of number of taxa and individuals, all sites downstream of the mine outfall to the Drish (with the exception of site 4) fall between sites 1 and 2, probably as a result of the confounding influence of habitat differences and other effects of the discharges (e.g. siltation, temperature, flow regime).

The fauna at sites with Q3 are typically dominated by 'Group C' taxa ('tolerant forms'). Taxa within this group have different types of response to heavy metals, with some (e.g. Baetidae, Simulidae, Hydracarina) having several records of tolerance to metals (Kelly, 1988; Norris et al., 1982) whilst others (Mollusca, Gammarus) are known to be sensitive to heavy metals. From the point of view of this study, it is the distribution of the latter groups along the Drish that is more interesting and both of these groups have only been found at sites 1 and 2 (both upstream of the discharge) in recent years (Figures. 6a and 6b).

Whilst Mollusca (snails, freshwater mussels) are generally regarded as sensitive to heavy metals and are most abundant upstream of the discharge, the change in substratum downstream may also exert an effect, particularly at site 3. Gastropods (snails – e.g. *Physa*) crawl across a surface removing the fine coating of algae and microorganisms. The predominance of silt at site 3 may have created a problem. It is possible that gastropods were present on the vegetation at downstream sites but this is not sampled for routine biological assessments. Sphariedae (pea mussels) have a variety of habitats within a stream, depending on the species. Whilst *Sphaerium* crawls about on plants with a long, tongue-like foot and cannot live in bare mud or silt, *Pisidium* is a filter-feeder that lives in mud (Hynes, 1963). The Q system does not distinguish between species of Sphariedae but neither is likely to be favoured by the physical changes in the river below the discharge.

Figure 6a. Distribution of Mollusca in the Drish River in 2004, 2005 and 2006



Gammarus (water-fleas) was abundant at site 1 but are low at all other sites (Figure 6b). This is a very common genus in hard waters and is tolerant to moderate levels of organic pollution although it is generally regarded as being sensitive to metal pollution. The low numbers recorded downstream of the discharge might be explained by the increase in metal concentrations.

4.2.2 Macrophytes

Systematic surveys of macrophytes were performed as part of the initial environmental impact study in 1991 but have not been performed subsequently although the three reports on benthic invertebrates (Sweeney, 2004, 2005, 2006) all include notes on the macrophyte taxa observed during these studies. Unfortunately, differences in the way that the studies were performed means that it is not possible to do more than make superficial comparisons of the data.

Little can be concluded about the effect of the mine on the aquatic plant communities based on the spatial surveys of Sweeney (2004, 2005, 2006). There was no obvious decrease in diversity downstream of the discharge (Figure 7), as might be expected if metals, in particular, were exerting a significant effect (indeed, site 4 had the richest flora of all sites visited). Filamentous algae were recorded at a number of sites, particularly below the discharge.

Figure 6b. Distribution of *Gammarus* in the Drish river in 2004, 2005 and 2006 surveys

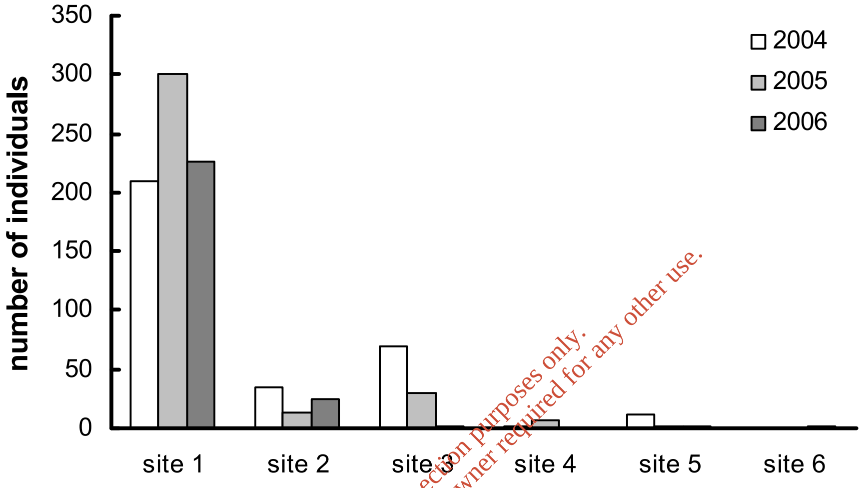
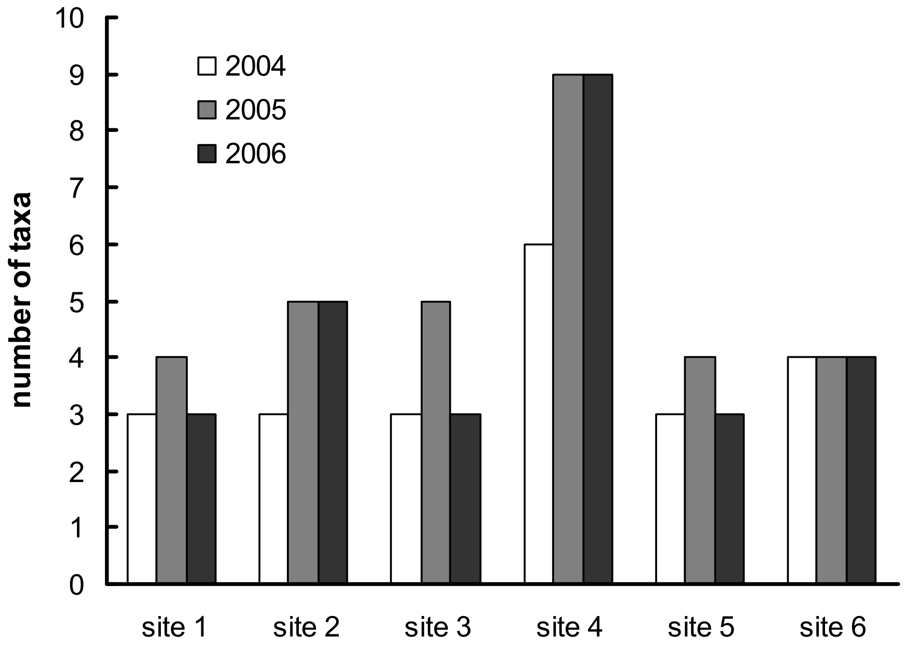


Figure 7. Macrophyte species richness recorded at biological sampling sites on the River Drish. Based on observations in Sweeney (2004, 2005, 2006)



Two of the sites visited by Sweeney (2004,2005,2006) were also included in the baseline study – u/s Castletown Bridge (site 4 in this study) and u/s Boolabeha Bridge (site 6). The flora at the former is described as having 'a proliferation of semi-eutrophic, eutrophic and pollution tolerant species' and has several species in common with those observed at the site by Sweeney (2004, 2005, 2006) with one important exception: the baseline survey reports that the filamentous alga *Cladophora glomerata* was the dominant plant ("approximately 90%" (*sic*)) with long, deep green filaments carpeting the river bed. Lower densities of 'filamentous algae' are reported by Sweeney (2005, 2006), with a maximum 40% cover of 'filamentous algae' reported in 2004. Similarly, at Boolabeha Bridge, *Cladophora* was reported to be 'abundant' in the baseline studies but 'filamentous algae' are now sparse. At both sites, *Oenanthe fluviatilis* (water dropwort) seems to be less abundant during recent surveys than it was during the baseline survey. More significantly, a sample of filamentous alga collected from site 5 in August 2006 and similar in macroscopic appearance to material observed at other sites downstream of the outfall in June 2006 was *Microspora flocculosa*, rather than *Cladophora*. This is significant as *Cladophora* is sensitive to elevated metal concentrations (Whitton et al., 1989) whilst there are a number of records of metal tolerant populations of *Microspora* (Kelly, 1988).

4.2.3 Fisheries

The baseline survey indicated that the Drish, in particular, was an important salmonid fishery and reported a significant number of spawning redds for both salmon and trout in the Drish from Castletown to the confluence with the Suir, along with healthy stocks of both salmon and trout and a variety of other fish. Anecdotal reports that the fishery has declined in recent years, are supported by electrofishing surveys reported in Lyons et al. (2006) who concluded that the fishery potential was limited and that there was poor recruitment of salmonids. However, there are also reports to the contrary, specifically a report by O'Grady (2006). He notes a decline between 1983 and 2004 at two of three sites for which comparative data are available but also notes differences in methodology that may affect the comparison and also comments that the 2004 stock levels, though lower than in the past, would still be regarded as good, in national terms. Recent studies do not appear to have examined the condition of redds but these are likely to be vulnerable to siltation so suspended solids from the discharge cannot be discounted as a cause of the decline in the fishery.

4.3 Accumulation and toxicity of metals

4.3.1 *Gammarus*

Metal concentrations in *Gammarus duebeni* were studied by Aquens Ltd (2006). Their study was limited by the low numbers of *Gammarus* found downstream of the discharges but samples of a size suitable for analysis were collected from sites 1 and 3 on the River Drish, as well as from sites upstream and downstream of the Rossestown discharge.

Results of these analyses show increases in all four metals at sites below the Lisheen outfalls, compared with concentrations observed upstream of the outfalls (Figs 8-11).

Aquens Ltd (2006) also demonstrate that tissue concentrations upstream of the outfalls are typical of those recorded from uncontaminated streams elsewhere.

Figure 8. Cadmium concentration in *Gammarus duebeni* from the Drish and Rossestown Rivers, April 2006. Concentrations upstream of the two discharges are both below the detection limit of 0.25 mg/kg

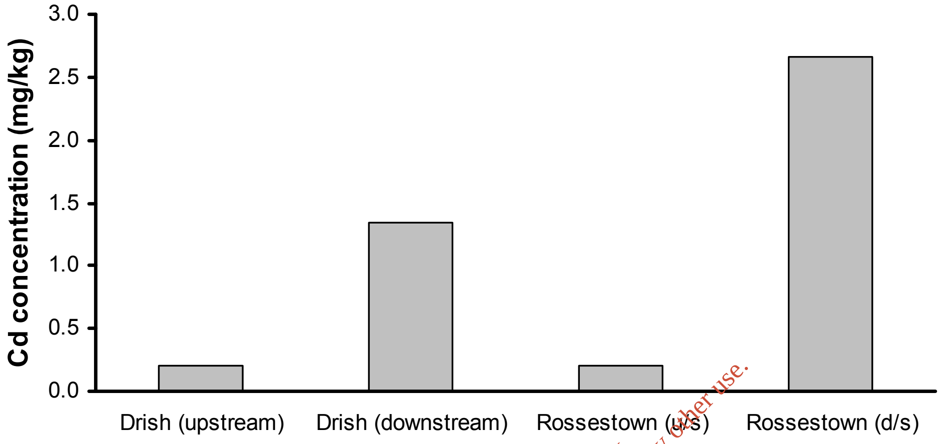


Figure 9. Copper concentration in *Gammarus duebeni* from the Drish and Rossestown Rivers, April 2006

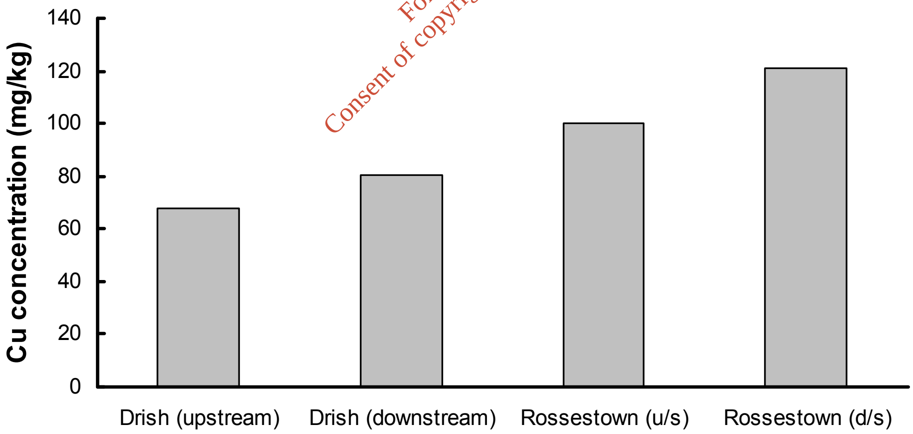


Figure 10. Lead concentration in *Gammarus duebeni* from the Drish and Rossestown Rivers, April 2006

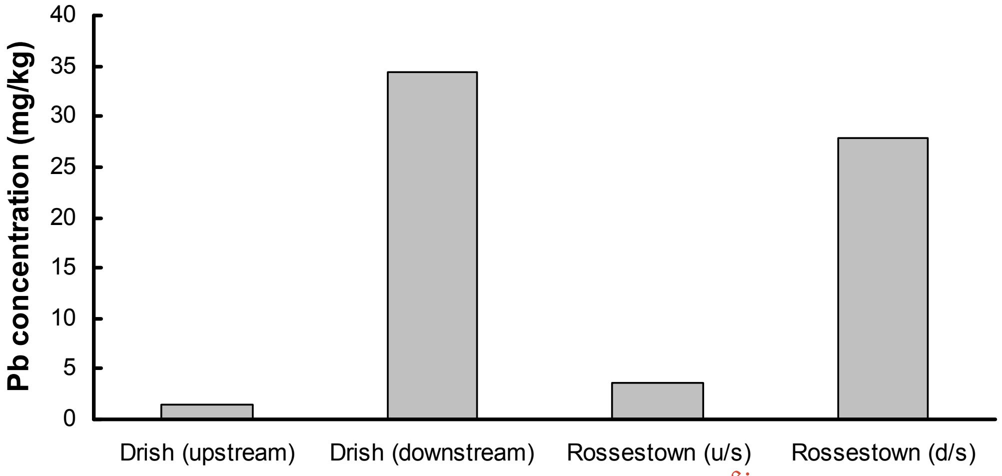
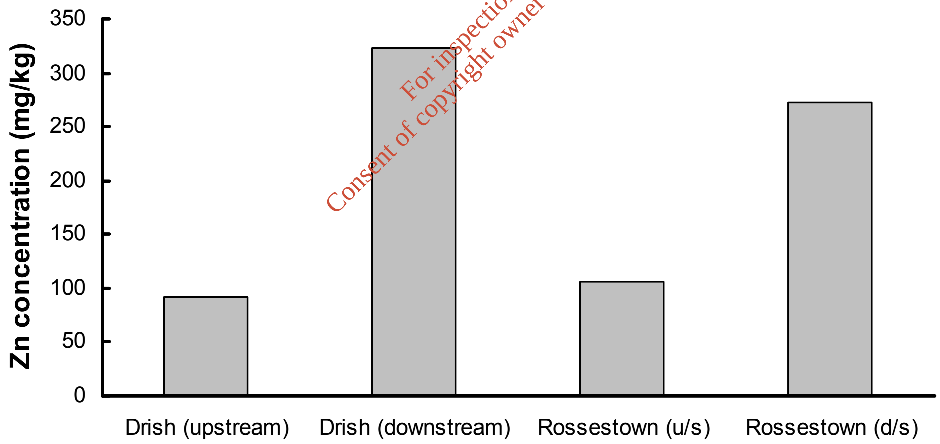


Figure 11. Zinc concentration in *Gammarus duebeni* from the Drish and Rossestown Rivers, April 2006



4.3.2 *Asellus*

Metal concentrations in a second invertebrate, *Asellus*, have also been studied (Baars et al., 2006). Like *Gammarus, Asellus* is a detritivore, feeding on dead leaves and bacterial growths in and around sediments, so it should be a good indicator of the bioavailabiity of metals in sediments. There is also evidence from the literature that *Asellus* is tolerant to elevated concentrations of heavy metals (Kelly, 1988).

Results show significant increases in metals at all sites on the Drish, with the highest concentrations observed at Drish Bridge (Figs 12-15). Concentrations in the Rossestown immediately below the discharge are also higher than the control site on the Drish.

Figure 12. Cadmium concentrations in *Asellus* from the Drish and Rossestown Rivers, 2006

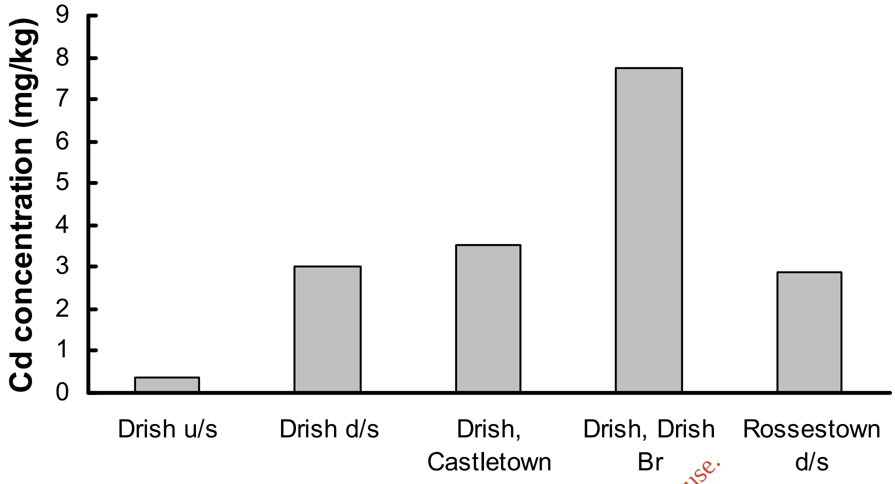


Figure 13. Copper concentrations in *Asellus* from the Drish and Rossestown Rivers, 2006

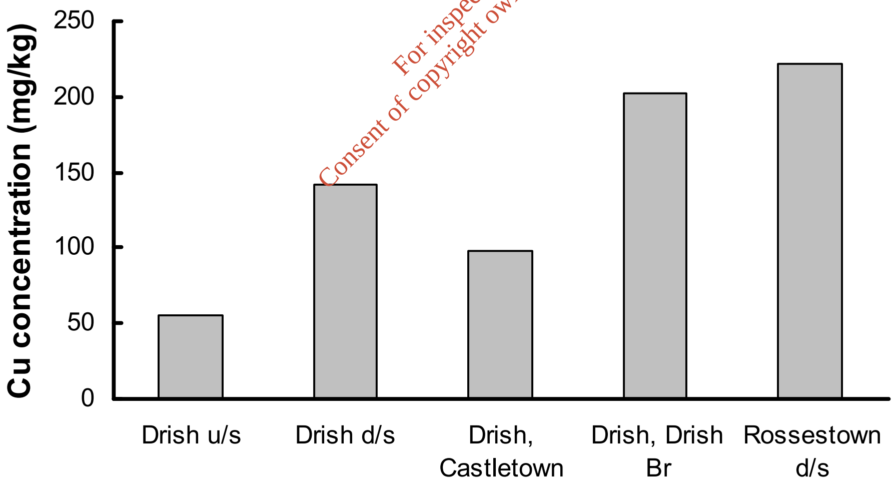


Figure 14. Lead concentrations in *Asellus* from the Drish and Rossestown Rivers, 2006. The mean concentration upstream of the discharge to the Drish is 0.75 mg/kg

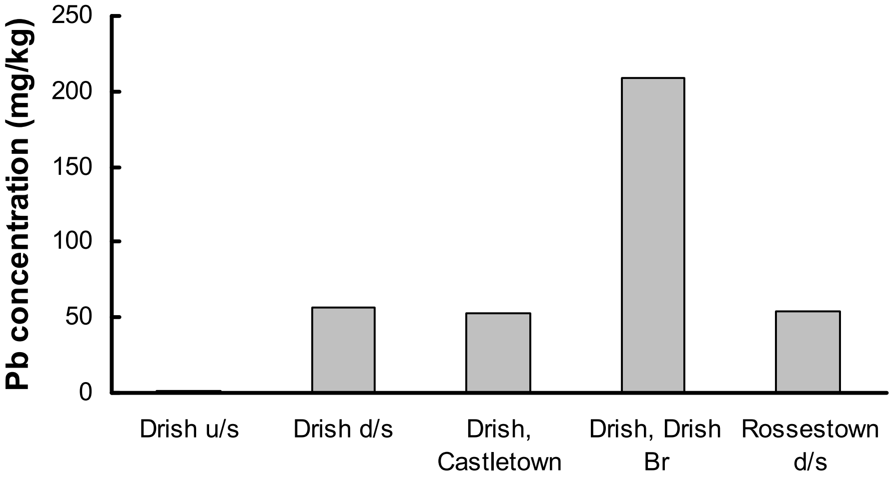
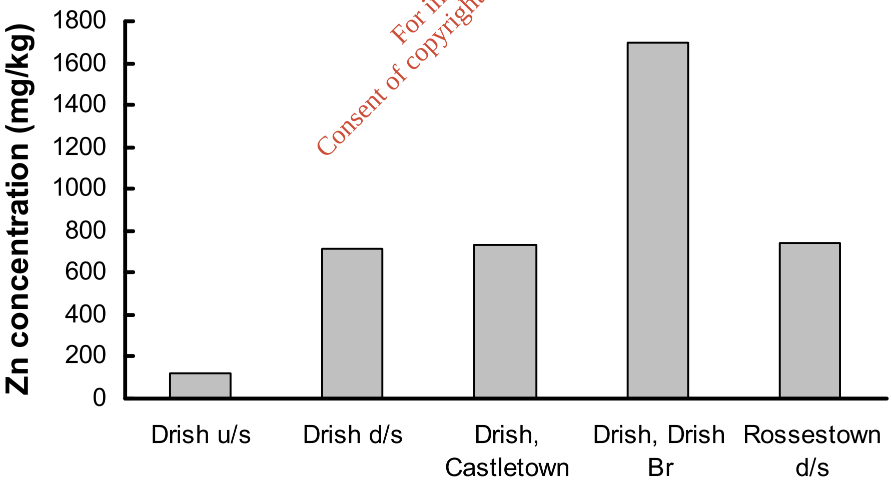


Figure 15. Zinc concentrations in *Asellus* from the Drish and Rossestown Rivers, 2006



4.3.3 Fish

Analysis of metal concentrations in fish have been performed with two separate objectives: first, as 'top consumer' in the river ecosystem, salmon and trout may be expected to accumulate metals to higher concentrations than are found in prey invertebrates, as a result of 'biomagnification'. This could make them, potentially, more vulnerable to elevated metal concentrations than these other taxa. Second, fish muscle tissue is one possible pathway by which humans may be exposed to the metals in the Drish and Rossestown.

A thorough survey of metal concentrations in fish tissues in the Drish, Rossestown and Suir was performed as part of the baseline survey (RPS Cairns Ltd, 1995) and more recently (Lyons et al., 2006). The results of the latter study are summarised in Table 11. On the whole, brown trout had higher metal concentrations than pike, which may reflect feeding strategies (brown trout feed on benthic organisms and will be in closer contact with sediments whilst pike feed in the water column). Most concentrations for trout in 2006 are higher than concentrations reported during the baseline study and show a trend of decreasing metal concentrations with distance from the outfall. These observations would suggest that the mine is responsible for the increased metal concentrations. Highest concentrations were observed in the kidneys and gills whilst concentrations in the muscles were substantially lower. A few fish also have elevated concentrations of As and Hg (Table 11 and Lyons *et al*., 2006) although the maximum concentrations recorded in fish muscle are still low compared to concentrations recorded in *Asellus* and *Gammarus* (see above).

4.3.4. Overview and implications of metal accumulation

Although data are available for just two invertebrate species and fish, some tentative conclusions about the pathways of metal accumulation, and its implications can be drawn. Data in chapter 3 has demonstrates the relatively high metal load of the sediments discharged to the Drish and Rossestown Rivers, coupled with high levels of organic matter. Microscopic examination of the sediments confirmed the organic nature of the sediments, and also revealed a large number of bacterial filaments. The identity of these is not clear, but *Beggiatoa*, a chemoautotrophic bacterium which obtains its energy by oxidizing sulphur compounds, is a strong candidate. Blooms of *Beggiatoa* at Lisheen occurred between August 2002 and April 2003 and studies by the mine at the time concluded that the likelihood of a reoccurrence of the blooms was dependent on nutrient concentrations in the discharge waters, specifically BOD and SO_4. Although the mine monitors nutrients in the discharges to prevent blooms, it is likely that *Beggiatoa* is present in lower numbers most of the time.

Asellus and *Gammarus* are both detritivores, meaning that they thrive on decaying organic matter and the organic-rich sediments in the Drish immediately downstream of the outfall are likely to provide ample sustenance. However, the sediments are also metal-rich, leading to high concentrations of metals recorded in both of these invertebrates. It would be interesting to compare metal concentrations in these taxa with those in invertebrates with different feeding strategies, but the numbers required for analyses probably preclude this. It is, however, plausible, that this is the reason why *Gammarus* (known to be metal-sensitive) is less abundant downstream of the discharge although changes in the nature of the substratum along the river make comparisons difficult.

Under normal circumstances, *Asellus* and *Gammarus* would both form a significant part of the diet of trout and salmon in an enriched lowland river such as the Drish. However, the low numbers of *Asellus* and *Gammarus* in the Drish mean that this is not likely to be a significant pathway and, instead, the diet of salmon and trout is likely to be dominated by other taxa, which will probably have lower body burdens of metals as their food is less metal-enriched than that of *Asellus* and *Gammarus*.

Direct comparisons between concentrations in invertebrates and fish are difficult as invertebrate concentrations represent the entire body burden whilst the fish are dissected to allow separate analyses of various tissues. Generally, concentrations in fish muscle tissue are lower than concentrations in invertebrates, whilst some analyses of other tissues (particularly kidneys) are higher. The kidneys function as ‘waste purification plants’ in the body and are more likely to accumulate metals than other tissues. However, the kidneys form a relatively small part of the total biomass of an organism, so the overall body burden is still likely to show little or no biomagnification, compared to the invertebrates. Reproductive stages are known to be much more sensitive to metals than adults and juveniles. Although concentrations in the Drish and Rossestown are low chronic effects on the fish cannot be ruled out. However, another possible cause of the poor state of the fishery may be the condition of the spawning redds (caused by physical siltation), and this deserves further investigation.

Table 11. Mean concentrations of metals in fish tissues from the Drish, collated from Lyons et al. (2006) compared with maximum concentrations reported in the baseline surveys (all units are mg/kg dry weight)

Site	species	tissue	As	Cd	Cr	Cu	Pb	Hg	Zn	n
3	Brown trout	kidney	29.5	7.15	7.15	33.2	7.15	7.15	1156	1
3	Brown trout	gill	3.58	1.44	1.04	3.26	14.7	0.37	1089	1
3	Brown trout	liver	4	0.71	5.17	415	0.5	3.79	245.7	1
3	Brown trout	muscle	20.66	0.14	0.46	1.53	0.14	2.65	40.7	1
3	Pike	kidney	5.89	4.54	3.37	14.7	4.11	2.44	608.6	6
3	Pike	gill	5.43	1.98	1.15	3.75	0.38	15.3	460.08	6
3	Pike	liver	19.23	17.23	18.01	43.42	17.63	17.11	175.68	6
3	Pike	muscle	6.06	0.82	0.49	0.97	0.2	0.47	37.14	6
4	Brown trout	kidney	3.91	3.4	1.5	10.64	8.08	0.84	399.96	9
4	Brown trout	liver	1.85	1.84	2.18	825	1.75	0.93	220.63	9
4	Brown trout	gill	2.37	1.08	0.91	3.31	5.96	0.26	43.75	7
4	Brown trout	muscle	1.24	0.14	0.41	2.1	0.2	0.31	36.7	9

4	Pike	gill	2.9	1.39	1.16	2.89	0.31	4.94	459.41	9
4	Pike	kidney	2.46	3.39	2.07	6.22	2.31	1.26	334.17	9
4	Pike	liver	1.85	0.84	1.26	53.82	0.88	0.67	235.08	9
4	Pike	muscle	3.61	0.14	0.43	1.02	0.18	0.58	38.07	9
6	Brown trout	gill	2.28	1.18	2.74	2.64	4.98	0.32	1164.33	6
6	Brown trout	kidney	3.39	3.66	3.66	10.43	3.62	1	628.28	8
6	Brown trout	liver	1.14	2.17	0.78	448	1.45	0.6	230.86	8
6	Brown trout	muscle	1.13	0.14	0.41	1.7	0.14	0.31	42.9*	8
6	Eel	muscle	0.56	0.14	0.5	1.28	0.14	0.52	79.29	4
6	Pike	kidney	2.1	3.08	1.99	5.32	1.28	0.56	474.8	1
6	Pike	gill	1.55	0.63	0.83	2.05	1.35	0.21	339.9	1
6	Pike	liver	0.7	0.5	0.44	32.4	0.9	0.43	190.1	1
6	Pike	muscle	0.6	0.14	0.28	0.58	0.14	0.39	20.04	1
8	Brown trout	gill	1.13	0.22	0.66	2.31	0.83	0.31	1119.87	13
8	Brown trout	kidney	2.53	1.1	1.74	18.73	1.18	1.01	745.26	14
8	Brown trout	liver	1.21	0.74	1.05	263	0.58	0.56	272.9	14
8	Brown trout	muscle	1.08	0.14	0.42	1.49	0.15	0.34	172	14
8	Eel	muscle	0.47	0.14	0.3	1.09	0.19	0.96	74.73	3
Baseline	**Brown trout**	**Muscle**	**1.4**	**< 0.05**			**< 5**	**0.33**	**18.5**	

4.4 Human exposure pathways

There are concerns that, if metals are entering the food chain, there may be consequences for human health in the Lisheen area. Two possible pathways are considered here: first, the local population is exposed to metals by eating fish caught from local rivers and, second, metals are ingested via cattle that use the Drish and other contaminated rivers as drinking water.

Risks to human health are discussed in Moraes (2006). This work is, necessarily, underpinned by a number of assumptions about the quantity of each product (fish, meat, milk) that is obtained from the local area, and the amount that is consumed in a year. Based on precautionary estimates (50% of beef and milk obtained from local area and consumed 365 days per year; 3% of the fish ingested by the local population consisting of animals fished downstream of the mine outfalls consumed 365 days per year), the report concludes that:

- Levels of aluminum, arsenic, iron and lead in water from at least one of the rivers are above European and/or World Health Organization drinking water guidelines. Arsenic and iron exceed drinking water guidelines even upstream of the mine outfalls. The aluminum exceedance is for one result, the average result for the period of measurement is well within limits.

- The levels of all chemicals meet the European criteria for quality of surface water intended for abstraction of drinking water after normal physical treatment, chemical treatment and disinfection. Therefore adequate treatment should be applied if water from both rivers is abstracted for human consumption.

- Risk due to ingestion of beef and milk of animals that consume water downstream of the outfalls from the mine is considered to be negligible.

- Risk due to ingestion of fish living in both rivers is also considered to be negligible.

Interestingly, Moraes (2006) also highlights concentrations of several metals as being above drinking water quality guidelines upstream as well as downstream of the discharge on the Drish and Rossestown Rivers, suggesting that concentrations in the catchment may be naturally elevated. Note, too, that neither river is a source of potable water, so the relationship with drinking water quality guidelines should not have a direct bearing on human health within the catchments.

In addition, analyses of milk from dairy cattle in the vicinity of the mine have not shown levels of zinc and lead outside the normal range (Table 12), and concentrations of Pb are well under the limit set by the EU (comparable standards for other metals have not been published). There is no obvious difference between stock that is known to drink from the River Drish (marked with an asterisk in Table 12) compared to stock that does not. Concentrations of these metals in cattle blood have also been measured and, again, concentrations are within the normal ranges

4.5 General conclusions

In conclusion, although there are only limited data available, these generally support the conclusions of previous reports, that the mine has an impact on the River Drish, which is particularly marked at Site 4, NE Castletown. In particular, the scarcity of two taxa that are generally common in hard water streams with moderate levels of nutrient / organic pollution (*Gammarus* and *Cladophora*) points to a likely impact of metals on the Drish although metal concentrations in the river water downstream of the outfalls, though elevated, are unlikely to be the sole cause of the changes.

All of these observations must be set in context; the Drish is unlikely to achieve ‘good ecological status’ regardless of the impact of Lisheen Mine, unless other impacts in the catchment are addressed as part of a programme of measures. On the other hand, the EPA has a statutory duty under the WFD to raise the status of the Drish so that it achieves good ecological status, so the condition of the Drish upstream of the discharge is unlikely to be a reason for not addressing the state of the river downstream in itself. The WFD does allow 'less stringent objectives' (LSO) to be applied in some instances but, in the present case it is important to note:

- The designation of LSOs does not affect the assessment of ecological status *per se* – it just means that the EPA can set a target quality lower than good ecological status for a particular water body.
- The EPA will have to make a case for each proposed LSO and there is still some uncertainty about how the process will work and what will / will not be allowed.
- Our understanding is that a LSO will apply to groundwater in the Lisheen area, but not to surface water. However, we have not had confirmation on this matter.

Table 12. Results of metal concentrations in milk, performed by Eurofins (Farmers' stock marked with an asterisk drink directly from the River Drish)

	Lead	Nickel	Zinc	Cadmium	Arsenic	Chromium	Copper	Mercury
Farmer	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	< 0.006	< 0.01	6.04	0.001	< 0.01	< 0.006	< 0.06	< 0.004
2	< 0.006	< 0.01	4.46	< 0.001	< 0.01	< 0.006	< 0.06	< 0.004
3	< 0.006	< 0.01	4.89	< 0.001	< 0.01	< 0.006	< 0.06	< 0.004
4	< 0.006	< 0.01	3.21	0.002	< 0.01	< 0.006	< 0.06	< 0.004
5	< 0.006	< 0.01	4.64	0.001	< 0.01	< 0.006	< 0.06	< 0.004
6	< 0.006	< 0.01	3.78	0.001	< 0.01	< 0.006	< 0.06	< 0.004
7*	< 0.006	< 0.01	3.64	0.001	< 0.01	< 0.006	< 0.06	< 0.004
8	< 0.006	< 0.01	3.39	0.001	< 0.01	< 0.006	< 0.06	< 0.004
9	< 0.006	< 0.01	4.85	0.002	< 0.01	< 0.006	< 0.06	< 0.004
10*	< 0.006	< 0.01	3.72	0.001	< 0.01	< 0.006	< 0.06	< 0.004
11	< 0.006	< 0.01	2.73	0.001	< 0.01	< 0.006	< 0.06	< 0.004
Limit[1]	0.02							

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[1] COMMISSION REGULATION (EC) No 466/2001 of 8 March 2001 setting maximum levels for certain contaminants in foodstuffs

Methodologies associated with the Q system are not ideal for assessing the impact of heavy metals. However, a standard sampling method and analysis period means that quantitative data are comparable insofar as they all represent the same sampling effort. Use of a quantitative sampling method (e.g. Surber samplers) is probably not going to yield significantly more useful results, and the depth of the river at some points will make their deployment difficult. Data analysis could, however, be refined in order to focus on the response to the mine discharges (the Q system is designed for monitoring organic / nutrient enrichment). Future invertebrate surveys may benefit from species-level identification (genus-level in a few cases, e.g. Chironomidae), rather than identification to the taxonomic level required for the Q system (see comment on Ephemeroptera, above) (Pascal Sweeney has an archive of preserved specimens, so it should, in theory, be possible to produce these data retrospectively).

Other components of the biota have not been assessed to date in detail (excluding the notes on dominant macrophytes discussed above). Ecological status assessments for the WFD require data on algae, macrophytes and fish as well as benthic invertebrates and a broader perspective on the biota of the River Drish would be useful. The diatoms (a group of microscopic algae) are relatively quick and easy to sample and will give a good indication of the relative contributions of both nutrient/organic and metal impacts. WFD-compatible methods for both are under development for Ireland (North-South Share project) and diatom samples have already been collected from sites 1 and 5 by Pascal Sweeney.

Concentrations of metals in fish tissues are elevated at locations downstream of the outfall (declining with distance from the outfall). Concentrations of lead fall within European limits but there is no European limit for zinc in fish muscle in terms of mass per unit tissue weight, and further evaluation of the potential effects is recommended. Elevated concentrations of metals were not found in either cattle blood or milk.

5. REVIEW OF THE LISHEEN MINE WATER TREATMENT SYSTEM

5.1 Introduction

To provide a better understanding of the water handling system and the contribution each source makes to the metal load being discharged into the Rossestown and Drish rivers an intensive programme of water sampling was undertaken over a 6 week period commencing 9th June 2006 and ending 18th of July 2006. Samples were taken at the following locations and analysed to determine both the total and dissolved metal concentrations:

- Mine Water Treatment Plant (MWTP) dirty water feed (MWTP 4)
- Reclaim water from the Tailings Management Facility (TMF)
- Mine Water Treatment plant treated water (MWTP 5)
- Reclaim Water Treatment Plant (RWTP) dirty water (MWTP2)
- Reclaim Water Treatment Plant treated water (MTWP 1)
- Concentrator discharge to the TMF
- F2/F3 Fissure Water discharge in to the holding pond
- Mine/reclaim water treatment plant and F2/F3 fissure discharge into the conditioning pond (MWTP 3).
- Canal Water discharge into the conditioning pond
- Discharge from the Conditioning Pond
- Treated effluent from the sewage treatment plant
- Drish Outfall
- Rossestown Outfall

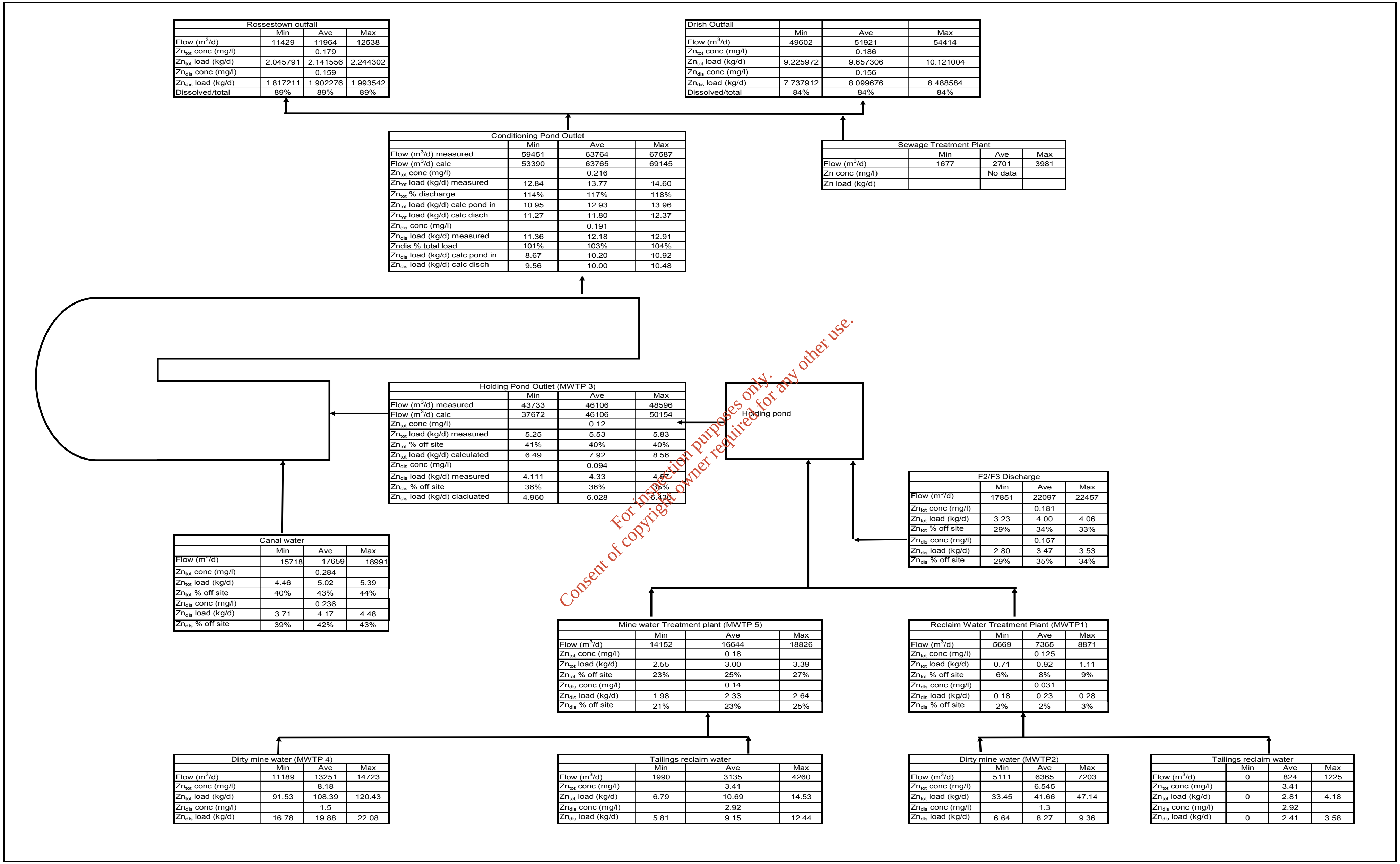
The average concentrations (Table 13) and flow measurements for this period have been used to develop mass balances for the prinicipal metals (zinc, lead and arsenic) and suspended solids loads discharged into the rivers. The results for these balances are summarised in Figures 16 to 19 respectively.

Where feasible, the mass balances have been validated by checking that the chloride, sodium and magnesium loads (flow x concentration) are conserved (as these elements are largely unaffected by the chemical reactions that occur within the water treatment system). In all cases the difference between the inlet and outlet load was less than 10%, and in most cases was less than 5%.

The significance of these results in terms of the performance of the existing water treatment system and potential improvements are discussed in the following subsections.

Table 13. Average Concentrations from June to July 2006 Study

Determinand		Water Treatment Plants					Holding pond		Conditioning pond		Outfalls	
		In			Out				In	out		
		MWTP	RWTP	TMF	MWTP	RWTP	F2F3	Out	Canal		Rossestown	Drish
pH		7.923	7.658	6.948	7.996	9.127	7.692	7.872	7.577	7.868	7.647	7.580
BOD	mg/L O_2										1.136	0.778
Sus Solids	mg/L	1998.946	1743.975	23.638	24.754	17.808	2.010	20.442	4.796	3.608	3.442	4.571
Sodium	mg/L Na	13.186	13.167	59.489	20.570	17.194	8.371	16.074	8.801	12.995	12.841	12.810
Ammonium	mg/L NH_4	1.948	1.758	6.470	2.356	2.196		1.511	0.586	1.175		0.165
	mg/L N	1.513	1.365	5.024	1.829	1.705		1.173	0.455	0.913		
Calcium	mg/L Ca	221.891	192.584	684.437	148.946	103.798	87.296	116.483	85.841	102.900	100.505	99.809
Magnesium	mg/L Mg	42.180	40.716	128.699	55.226	44.461	30.298	45.254	30.717	38.499	37.882	38.083
Potassium	mg/L K	5.086	4.931	83.802	8.524	7.639	3.636	6.628	4.847	8.109	5.946	6.851
Fluoride	mg/L F	0.157	0.153	0.504	0.138	0.106	0.062	0.107	0.084	0.101	0.082	0.080
Chloride	mg/L Cl	18.476	18.220	92.712	30.596	25.187	16.830	25.236	17.315	21.857	21.332	21.412
Nitrite	mg/L N	0.225	0.222	1.466	0.319	0.272	0.061	0.181	0.053	0.157	0.031	0.103
	mg/L NO_2	0.740	0.730	4.813	1.048	0.892	0.200	0.595	0.173	0.515	0.101	0.337
Nitrate	mg/L N	2.332	2.320	3.959	2.699	2.268	0.907	2.579	0.965	1.416	2.481	2.259
	mg/L NO_3	10.322	10.269	17.524	11.948	10.041	4.013	11.416	4.271	6.268	10.982	10.000
Phosphate	mg/L PO_4	0.010	0.008	0.006	0.010	0.021		0.010	0.008	0.092	0.014	0.021
Sulphate	mg/L SO_4	234.775	223.673	2627.315	599.345	427.400	23.044	395.307	33.355	245.512	235.261	236.980
Arsenic(Total)	mg/L As	0.294	0.347	0.014	0.021	0.018	0.014	0.016	0.025	0.017	0.013	0.015
Arsenic(Diss)	mg/L As	0.019	0.043	0.012	0.015	0.015	0.005	0.012	0.007	0.012	0.007	0.008
Iron(Total)	mg/L Fe	12.272	8.838	0.054	0.038	0.101	0.009	0.025	0.598	0.197	0.117	0.168
Iron(Diss)	mg/L Fe	0.014	0.200	0.047	0.042	0.033	0.006	0.011	0.024	0.043	0.010	0.008
Lead(Total)	mg/L Pb	7.222	6.116	0.136	0.029	0.062	0.007	0.015	0.018	0.014	0.013	0.015
Lead(Diss)	mg/L Pb	0.038	0.302	0.113	0.009	0.019	0.005	0.008	0.006	0.009	0.006	0.007
Zinc(Total)	mg/L Zn	8.179	6.545	3.410	0.179	0.125	0.181	0.120	0.284	0.216	0.179	0.186
Zinc(Diss)	mg/L Zn	1.499	1.302	2.922	0.139	0.031	0.157	0.094	0.236	0.191	0.159	0.156



Rossestown outfall

	Min	Ave	Max
Flow (m^3/d)	11429	11964	12538
Zn_{tot} conc (mg/l)		0.179	
Zn_{tot} load (kg/d)	2.045791	2.141556	2.244302
Zn_{dis} conc (mg/l)		0.159	
Zn_{dis} load (kg/d)	1.817211	1.902276	1.993542
Dissolved/total	89%	89%	89%

Drish Outfall

	Min	Ave	Max
Flow (m^3/d)	49602	51921	54414
Zn_{tot} conc (mg/l)		0.186	
Zn_{tot} load (kg/d)	9.225972	9.657306	10.121004
Zn_{dis} conc (mg/l)		0.156	
Zn_{dis} load (kg/d)	7.737912	8.099676	8.488584
Dissolved/total	84%	84%	84%

Conditioning Pond Outlet

	Min	Ave	Max
Flow (m^3/d) measured	59451	63764	67587
Flow (m^3/d) calc	53390	63765	69145
Zn_{tot} conc (mg/l)		0.216	
Zn_{tot} load (kg/d) measured	12.84	13.77	14.60
Zn_{tot} % discharge	114%	117%	118%
Zn_{tot} load (kg/d) calc pond in	10.95	12.93	13.96
Zn_{tot} load (kg/d) calc disch	11.27	11.80	12.37
Zn_{dis} conc (mg/l)		0.191	
Zn_{dis} load (kg/d) measured	11.36	12.18	12.91
Zndis % total load	101%	103%	104%
Zn_{dis} load (kg/d) calc pond in	8.67	10.20	10.92
Zn_{dis} load (kg/d) calc disch	9.56	10.00	10.48

Sewage Treatment Plant

	Min	Ave	Max
Flow (m^3/d)	1677	2701	3981
Zn conc (mg/l)		No data	
Zn load (kg/d)			

Holding Pond Outlet (MWTP 3)

	Min	Ave	Max
Flow (m^3/d) measured	43733	46106	48596
Flow (m^3/d) calc	37672	46106	50154
Zn_{tot} conc (mg/l)		0.12	
Zn_{tot} load (kg/d) measured	5.25	5.53	5.83
Zn_{tot} % off site	41%	40%	40%
Zn_{tot} load (kg/d) calculated	6.49	7.92	8.56
Zn_{dis} conc (mg/l)		0.094	
Zn_{dis} load (kg/d) measured	4.111	4.33	4.57
Zn_{dis} % off site	36%	36%	35%
Zn_{dis} load (kg/d) clacluated	4.960	6.028	6.436

Canal water

	Min	Ave	Max
Flow (m^3/d)	15718	17659	18991
Zn_{tot} conc (mg/l)		0.284	
Zn_{tot} load (kg/d)	4.46	5.02	5.39
Zn_{tot} % off site	40%	43%	44%
Zn_{dis} conc (mg/l)		0.236	
Zn_{dis} load (kg/d)	3.71	4.17	4.48
Zn_{dis} % off site	39%	42%	43%

F2/F3 Discharge

	Min	Ave	Max
Flow (m^3/d)	17851	22097	22457
Zn_{tot} conc (mg/l)		0.181	
Zn_{tot} load (kg/d)	3.23	4.00	4.06
Zn_{tot} % off site	29%	34%	33%
Zn_{dis} conc (mg/l)		0.157	
Zn_{dis} load (kg/d)	2.80	3.47	3.53
Zn_{dis} % off site	29%	35%	34%

Mine water Treatment plant (MWTP 5)

	Min	Ave	Max
Flow (m^3/d)	14152	16644	18826
Zn_{tot} conc (mg/l)		0.18	
Zn_{tot} load (kg/d)	2.55	3.00	3.39
Zn_{tot} % off site	23%	25%	27%
Zn_{dis} conc (mg/l)		0.14	
Zn_{dis} load (kg/d)	1.98	2.33	2.64
Zn_{dis} % off site	21%	23%	25%

Reclaim Water Treatment Plant (MWTP1)

	Min	Ave	Max
Flow (m^3/d)	5669	7365	8871
Zn_{tot} conc (mg/l)		0.125	
Zn_{tot} load (kg/d)	0.71	0.92	1.11
Zn_{tot} % off site	6%	8%	9%
Zn_{dis} conc (mg/l)		0.031	
Zn_{dis} load (kg/d)	0.18	0.23	0.28
Zn_{dis} % off site	2%	2%	3%

Dirty mine water (MWTP 4)

	Min	Ave	Max
Flow (m^3/d)	11189	13251	14723
Zn_{tot} conc (mg/l)		8.18	
Zn_{tot} load (kg/d)	91.53	108.39	120.43
Zn_{dis} conc (mg/l)		1.5	
Zn_{dis} load (kg/d)	16.78	19.88	22.08

Tailings reclaim water

	Min	Ave	Max
Flow (m^3/d)	1990	3135	4260
Zn_{tot} conc (mg/l)		3.41	
Zn_{tot} load (kg/d)	6.79	10.69	14.53
Zn_{dis} conc (mg/l)		2.92	
Zn_{dis} load (kg/d)	5.81	9.15	12.44

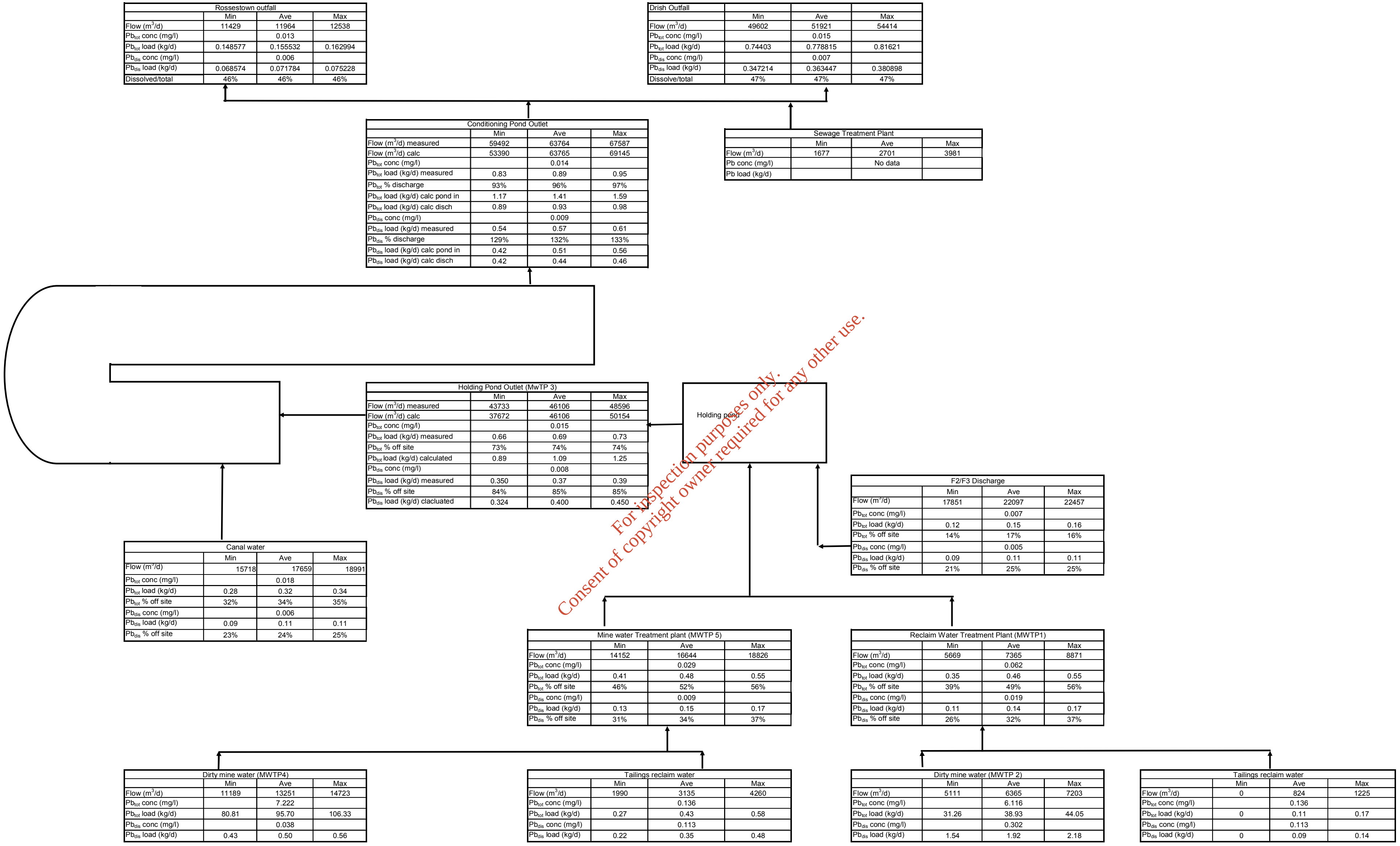
Dirty mine water (MWTP2)

	Min	Ave	Max
Flow (m^3/d)	5111	6365	7203
Zn_{tot} conc (mg/l)		6.545	
Zn_{tot} load (kg/d)	33.45	41.66	47.14
Zn_{dis} conc (mg/l)		1.3	
Zn_{dis} load (kg/d)	6.64	8.27	9.36

Tailings reclaim water

	Min	Ave	Max
Flow (m^3/d)	0	824	1225
Zn_{tot} conc (mg/l)		3.41	
Zn_{tot} load (kg/d)	0	2.81	4.18
Zn_{dis} conc (mg/l)		2.92	
Zn_{dis} load (kg/d)	0	2.41	3.58

Figure 16. Zinc mass balance



Rossestown outfall			
	Min	Ave	Max
Flow (m^3/d)	11429	11964	12538
Pb_{tot} conc (mg/l)		0.013	
Pb_{tot} load (kg/d)	0.148577	0.155532	0.162994
Pb_{dis} conc (mg/l)		0.006	
Pb_{dis} load (kg/d)	0.068574	0.071784	0.075228
Dissolved/total	46%	46%	46%

Drish Outfall			
	Min	Ave	Max
Flow (m^3/d)	49602	51921	54414
Pb_{tot} conc (mg/l)		0.015	
Pb_{tot} load (kg/d)	0.74403	0.778815	0.81621
Pb_{dis} conc (mg/l)		0.007	
Pb_{dis} load (kg/d)	0.347214	0.363447	0.380898
Dissolve/total	47%	47%	47%

Conditioning Pond Outlet			
	Min	Ave	Max
Flow (m^3/d) measured	59492	63764	67587
Flow (m^3/d) calc	53390	63765	69145
Pb_{tot} conc (mg/l)		0.014	
Pb_{tot} load (kg/d) measured	0.83	0.89	0.95
Pb_{tot} % discharge	93%	96%	97%
Pb_{tot} load (kg/d) calc pond in	1.17	1.41	1.59
Pb_{tot} load (kg/d) calc disch	0.89	0.93	0.98
Pb_{dis} conc (mg/l)		0.009	
Pb_{dis} load (kg/d) measured	0.54	0.57	0.61
Pb_{dis} % discharge	129%	132%	133%
Pb_{dis} load (kg/d) calc pond in	0.42	0.51	0.56
Pb_{dis} load (kg/d) calc disch	0.42	0.44	0.46

Sewage Treatment Plant			
	Min	Ave	Max
Flow (m^3/d)	1677	2701	3981
Pb conc (mg/l)		No data	
Pb load (kg/d)			

Holding Pond Outlet (MwTP 3)			
	Min	Ave	Max
Flow (m^3/d) measured	43733	46106	48596
Flow (m^3/d) calc	37672	46106	50154
Pb_{tot} conc (mg/l)		0.015	
Pb_{tot} load (kg/d) measured	0.66	0.69	0.73
Pb_{tot} % off site	73%	74%	74%
Pb_{tot} load (kg/d) calculated	0.89	1.09	1.25
Pb_{dis} conc (mg/l)		0.008	
Pb_{dis} load (kg/d) measured	0.350	0.37	0.39
Pb_{dis} % off site	84%	85%	85%
Pb_{dis} load (kg/d) clacluated	0.324	0.400	0.450

F2/F3 Discharge			
	Min	Ave	Max
Flow (m^3/d)	17851	22097	22457
Pb_{tot} conc (mg/l)		0.007	
Pb_{tot} load (kg/d)	0.12	0.15	0.16
Pb_{tot} % off site	14%	17%	16%
Pb_{dis} conc (mg/l)		0.005	
Pb_{dis} load (kg/d)	0.09	0.11	0.11
Pb_{dis} % off site	21%	25%	25%

Canal water			
	Min	Ave	Max
Flow (m^3/d)	15718	17659	18991
Pb_{tot} conc (mg/l)		0.018	
Pb_{tot} load (kg/d)	0.28	0.32	0.34
Pb_{tot} % off site	32%	34%	35%
Pb_{dis} conc (mg/l)		0.006	
Pb_{dis} load (kg/d)	0.09	0.11	0.11
Pb_{dis} % off site	23%	24%	25%

Mine water Treatment plant (MWTP 5)			
	Min	Ave	Max
Flow (m^3/d)	14152	16644	18826
Pb_{tot} conc (mg/l)		0.029	
Pb_{tot} load (kg/d)	0.41	0.48	0.55
Pb_{tot} % off site	46%	52%	56%
Pb_{dis} conc (mg/l)		0.009	
Pb_{dis} load (kg/d)	0.13	0.15	0.17
Pb_{dis} % off site	31%	34%	37%

Reclaim Water Treatment Plant (MWTP1)			
	Min	Ave	Max
Flow (m^3/d)	5669	7365	8871
Pb_{tot} conc (mg/l)		0.062	
Pb_{tot} load (kg/d)	0.35	0.46	0.55
Pb_{tot} % off site	39%	49%	56%
Pb_{dis} conc (mg/l)		0.019	
Pb_{dis} load (kg/d)	0.11	0.14	0.17
Pb_{dis} % off site	26%	32%	37%

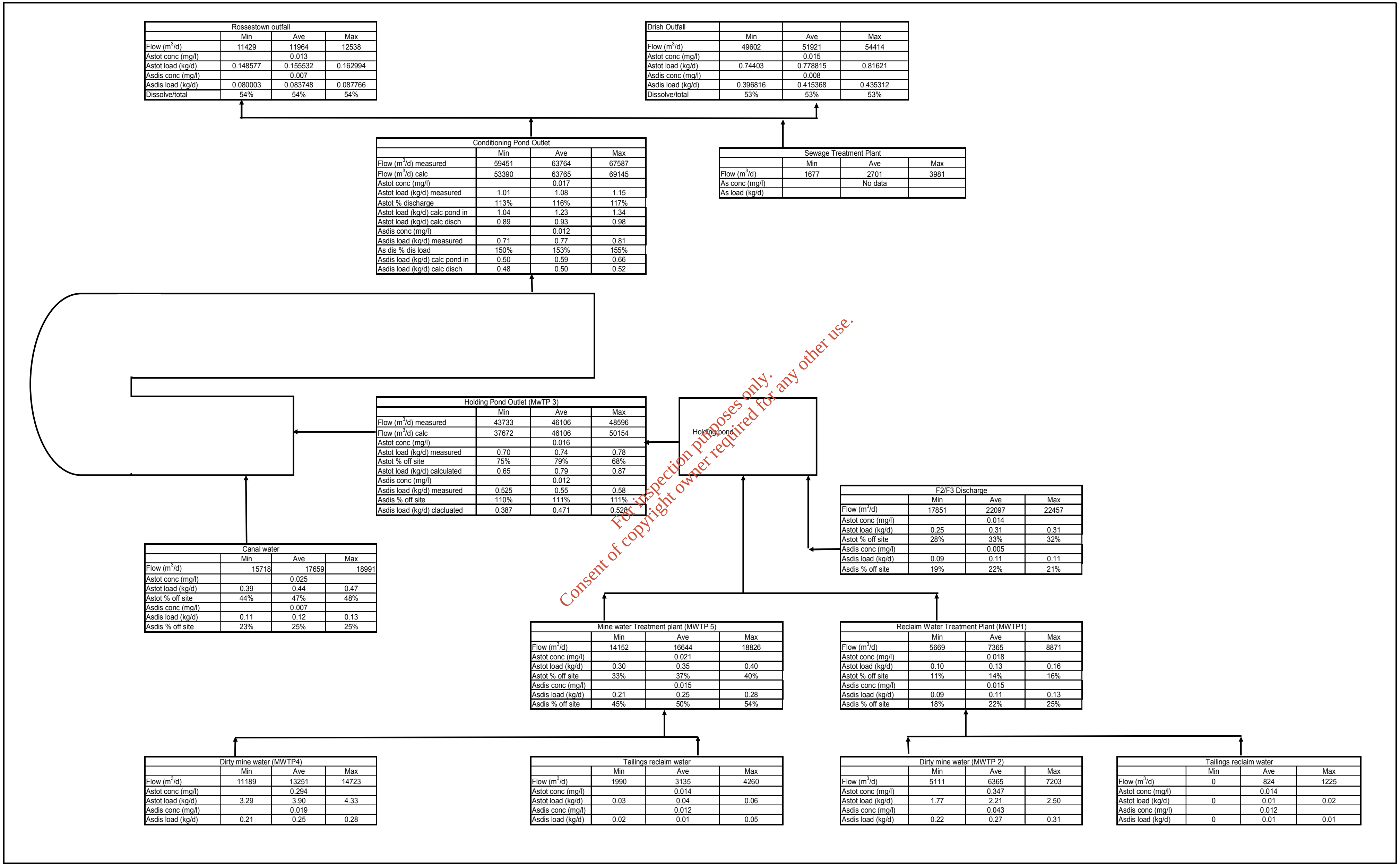
Dirty mine water (MWTP4)			
	Min	Ave	Max
Flow (m^3/d)	11189	13251	14723
Pb_{tot} conc (mg/l)		7.222	
Pb_{tot} load (kg/d)	80.81	95.70	106.33
Pb_{dis} conc (mg/l)		0.038	
Pb_{dis} load (kg/d)	0.43	0.50	0.56

Tailings reclaim water			
	Min	Ave	Max
Flow (m^3/d)	1990	3135	4260
Pb_{tot} conc (mg/l)		0.136	
Pb_{tot} load (kg/d)	0.27	0.43	0.58
Pb_{dis} conc (mg/l)		0.113	
Pb_{dis} load (kg/d)	0.22	0.35	0.48

Dirty mine water (MWTP 2)			
	Min	Ave	Max
Flow (m^3/d)	5111	6365	7203
Pb_{tot} conc (mg/l)		6.116	
Pb_{tot} load (kg/d)	31.26	38.93	44.05
Pb_{dis} conc (mg/l)		0.302	
Pb_{dis} load (kg/d)	1.54	1.92	2.18

Tailings reclaim water			
	Min	Ave	Max
Flow (m^3/d)	0	824	1225
Pb_{tot} conc (mg/l)		0.136	
Pb_{tot} load (kg/d)	0	0.11	0.17
Pb_{dis} conc (mg/l)		0.113	
Pb_{dis} load (kg/d)	0	0.09	0.14

Figure 17. Lead mass balance



Rossestown outfall	Min	Ave	Max
Flow (m^3/d)	11429	11964	12538
Astot conc (mg/l)		0.013	
Astot load (kg/d)	0.148577	0.155532	0.162994
Asdis conc (mg/l)		0.007	
Asdis load (kg/d)	0.080003	0.083748	0.087766
Dissolve/total	54%	54%	54%

Drish Outfall	Min	Ave	Max
Flow (m^3/d)	49602	51921	54414
Astot conc (mg/l)		0.015	
Astot load (kg/d)	0.74403	0.778815	0.81621
Asdis conc (mg/l)		0.008	
Asdis load (kg/d)	0.396816	0.415368	0.435312
Dissolve/total	53%	53%	53%

Conditioning Pond Outlet	Min	Ave	Max
Flow (m^3/d) measured	59451	63764	67587
Flow (m^3/d) calc	53390	63765	69145
Astot conc (mg/l)		0.017	
Astot load (kg/d) measured	1.01	1.08	1.15
Astot % discharge	113%	116%	117%
Astot load (kg/d) calc pond in	1.04	1.23	1.34
Astot load (kg/d) calc disch	0.89	0.93	0.98
Asdis conc (mg/l)		0.012	
Asdis load (kg/d) measured	0.71	0.77	0.81
As dis % dis load	150%	153%	155%
Asdis load (kg/d) calc pond in	0.50	0.59	0.66
Asdis load (kg/d) calc disch	0.48	0.50	0.52

Sewage Treatment Plant	Min	Ave	Max
Flow (m^3/d)	1677	2701	3981
As conc (mg/l)		No data	
As load (kg/d)			

Holding Pond Outlet (MwTP 3)	Min	Ave	Max
Flow (m^3/d) measured	43733	46106	48596
Flow (m^3/d) calc	37672	46106	50154
Astot conc (mg/l)		0.016	
Astot load (kg/d) measured	0.70	0.74	0.78
Astot % off site	75%	79%	68%
Astot load (kg/d) calculated	0.65	0.79	0.87
Asdis conc (mg/l)		0.012	
Asdis load (kg/d) measured	0.525	0.55	0.58
Asdis % off site	110%	111%	111%
Asdis load (kg/d) clacluated	0.387	0.471	0.528

F2/F3 Discharge	Min	Ave	Max
Flow (m^3/d)	17851	22097	22457
Astot conc (mg/l)		0.014	
Astot load (kg/d)	0.25	0.31	0.31
Astot % off site	28%	33%	32%
Asdis conc (mg/l)		0.005	
Asdis load (kg/d)	0.09	0.11	0.11
Asdis % off site	19%	22%	21%

Canal water	Min	Ave	Max
Flow (m^3/d)	15718	17659	18991
Astot conc (mg/l)		0.025	
Astot load (kg/d)	0.39	0.44	0.47
Astot % off site	44%	47%	48%
Asdis conc (mg/l)		0.007	
Asdis load (kg/d)	0.11	0.12	0.13
Asdis % off site	23%	25%	25%

Mine water Treatment plant (MWTP 5)	Min	Ave	Max
Flow (m^3/d)	14152	16644	18826
Astot conc (mg/l)		0.021	
Astot load (kg/d)	0.30	0.35	0.40
Astot % off site	33%	37%	40%
Asdis conc (mg/l)		0.015	
Asdis load (kg/d)	0.21	0.25	0.28
Asdis % off site	45%	50%	54%

Reclaim Water Treatment Plant (MWTP1)	Min	Ave	Max
Flow (m^3/d)	5669	7365	8871
Astot conc (mg/l)		0.018	
Astot load (kg/d)	0.10	0.13	0.16
Astot % off site	11%	14%	16%
Asdis conc (mg/l)		0.015	
Asdis load (kg/d)	0.09	0.11	0.13
Asdis % off site	18%	22%	25%

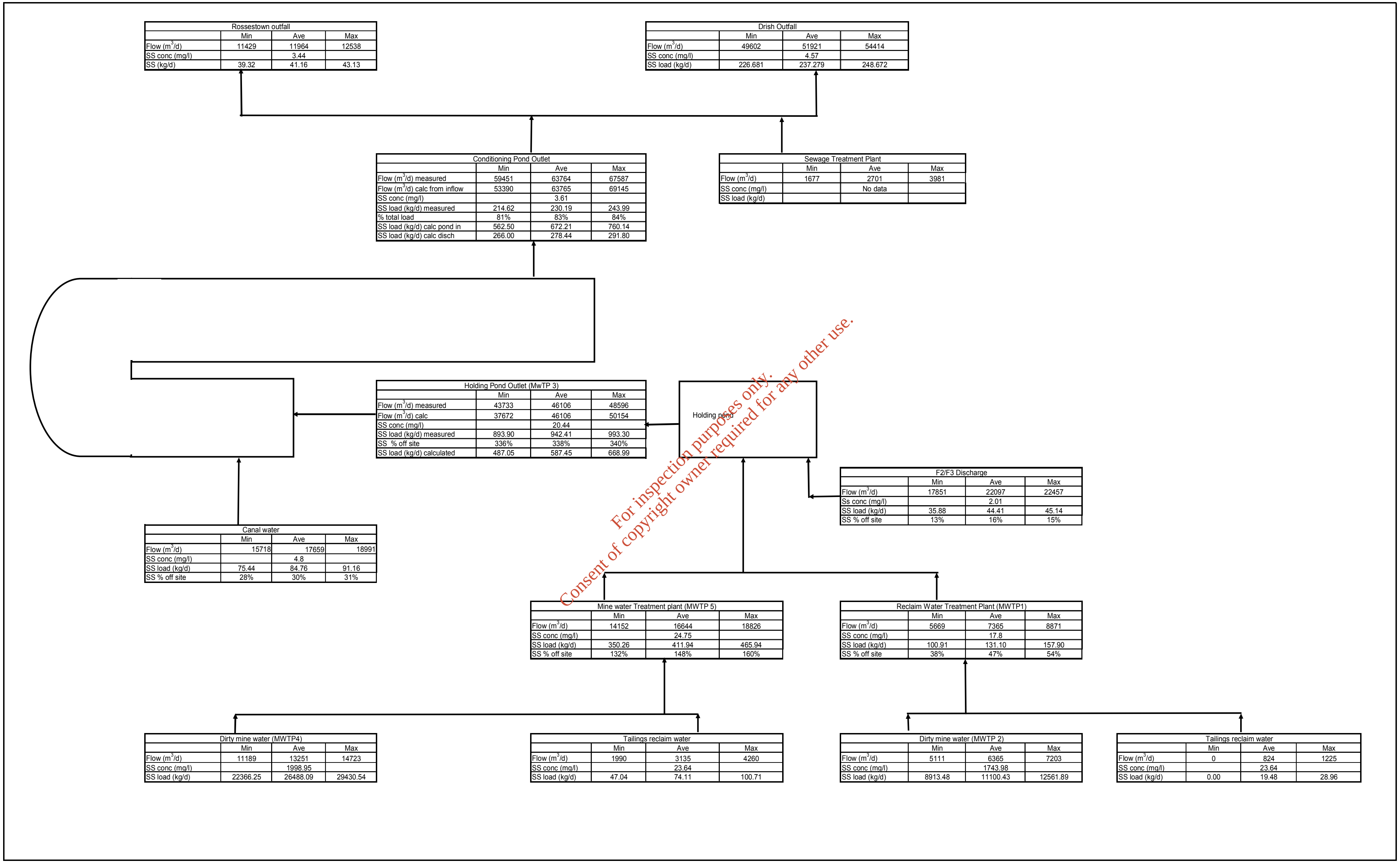
Dirty mine water (MWTP4)	Min	Ave	Max
Flow (m^3/d)	11189	13251	14723
Astot conc (mg/l)		0.294	
Astot load (kg/d)	3.29	3.90	4.33
Asdis conc (mg/l)		0.019	
Asdis load (kg/d)	0.21	0.25	0.28

Tailings reclaim water	Min	Ave	Max
Flow (m^3/d)	1990	3135	4260
Astot conc (mg/l)		0.014	
Astot load (kg/d)	0.03	0.04	0.06
Asdis conc (mg/l)		0.012	
Asdis load (kg/d)	0.02	0.01	0.05

Dirty mine water (MWTP 2)	Min	Ave	Max
Flow (m^3/d)	5111	6365	7203
Astot conc (mg/l)		0.347	
Astot load (kg/d)	1.77	2.21	2.50
Asdis conc (mg/l)		0.043	
Asdis load (kg/d)	0.22	0.27	0.31

Tailings reclaim water	Min	Ave	Max
Flow (m^3/d)	0	824	1225
Astot conc (mg/l)		0.014	
Astot load (kg/d)	0	0.01	0.02
Asdis conc (mg/l)		0.012	
Asdis load (kg/d)	0	0.01	0.01

Figure 18. Arsenic mass balance



Rossestown outfall	Min	Ave	Max
Flow (m^3/d)	11429	11964	12538
SS conc (mg/l)		3.44	
SS (kg/d)	39.32	41.16	43.13

Drish Outfall	Min	Ave	Max
Flow (m^3/d)	49602	51921	54414
SS conc (mg/l)		4.57	
SS load (kg/d)	226.681	237.279	248.672

Conditioning Pond Outlet	Min	Ave	Max
Flow (m^3/d) measured	59451	63764	67587
Flow (m^3/d) calc from inflow	53390	63765	69145
SS conc (mg/l)		3.61	
SS load (kg/d) measured	214.62	230.19	243.99
% total load	81%	83%	84%
SS load (kg/d) calc pond in	562.50	672.21	760.14
SS load (kg/d) calc disch	266.00	278.44	291.80

Sewage Treatment Plant	Min	Ave	Max
Flow (m^3/d)	1677	2701	3981
SS conc (mg/l)		No data	
SS load (kg/d)			

Holding Pond Outlet (MwTP 3)	Min	Ave	Max
Flow (m^3/d) measured	43733	46106	48596
Flow (m^3/d) calc	37672	46106	50154
SS conc (mg/l)		20.44	
SS load (kg/d) measured	893.90	942.41	993.30
SS % off site	336%	338%	340%
SS load (kg/d) calculated	487.05	587.45	668.99

F2/F3 Discharge	Min	Ave	Max
Flow (m^3/d)	17851	22097	22457
Ss conc (mg/l)		2.01	
SS load (kg/d)	35.88	44.41	45.14
SS % off site	13%	16%	15%

Canal water	Min	Ave	Max
Flow (m^3/d)	15718	17659	18991
SS conc (mg/l)		4.8	
SS load (kg/d)	75.44	84.76	91.16
SS % off site	28%	30%	31%

Mine water Treatment plant (MWTP 5)	Min	Ave	Max
Flow (m^3/d)	14152	16644	18826
SS conc (mg/l)		24.75	
SS load (kg/d)	350.26	411.94	465.94
SS % off site	132%	148%	160%

Reclaim Water Treatment Plant (MWTP1)	Min	Ave	Max
Flow (m^3/d)	5669	7365	8871
SS conc (mg/l)		17.8	
SS load (kg/d)	100.91	131.10	157.90
SS % off site	38%	47%	54%

Dirty mine water (MWTP4)	Min	Ave	Max
Flow (m^3/d)	11189	13251	14723
SS conc (mg/l)		1998.95	
SS load (kg/d)	22366.25	26488.09	29430.54

Tailings reclaim water	Min	Ave	Max
Flow (m^3/d)	1990	3135	4260
SS conc (mg/l)		23.64	
SS load (kg/d)	47.04	74.11	100.71

Dirty mine water (MWTP 2)	Min	Ave	Max
Flow (m^3/d)	5111	6365	7203
SS conc (mg/l)		1743.98	
SS load (kg/d)	8913.48	11100.43	12561.89

Tailings reclaim water	Min	Ave	Max
Flow (m^3/d)	0	824	1225
SS conc (mg/l)		23.64	
SS load (kg/d)	0.00	19.48	28.96

Figure 19. Suspended solids mass balance

5.2 Mine water and reclaim water treatment plants

5.2.1 Operating principles

Both the mine and reclaim water treatment plants operate in a similar manner:

- The dirty mine water together with excess water reclaimed from the tailings management facility are fed into a reaction tank together with recirculated solids from the clarifier underflow.
- Lime is added to raise the pH to the target value (between 9 and 10).
- The treated water is then discharged into a conventional thickener/clarifier unit where polymer is added to promote solids/liquid separation.
- The pH of the clarified water is reduced using sulphuric acid prior to discharging it into the holding pond (different target pH values are adopted for each plant).
- Sludge from the clarifier underflow is either recirculated back to the reaction vessel or pumped to the tailings management facility.

5.2.2 Overall water quality

The water quality data collected over the monitoring period reveals that:

- The primary purpose of both plants is the removal of suspended solids and metals.
- The average pH of the water discharged from the MWTP was approximately 8.
- The average pH of the water discharged from the RWTP was 9.1 compared to an influent pH of 7.6.
- The average dissolved zinc concentration in the water discharged from the MWTP was 0.139mg/l compared to 0.03mg/l from the RWTP, whilst the total zinc concentrations were 0.179mg/l and 0.125mg/l respectively.
- The average total lead concentrations in the water discharged from the two plants were 0.029mg/l and 0.062mg/l for the MWTP and the RWTP respectively
- The average total arsenic concentrations in the discharges from the two plants were similar at 0.021mg/l and 0.018mg/l respectively
- The average suspended solids concentrations were 24.8mg/l for the MWTP and 17.8mg/l for the RWTP.

5.2.3 Zinc concentrations

Figures 20a and 20b show the variation in the total and dissolved zinc concentrations measured in the water treated by both plants. These show that both the average total and dissolved zinc concentrations were higher in the MWTP discharge.

Figure 20a. Water treatment plant variation in dissolved zinc concentration with pH

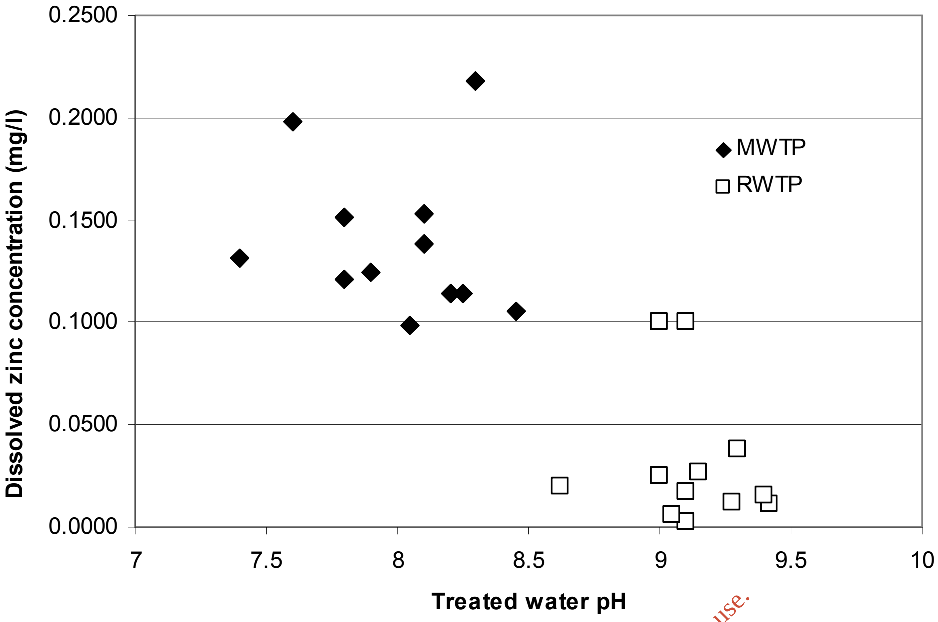
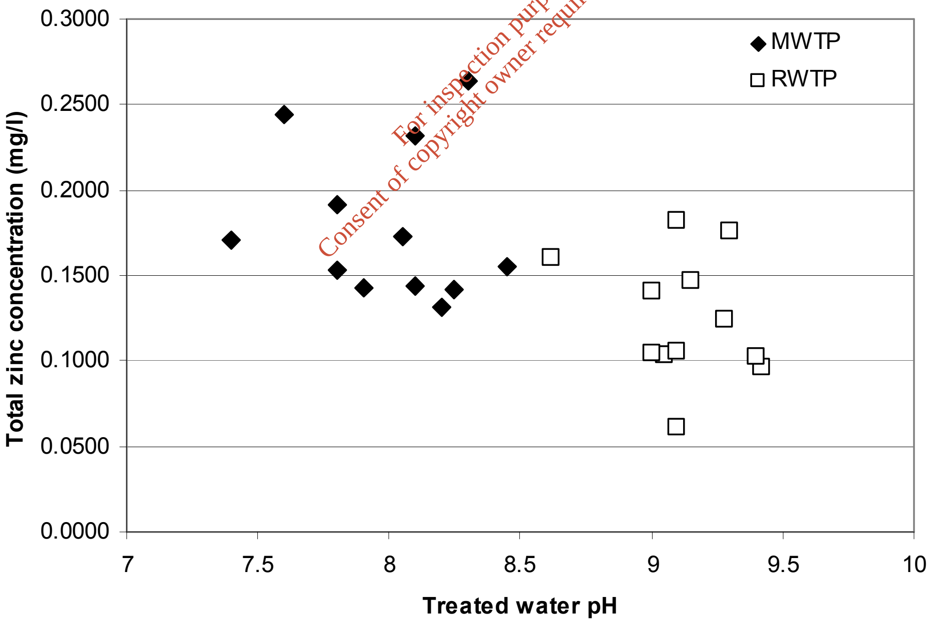


Figure 20b. Water treatment plant variation in total zinc concentration with pH



5.2.4 Lead concentrations

Figures 21a and 21b show the total and dissolved lead concentrations in the treated waters.

Figure 21a. Water treatment plant variation in dissolved lead concentration with pH

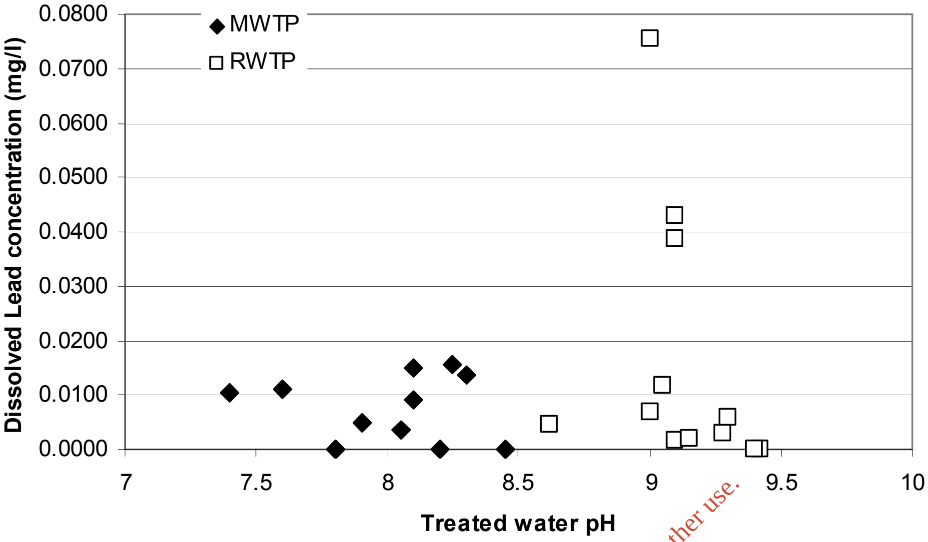
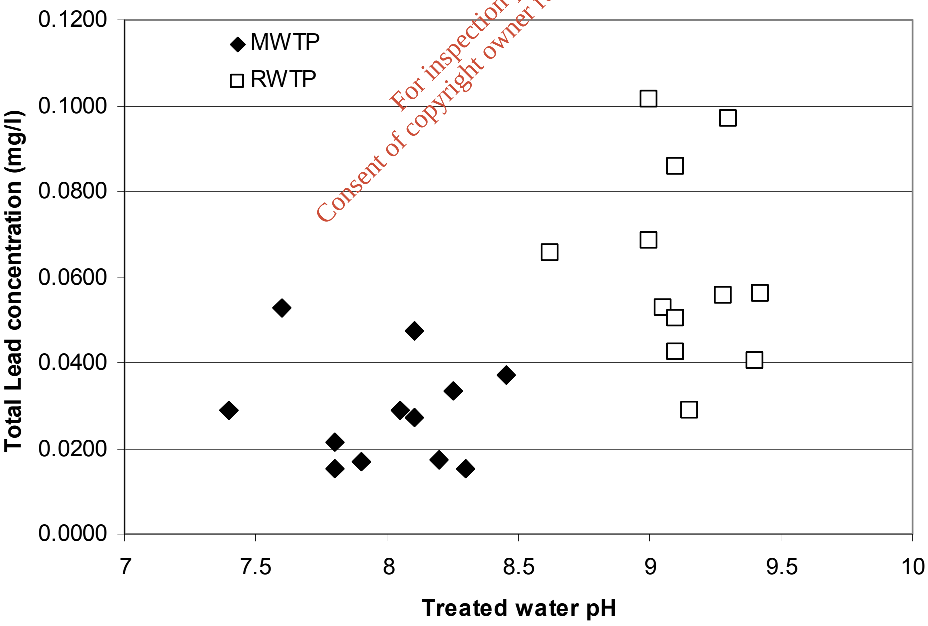


Figure 21b. Water treatment plant variation in total lead concentration with pH



5.2.5 Arsenic concentrations

The variation of the total and dissolved arsenic concentrations in the water discharged from the WTPs is shown in Figures 22a and 22b respectively. This would appear to show one unrepresentative result and that neither the total nor dissolved arsenic concentrations vary significantly with the treated water pH.

Figure 22a. Water treatment plant variation in dissolved arsenic concentration with pH

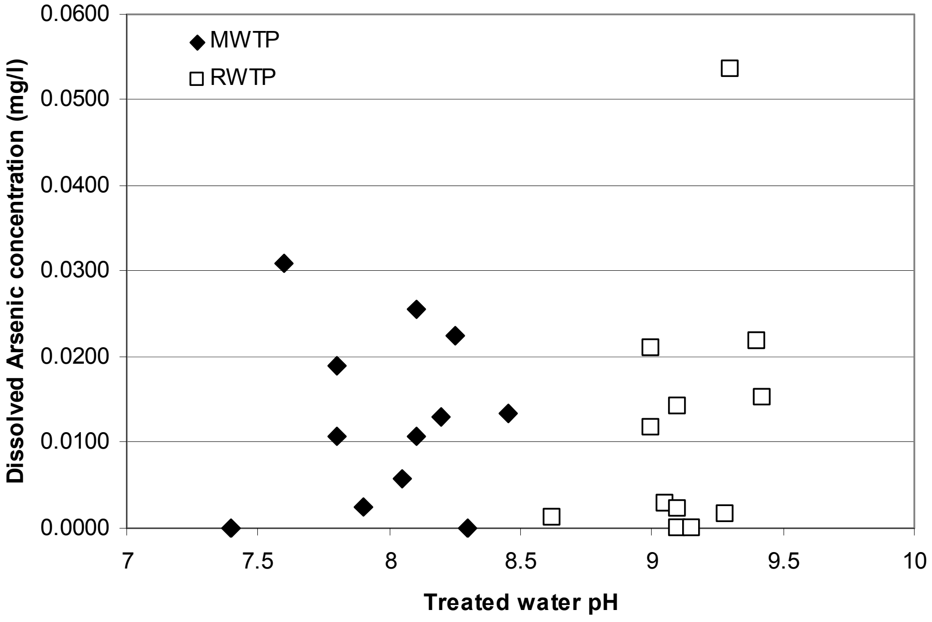
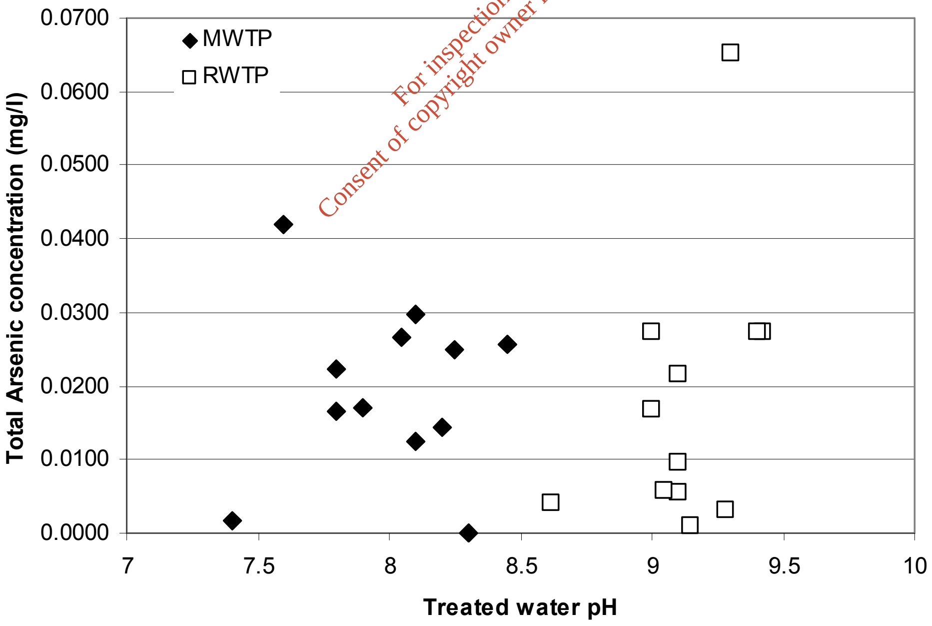


Figure 22b. Water treatment plant variation in total arsenic concentration with pH



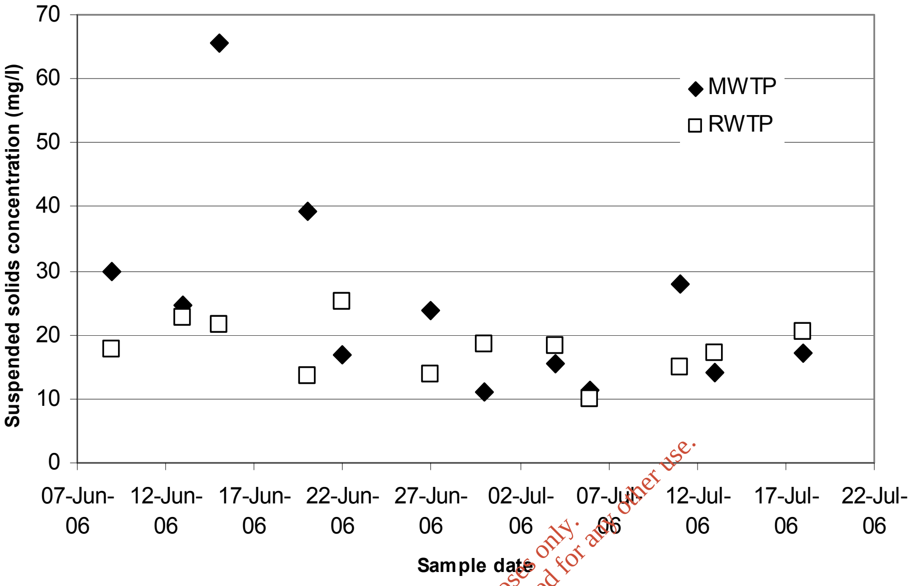
5.2.6 Suspended solids concentration

Figure 23 shows the variation in the treated water suspended solids concentrations and reveals that:

- Suspended solids concentrations as low as 10mg/l can be achieved by both treatment plants (this is consistent with the simple settlement tests undertaken by the Newcastle University team as part of this study). This demonstrates a considerable improvement over the design suspended solids value of 20 mg/l, due to ongoing plant modifications and optimisation.

- The solids concentration achieved by the RWTP shows less variation than that from the MWTP. This may reflect the fact that the RWTP typically treats a smaller flow.

Figure 23. Water treatment plant variation in suspended solids concentration



5.2.7 Water treatment plant conclusions

Although only a small data set has been collected over the 6 week period of intense monitoring the results provide a good insight into the operation of the MW and the RW treatment plants.

In terms of zinc removal the data demonstrates that the RWTP is more effective than the MWTP.

The arsenic data appear to contain one outlying data point and showed no apparent variation in concentration with pH. This is consistent with data obtained from other mine water treatment projects. Should the mine wish to decrease the arsenic concentration in the future it would probably be necessary to add iron (or aluminium) to precipitate arsenic as a ferric arsenate ($FeAsO_4.xFe(OH)_3$) compound. It is understood that trials are currently underway to establish the potential benefits of iron / aluminium addition.

The data on lead concentrations is less clear. The dissolved concentration appears to show 3 outliers containing apparently untypically high concentrations. If these are ignored the dissolved lead concentrations show very little difference between the two plants

Tables 14 and 15 summarise the metal and suspended solids load discharged from the MWTP and the RWTP and also quotes these as a percentage of the load discharged off site into the Drish and Rossestown. The dissolved metal load from the two plants contributes between 25% (zinc) and 89% (arsenic) of the load released into the two rivers. Table 14 shows that the addition of iron/aluminium to precipitate the dissolved arsenic could significantly reduce the dissolved arsenic load. However further studies would be required to establish what effect this would have on the total arsenic load.

In terms of the total metal load, both plants contribute between 33% (zinc) and 101% (lead) of the load discharged off site. Theoretically the two plants contribute 187% suspended solids load, but this (together with the total metal concentrations) is attenuated by sedimentation in the Holding and Conditioning ponds.

Table 14. MWTP Estimated Average Treated Water Load

	Zinc		**Lead**		**Arsenic**		**Solids**
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
Daily	3kg	2.3kg	0.48kg	0.15kg	0.35kg	0.25kg	412kg
Annually	1.1t	0.84t	0.18t	0.05t	0.12t	0.12t	150t
% Discharge	25%	23%	52%	34%	37%	50%	148%

Table 15. RWTP Estimated Average Treated Water Load

	Zinc		**Lead**		**Arsenic**		**Solids**
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
Daily	0.92kg	0.23kg	0.46kg	0.14kg	0.13kg	0.11kg	121kg
Annually	0.33t	0.08t	0.17t	0.05t	0.05t	0.04t	48t
% Discharge	8%	2%	49%	32%	14%	22%	47%

The suspended solids concentration produced by the MWTP shows more variation than that produced by the RWTP and during the monitoring period the RWTP discharge was 0.29 of a pH unit higher than the MWTP. Based on the limited data set available it is recommended that the Mine endeavour to optimise the operational pH adopted for both plants and reduce the fluctuations in the suspended solids concentration.

It is important to recognise that overall both plants are achieving a significant reduction in the suspended solids/total metal loads and on that basis play a major role in managing the amount of the metal discharged off site. It is recommended that the Mine continue to further optimisation the performance of both plants to improve their effectiveness. Depending on the success of the ongoing optimisation studies it is possible that the plant could provide limited additional treatment capacity for the partial treatment of the Canal or F2/F3 fissure waters (*cf.*Sections 2.1, 5.3.2 and 5.3.3).

5.3 Conditioning pond and holding pond

5.3.1 Overall performance

Table 16 provides an overall comparison of the load entering the Holding/Conditioning Ponds (from the WTPs, F2/F3 Fissure Water and the Canal Water) with that leaving via the Conditioning Pond outlet. This comparison shows that:

- There appears to be a 10 to 15% increase in the dissolved metal concentrations in the water discharged from the Conditioning Pond. Depending on the accuracy of the data this suggests that all the dissolved metals pass through the ponds without attenuation, or that possibly some redissolution of metal particulates is occurring.

- There appears to be a reduction in the total lead and arsenic concentrations, but no change in the total zinc load.
- The reduction in the lead and arsenic concentrations is directly proportional to the overall reduction in the suspended solids load.

Table 16. Holding/Conditioning Pond Overall Load Balance

	Zinc		**Lead**		**Arsenic**		**Solids**
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
Total inlet	12.9kg	10.2kg	1.41kg	0.51kg	1.23kg	0.59kg	672kg
Outlet	13.8kg	12.2kg	0.89kg	0.57kg	1.09kg	0.77kg	231kg
Outlet/inlet	107%	120%	63%	112%	89%	131%	34%

On the basis of the data presented in Table 16 it can be concluded that the Holding/Conditioning ponds are having a limited effect on the metal loading discharged off site, but are significantly reducing the suspended solids concentration.

5.3.2 Holding pond

The Holding Pond receives treated water from the MWTP and RWTP plants together with the untreated F2/F3 Fissure Water, and discharges this via a monitoring weir into the Conditioning Pond. Although the F2/F3 water appears visually clean, it contains relatively high dissolved metal concentrations and, as result, contributes between 18% and 37% of the total metal load released off site (Table 17).

Table 17. Estimated Average Load from the F2/F3 Fissure Water

	Zinc		**Lead**		**Arsenic**		**Solids**
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
Daily	4.00kg	3.47kg	0.15kg	0.11kg	0.31kg	0.11kg	44.4kg
Annually	1.5t	1.27t	0.05t	0.04t	0.11t	0.04t	16.2t
% Discharge	34%	35%	17%	25%	33%	22%	16%

Table 18 summarises the mass balance calculated for the Holding Pond and appears to show:

- A circa 35% reduction in both the total and dissolved zinc concentrations due to reactions between the WTP water and the F2/F3 flow.
- A 38% reduction in total lead concentration due to sedimentation
- Very little reduction in the dissolved lead and arsenic concentrations (these are effectively passing through the holding lagoon unchanged)
- An increase in the suspended solids load leaving the pond

Table 18. Holding Pond Daily Load Balance

	Zinc		Lead		Arsenic		Solids
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
WTPs	3.92kg	2,56kg	0.94kg	0.29kg	0.46kg	0.44kg	542kg
F2/F3	4.0kg	3.47kg	0.15kg	0.11kg	0.31kg	0.11kg	44.41kg
Total in	**7.92kg**	**6.03kg**	**1.09kg**	**0.40kg**	**0.79kg**	**0.47kg**	**587kg**
Discharge (MWTP3)	5.53kg	4.15kg	0.69kg	0.37kg	0.74kg	0.55kg	942kg
% Change	70%	72%	63%	93%	94%	117%	160%

5.3.3 Conditioning pond

The Conditioning Pond receives the overflow from the Holding Pond (MWTP3) together with the untreated Canal Water. As per the F2/F3 Fissure Water, the Canal Water appears visually clean, but actually contains relatively high dissolved metal concentrations and as a result contributes between 34% and 43% of the total metal load released off site (Table 19).

Table 19. Canal Water Estimated Average Load

	Zinc		Lead		Arsenic		Solids
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
Daily	5.02kg	4.17kg	0.32kg	0.11kg	0.44kg	0.12kg	84.8kg
Annually	1.83t	1.52t	0.12t	0.04t	0.16t	0.04t	31t
% Discharge	43%	42%	34%	24%	47%	25%	30%

Table 20 provides a summary of the metal loads entering and leaving the Conditioning Pond based on the flow and water quality data provided for the Holding Pond overflow weir and the Canal discharge. The data appear to reveal that more zinc, dissolved lead and dissolved arsenic are being discharged from the Conditioning Pond than entering it. However unlike zinc, there is a circa 10% reduction in the total lead and arsenic concentrations. Comparison of the influent load with that discharged to river (also shown in Table 20) appears to show that more zinc is discharged off site than enters the Conditioning Pond. The source of these discrepancies should be further investigated and possibly relate to the accuracy of the flow and/or water quality data for the holding pond overflow weir. It is, for example, possible that the flow over the weir is stratified in terms of suspended solids concentration and possibly temperature.

Table 20. Conditioning Pond Daily Load Balance

	Zinc		Lead		Arsenic		Solids
	Total	Dissolve	Total	Dissolve	Total	Dissolve	
Holding (MWTP3)	5.53kg	4.33kg	0.69kg	0.37kg	0.74kg	0.55kg	942kg
Canal	5.02kg	4.17kg	0.32kg	0.11kg	0.44kg	0.12kg	84.8kg
Total in	**10.55kg**	**8.50kg**	**1.01kg**	**0.48kg**	**1.18kg**	**0.67kg**	**1027kg**
Outlet	13.8kg	12.2kg	0.89kg	0.57kg	1.08kg	0.77kg	230kg
To river	11.8kg	10.0kg	0.93kg	0.44kg	0.93kg	0.50kg	278kg

It has been suggested that the load discharged off site from the Conditioning Pond outlet could be significantly reduced by raising the outlet level of both the Drish and Rossestown discharge pipes. Complete removal of suspended solids would theoretically reduce the lead load by up to 54%, but would only reduce the zinc load by circa 18%. However in practice, the reduction in the suspended solids load is likely to be limited by the colloidal nature of metal hydroxide particles (*cf.* Section 2.4). It is therefore recommended that a series of samples are taken at different levels in the water column within 10m of the discharge pipes to establish whether there is any benefit in raising the outlet pipes.

Table 21. Rossestown discharge water quality

Determinand	Units	Conditioning pond	Rossestown Outfall	Out/in % change
pH		*7.868*	7.647	97%
BOD	mg/L O_2		1.136	
Sus Solids	mg/L	*3.608*	3.442	95%
Sodium	mg/L Na	*12.995*	12.841	99%
Ammonium	mg/L NH_4	*1.175*		0%
	mg/L N	*0.913*		0%
Calcium	mg/L Ca	*102.900*	100.505	98%
Magnesium	mg/L Mg	*38.499*	37.882	98%
Potassium	mg/L K	*8.109*	5.946	73%
Fluoride	mg/L F	*0.101*	0.082	81%
Chloride	mg/L Cl	*21.857*	21.332	98%
Nitrite	mg/L N	*0.157*	0.031	20%
	mg/L NO_2	*0.515*	0.101	20%
Nitrate	mg/L N	*1.416*	2.481	175%
	mg/L NO_3	*6.268*	10.982	175%
Phosphate	mg/L PO_4	*0.092*	0.014	15%
Sulphate	mg/L SO_4	*245.512*	235.261	96%
Arsenic(Total)	mg/L As	*0.017*	0.013	75%
Arsenic(Dissolved)	mg/L As	*0.012*	0.007	58%
Iron(Total)	mg/L Fe	*0.197*	0.117	60%
Iron(Dissolved)	mg/L Fe	*0.043*	0.010	24%
Lead(Total)	mg/L Pb	*0.014*	0.013	90%
Lead(Dissolved)	mg/L Pb	*0.009*	0.006	70%
Zinc(Total)	mg/L Zn	*0.216*	0.179	83%
Zinc(Dissolved)	mg/L Zn	*0.191*	0.159	83%

5.3.4 Rossestown outfall water quality

The water quality information for the Conditioning Pond outlet and Rossestown Outfall has been used to provide an insight into the chemical changes that occur within the Rossestown discharge pipe (Table 21). This shows a 175% increase in the nitrate concentration which is indicative that biological nitrification is occurring within the discharge pipe. The nitrification proceeds in two stages, with the conversion of ammonium to nitrite (NO_2^-) which is then converted into nitrate (NO_3^-). In most cases the conversion to nitrite is the rate limiting step and consequently virtually all the ammonium is converted into nitrate with very low residual nitrite concentrations remaining. Nitrification also releases acidity and therefore depending on the amounts of alkalinity present in the water, the process is accompanied by a drop in pH. Examination of the water quality data summarised in Table 21 reveals that virtually all the ammonium has been converted to nitrate and that the discharge pH is slightly lower (0.2 of a pH unit) than at the Conditioning Pond outlet.

Bacteria growth requires a number of trace elements including phosphate and this is reflected in the 27% reduction in the phosphate concentration shown in Table 21.

Table 21 also shows an apparent reduction in the total metal concentrations, whilst the concentrations of chloride, sodium, magnesium are conserved. As the pipeline has been in use for a number of years the system is likely to be in equilibrium and therefore the inlet and outlet total metal concentrations should be identical. This suggests that the total metal analyses may not be fully representative. The apparent biological activity within the pipe, together with presence of visible flocs suggests that the suspended solids concentration at the outfall could be higher than the average recorded value of 3.4mg/l. This apparent discrepancy may be due to orientation problems with the auto-sampler inlet. It is understood that the inlet to the auto sampler faces downstream and due to the relatively high water velocity the larger flocs could be swept passed the sampler inlet. This should be further investigated by analysis of a bulk sample as already outlined in Section 2.2 of this report.

Table 22. Rossestown Outfall Metal and Suspended Solids Loads

	Zinc		**Lead**		**Arsenic**		**Solids**
	Total	Dissolved	Total	Dissolved	Total	Dissolve	
Daily	2.14kg	1.90kg	0.16kg	0.07kg	0.16kg	0.08kg	41.2kg
Annually	0.78t	0.69t	0.06t	0.03t	0.06t	0.03t	15.0t

Table 22 shows that based on the average flow rate and measured concentrations, some 15t/yr of suspended solids and 0.78t/yr of zinc are released into the Rossesstown River. However, for the reasons listed above it is possible that these figures may well be an under-estimate of the suspended solids and total metal loads discharged into the Rossestown river

Examination of Table 22 reveals that theoretically the .15tonnes of suspended solids released into the river contained the following particulate loads (i.e the difference between the total and dissolved concentrations):

- 0.09tonnes/yr of particulate zinc
- 0.03tonnes/yr of particulate lead
- 0.03tonnesyr of particulate arsenic.

This suggests that the metal concentrations in the suspended solids should be:

- 6,000mg/kg of zinc
- 2,000mg/kg of lead
- 1,940mg/kg of arsenic

However laboratory tests on a sludge sample taken immediately downstream of the Rossestown discharge revealed:

- 23,000mg/kg of zinc

- 5,000mg/kg of lead
- 1,400mg/l of arsenic
- 24% of the dry weight loss on ignition, indicating that approximately ¼ of the sludge is organic matter.
- The sludge is highly reactive with acid suggesting that a substantial part of the remaining 73% of the material was possibly carbonate based
- Approximately 90% of the solids settled at a rate in excess of 3m/hr

The composition and location of the sludge (immediately downstream of the Rossestown outfall) suggests that this comprises predominantly organic solids that have slough off the walls of the discharge pipe, rather than the finer inorganic solids discharged from the Conditioning Ponds. The high metal concentrations and organic matter content indicates that most of this material is likely to be biological growth that has sloughed of the walls of the discharge pipe, rather than inorganic solids carried over from the conditioning pond. The relatively high metal concentration, together with the reduction in the dissolved metal concentrations summarised in Table 22 implies that some bio-accumulation of the metals is occurring.

It is understood that the Mine have received a quotation to clean both pipes for €66,000 subject to provision of access ports into the pipe every 500m. The cost of providing these ports is uncertain as the pipe operates partly as a pumped main and partly by gravity. It is therefore possible that the installation of these ports could cost some €150,000 to €200,000. As biological growth on the discharge pipe walls can not be avoided, cleaning the pipe would only result in a short-term reduction in the suspended solids load and therefore this option may need to be regularly repeated. Assuming that it is repeated every twelve months the cost of pipe cleaning over the next 5 years could be of the order of €500,000.

As the biochemical mechanisms operating in the discharge pipe appear to be promoting metals precipitation it might be more appropriate to maintain/promote these processes and intercept the resultant solids at a suitable location close to the discharge point. In addition to reducing the overall solids load, removal of the suspended solids would theoretically also reduce the current total metal . However, in view of the uncertainty regarding the total metal load at the outfall and the settlement characteristics of the suspended solids it is recommended that a site trial is undertaken.

5.3.5 Drish outfall water quality

Table 23 provides a comparison of the Conditioning Pond outlet and the Drish Outfall chemistry and the apparent resultant change. As per the Rossestown outfall, this shows a reduction in the metal and nitrate concentrations.

Comparison of the ammonium data shows an average reduction of 0.785mg/l (as N) between the Conditioning Pond outlet (0.913mg/l) and the outfall (0.128mg/l). This was accompanied by a 0.843mg/l increase in the nitrate concentration from 1.416mg/l to 2.259mg/l (as N) and a 0.3 unit drop in pH.

Further biological activity is also likely to be occurring due the presence of BOD in the sewage treatment plant effluent (18.38mg/l) and possibly the Conditioning Pond overflow. Although the BOD of the water discharged into the Drish was measured

(0.778mg/l), measurements were not taken for the water leaving the Conditioning Pond and therefore it is not possible to calculate what change in BOD load occurs in the Drish discharge pipe, nor the amount of biomass generated.

Table 23 also shows an apparent reduction in the dissolved and total metal concentrations, whilst the chloride, sodium and magnesium concentrations remain constant. Although the dissolved metal concentrations could alter due to ongoing reactions, the total metal concentrations should remain constant in an established system operating at equilibrium. As per the Rossestown discharge it is therefore recommended that further studies are undertaken to confirm that the discharge samples are representative.

Table 23. Drish Outfall Pipe Water Chemistry

Determinand	Units	Conditioning pond	Drish Outfall	Change %
pH		7.868	7.580	
BOD	mg/L O_2		0.778	
Suspended Solids	mg/L	3.608	4.571	127%
Sodium	mg/L Na	12.995	12.810	99%
Ammonium	mg/L NH_4	1.175	0.165	14%
	mg/L N	0.913	0.128	0%
Calcium	mg/L Ca	102.900	99.809	97%
Magnesium	mg/L Mg	38.499	38.083	99%
Potassium	mg/L K	8.109	6.851	84%
Fluoride	mg/L F	0.101	0.080	79%
Chloride	mg/L Cl	21.857	21.412	98%
Nitrite	mg/L N	0.157	0.103	65%
	mg/L NO_2	0.515	0.337	65%
Nitrate	mg/L N	1.416	2.259	160%
	mg/L NO_3	6.268	10.000	160%
Phosphate	mg/L PO_4	0.092	0.021	23%
Sulphate	mg/L SO_4	245.512	236.980	97%
Arsenic(Total)	mg/L As	0.017	0.015	84%
Arsenic(Dissolved)	mg/L As	0.012	0.008	69%
Iron(Total)	mg/L Fe	0.197	0.168	85%
Iron(Dissolved)	mg/L Fe	0.043	0.008	19%
Lead(Total)	mg/L Pb	0.014	0.015	104%
Lead(Dissolved)	mg/L Pb	0.009	0.007	81%
Zinc(Total)	mg/L Zn	0.216	0.186	86%
Zinc(Dissolved)	mg/L Zn	0.191	0.156	82%

Subject to the above caveat, Table 24 provides a summary of the metal and suspended solids loads being discharged via the Drish outfall. On average some 87 tonnes/yr of sediment is discharged into the Drish River containing approximately:

- 0.6 tonnes/yr of particulate zinc
- 0.2 tonnes/yr of particulate lead
- 0.15 tonnes/yr of particulate arsenic.

On this basis the anticipated metal concentrations in the suspended solids should be:

- 6,900mg/kg of zinc
- 2,300 mg/kg of lead
- 1,700 mg/kg of arsenic

It is unclear why these concentrations are slightly different to those recorded for the Rossestown Outfall and this should be investigated as part of the investigation into total and suspended solids loads being discharged from both outfalls. These concentrations are lower than those measured for the Rossestown sediment and those measured immediately downstream of the Drish Outfall. As per the Rossestown solids it is likely that the Drish material contains a relatively high organic content and that bio-accumulation/filtering is responsible for the high metal contents.

Table 24. Drish Outfall Metal and Suspended Solids Loads

	Zinc		**Lead**		**Arsenic**		**Solids**
	Total	Dissolved	Total	Dissolved	Total	Dissolve	
Daily	9.66kg	8.1kg	0.78kg	0.36kg	0.78kg	0.42kg	237kg/d
Annually	3.5t/yr	2.9t/yr	0.3t/yr	0.1t/yr	0.3t/yr	0.15t/yr	86.5t/yr

Analysis of Table 24 indicated that complete removal of the suspended solids load from the Drish discharge would reduce the metal load entering the river by the following amounts:

zinc	16%
lead	54%
arsenic	46%

However as per the Rossestown Outfall, the amount of load reduction that can be practically achieved is dependent on the settling characteristics of the sludge and can only be reliably determined by undertaking a field trial.

5.4 Mitigating measures

5.4.1 Reduction in the suspended solids load

An inspection of the Drish and Rossestown rivers immediately downstream of the mine water outfalls reveals the localised build up of sludge with a high metal content. Although this material could be removed by localised suction dredging, further accumulation is likely to occur unless measures are put in place to periodically clean the pipes, intercept the solids sloughing off the walls or prevent the organic growth. As summarised in the above subsections, a removal of the suspended solids load immediately prior to discharge into the river would also beneficially reduce the total zinc load by up to 10% and both the lead and arsenic loads by up to 50%. The degree of reduction that can be practically achieved is however dependent on the settling velocity of the sludge particles and can only be determined by an on site field trial. Such a trial would also enable the settled sludge volume and the amount of material removed to be determined. The estimated cost of a trial is circa €15,000 assuming that the mine supply the transfer pumps and operate the system under our guidance.

Based on a preliminary laboratory analysis of the sample taken immediately downstream of the Rossestown outfall some 90% of the solids settle at a rate greater than 3 m/hr. At this settling velocity the settlement areas required are given in Table 25.

Table 25. Outfall Clarification Requirement

Location	Assumed Peak Flow Rate		Required Settlement Area
Rossestown Outfall	15,000m^3/d	625m^3/h	200m^2
Drish Outfall	60,000m^3/d	2,500m^3/h	830m^2

Given the magnitude of the flow to be treated and the relatively low solids loading, the material sloughing of the walls of the pipes can be most cost effectively intercepted using lamella clarifiers. Figure 23 shows the general arrangement of a lamella clarifier designed to provide 300m^2 of effective settlement area. This unit has a foot print approximately 6m long and 4m wide and is approximately 6m tall. Subject to resolving any land ownership issues, treatment of the Rossestown flow could be achieved by one such unit whilst 3 units would be required at the Drish Outfall. These could be installed above ground provided the water is pumped into units. This would require a 50kW pump at Rossestown and 3No 50 kW pumps at the Drish Outfall. Sludge would be removed by gravity either into a holding tank or directly into a suction tanker for disposal.

As pumping the water into the units may break up the flocs and adversely affect the settlement characteristics it would be beneficial to bury the units thereby allowing gravity flow into and out of the units. Settled solids would be removed via a lift pump and transferred either directly into road tankers or withdrawn at a constant rate into a holding tank for thickening and subsequent disposal.

The budget cost for the supply of 4No lamella clarifiers is circa €360,000 excluding civils. If the units were surface mounted it is estimated that a further €225,000 would be required to provide an intake sump and low head transfer pumps to feed the units. Additional cost would also be incurred in providing a suitable power supply and operating the system.

Burying the units to allow gravity flow would require the excavation of a hole up to 6m deep. The cost of this is largely dependent on the ground conditions and extent of the temporary works required to facilitate installation. These are currently unknown and would need to be confirmed by a ground investigation. However assuming that the ground is suitable for the installation of a sheet piled wall and excavation with conventional earthmoving equipment, it is estimated that the cost of the civils works at Rossestown would be of the order of €190,000 and €415,000 at the Drish outfall. The budget cost of installing a gravity based solids removal at the two outfalls is therefore of the order of €965,000, as summarised in Table 26.

The build up and sloughing of organic matter from the walls of the discharge pipes could be theoretically prevented by introducing a biological treatment stage to remove the ammonium prior to discharging the water off site. This would be achieved by using a high rate trickling filter or similar biological treatment device to treat the water discharged from the Conditioning Pond. Such a facility would be designed to replicate the ammonium nitrification process which currently take place in the discharge pipes and collect the resultant solids. However due to the large volume to be treated (>60MLD) the practicalities and cost of such an option would be considerably more expensive than intercepting the solids at the discharge points into the river.

Table 26. Budget Cost for the installation of Gravity Based Settlement System

	Rossestown Outfall	Drish Outfall
Supply of clarifiers	€90,000	€270,000
Excavation and civils works	€190,000	€415,000
Budget total	€280,000	€685,000

5.4.2 Reduction in the dissolved metal load

The relatively high dissolved zinc load in the F2/F3 Fissure Water and the Canal Water could be reduced by increasing the pH to circa 9. Because the mine water already has a circum neutral pH and the dissolved metal concentrations are relatively low very little lime would be required. Ignoring any buffer present in the water it is estimated that about 20 tonnes/yr of lime would need to be added to treat the F2/F3 Fissure Water, with a similar amount required to treat the Canal Water. It is anticipated that raising the pH to 9 should reduce the dissolved zinc concentration to circa 0.05mg/l. The dissolved lead and arsenic concentration in the F2/F3 and Canal waters is however relatively low and therefore a smaller reduction in the dissolved concentrations of these metals would be achieved. To substantially reduce the dissolved concentration of these metals it might be necessary to add ferric iron to promote co-precipitation. The addition of ferric iron in the form of either ferric sulphate or ferric chloride would involve significant ongoing expense and would also increase the lime demand and sludge production

Whilst precipitating the dissolved metals can be achieved relatively easily the resultant precipitate may be difficult to settle due to the small particle size and low suspended solids concentration (which will limit the effectiveness of flocculants). Some settlement could be achieved in the conditioning pond which, based on its plan area and an assumed daily flow of 66,000m^3, is theoretically capable of removing solids with a settling velocity greater than 0.3m/hr. However the data available from the sampling programme indicated that a significant proportion of the suspended solids load currently passes through the pond. Its effectiveness in removing any additional solids would therefore need to be carefully assessed before adopting this as a method of improving water quality, and further investigations would be required before pursuing such a course.

5.5 Further Investigations

To establish whether the biomass sloughing of the walls of the discharge pipes is the source of the metal rich sediment accumulating in the river and, if appropriate, to develop a treatment system, it is recommended that the following additional investigations are undertaken.

1. A bulk sample of water should be taken from both discharges to establish whether the suspended solids data collected by the autosamplers is fully representative.
2. A sufficiently large sample of the flocs should be recovered to allow detailed assessment of chemical and settling characteristics of the flocs (note the sample should be carefully taken to avoid them being broken up by the sampling pump)
3. The chemical data for the flocs should be compared with the river sediment to establish whether the flocs are the source of the material accumulating in the river.
4. Further chemical analysis should be undertaken on the water leaving the conditioning ponds and discharged to the river. This should include a suite of both organic and inorganic determinands
5. On the assumption that this testing demonstrates that the flocs are the source of the sediment accumulating in the rivers, a trial should be undertaken to establish the viability of recovery of these solids using a lamella clarifier or similar device.
6. The data from the chemical analysis and field trial should, if conclusive, be used to develop and implement a full-scale solids removal system

It is estimated that the sampling and pilot trial work could be undertaken in a period of 2 months. The design of the full-scale system would take a further 3 to 4 months to design and it is anticipated that construction would take a further 6 months.

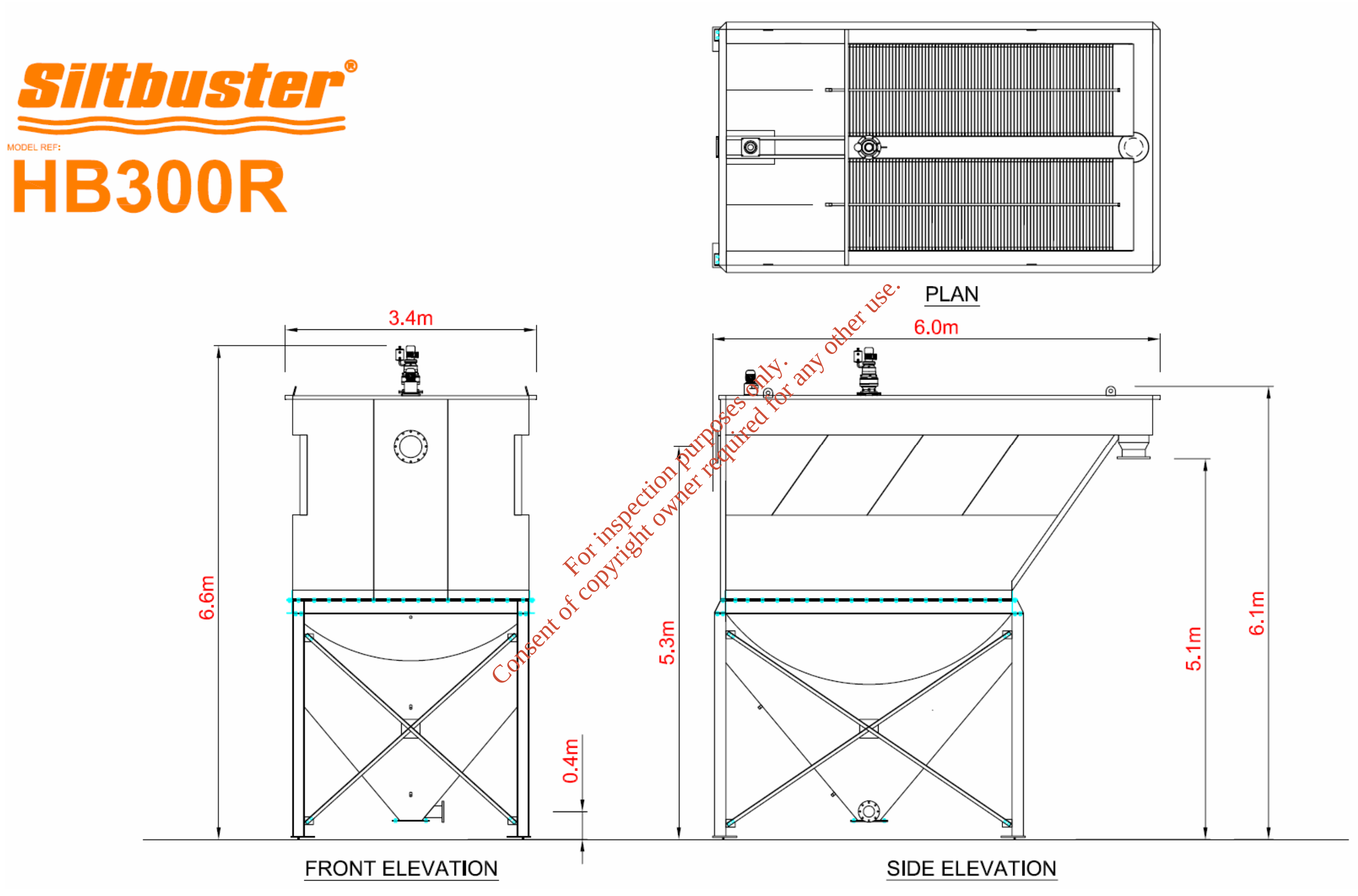


Figure 24. Typical Details for a 300m^2 Effective Area Lamella Clarifier

6. OVERALL CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The purpose of this investigation has been to address a number of issues relating to contamination of the Rivers Drish and Rossestown with metals arising from the Lisheen mine's two outfalls to these rivers. Specifically, the scope of works covered three key issues:

1. An assessment of the precise nature and severity of sediment contamination in the Rivers Drish and Rossestown, and in particular an assessment of the potential impact on the health of higher animals (principally fish and dairy farm livestock).
2. An investigation of the most appropriate approach to remediating the problem.
3. Identification of methods of minimising the possibility of a recurrence of the problem over the remaining life of the mine (currently projected as 8 years from 2006).

Conclusions and recommendations have been made at the end of each of the 4 technical chapters that address the scope of works above. However, these conclusions and recommendations are reiterated here, together, for completeness.

6.2 Water quality and quantity

A logical place to start the report was with a review of the volume and quality of water treated by the mine, and discharged to the two rivers. The conclusions and recommendations drawn are as follows:

- Zinc and lead concentrations in the discharges to the Rivers Drish and Rossestown are within Integrated Pollution Control limits set by the Environmental Protection Agency for the vast majority of the time (based on data from the start of 2005).
- The very high volumes of water that it is necessary for the mine to discharge result in metal loads to the rivers being approximately 13 kg/d Zn and 1 kg/d Pb (though it is worth noting than in 2005 water treatment at the mine resulted in mean removal of 90% of the total Zn load and 99% of the total Pb load).
- Inspection of flows and metal concentrations around the mine reveals that in excess of 70% of the total Zn load entering the holding and conditioning ponds actually arises from the F2/F3 water and the Canal.
- The conditioning pond does very little to attenuate metal loadings, and this appears to be because Zn in particular is present largely in a dissolved (filterable) phase i.e. it will remain in solution at the current pH of the conditioning pond, and will therefore be carried over to the outfalls, rather than settle out.
- Suspended solids concentrations of the two outfalls are well within IPC limits. However, we recommend that suspended solids concentrations at the outfalls are checked by the collection of large (10 – 20 L) grab samples, since it is possible that the velocity of water at the outfalls prevents representative uptake of particulates by the autosamplers at these locations. We also recommend that these particulates are analysed for metals content, to assess whether they are in fact a major contributor to the elevated sediment-metal concentrations in the two rivers.

6.3 River sediment-metal concentrations

The results of an investigation into the concentrations of metals associated with sediments of the Rivers Drish and Rossestown were the catalyst for the current investigation. Two subsequent sampling and analysis exercises have been undertaken given the highly elevated concentrations of lead and zinc found during the initial study. These data have been critically reviewed, with the following conclusions and recommendations:

- Metal concentrations in the water column of the rivers below the discharges to the Rivers Drish and Rossestown are not excessively high, but are at the lower end of the range at which toxic effects may become apparent.
- Three independent sampling and analysis exercises have been undertaken to establish sediment-metal concentrations in the Rivers Drish and Rossestown. The first of these exercises indicated highly elevated concentrations of zinc and lead in the sediments, and were the catalyst to this, and many other investigations, commissioned by Lisheen mine. However, subsequent sampling and analysis exercises (undertaken by Bord na Móna and Minerex / Macaulay Enterprises), have shown highly varied results, even for samples taken from the same locations. There are a number of possible reasons for this, most notably:
    - spatial and temporal heterogeneity in distribution of metals in river sediments
    - variation in the sampling procedures used
    - variation in the precise method of analysis of sediments
- There is clearly a need to clarify this matter, and as a first step we would recommend reaching agreement with the EPA on the precise sampling and analysis methodology to be used, and one which will provide the Lisheen mine, the EPA, and external experts, with confidence in the results of future analysis (the EPA has suggested to the Lisheen mine that appropriate limits for Pb and Zn in sediments are < 1,000 mg/kg and < 5,000 mg/kg respectively).
- A related matter is that of the extraction procedure used for the determination of sediment-metal concentrations. Aqua Regia (or equivalent) extraction has been used by all 3 laboratories to date. However, this is an aggressive extraction procedure, which is not necessarily representative of that portion of metals that may be 'bioavailable'. Therefore Macaulay Enterprises recently conducted a parallel extraction using acetic acid, which gives a far better indication of the likely bioavailability of metals. The results (Tables 6 and 7, pages 12 and 13) indicate that the acetic acid procedure extracts approximately 70% less Pb, and 85% less Zn, implying that a large proportion of the sediment-metals may in fact not be 'bioavailable'. Again, we recommend that clarification from the Irish EPA is sought on this matter.
- Notwithstanding the comments above, visual inspection alone reveals accumulation of sediment adjacent to, and immediately downstream from, the two mine outfalls. In these areas, and potentially other 'hotspots' of contamination downstream (following confirmation by agreed sampling and analysis), we recommend selective removal and disposal of sediment. There is a serious risk of causing pollution if such an exercise is undertaken, however, and therefore close attention will need to be paid to addressing this risk, and consulting fully with the EPA. The most feasible method of removal is likely to be the installation of silt curtains or fences in appropriate downstream locations (to prevent dispersion of sediment) followed by hydraulic suction of sediment from the heavily contaminated zones. Specialist contractors can be contacted if it is necessary to discuss this further.

6.4 Ecological impacts of sedimentation / elevated metal concentrations

The ecological impacts of the elevated metal concentrations in the sediments of the two rivers are clearly of concern. A review of these aspects, data for which principally focus on the River Drish, concludes as follows:

- Under the Irish classification system the River Drish is of moderate ecological status in terms of benthic macroinvertebrate abundance and diversity, even at locations upstream of the Lisheen outfall. Deterioration in quality downstream of the outfall appears to principally relate to sedimentation rather than toxicity, with the exception of the stretch of the river at NE Castletown.
- Metal-sensitive species, such as those of the families of *Mollusca* and *Gammarus*, are typically only found in abundance at sites upstream of the Lisheen outfall, and concentrations of cadmium, copper, lead and zinc are found in elevated concentrations (i.e. above reported baseline concentrations) in the tissue of both *Gammarus* and *Asellus*.
- There appears to have been a decrease in the abundance of the macroalga *Cladophora*, which is a metal-sensitive species.
- Preliminary results suggest that there are elevated concentrations of zinc in fish muscle at locations downstream of the outfall. There is no European limit for zinc in fish muscle.
- Aquens Ltd identified a single brown trout (out of a sample of approximately 200 fish) downstream of the outfall to the Drish with elevated concentrations of arsenic and mercury.
- Of the metals analysed none was evident in elevated concentrations in cattle milk or blood.

6.5 Review of the Lisheen mine water treatment system

If selective removal of sediment from the rivers is undertaken (Section 6.3), then minimising the potential for further deposition of sediment is clearly desirable. For this reason a thorough review of current mine water treatment at the Lisheen mine has been carried out, with the following conclusions and recommendations:

- A review of the performance of the Mine Water Treatment Plant (MWTP) and Reclaim Water Treatment Plant (RWTP) illustrates that the optimum pH for zinc removal in these plants is 9.0 – 9.5.
- Further optimisation of the treatment plant may also result in some scope for treating at least a portion of the F2/F3 Fissure water and / or Canal water with the existing facilities. This is however unlikely to allow anything other than treatment of a small proportion of the F2/F3 Fissure or Canal water.
- An additional option available for reducing the metal concentrations in the F2/F3 and Canal waters is lime dosing. It is estimated that approximately 40 tonnes/yr of lime would be required to raise pH of the F2/F3 Fissure water and Canal water to that required for effective metal removal.
- Although the holding and conditioning ponds are important in terms of suspended solids removal, they have little effect on attenuation of metal loads, in likelihood for the reasons outlined in Section 6.2, above.
- Metal load data suggests that there is in fact a greater combined mass of zinc discharging to the rivers than there is entering the conditioning pond. This requires further investigation. It is possible that this relates to inaccuracy in water

quality assessment due to stratification across the weir between the holding pond and conditioning pond, and therefore this should be investigated by sampling at various depths. A similar sampling exercise in the area of the conditioning pond outlet will establish whether raising the outlet point is likely to result in any measurable improvements in terms of final discharge metal concentrations.

- Deposition of particulates may be a significant contributor to the sediment-metal contamination problem in the vicinity of the two outfalls in particular. In the first instance we recommend collection of large grab samples from the outfalls for suspended solids determination and chemical analysis of particulates, as noted in Section 6.2. Beyond this action, installation of settlement facilities at the outfalls may help to reduce the mass of suspended solids discharged to the two rivers. Pilot trials are recommended to determine the settlement velocity of these sediments, and therefore the size and effectiveness of units required. A pilot-scale test could be undertaken for a cost of approximately €15,000. If successful, full-scale gravity-fed lamella plate clarification units at each of the outfalls have a budget cost estimate of €965,000.

6.6 Recommendations

It is recommended that a stepwise approach is followed by the Lisheen mine to address the issues detailed in this report. By adopting such a strategy it should be possible to monitor, in a measurable way, the benefits accruing from individual actions. The recommendations outlined below broadly fall into three categories:

1. Immediate actions to address the current problems of sedimentation in the Rivers Drish and Rossestown
2. Additional monitoring, to clarify issues relating to the nature of suspended solids in the two discharges and possible improvements to mine water treatment
3. Monitoring of river water quality, both chemical and biological

6.6.1 Sediment removal

It is recommended that targeted removal of sediments is undertaken as an immediate action (i.e. targeting those areas where Zn and Pb concentrations exceed 5,000 mg/kg and 1,000 mg/kg respectively). Some short-term downstream effects, due to disturbance of sediment, are almost inevitable. In an effort to minimise such problems it is advised that removal of the material is undertaken by some form of hydraulic suction, rather than more conventional dredging. The temporary installation of silt curtains or fences in downstream locations is also recommended, to minimise the volume of material washed downstream. Clearly there will be a need to closely monitor downstream water quality before, during, and after sediment removal and, if such a course of action is followed, close liaison with the Irish EPA will of course be required. The precise details of the approach to sediment removal is the preserve of specialist contractors (the exact means by which it is most effectively undertaken depending on issues such as river flow volume, velocity and depth, as well as the nature of the sediment). Contact with appropriate companies can be made if required.

Minerex (2006) calculated that the total volumes of sediment in the Drish and Rossestown are 13,511 m^3 and 3,267 m^3 respectively. However, some major assumptions were made in deriving these values. In particular it was assumed that the volume of sediment between sample points remained the same. In the vicinity of the outfalls it seems most unlikely that this is the case, since visual observation alone is sufficient to suggest that sediment volume rapidly decreases with distance from the outfall. Coupled with the dynamic nature of sediment behaviour in riverine environments, it is therefore recommended that whilst the results of Minerex (2006) can be used as a guide to locations for selective sediment removal, visual observations of sediment 'hotspots', identified by walkover surveys, will be important to ensure the sediment removal exercise is conducted as effectively as possible.

Disposal of sediment removed will clearly need to be to a contained facility, and the existing Tailings Management Facility (TMF) on the Lisheen mine site is the obvious choice.

The sediment removal exercise should proceed as soon as possible, and it is understood that the Lisheen Mine has already had discussions with possible contractors to undertake this work. Therefore completion of this exercise before the end of 2006 should be feasible as long as flow conditions in the two rivers are suitable.

6.6.2 Minimising future sedimentation in the Rivers Drish and Rosseetown

The suspended solids concentrations in the two discharges are well within the EPA's Integrated Pollution Control Licence conditions the vast majority of the time. Nevertheless, visual observations at the outfalls to the Rivers Drish and Rossestown suggest that what little suspended matter there is in the discharge waters is similar in appearance to that which accumulates in the two rivers immediately adjacent to the outfalls. Preliminary analyses show that this suspended matter does have elevated concentrations of Zn and Pb. It seems that this suspended matter may arise from 'sloughing' of accumulated material from the insides of the two discharge pipes. However, the analytical results available are not sufficient to be certain that this is the main cause of sedimentation in the two rivers.

To establish whether the biomass sloughing of the walls of the discharge pipes is the source of the metal rich sediment accumulating in the river and, if appropriate, to develop a treatment system, it is recommended that the following additional investigations are undertaken.

1. A bulk sample of water should be taken from both discharges to establish whether the suspended solids data collected by the auto-samplers is fully representative.
2. A sufficiently large sample of the flocs should be recovered to allow detailed assessment of chemical and settling characteristics of the flocs (note the sample should be carefully taken to avoid them being broken up by the sampling pump)
3. The chemical data for the flocs should be compared with the river sediment to establish whether the flocs are the source of the material accumulating in the river.
4. Further chemical analysis should be undertaken on both the water leaving the conditioning ponds and that discharged to the river. This should include a suite of both organic and inorganic determinants, conducted on both total and dissolved samples (pH, temperature, conductivity, alkalinity, Ca, Mg, Na, K, Fe, Zn, Pb, As, Cd, Al, Hg, HCO_3^-, Cl, SO_4, NH_3, NO_3, Biochemical Oxygen

Demand (BOD), Total Organic Carbon (TOC), and Loss on Ignition (LOI) and suspended solids on the total sample)

5. On the assumption that this testing demonstrates that the flocs are the source of the sediment accumulating in the rivers, a trial should be undertaken to establish the viability of recovery of these solids using a lamella clarifier or similar device.
6. The data from the chemical analysis and field trial should, if conclusive, be used to develop and implement a full-scale solids removal system

It is estimated that the sampling and pilot trial work could be undertaken in a period of 2 months. The design of the full-scale system would take a further 3 to 4 months to design and it is anticipated that construction would take a further 6 months.

6.6.3 Chemical and biological monitoring of Rivers Drish and Rossetown

In addition to the analyses outlined above, there is clearly a requirement to closely monitor the chemical and biological of the Rivers Drish and Rossestown, to evaluate improvements arising from the actions detailed above. With immediate effect it is recommended that water samples are collected routinely (at least monthly) from the sample points at which sediments have previously been collected. Samples must definitely be collected for determination of both total and dissolved metal concentrations. The analysis should include the usual suite of inorganic constituents (i.e. pH, temperature, conductivity, alkalinity, Ca, Mg, Na, K, Fe, Zn, Pb, Cd, As, Al, Hg, HCO_3^-, Cl, SO_4 and suspended solids for the total sample).

Collection and analysis of sediment samples from the rivers will need to be undertaken at some stage. However, little is likely to be learned by taking samples immediately after removal of the sediment. This is because the approach to sediment sampling is to actively seek out areas of the river bed where sediment is present. Therefore if, for example, 90% of the sediment is removed, the 10% left is still likely to exhibit the high metal concentrations shown by previous analyses, albeit the total mass of sediment will be greatly reduced. More useful insights will be gained by first following the recommendations provided in Section 6.6.2, above, aimed at reducing the mass of suspended solids discharged to the rivers, and then allowing a period of time to elapse in order for any remaining sediment to disperse. It is difficult to be prescriptive about the length of time to leave before collecting further sediment samples since it will depend on hydrological conditions in the rivers; several storm events, resulting in high river flows, should be allowed to occur before taking sediment samples again. It would therefore be beneficial to collate flow-rate data for the two rivers following implementation of the measures outlined above. Such data should be available from the Irish EPA. It may be prudent for the Lisheen Mine to make its own flow measurements at key monitoring points (e.g. downstream of the two outfalls) since this will enable calculation of metal loading in the two rivers (as long as simultaneous water samples are collected for determination of metasl concentrations).

Elevated concentrations of metals are evident in benthic macroinvertebrates in the Rivers Drish and Rossestown. Following implementation of the measures detailed above it is recommended that biological monitoring is conducted with a view to meeting the following ecological targets:

- Achieve Q3, or higher, without '/0' or '*' suffixes at all sites downstream (provided that the upstream sites are not of lower biological water quality).
    - Removing siltation should result in increases in numbers of those insect taxa which need open spaces between stones. These include Elmidae (riffle beetles) and nymphs of the mayfly *Baetis muticus*, which live in interstitial spaces. Numbers of Hydropsychidae (uncased Trichoptera) should also increase, as these insects need spaces between stones in which to construct webs to trap food.
    - Removing toxic effect should increase numbers of *Gammarus, Asellus*, Mollusca.
    - Increase sampling frequency from once per year to three times per year (Spring, Summer, Autumn) to show changes
    - Identify everything to the lowest taxonomic level practicable, to give other data analysis options.

- Diatom assemblage shows no significant reduction in diversity between site 1 and sites 4, 5, and 6 (sites 2 and 3 are difficult for diatom sampling, site 4 may be too deep).
    - Use 'DARES' methodology, samples collected at same time as invertebrate samples
    - Also check for presence / abundance of distorted valves (a good indicator of metal enrichment)
    - Data analysis to include multivariate analyses of community composition and diversity metrics

- No obvious accumulations of fine sediment within sampling reaches.
    - The RIVPACS methodology would be appropriate – based on visual estimates of the percentage of the substratum belonging to different Wentworth size categories (boulder/cobble, pebble/gravel, sand, silt/clay).
    - Again, these surveys to take place at same time as invertebrate sampling.

We would expect to see an obvious faunal / floral change after one year (populations of *Asellus* and *Gammarus* etc will need a few generations to build up numbers). Diatoms will need a baseline survey before works commence in Autumn 2006. If sediment removal can start in Autumn 2006, then winter floods should help to flush finer sediments out of sites 4 - 6 and hasten improvement (*cf* comments above regarding sediment sampling). Lisheen Mine should liaise with the Irish EPA to establish whether any of the biological data identified above is already available via its routine monitoring programme.

6.6.4 Additional measures

It is hoped that the measures outlined above, aimed principally at addressing the current sedimentation problem in the two rivers, and minimising the occurrence of such problems in the future, will achieve the necessary improvements to the chemistry and ecology of the Rivers Drish and Rossestown. This will only be known with certainty following the implementation of the actions detailed in the paragraphs above. If additional measures are required this is likely to require addressing reductions in the dissolved concentrations of metals. Approaches to accomplishing this are outlined in Section 5.4.2 of this report.

6.6.5 Suggested timetable for implementation of measures

A suggested timetable for implementation of the measures outlined above is provided in Figure 25.

Action	2006			2007												2008					
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
Existing sediment removal	■	■	■																		
Suspended sampling and analysis	■	■																			
Suspended solids treatment system design			■	■	■																
Suspended solids treatment system installation					■	■	■	■	■	■											
Sediment sampling													■						■		
River water quality sampling	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Commence biological monitoring																		■	■	■	■
Evaluate improvements; consider other measures																				■	■

Figure 25. Suggested timetable for implementation of measures

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