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Chapter 5 Mary Kathleen catchment area

5.1 Introduction

Sediment analysis is useful for the identification, monitoring and environmental review of contaminants in a drainage system. Trace metals enter the sediments by many processes including erosion, direct adsorption from the water column or by deposition of enriched suspended solids such as dead algae. Various mechanisms can result in the subsequent remobilisation of these metals including a change in pH or redox condition, re-suspension of sediment particles and uptake directly from contaminated sediments.

The climatic influence on the hydrological regime at the Mary Kathleen minesite is of primary significance to drainage and sediment transport. Mary Kathleen has a wet-dry climate with a distinct wet season, bringing monsoonal rain between December and March, followed by a distinct dry season. Cameron Creek is the main catchment system from the mine site.

The main objectives of this chapter are to establish the sources and magnitude of contamination and radioactivity and determine background and anomalous values of uranium and other contaminants from the mine site in water and stream sediments within the local catchment area. In addition, naturally mineralised areas in the Cameron Creek catchment and mining induced activities are likely to have at least some impact on the current and former uranium loadings of the Cameron Creek catchment and this study will attempt to quantify the effects.

5.2 Description

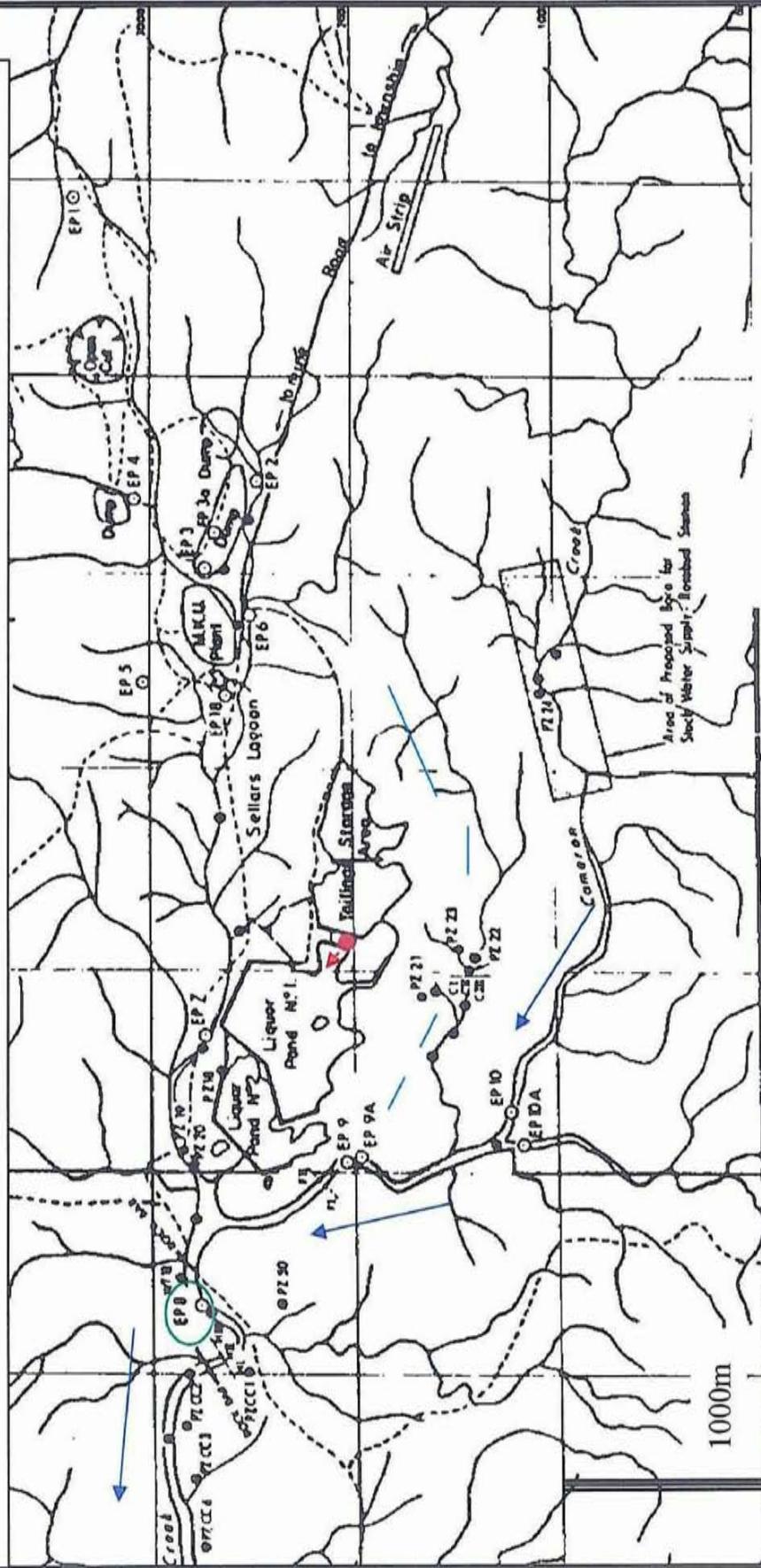
5.2.1 Location and environmental history

Cameron Creek is an ephemeral stream in the Flinders River catchment system (Figure 5.1). The drainage pattern of Cameron Creek flows in a northerly direction toward the Gulf of Carpentaria. Flood conditions can develop from cyclonic influences in the Gulf. Semipermanent waterholes and billabongs are common in Cameron Creek year round. Background groundwater quality was described as slightly brackish (> 100 mg/L TDS) with a neutral pH and Na, Mg and Ca as dominant cations and bicarbonate as the dominant anion followed by chloride and sulphate (MINENCO, 1985).

Rainfall infiltrates the soil and outcrops of fractured rock in the mine surrounds and recharges the aquifer, which flows down dip through the weathered zone into the alluvial aquifer in the valley floor (Flanagan et al., 1983). Underflow along Cameron Creek in the alluvium is prevented by impermeable rock bars, which force the groundwater to the surface for evaporation (MINENCO, 1985). Westwards from the tailings storage area, deeply weathered fracture zones cut through low ridges and allow the transfer of groundwater to an adjacent valley alluvial aquifer into West Cameron Creek (Flanagan et al., 1983).

Heavy wet seasons in 1982-83 and 1983-84 caused the level of liquor in one of the subsidiary evaporation ponds to rise faster than anticipated, necessitating the release of some 1900 cubic metres of it into Cameron Creek, via a syphon, on 16 February 1984. A clean up program was instigated in Cameron Creek and after detailed examination it was considered that there would be no significant long-term effects from the release (MINENCO, 1985).

Figure 5.1 Cameron Creek drainage pattern illustrating the direction of stream flow, environmental sample points and the tailings seepage zone.



Key

- Tailings Seepage
- Groundwater
- Direction of stream flow

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**AUSTALIAN GROUNDWATER ENVIRONMENTAL SAMPLING POINTS
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Predictive modelling of hydrological processes and solute transport from the rehabilitated minesite to Cameron Creek and Cameron River was carried out (MINENCO, 1985) to determine the long term impact on the levels of Total Dissolved Solids (TDS), sulphate and chloride (Appendix 11). Chlorine was used in the ore treatment process and consequently exists in tailings water from the first operation. Zones of contamination were defined in West Cameron Creek near PZ 21, 22 and 23 at monitoring point E9 and the area upstream of rock bar at EP8 (MINENCO, 1985).

Table 5.1. Summary of TDS, SO₄ and Cl, concentration predictions at EP8 and EP14 (MINENCO, 1985).

Seasonal monthly averages		
	Wet Season	Dry Season
EP8		
TDS	<2000 mg/L after 1995 <400 mg/L after 2020	<4000 mg/L after 2000 <3000 mg/L after 2020
SO ₄	<3000 mg/L after 1990 <1000 mg/L after 2000	<3000 mg/L after 2000 <1000 mg/L after 2010
Cl	<100mg/L after 1990 <50mg/L after 2010	<400mg/L after 1990 <300mg/L after 2010
EP14		
TDS	<1500 mg/L after 1995	<4000 mg/L after 1995 <1500 mg/L after 2010
SO ₄	<1000 mg/L after 1990	<1000 mg/L after 1990

Water quality monitoring and sediment sampling programs confirmed that the main potential contaminant in surface and ground waters upstream of the rock bar at EP8 was sulphate followed by sodium, chloride and calcium. Neither iron nor manganese appeared to be significant constituents in the sediments (MINENCO, 1985). Also, runoff events during the wet season were predicted to flush out salts. However, small runoff events might mobilise additional salts and concentrate them at the rock bars (MINENCO, 1985).

Interpretation of the hydrogeology of the area was that any seepage from operational activities would be contained within the local catchment areas would be is clarified by the alkaline soils to a quality which meets the standards for cattle usage, which is the main industry in the region. The movement of heavy metals, radionuclides and acidity was thought to be severely retarded by the soils (MINENCO, 1985). There was no evidence that uranium or any of its daughters were moving from the waste disposal area. Sulphate was the main contaminant in the groundwater system (MINENCO, 1985).

5.2.2 Survey design

The catchment survey investigated the extent of mobilisation and transport of uranium and other contaminants from the former plant, waste rock piles, tailings storage area and the evaporation ponds into the local drainage system. A regional (16 km) and local scale sampling of 5 soils and 63 stream sediments in the catchment was undertaken and a geochemical database created. Ten water quality measurements were taken from ponds within Cameron Creek north of the tailings dam, of which two were submitted for chemical analysis.

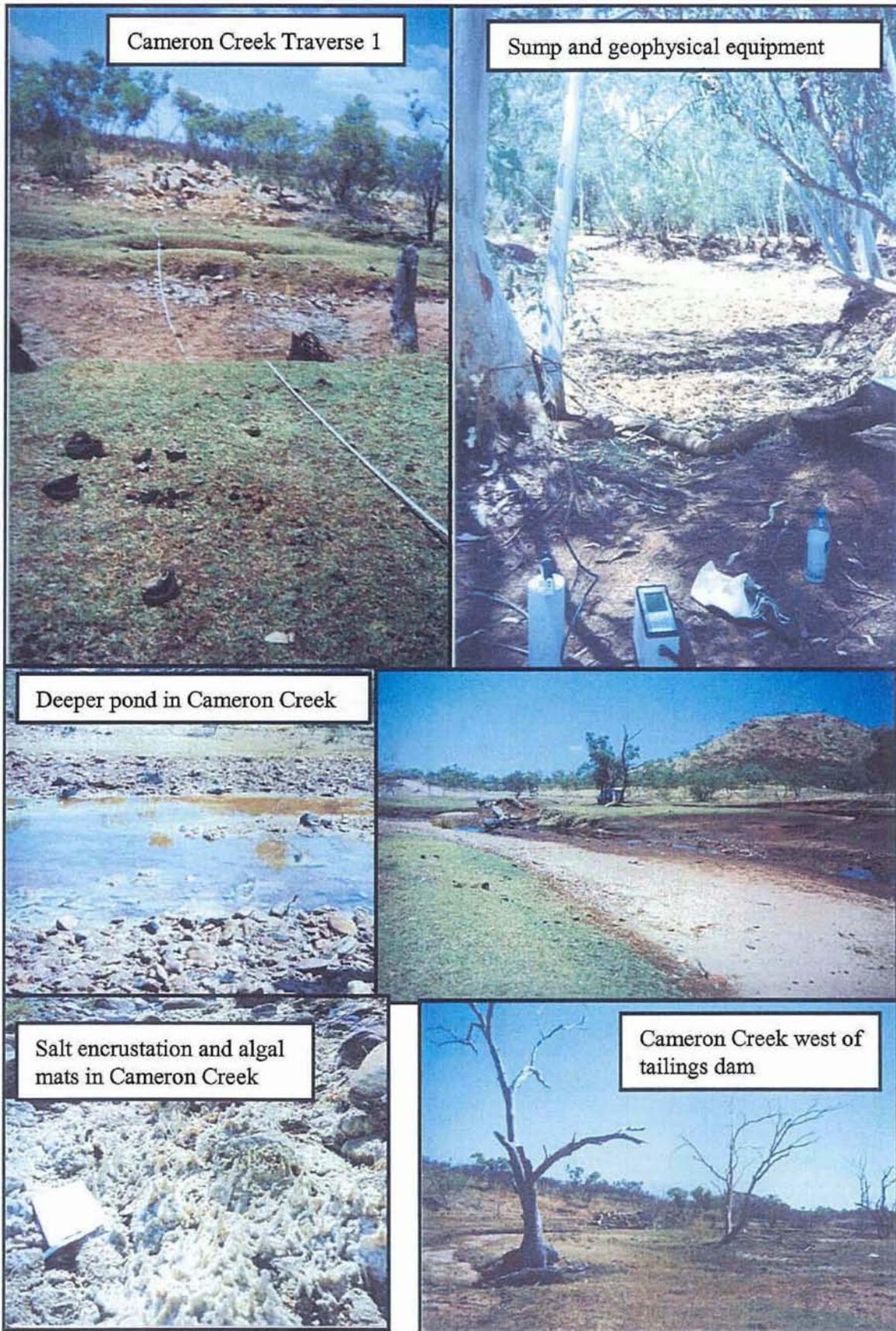
Total count spot measurements were taken around the old township, in drainage channels surrounding waste rock areas, downstream from the tailings and evaporation ponds and downstream in Cameron Creek. Exposure rate (mSv/yr) traverses were conducted in the old township, in the sump and within the creek near bore 28. Background total count spot readings were taken in the large western tributary of Cameron Creek 1.5 km south west of the tailings dam.

5.3 Stream sediments

5.3.1 Characteristics

The creek channels contain 2 to 5 metres of shallow alluvium, commonly coarse angular sands and cobble gravels. The alluvium is not continuous but is broken up into small basins separated by outcropping bars of unweathered bedrock. Two significant rock bars restrict the outflow of surface and underground water from the catchment area. White salts are evident in drainage channel sediments below the mine site (Figure 5.2).

Figure 5.2. Collage of photographs taken in the Cameron creek catchment area (Photographed 10-10-1999).



5.3.2 Geochemistry

Stream sediment samples were collected from the Cameron creek catchment area (Figure 5.3) (excluding waste rock and tailings dam area samples previously discussed). Samples were sieved to $< 2\text{mm}$ to $63\ \mu\text{m}$ fractions, the sample was further sifted to $< 63\ \mu\text{m}$ if enough sample remained. These samples were submitted for major and trace element analysis, (Table 5.2) and are grouped into localities for easy reference. Note: some samples only have a coarse grain fraction analysis.

Figure 5.3. Coarse scale (1:100000) map with selected Cameron Creek catchment sample sites.

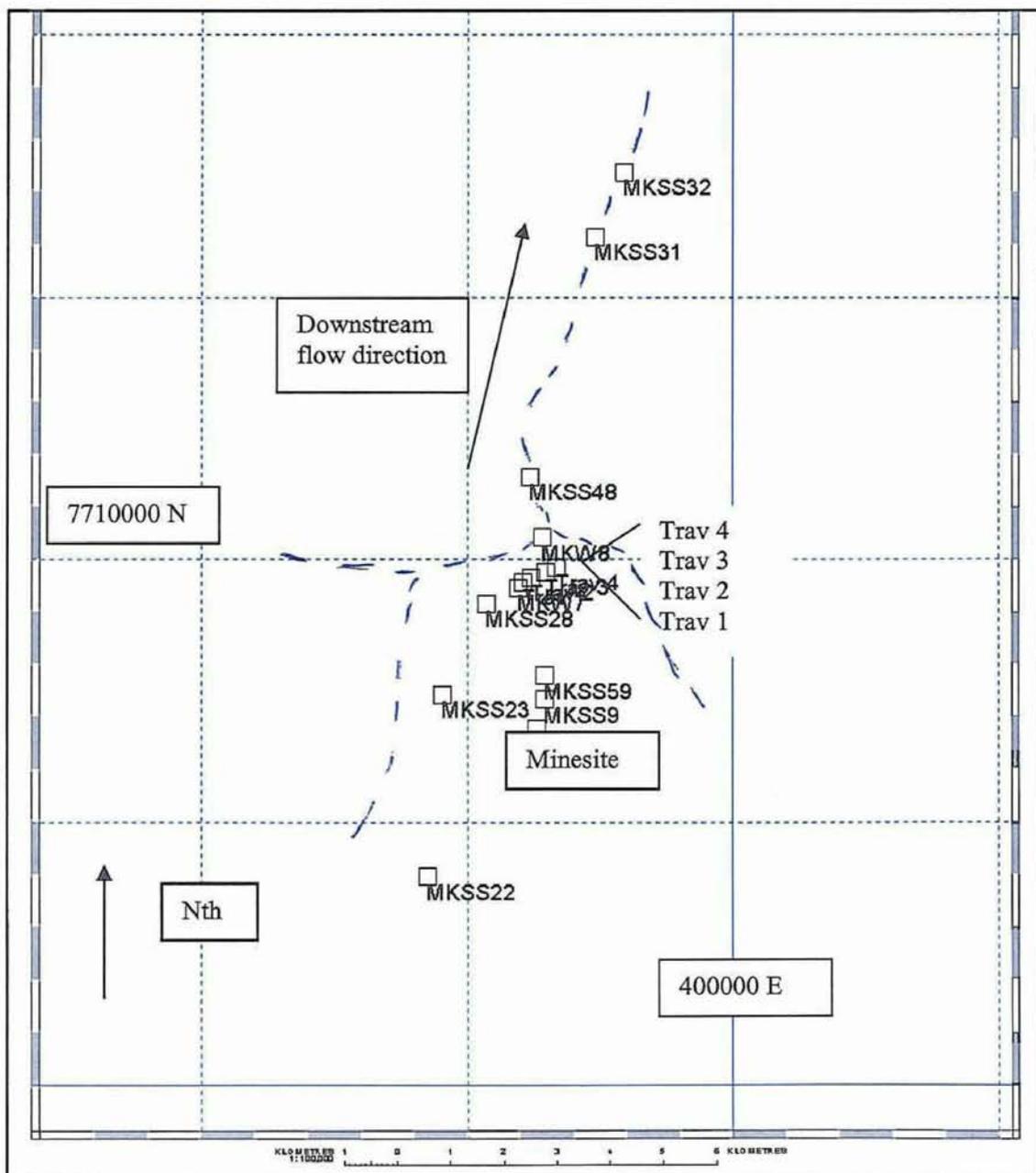


Table 5.2. Major (wt%) and trace element analysis (ppm) geochemistry of stream sediments sampled from the Cameron Creek catchment area (A samples sieved < 2mm to 63 µm and B samples < 63µm). Samples are grouped into sample areas and brief summary of geochemistry for each area is given.

Table 5.2.a Major (wt%) and trace element analysis (ppm) geochemistry of background stream sediments.

West of tailings

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKS14	1.3	4.2	3.4	0.6	1.1	<1	717	110	35	51	472	10	1140	15	41	94	36	8	78	62	32
MKSS23A	0.9	6	2	0.6	0.4	<1	473	76	56	40	449	21	285	8	117	41	13	4	154	27	21
MKSS23B	0.8	5.3	2.1	0.6	0.7	6	578	161	83	81	606	24	436	16	267	61	24	5	147	68	52
MKSS24A	1.2	3.9	3.8	0.7	1.3	<1	591	85	51	40	381	18	412	13	67	68	30	6	94	36	28
MKSS24B	1.5	5.7	2.1	0.7	1.1	5	539	198	92	103	504	20	654	21	170	67	71	15	131	87	46

South of Township

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKS13	4.6	9.3	1.1	3.2	1.9	<1	168	43	143	18	1400	48	1030	6	84	104	5	1	350	44	74
MKSS21A	1.4	4.9	2.4	1	1.3	<1	847	77	129	31	402	22	407	9	77	72	13	5	132	31	30
MKSS21B	1.7	6.2	2.7	0.8	0.9	<1	673	113	135	58	407	17	618	16	112	56	28	7	155	66	31
MKSS22A	2.8	7.2	2.5	1.6	1.1	<1	636	91	146	39	833	29	575	7	120	88	9	5	228	34	58
MKSS22B	1.7	5.6	1.8	0.9	0.8	<1	760	119	158	67	477	20	791	12	178	65	22	6	147	54	48

Background stream sediment samples have minimal As (<7 ppm), Pb (<17 ppm), U (<17 ppm) and low sulphur (< 300 ppm) concentrations. Samples from south of the township have elevated Cu levels compared to west of the tailings dam, possibly indicating localised copper mineralisation.

Table 5.2.b Major (wt%) and trace element analysis (ppm) geochemistry of stream sediments east of the tailings dam and downstream from waste rock and processing areas.

Close to minesite

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS8A	1.3	2.2	4.2	0.3	1	<1	472	122	31	72	319	17	276	13	136	62	20	7	46	22	20
MKSS8B	1.9	5	1.9	0.7	1	11	360	424	94	259	645	32	673	27	555	69	87	21	111	69	52
MKSS9A	7.3	5.4	3.1	0.3	0.8	10	388	285	35	187	1120	16	350	16	56	59	26	10	82	52	19
MKSS9B	4.4	6.2	1.2	0.7	1.1	15	422	568	105	363	1040	43	928	33	215	69	66	30	132	75	42
MKSS19B	3.3	6.7	1.6	1.1	0.8	34	410	1660	360	1090	1640	74	1280	65	1100	56	89	80	131	61	85
MKSS19A	2.6	5.5	2.6	1	0.9	27	430	1130	297	750	1150	63	869	55	671	59	58	61	108	41	75
MKSS25A	2.8	4.7	1.6	0.8	1.1	23	460	1220	172	759	657	37	735	36	188	67	41	54	93	32	36
MKSS25B	5.9	7.6	1.7	0.9	0.9	59	283	3830	311	1940	1090	47	2280	83	331	53	94	92	127	59	58

Elevated levels of As, Ce, Cu, La and U compared to background samples exist in both size fractions in this area.

Table 5.2.c Major (wt%) and trace element analysis (ppm) geochemistry of stream sediments near bore 28 and within the sump.

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS87A	2.1	6.3	2	1	0.7	25	331	1450	254	805	928	62	1030	53	425	50	93	73	118	70	92
MKSS58A	2.4	5.4	2	1	0.9	17	404	706	305	490	997	68	742	31	329	62	46	58	120	48	66
MKSS58B	2.7	5.8	2	1	1	20	319	897	356	548	904	68	886	30	339	61	60	58	131	57	67
MKSS59A	4.2	5.4	2.9	0.7	0.9	24	429	1110	168	726	1170	44	677	38	186	63	51	58	98	42	63
MKSS59B	4.2	8	1.8	1.2	0.9	42	363	2220	379	1560	1640	78	1500	79	347	57	89	109	140	57	142
MKSS65A	2.5	5.7	2	1	0.9	23	359	1050	265	702	893	62	930	45	1000	54	65	62	121	52	75
MKSS65B	2.2	6.4	1.7	1.1	0.7	23	298	1210	302	745	970	66	1010	51	1230	50	79	70	131	55	92
MKSS66A	1.8	6.6	1.8	1.1	0.7	23	348	1010	315	662	1030	70	923	53	734	49	78	61	143	59	89
MKSS66B	1.9	6.8	1.7	1.1	0.7	21	310	1020	302	653	1040	66	920	49	900	50	79	57	140	59	92

Concentrations of As (>17 ppm), Ce (> 800 ppm), Cu (> 250 ppm), La (> 450 ppm), Mn (>800 ppm), Pb (>30 ppm) and U (<55 ppm) are significantly higher than background samples.

Table 5.2.d Major (wt%) and trace element analysis (ppm) geochemistry of stream sediments from a small creek entering Cameron Creek (395801 E, 7709391 N) from the tailings area.

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS36A	2	4	2.9	1.4	3	<1	476	104	58	59	850	22	536	11	21700	107	24	12	103	37	32
MKSS36B	1.5	4.8	2.2	1.7	2.4	<1	413	221	82	114	1270	20	623	16	12400	84	53	26	119	62	40
MKSS38A	1.9	4.4	2	0.9	1	10	502	481	75	315	2380	34	782	18	539	93	40	12	100	44	42
MKSS38B	2.9	5.8	1.9	0.9	0.7	22	323	1430	106	932	3280	37	1220	28	748	92	90	19	120	65	52
MKSS39A	1.5	3.6	1.3	0.8	1.3	<1	558	128	48	80	2010	31	496	12	1220	92	18	6	88	29	32
MKSS39B	2.6	5.5	1.9	1	0.8	14	316	902	112	611	6310	39	990	25	6890	116	78	23	117	69	56
MKSS30A	2.1	3.7	2.5	1.6	2.2	<1	491	79	41	39	415	18	398	7	16710	122	24	26	104	32	24
MKSS30B	2	4.3	2.4	1.5	1.7	<1	462	165	48	80	393	15	596	16	13400	138	53	54	112	63	28
MKSS44A	3.4	1.8	3.5	0.6	1	<1	427	47	21	22	227	12	255	0	5450	484	12	42	51	16	14

Concentrations of Na increase from generally less than 1 wt% to up to 3 wt% in this stream. MKSS38B and MKSS39B, the fine fraction sampled closer to the tailings dam, have the highest As, Ce, Cu, La and Mn values, which are elevated compared to background levels. MKSS36A&B and MKSS30A&B, sampled at the stream creek junction, have elevated S levels.

Table 5.2.e Major (wt%) and trace element analysis (ppm) geochemistry of stream sediments from a hillside between Cameron Creek and Western Cameron Creek.

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKS15	1	2.7	2	0.4	2.3	<1	209	155	17	71	311	11	464	11	65	71	59	9	93	55	21
MKSS28A	2	3.9	3.4	0.9	1.7	<1	472	121	28	67	534	22	718	12	380	93	32	7	87	43	39
MKSS28B	3.2	4.8	2.2	1	1.6	5	307	345	35	167	689	22	1230	20	1010	99	99	17	128	92	46
MKSS29A	1.2	3.6	3.1	0.8	1.2	<1	553	74	48	33	353	18	372	9	90	64	21	5	93	30	27
MKSS29B	1.5	4.8	2.8	0.7	1.1	<1	525	139	62	68	400	17	563	16	134	63	57	12	125	72	33

Sampled north of the minesite, 500m upstream from the small creek Cameron creek junction (mentioned in Table 5.2d), this sample has similar levels of major and trace elements as the background samples.

Table 5.2.f Major (wt%) and trace element analysis (ppm) geochemistry of stream sediments Cameron Creek below the tailings dam.

Stream sediments were sampled in four traverses (southern side to the northern side of the creek) across the creek with Traverse 4 the furthest from the tailings dam area. Many samples have only the 2 mm to 63 µm fraction size due to the nature of the stream sediments within Cameron Creek.

Traverse 1

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS73A	2	4.2	2.5	0.8	1.4	<1	599	112	53	58	374	17	577	13	317	81	34	8	106	47	31
MKSS74A	2	2.2	3.5	0.8	1.8	<1	405	39	25	17	219	10	235	5	9750	115	10	10	58	18	15
MKSS75A	1.8	5.3	3.1	1	1.3	<1	534	69	50	30	470	20	537	9	85	75	21	5	152	38	30
MKSS76A	1.8	5.2	2.6	1	1.3	<1	509	65	49	29	459	20	523	8	78	75	20	5	147	38	30
MKSS45A	1.2	2.2	2.9	0.9	1.4	<1	439	43	22	21	308	13	248	7	10500	96	14	14	59	17	14
MKSS46A	0.9	2.1	3.9	0.5	1.1	<1	469	41	27	19	225	13	253	5	1160	68	17	6	58	19	15
MKSS53A	0.9	2.5	3.4	0.5	1.1	<1	454	45	27	21	263	13	256	6	391	67	27	8	68	21	15
MKSS53B	3.3	5.1	2.3	1.7	1.1	<1	441	158	76	75	484	25	653	12	11900	194	50	43	136	58	73

Traverse 2

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS77A	3.1	4.1	2.6	0.9	1.4	<1	481	86	34	45	425	16	429	8	79	124	29	5	125	37	22
MKSS78A	1.6	6.3	1.5	2.9	2.8	<1	280	78	92	35	526	54	619	7	3340	98	18	6	242	28	44
MKSS79A	1.7	5.1	2.6	0.9	1.3	<1	542	80	44	42	426	20	530	8	95	76	31	6	136	46	29
MKSS80A	1.6	4.9	3.3	0.9	1.3	<1	521	84	42	41	425	19	457	11	92	75	27	7	132	44	31
MKSS50A	1.8	5.6	1.7	2.8	1.6	<1	359	76	87	36	577	64	803	6	635	94	17	8	184	37	46
MKSS51A	1.3	5.3	2.2	2.5	1.8	<1	292	56	47	33	359	49	542	6	2480	66	18	8	162	35	45
MKSS51B	1.6	6.3	1.1	3.4	2.5	<1	175	71	72	43	364	64	666	5	6350	88	18	12	196	46	87

Traverse 3

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS81A	1.4	3.8	3.7	0.8	1.3	<1	478	61	37	29	369	17	417	6	63	81	18	6	102	31	25
MKSS82A	4.9	6.4	1.2	4.1	1.4	<1	196	91	52	49	678	36	677	6	52	139	13	4	180	44	46
MKSS26A	1.7	6.6	1.7	1.3	1.3	8	372	99	52	50	553	23	425	9	6880	85	123	24	174	48	28
MKSS26B	2.1	5.7	1.8	3.1	1.5	<1	310	163	83	76	594	21	450	11	19700	138	46	67	148	56	45

Traverse 4

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS83A	3	4.7	3	0.9	1.2	<1	450	142	88	68	770	23	495	16	177	79	26	9	109	42	37
MKSS84A	5	4	2.7	1.1	1.4	6	365	66	37	33	438	17	313	8	6680	91	17	12	86	31	26
MKSS85A	1.9	4.5	3.2	1.1	1.3	<1	524	79	49	38	425	19	589	6	91	80	21	5	125	40	29
MKSS55A	1.8	2.2	3.4	0.5	1.1	<1	456	39	55	18	374	13	260	8	543	108	10	18	57	19	16

Samples in close proximity to Traverse 1-4.

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS20A	4.8	4.5	2.6	0.8	1.4	7	409	102	51	62	999	32	364	21	459	72	15	9	94	31	44
MKSS34A	5.9	5.1	2.3	1.1	1.4	6	421	65	363	34	1010	36	482	10	186	83	11	3	130	26	41
MKSS61A	3.1	3.7	3	0.9	1.2	<1	453	85	47	47	632	20	401	10	3350	129	26	42	90	31	27
MKSS61B	3.5	4.9	1.8	1.6	1	<1	335	245	107	129	1260	30	661	16	6960	160	39	110	119	53	49
MKSS62A	3.8	3.7	2.7	1.3	1.2	<1	426	82	42	42	741	20	369	10	7960	270	18	98	94	33	24
MKSS62B	4.6	4.7	1.7	3.3	1	<1	316	187	98	100	2090	30	485	14	9170	232	36	328	119	56	38
MKSS20B	7	5.9	1.5	1.3	1	12	377	345	149	223	2480	75	856	32	6930	81	43	31	127	45	83
MKSS34B	4.5	5	1.6	0.9	1.2	8	293	102	212	51	891	32	623	18	336	62	21	4	123	33	64
MKSS60B	7.1	4.4	1.3	1.8	1.3	9	242	329	116	195	3370	38	630	22	31810	261	30	158	93	33	60
MKSS42A	1.8	2.7	1.6	1.1	2.2	<1	462	60	32	28	364	15	311	11	17110	126	17	10	71	22	21
MKSS40A	1.5	4.4	1.5	0.8	1.4	<1	503	55	36	24	431	20	380	10	732	72	32	4	123	29	25

Generally the stream sediments major and trace element geochemistry is similar the to background samples. Exceptions to this are elevated (>6000 ppm) S in MKSS26, MKSS42, MKSS45, MKSS60, MKSS84, elevated (> 100 ppm) U in MKSS60, MKSS61, MKSS62 and elevated Cu (> 200 ppm) in MKSS34. It is likely that anomalous values of Cu, La, Ce, Mn, S and U in stream sediments have come from the erosion of natural outcrops of Mary Kathleen mineralisation prior to mining.

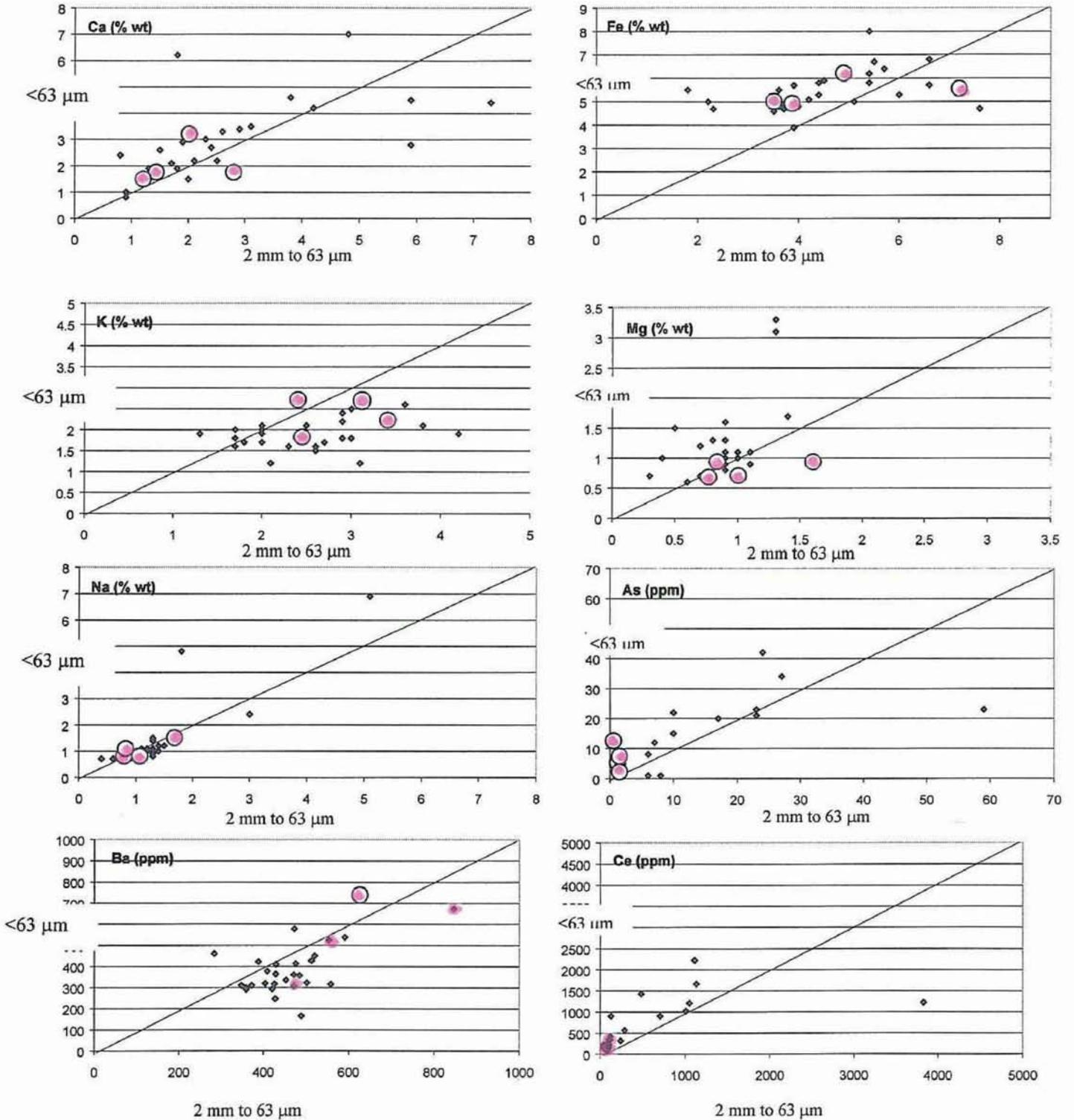
Table 5.2.g Major (wt%) and trace element analysis (ppm) geochemistry of downstream stream sediments in Cameron Creek.

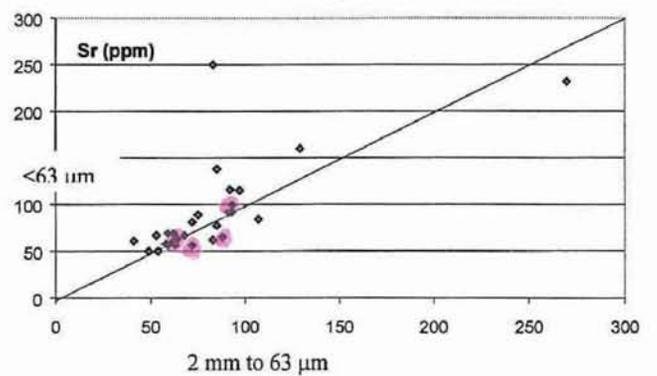
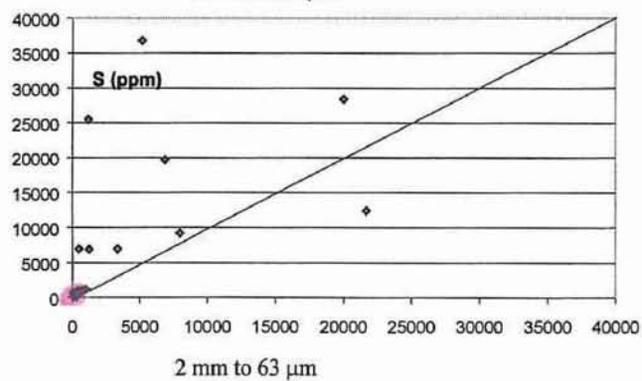
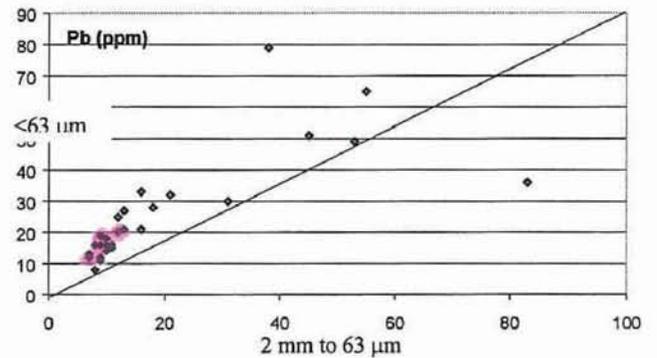
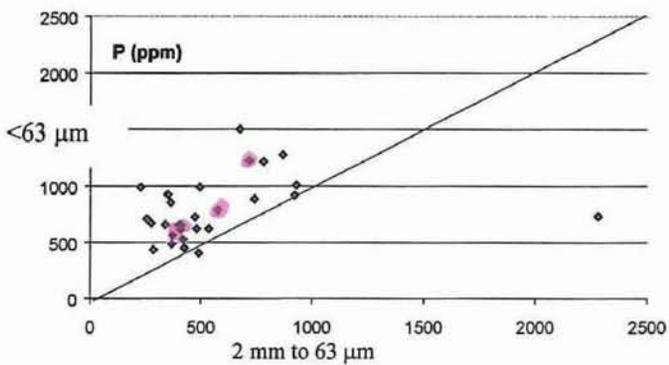
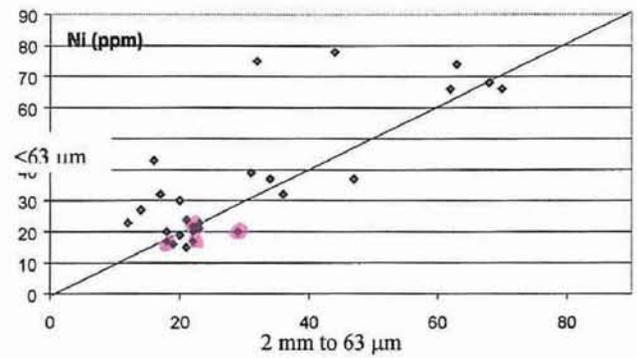
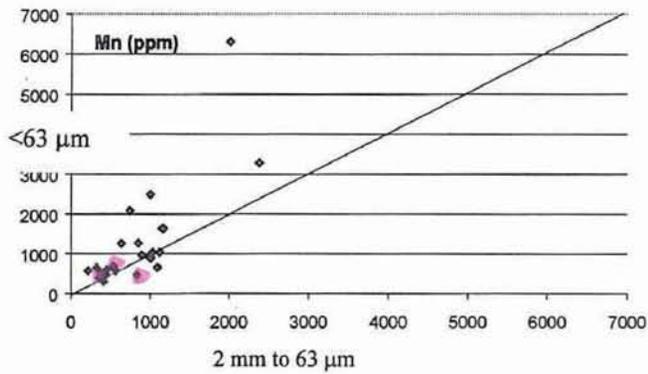
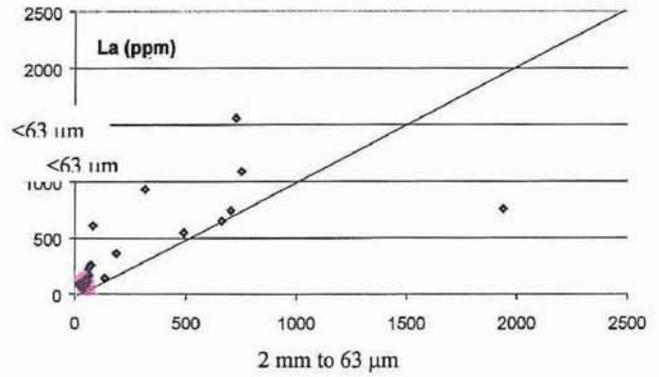
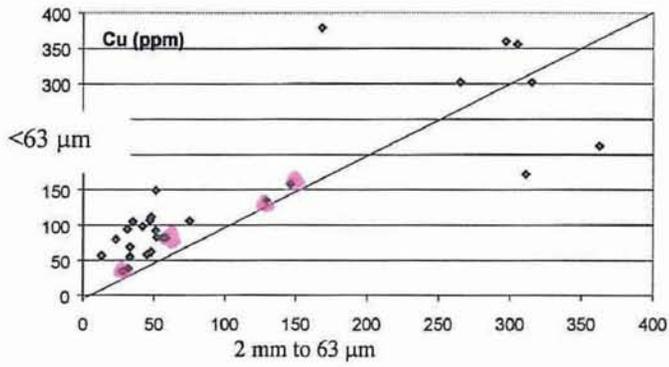
	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
MKSS49A	2.9	3.9	2.1	1.1	5.1	<1	428	85	45	44	412	21	490	8	20010	91	21	8	99	38	30
MKSS49B	3.4	3.9	1.2	1.1	6.9	<1	246	122	58	62	298	15	405	8	28400	91	30	13	85	47	34
MKSS33A	2.3	3.5	1.7	0.9	1.8	<1	489	56	33	26	430	19	339	7	5170	97	16	10	91	25	23
MKSS33B	3	4.6	2	1.3	4.8	<1	165	136	55	67	504	16	661	13	36800	115	42	26	115	56	32
MKSS52A	1.8	2.3	2.5	0.5	1.3	<1	485	38	23	20	324	14	255	9	1140	83	9	8	60	20	16
MKSS52B	6.2	4.7	2.1	1.5	1.4	<1	356	150	80	76	647	27	712	12	25510	250	40	46	122	52	38
MKSS47A	0.9	4.4	3	0.7	0.6	6	359	238	32	135	402	20	420	16	264	58	72	7	89	59	36
MKSS47B	1	5.3	2.5	0.7	0.7	<1	291	315	39	144	398	19	528	21	230	58	98	10	109	68	45
MKSS48A	0.8	1.8	3.6	0.4	1.1	<1	520	42	13	20	218	12	228	9	22	75	15	3	47	17	16
MKSS48B	2.4	5.5	2.6	1	1.1	<1	451	225	57	95	570	23	992	19	737	89	58	9	131	65	52
MKSS31A	2.1	4.2	2.9	0.9	1.5	<1	513	68	33	36	563	23	474	11	212	85	18	9	114	31	32
MKSS32A	1.6	4.2	2.9	1	1.8	<1	484	55	32	29	446	23	385	9	153	77	11	4	120	25	28
MKSS31B	2.2	5.1	2.4	1.1	1.2	<1	427	170	69	84	580	23	726	15	602	77	52	21	135	62	40

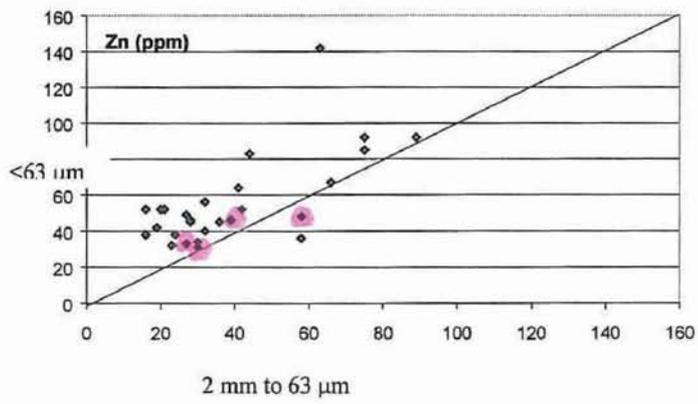
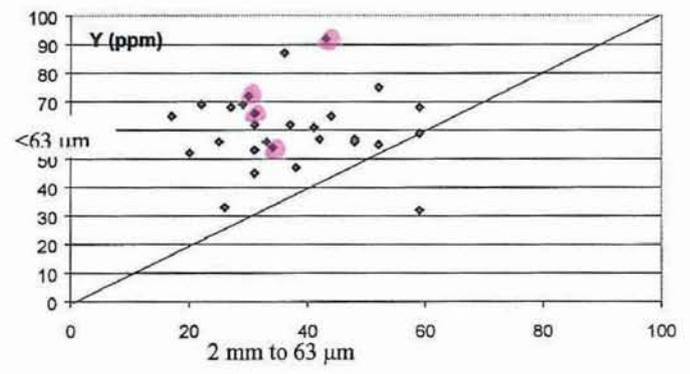
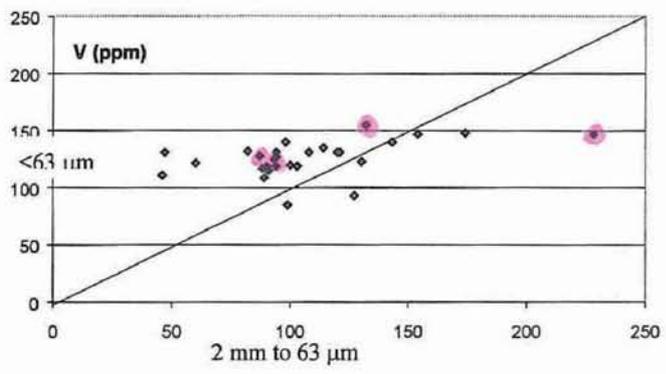
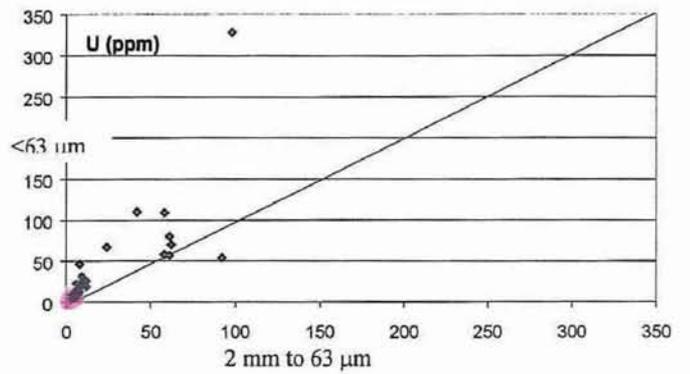
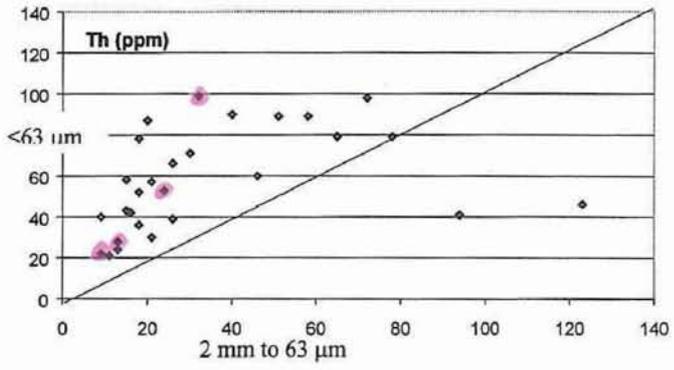
Elevated levels (> 2 wt%) of Na have been measured in several samples. Concentrations of S also increase to above 1000 ppm in six samples. MKSS31 and MKSS32, which were sampled the furthest from the minesite, have concentrations similar to background samples. Natural dispersion of U and REE elements into the regolith and stream system can be assumed to have been occurring prior to mining.

Most samples in the above tables have higher concentrations of elements in the fine fraction. Na, Ba and Ni is found equally in the coarse and fine grained fraction, and potassium is found predominantly in the 2 mm-63 µm fraction (Figure 5.4).

Figure 5.4. Scatter plots of medium grained (2 mm to 63 μm) and fine grained (<63 μm) fractions for stream sediments sampled from the Cameron Creek drainage area and background (MKSS21, MKSS22, MKSS28, MKSS29), (excluding stream sediment sampled from the tailings dam and waste rock areas). Key Background samples = \odot .







Organic carbon analysis shows very low organic matter within the Cameron Creek catchment area (Table 5.4). The detected low organic carbon contents in the sediments are the result of low organic matter within the channel. In all samples with two size fractions analysed, the < 63µm fraction has higher organic carbon content. In the sump a liberal amount of cattle dung was observed and could be responsible for the higher content (2.92 %) in the sump, and account for some of the organic content in the catchment area. The decay products of algae are another possible source of organic matter.

Table 5.4. Organic carbon analysis for a selection of stream sediment samples (2 mm and <63µm fractions).

Sample No.	2 mm to 63µm	< 63µm	NonCO ₃ -C %	Location
MKO2	MKSS31A		0.26	Cameron Ck, 12 km downstream
MKO21		MKSS31B	0.78	Cameron Ck, 12 km downstream
MKO3	MKSS38A		1.63	up small stream
MKO4	MKSS43A		0.18	Cameron Creek
MKO5	MKSS49A		0.14	near P2CC1
MKO6	MKSS56A		0.15	Cameron Creek
MKO7	MKSS40A		0.06	Cameron Creek
MKO24		MKSS40B	1.72	Cameron Creek
MKO8	MKSS52A		0.04	down Cameron Creek 1km
MKO25		MKSS60B	1.62	Cameron Creek and sm ck
MKO19	MKSS62A		0.65	near sump
MKO20		MKSS62B	1.65	near sump
MKO9	MKSS64A		2.92	sump rim
MKO18		MKSS64B	1.95	sump rim
MKO10	MKSS65 A		2.17	sump pit base
MKO17		MKSS65B	2.47	sump pit base

5.4 Stream water

Cameron Creek had numerous small ponds and billabongs during the 1999 dry season sampling. The water was shallow (<20cm in most cases), grey orange in colour with salt crusts prominent at the edge of the water, covering algal mats and stream pebbles (Figure 5.5). Small fish were also observed in larger ponds (depth 10-50cm, diameter 2-4m). Figure 5.6 is the water sample map. Ten water quality measurements (Table 5.5) were taken in the field and two of those were submitted for water chemistry analysis (MKW7 1km downstream from tailings seepage area and MKW8 1km downstream from MKW7). Table 5 details the major ionic composition and trace metal analyses from Corella Dam (background) and Cameron Creek samples.

Figure 5.5. Photograph of MKW19 with water quality meter (Photographed 10-10-1999).

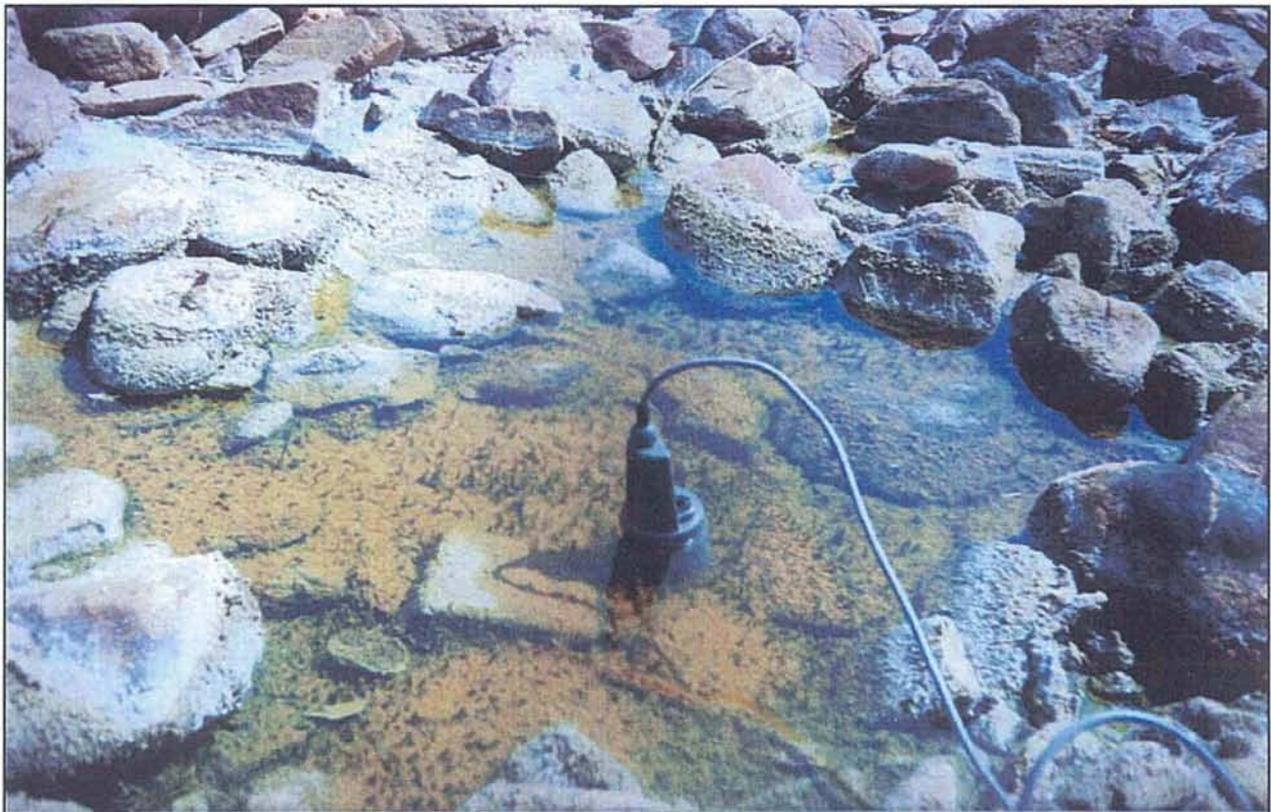
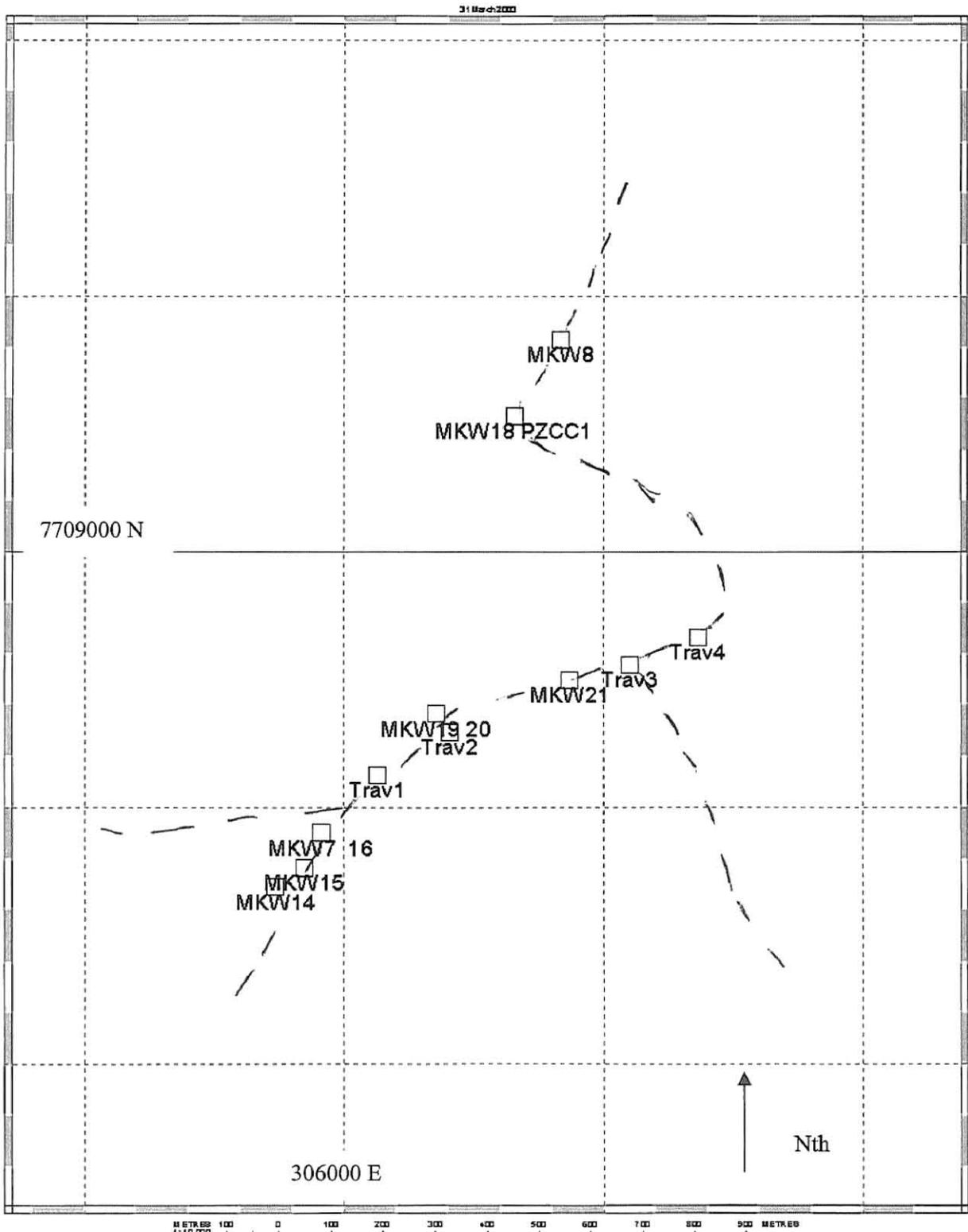


Figure 5.6. Water quality sample map showing start of traverse lines for reference (scale approx 1:10000).



Water quality measurements indicate the pools are slightly alkaline and brackish (Table 5.5). Dissolved oxygen over 5 mg/l is present in seven samples and is able to sustain aquatic life (ANZECC 1995). Each pool tends to have a relatively consistent range of water quality values, however MKW14 and MKW18 have significantly higher conductivities and may suggest evaporative concentration of salts.

Table 5.5 Water quality measurements (in field measurements).

Sample	In field water quality measurements				
	pH	Cond ms/cm	DO mg/l	Temp °C	Sal%
MKW7	8.42	27.6	15.10	27	1.71
MKW8	8.17	16.1	14.30	19.6	0.94
MKW14	8.34	54.2	8.11	32	3.63
MKW15	7.82	21.7	3.50	31.3	1.31
MKW16	8.24	21.8	5.75	32.6	1.32
MKW17	8.41	17.9	11.50	30	1.03
MKW18	8.11	46.4	7.66	31.4	3.06
MKW19	8.24	7	2.12	30	0.49
MKW20	8.67	7.9	1.10	28.5	0.41
MKW21	8.2	16	6.02	30.5	0.94

Waters in Cameron Creek have high conductivity, TDS, Na, SO₄, Cl and high metal concentration (Fe, Mg, U and Zn) compared to background water (Table 5.6). MKW7 contains higher major ionic and trace metal levels than MKW8, in particular copper, uranium and nickel. The proximity of MKW7 to the tailings seepage point indicates that seepage waters from the tailings dam enters Cameron Creek.

Table 5.6. Chemistry of Corella dam (MKW1) and Cameron Creek water samples (MKW7, MKW8) with ANZECC (2000) guidelines.

Parameter	MKW1	MKW7	MKW8	Guidelines values (Livestock)
pH	8.38	8.6	8.3	-
Conductivity ($\mu\text{S/cm}$)	206	65600	32300	
Total Hardness ($\text{mg CaCO}_3/\text{L}$)	70.9	70000	6680	
Total Alkalinity ($\text{mg CaCO}_3/\text{L}$)	81	685	518	
Total Dissolved Solids (mg/L)	105	37100	17000	5000-10000 mg/L (Max)
Sodium (mg/L)	12.4	4500	3100	
Potassium (mg/L)	4.6	21	7	
Calcium (mg/L)	21.3	640	450	
Magnesium (mg/L)	4.3	4200	1350	
Sulphate (mg/L)	9.1	25800	10400	> 2000 mg/L (Max)
Chloride (mg/L)	4.9	1500	1340	
Bicarbonate (mg/L)	98.8	540	632	
Carbonate (mg/L)	<1	145	<1	
Copper ($\mu\text{g/L}$)	<0.5	4141	<5	1000 $\mu\text{g/L}$ (Cattle)
Iron (mg/L)	0.12	7.88	67	
Manganese (mg/L)	<0.001	0.004	0.036	
Molybdenum ($\mu\text{g/L}$)	<1	18	17	
Nickel ($\mu\text{g/L}$)	<0.2	38	<15	1000 $\mu\text{g/L}$
Lead ($\mu\text{g/L}$)	<1	<1	<1	
Uranium ($\mu\text{g/L}$)	1	4750	2880	200 $\mu\text{g/L}$
Zinc ($\mu\text{g/L}$)	<10	44	38	

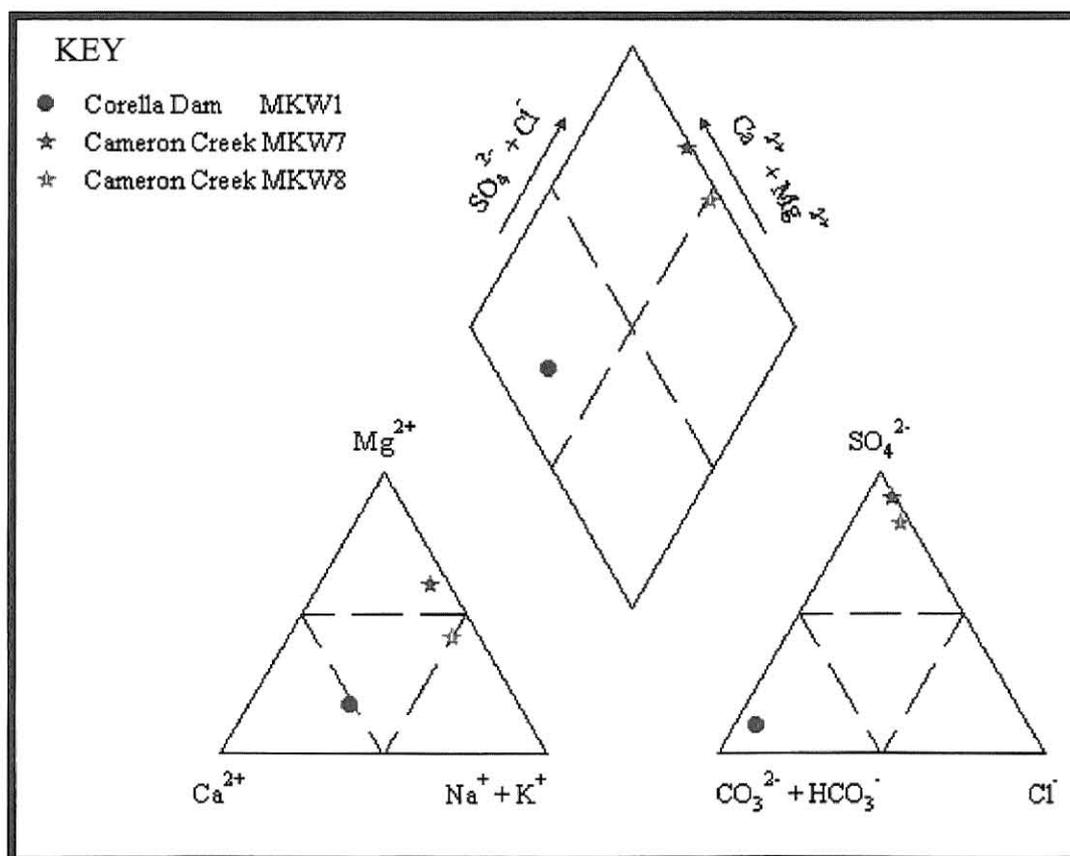
Water samples were collected during the dry and it is assumed that salinity, alkalinity, SO_4 etc. are higher in evaporated waters such as in Cameron Creek lagoons in the dry season.

The hardness-modified trigger value for 80% Level of Protection in MKW7 was exceeded for Cu (Appendix 8). Water quality guidelines for livestock have been exceeded for uranium, total dissolved solids (5000 – 10000 mg/L) which can cause loss of production and a decline in animal health and also in sulphate (> 2000 mg/L) which may

cause chronic health problems particularly in hot conditions when water consumption is high.

Plotting water analyses on a Piper diagram analysis (Figure 5.7) illustrates relatively enriched in Cameron creek is relatively enriched in Mg and Na compared to background waters.

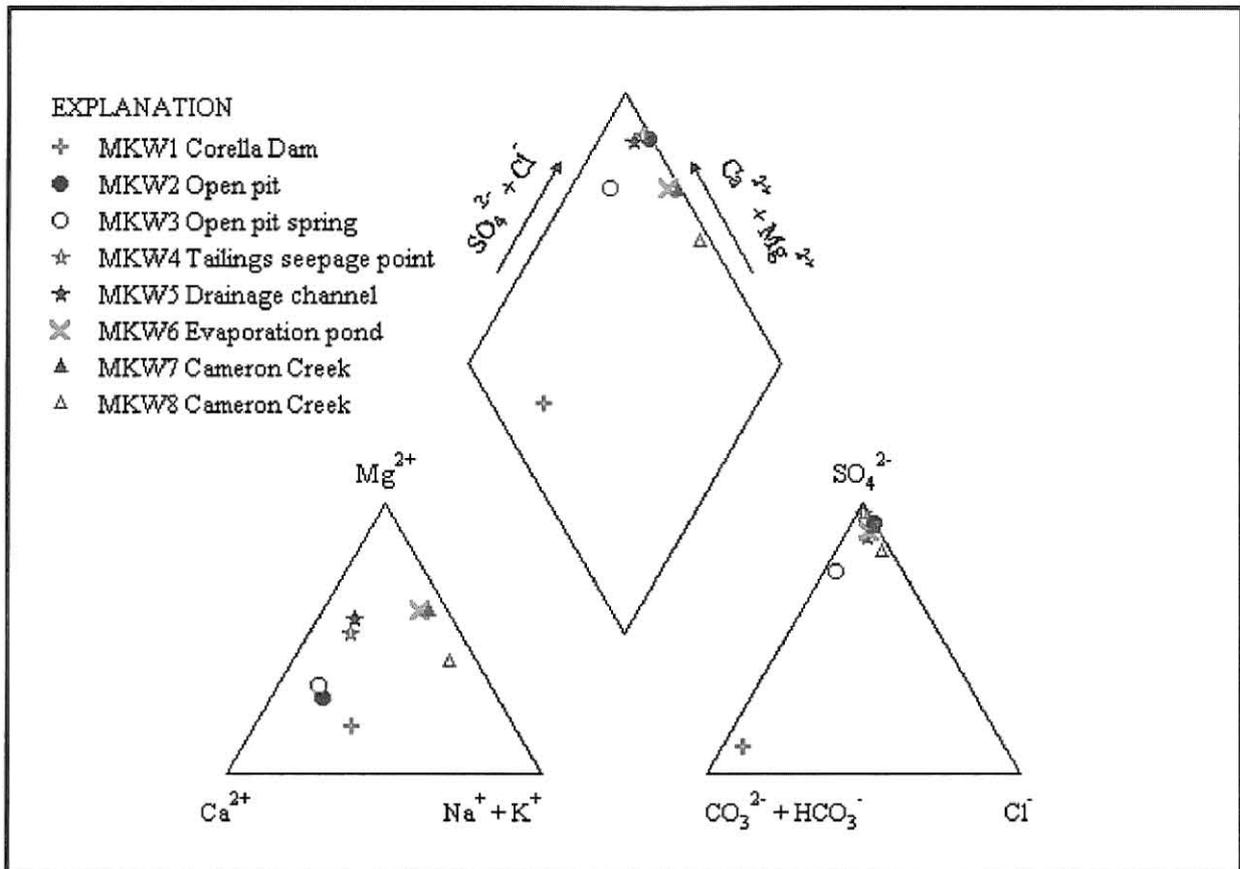
Figure 5.7. Piper diagram illustrating the chemistry of Cameron Creek and Corella Dam waters.



The shallow pools in the Cameron Creek system are saline (0.3-3%), strongly enriched in SO_4 (25.8 mg/L) and U (5.1 mg/L) compared to Corella dam where salinity is <0.01 , SO_4

(12.4 mg/L) and U (0.001 mg/L) have significantly lower levels. Dry season sampling also highlights the extreme hardness (6680 mg/L) and TDS (17000) levels in Cameron Creek compared to Corella dam hardness (70.9 mg/L) and TDS (105 mg/L).

Figure 5.8 Piper diagram for eight water samples from the Mary Kathleen minesite.



The piper diagram in Figure 5.8 illustrates the chemical character of the waters collected during the dry season. The general chemical character of the waters, except Corella dam, ranges through a mix of Ca^{2+} - Mg^{2+} - Na^{+} - K^{+} dominated cation composition. The anion compositions are sulphate dominated. The cation composition most likely varies as a result of the differences in the chemistry of the rocks and sediment with which the waters come into contact, as well as the hydrological regime (e.g. high evaporation) existing. The sulphate-dominated waters may result from the oxidation of pyrite in surrounding rocks and the transport of SO_4 in the catchment area.

5.5 Radiometric Survey

5.5.1 Survey design

The geophysical survey involved taking total count (cps) spot readings and exposure rate (mSv/yr) traverses in the Cameron Creek catchment including in the sump, the creek near bore 28, the township and background areas. Exposure rates for environmental data ($\mu\text{R/hr}$, nSv/hr) were recorded using a GR-320 Spectrometer and total count (cps) rates were recorded using a Scintrex BGS-1SL scintillometer.

5.5.2 Geophysical analysis

Total count (cps) spot readings were taken in background areas, close proximity to the waste rock areas (Figure 5.9) and past the tailings area downstream in Cameron Creek. Traverses along the drainage channel near bore 28 (Figure 5.10) and within the sump (Figure 5.11) investigated exposure rates where known tailings spills occurred during mining.

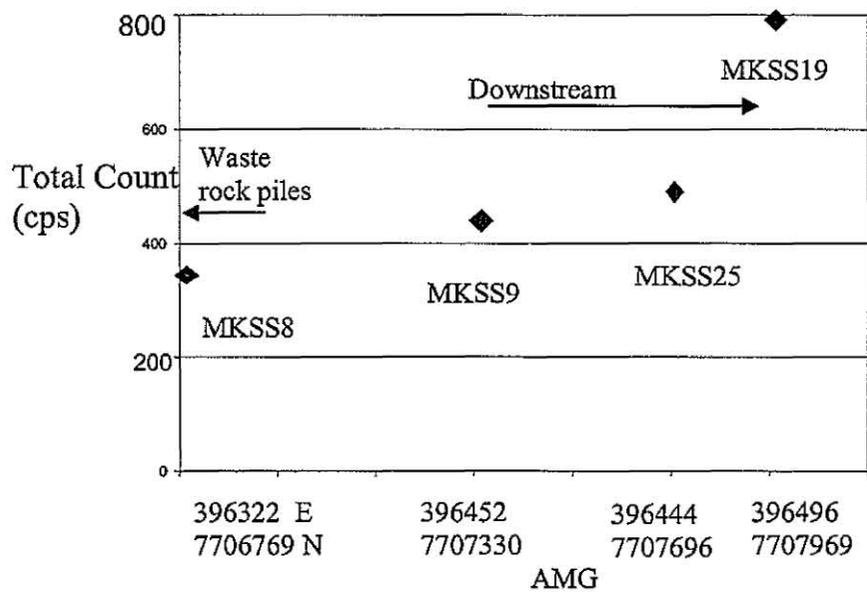
Background points

Three spot readings were taken in the large western tributary of Cameron Creek. The maximum total count reading was 200 cps and the minimum reading was 120 cps. MKS13 (394195E 7703990N) on the ridge between the headwaters of Cameron Ck, north west of the historic town ship was recorded at 90cps and can also be considered a background sample.

Close proximity to waste rock and processing areas.

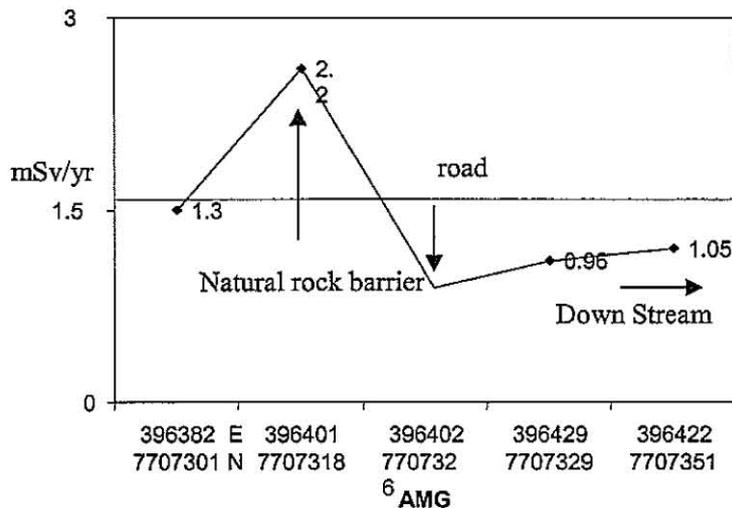
Four spot readings (Figure 5.9) were taken between the old mill site near waste rock piles and east of the evaporation ponds. The maximum total count reading was 800 cps east of the evaporation ponds and the minimum reading was 350 cps just down from the mill area.

Figure 5.9. Total count (cps) spot readings located in the drainage channel downstream of the waste rock piles and processing site.



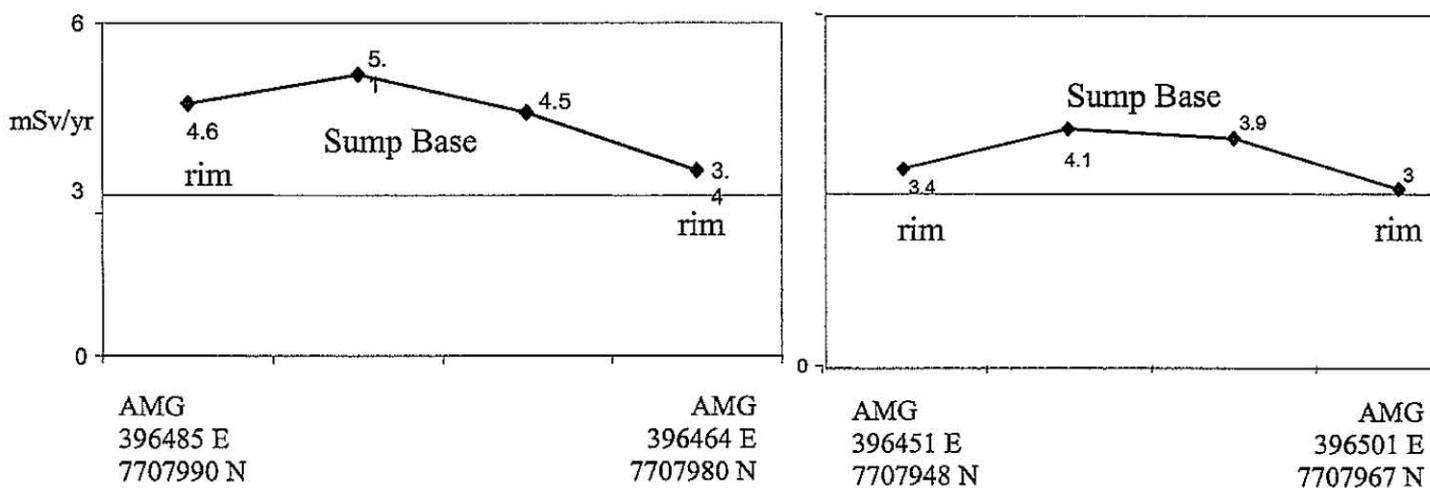
The 'lunch creek' near bore 28 (Figure 5.10) was investigated to determine if tailings spills during mining have a remnant radiometric signature. The maximum exposure rate (2.2 mSv/yr) was taken where sediment is deposited near a natural rock barrier during surface runoff. The minimum exposure rate (0.96 mSv/yr) was detected just past the road. Geophysical assay data was also recorded during this traverse. Equivalent U (ppm) measurements of less than 26 ppm were recorded.

Figure 5.10. Exposure rate (mSv/yr) traverse along creek bed near bore 28 (396382E 7707301N).



The sump (Figure 5.11) was investigated to determine if drainage from the waste rock piles was collected in the topographic low and if there was an associated anomalous radiometric signature. The maximum exposure rate (5.1 mSv/yr) was taken at the lowest point in the sump. The minimum exposure rate (3 mSv/yr) was taken at the rim of the sump.

Figure 5.11. Sump exposure rate data (mSv/yr).

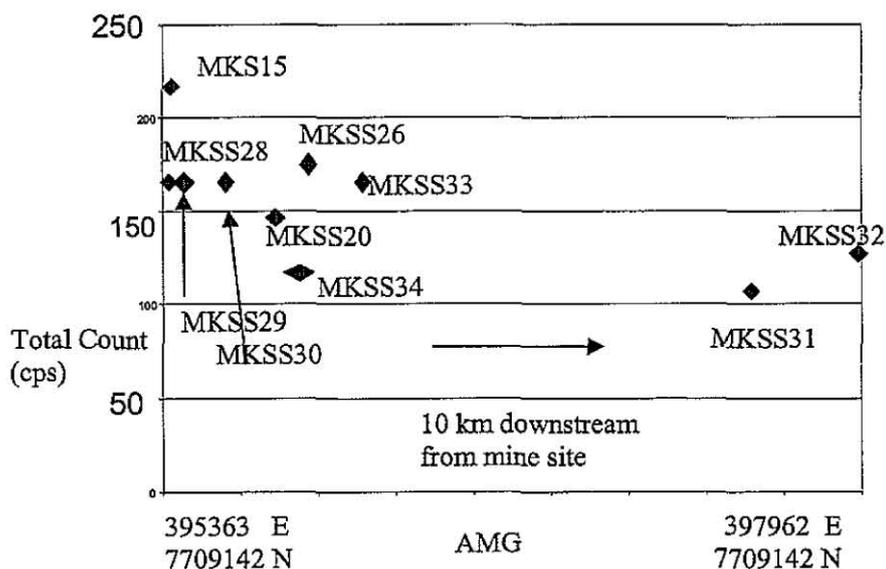


Geophysical assay data was also recorded in the sump. Equivalent U (ppm) measurements of up to 80 ppm are recorded in the base of the sump.

Downstream from the tailings area

Ten total count (cps) spot samples were investigated past the tailings dam in the Cameron Creek drainage area (Figure 5.12) to determine anomalous radiometric points downstream from the mine site. The maximum total count reading was 220 cps on a hillside between Cameron Creek and the large western tributary and the minimum reading was 110 cps approximately 10 km downstream from the mine site.

Figure 5.12. Cameron Creek downstream from tailings area total count data (cps).



Township – upstream from minesite

Dose rates were recorded within the old township, surveying close to the old fire station and laundry foundations. The maximum readings, fire station 6.4 mSv/yr and laundry 3.4 mSv/yr, were taken over a small wall constructed of rock and mortar.

Table 5.7. Fire station and Laundry exposure rate data (mSv/yr).

Firestation

	Easting	Northing	mSv/yr
1	393682	7702038	2.6
2	393670	7702033	6.4
3	393676	7702073	1
4	393654	7702075	1
5	393659	7702044	6

Laundry

	Easting	Northing	mSv/yr
1	393727	7701888	1.4
2	393746	7701937	1.3
3	393699	7701959	3.4

Traverse F (Table 5.8) starts close to PZ21 west of the tailings dam and is within the Cameron Creek channel. Green grasses and several large (10 m+) dying trees were observed at this location. Dose rates are at background levels.

Table 5.8. Traverse F exposure rate data (mSv/yr).

	Easting	Northing	mSv/yr
1	395320	7708590	1.3
2		10m away	1.2
3		20m away	1.1
4		30m away	0.8

Table 5.9 summaries maximum and minimum values from the surveyed areas. Highest total count readings correspond to stream sediments in close proximity to waste rock piles. Maximum exposure rates correspond to the base of the sump.

Table 5.9. Maximum and minimum total count (cps) and exposure rates (mSv/yr) at four locations in the Cameron Creek catchment area compared to background values.

Summary	Minimum	Maximum
Total Count (cps)		
Background	120	200
near waste rocks	350	800
Cameron Creek	110	220
Exposure rate (mSv/yr)		
Bore 28	0.96	2.2
Sump	3	5.1
Background (UNSCEAR 2000)		2.4

5.6 Discussion

5.6.1 Stream sediments

Metals (e.g. Fe, Cu, Ni, Mn, Pb, S, U and Zn) concentrate in < 63 μ m fraction stream sediments. K is found in the coarser grained fraction and is probably derived from micas and feldspars within stream sediments. In the fine fraction oxy-hydroxides probably hold As and Fe, and mineral efflorescences holding Na, S, Mg, rich precipitates.

Co-precipitation and adsorption are likely processes responsible for metal (U,Y) metalloid (As) and rare earth element (Ce, La) enrichment out of solution within Cameron Creek stream sediments. Evaporation during the dry season also promotes the precipitation of sulphate rich evaporative sediments within the drainage system. Cameron Creek acts like a uranium sink with regular flushing events distributing low levels of uranium further downstream.

Background stream sediment uranium levels are low, and are < 10 ppm in the majority of the Cameron Creek stream sediment samples. However, uranium concentrations are very high in sampled water, indicating uranium is being flushed from the tailings dam, rather than originating from the weathering of stream sediments.

5.6.2 Stream water

Water samples were collected during the dry season. Water quality should vary with rainfall and runoff, with any stream flow having a considerable diluting effect. Chemical changes in the analysed surface waters in the dry season are due to the evaporation of surface waters in ponded areas and the concentration of soluble elements and compounds (e.g. alkalis, sulphate, chloride, bicarbonate, uranium). Subsurface seepage of strongly saline waters from the evaporation ponds into the local drainage system, is indicated by high Cu, U and SO₄ in waters closer to the tailings dam.

In rivers, uranium transport is dominated by surface adsorbed uranium on colloids and particles (Ragnarsdottir & Charlet. 2000), Cameron Creek waters have extremely high TDS, which indicates uranium may be present, adsorbed onto colloidal particles.

High resolution ground geophysics could be used as a tool to monitoring the tailings dam seepage into Cameron Creek during both the dry and the wet seasons. By resolving geological structures relevant to hydrological processes and mapping resistivity contamination pathways could be better defined.

A detailed groundwater monitoring program to ascertain the current chemical signature of the surrounding groundwater is desirable. Infiltration of rainwater through the tailings dam site, the evaporation pond and the mill site gives rise to the potential for groundwater contamination by heavy metals.

5.6.3 Radioactivity and exposure assessment

The radiometric survey shows there is localised elevated radioactivity in stream sediments of the local drainage system downstream of the minesite. Total count readings are highest (800 cps) in the drainage from the former plant site and waste rock piles 500 m downstream. The sump has elevated exposure rates 5.1 mSv/yr. Radiation levels in Cameron Creek sediments were at background levels.

5.7 Summary

Natural dispersion of U and REE elements into the regolith and stream system can be assumed to have been occurring prior to mining. However, the main source of contamination into Cameron Creek is from the tailings dam and evaporation ponds area. Anomalous As, Cu, Ni, Pb and U stream sediment geochemistry is found closer to the tailings dam. Stream sediments exceed the ISQC-low and the ISQG-high guidelines for Cu and Ni in the sump, near bore 28 and in small streams emanating from the tailings seepage area.

The proximity of the water samples to the tailings dam seepage area, combined with high evaporation rates and low flushing events concentrates uranium in the watercourse. Quality guidelines for Cu, U, TDS and SO₄ have been exceeded and could pose a potential risk to cattle in the dry season.

Total count background levels are less than 220 total count (cps). Exposure rates are less than 2.2 mSv/yr, which is considered an acceptable background value.

This study has also found uranium loading in stream sediments derived from naturally mineralised areas in the catchment forms a very small amount of contamination as levels for uranium are generally < 20 ppm within Cameron creek.