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Hydrochemistry in Groundwater Development: Report on an Advisory Visit to Malaŵi

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1. SUMMARY OF VISIT

1.1 Itinerary.

12-13	October	Gatwick Airport - Blantyre - Lilongwe
14		Meetings of introduction with Mr L L B Munthali (Controller, DLVW) and Mr A E Farrant (Water Engineer-in-Chief, DLVW).
15		Office work, Lilongwe
16		Meetings with Mr A E Farrant and Dr A Edwards (Chief Water Resources Officer, DLVW). Meetings with Ministry of Health, Water Resources Branch Laboratory, Lilongwe Water Board.
17		Public holiday in Malawi. Office work.
20-24		Hydrochemistry data files, Groundwater Section.
27-30		Ditto; also preparation of field hydrochemical equipment.
31		Meeting at Urban Supplies Branch, DLVW. Also visit Medical Auxiliary Training School, Lilongwe.
1	November	Office and lab work, Lilongwe.
2		Travel Lilongwe to Ngabu (Lower Shire Valley) by road.
3-5		Hydrochemical field studies in Lower Shire Valley. Test and sample rural supply boreholes and well.
6		Meeting in Ngabu office of Shire Valley Agricultural Consolidation Project.
7		Travel Ngabu to Zomba via Blantyre. Visits in Blantyre at Central Pathology lab, Q.E. Central Hospital; Blantyre Water Board; Malawi Bureau of Standards; Christian Services Committee Planning Unit.
8		Visit to Geological Survey laboratory, Zomba. Travel to Lilongwe.
10		Office work. Visit Chitedze Agricultural Research Station laboratory, near Lilongwe.
11-13		Report preparation and water sampling at Timadzi.
14		Debriefing meetings with Mr B Ulaya (Under-Secretary, DLVW), Dr A Edwards and Mr A E Farrant.
14-15		Lilongwe-Blantyre-Heathrow Airport.

1.2 Contacts made during visit.

Department of Lands, Valuation and Water,: Lilongwe.

Mr L L B Munthali (Controller, since retired)
Mr A E Farrant (Water Engineer-in-Chief)
Dr A Edwards (Chief Water Resources Officer)
Mr S M N Mainala (Senior Hydrogeologist)
Messrs. P J Chilton & D R C Grey (Consultant Hydrogeologists)
Mr S de Souza (Principal Water Engineer, Urban Supplies Branch)
Mr W van Gorkum (Urban Supplies Branch)
Mr N Mndala (Water Resources Branch Laboratory)
Mr K Jellema (Wells Programme Officer)

Ministry of Health, Lilongwe.

Mr P A Chindamba (Chief Health Inspector)

Lilongwe Water Board.

Mr Bwanali (Engineer to Lilongwe Water Board)
Mr Chipeta (Trainee Chemist)
(Mrs van Gorkum) (Volunteer assisting in laboratory)

Medical Auxiliary Training School, Kamuzu Central Hospital, Lilongwe.

Mr R Giaconti (Microbiology Tutor)

Shire Valley Agricultural Consolidation Project, Ngabu.

Mr H Staal (Hydrogeologist; attached to DLVW)

Central Pathology Lab, Queen Elizabeth Central Hospital, Blantyre.

Dr B Paul (Senior Pathologist)

Blantyre Water Board.

Mr A D Kalea (Quality Control Officer)
(Mr Chipofya) (Senior Chemist)

Malawi Bureau of Standards, Blantyre.

Mr R Davies (Principal Chemist)

Christian Services Committee of the Churches in Malawi, Blantyre.

Mrs J Paul (Planning and Research Officer)
Mr I Chirwa (Assistant in Planning Department)

Geological Survey Department, Zomba.

Dr R Johnson (Chief Geologist)

Dr M J Crow (Superintending Geologist)

(Mr R Banda) (Senior Laboratory Technician)

Agricultural Research Station, Chitedze, near Lilongwe.

(Mr Mtabwa) (Senior Chemist)
Mr Chilalira (Senior Soil Chemist)

(Names in parentheses are relevant contacts but were absent at the time of my visit).

2. INTRODUCTION

The report results from an advisory visit made at the request of the Government of Malawi to the Overseas Development Administration, U.K. The author spent 5 weeks with Groundwater Project staff within the Water Resources Branch of the Department of Lands, Valuation and Water situated in Capital City, Lilongwe. The Groundwater Project is supported by ODA in providing two full-time consultant hydrogeologists on secondment from the Institute of Geological Sciences, London.

The purpose of this visit was to assist the Groundwater Project in formulating priorities and requirements for future hydrochemical aspects of groundwater development in Malawi. Specific aims were defined as:

(a) to summarise present hydrochemical information and to report implications with respect to groundwater development;

(b) to discuss arrangements for inorganic and biological water analysis with other relevant parties and to advise on additional equipment and staffing for chemical laboratories for groundwater work;

(c) to advise on long-term hydrochemical input to groundwater resources section for application of geochemical techniques to hydrogeological evaluation, identification of groundwater quality problems and their causes and formulation of measures for improvement, and training of Malawian staff in field, analytical and interpretative methods.

The author acknowledges the cooperation and assistance provided during his visit by: Mr L L B Munthali (Controller, Dept. of Lands, Valuation and Water), Mr A E Farrant (Water Engineer-in-Chief, D.L.V.W.), Dr A Edwards (Chief Water Resources Officer, Water Resources Board), Mr S M Mainala (Geologist, Groundwater Project), Mr P M Marcello (Officer-in-Charge, Borehole Fund), Messrs. P J Chilton and D R C Grey (Consultant Hydrogeologists, Groundwater Project), Dr A N Mandeville (Principal Hydrologist), and staff of the Water Resources Branch, Department of Lands, Valuation and Water.

3. EXISTING HYDROCHEMICAL DATA

3.1 Data archive and reliability.

3.1.1 Existing chemical information on groundwater comprises in excess of 1000 major element chemical analyses, some only partial analyses, in 'X-files' of the Geological Survey archives. These data have accumulated over the past ten years or so, and represent the analyses of routine samples collected by Groundwater Section staff of the Geological Survey prior to the establishment of the Groundwater Project in DLVW. The analytical data are from measurements made in the Survey laboratory (para. 5.1.3.) on samples assumed to have been collected without any filtration or other treatment. Specifically, field determinations have not been made in the past of the unstable chemical parameters, e.g. pH and alkalinity.

3.1.2 At the time of the present visit, a substantial number of these data had been transferred onto the new 'Cardex' file system initiated by the Groundwater Project. Comprehensive borehole data is now stored and accessed according to a revised numbering system identifying location within the basic water resources units and sub-units of Malawi (Figure 1). Units for which these new files have been completed are:

1	(Lower Shire)
2	(Lake Chilwa)
3	(S.W. Lakeshore - Bwanje)
15	(Nkhotakota Lakeshore - Salima)
17	(Karonga Lakeshore)
9	(Songwe/Lufira)
8A	(North Rukuru - part only)

The order of priority with which data has been transferred has been set by the requirements of the National Irrigation Study, which accounts for the predominance of lakeshore units in the above list. The groundwater within these units is developed from alluvial and colluvial sediments and also from the zone of weathered bedrock underlying these sediments and outcropping away from the lakeshore towards the Escarpment and Plateau Zones.

3.1.3 The reliability of archived chemical data can be assessed both by consideration of the technique used and also by calculation of the state of charge balance between cations and anions in solution. However, beyond these criteria, it is impossible to eliminate systematic or random analytical errors, or errors due to poor sampling or storage procedures. These constraints must be borne in mind when interpreting archived data, which should serve as a means of identifying potential problem areas for follow-up investigation including further sampling and analysis if warranted.

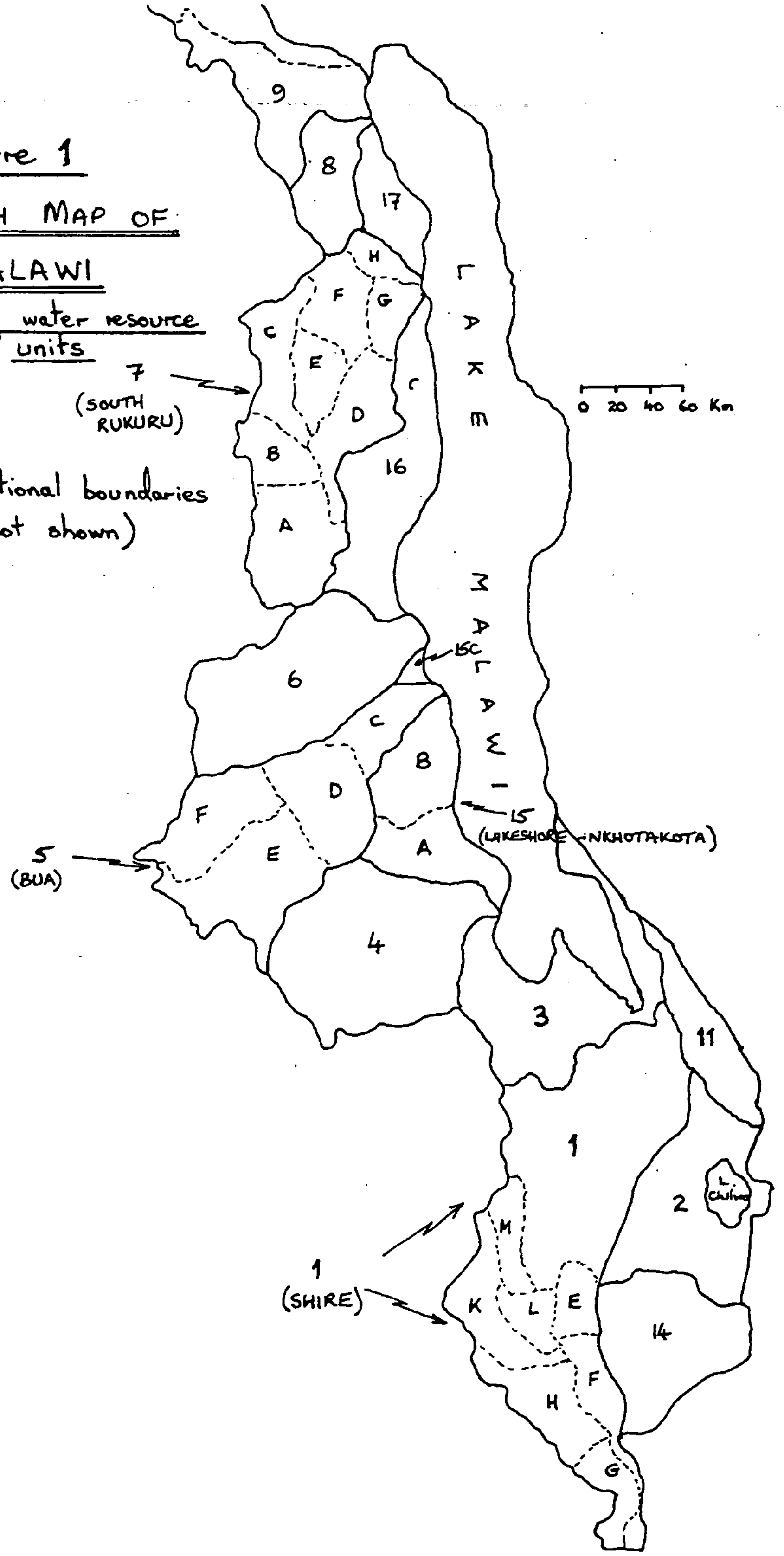
Figure 1

SKETCH MAP OF

MALAWI

showing water resource units

(international boundaries are not shown)



Reported values of pH and alkalinity (HCO_3^-) are not field-measured values and therefore should be considered with caution, particularly pH for which widely scattered values are listed. Determinations of Ca^{2+} and Mg^{2+} were made by EDTA titration, and of Na^+ and K^+ by flame photometry. Cl^- was analysed by argentiometric titration using potassium chromate indicator, and SO_4^{2-} by gravimetry of $BaSO_4$ precipitate. Suspicion over the accuracy of some Cl^- analyses has been expressed by Bradford (1973) who reports that some analyses were readjusted to bring charge imbalance to better than ±5%. The minor anionic components NO_3^- and F^- were determined by colourimetry and the latter by specific ion electrode more recently; these two components are of particular interest in view of their implications with respect to potability. Fe was analysed by means of complexation and colourimetry. However it must be noted that, in the absence of filtration during sampling, the Fe analyses must represent total dissolved, colloidal and particulate iron rather than strictly dissolved iron only. This could account for the anomalously high Fe values, sometimes in excess of 20 mg/l, although this value of total iron contained in water at the pump-outlet is of great significance in determining its acceptability to the water drawer (but refer to section 4.2).

3.1.4 Electrical conductivity (EC) measurements are reported on virtually all analysed samples. These have been determined at controlled temperature and subsequently corrected to values for 25°C. The total dissolved solids (TDS) figure appearing on some files seems to be always a figure arrived at by calculation from EC using the arbitrary factor of 1.56; the TDS values are therefore at best estimates and at worst derived from erroneous EC values. In particular, several EC values recorded for samples in unit 1 (Lower Shire Valley) are suspect and may represent data transfer errors. In this report, reference will be made to Total Determined Equivalents (TDE, expressed in Meq/l) which is calculated from the full major element analysis, and therefore eliminates reference to possibly erroneous EC and TDS values. TDE provides an adequate yardstick of total mineralisation, and is related very approximately to EC by a factor usually between x45 and x55 in most of these groundwaters, although a factor between x30 and x45 applies to the groundwaters with lowest mineralisation (e.g. in Bua catchment).

Some areas for which boreholes and hydrochemical data has been transferred to the 'Cardex' system have been selected to investigate hydrogeochemical relationships. As far as is possible, the areas have been chosen to represent a range of geological and physiographic environments in Malawi. The data are summarised in Appendix 1.

3.2 Nkhotakota Lakeshore Catchment, Salima Sub-Unit 15A.

3.2.1 This sub-unit comprises the Salima lakeshore plain extending away from the lake towards the undulating scarp-foot area. The moderate relief of the escarpment itself in this region offers relatively poor groundwater resources, which is reflected in the virtual absence of deep boreholes in this zone. The underlying geology comprises biotite-gneiss and charnockite of the basement complex, the latter occurring in a band striking NE with its inferred northerly boundary with the biotite-gneiss passing roughly through Chitala. The outcrop of weathered basement in the scarp-foot becomes covered by so-called 'lakeshore colluvium' in the lakeshore plain; thicknesses of this colluvial cover described in drilling logs range up to 72 m. 'Weathered' or 'decomposed' gneiss are logged extending to depths up to 61 m below red clay soils in the scarp-foot area. The boreholes in this sub-unit for which full chemical analyses are on record are drilled to depths up to 72 m, although most commonly drilled depths are in the range 35-60 m.

3.2.2 Recorded EC values in this sub-unit range from 180 to 4570 µS cm^{-1}, for which the calculated TDS values (refer to para. 3.1.4) are in the corresponding range 115-2900 mg/l. The corresponding 'total equivalents' values calculated from analyses are in the range 4.5 to 132 meq/l. The distribution of mineralisation in groundwaters shows no consistent pattern in this area, in terms of position on the piezometric surface sloping towards the lakeshore, depth of well, or recorded geology. However an area of generally high-SO_4 groundwater is found in the weathered basement south and east of Chitala (Fig. 2). SO_4 concentrations in this zone rise to 1739 mg/l, whilst anomalous SO_4 values also occur apparently randomly in other boreholes in the sub-unit, in one instance reaching 2400 mg/l in a borehole penetrating the lakeshore alluvium.

3.2.3 Cl^- concentrations are mostly low to very low, with values sometimes below 10 mg/l and usually below 60 mg/l. Two boreholes with 376 and 256 mg/l Cl^- are found in this sub-unit.

3.2.4 The waters may be classified as predominantly Ca-(Mg)-HCO_3 with total equivalents (TDE) in the range 4-40 meq/l. There is a continuous series of compositions towards those dominated by sodium among the cations and by sulphate among the anions. The compositional ranges are summarised as follows:

Ca-(Mg)-(Na)-HCO_3-(SO_4)	TDE = 4- 40 meq/l	(TDS = $\sim$110-1100 mg/l)
Na-(Ca)-(Mg)-HCO_3-(SO_4)	12- 34 meq/l	
Ca-(Mg)-(Na)-SO_4-(HCO_3)	25- 96 meq/l	
Na-(Ca)-(Mg)-SO_4-(HCO_3)	52 & 132 meq/l	
Ca-Cl-HCO_3	28 meq/l	

The trilinear diagram (Figure 3) illustrates the scatter of compositions reflecting the variation in SO_4^{2-} concentrations.

3.2.5 The increases in SO_4^{2-} above about 100 mg/l correlate quite well with increases in dissolved Ca^{2+} (Figure 4), but not with any other ionic species. This strongly suggests that sources of gypsum, $CaSO_4$, occur locally in the aquifer matrix. This is supported further by calculations of the state of equilibrium of the water samples with respect to gypsum (Bath, 1980), represented by the

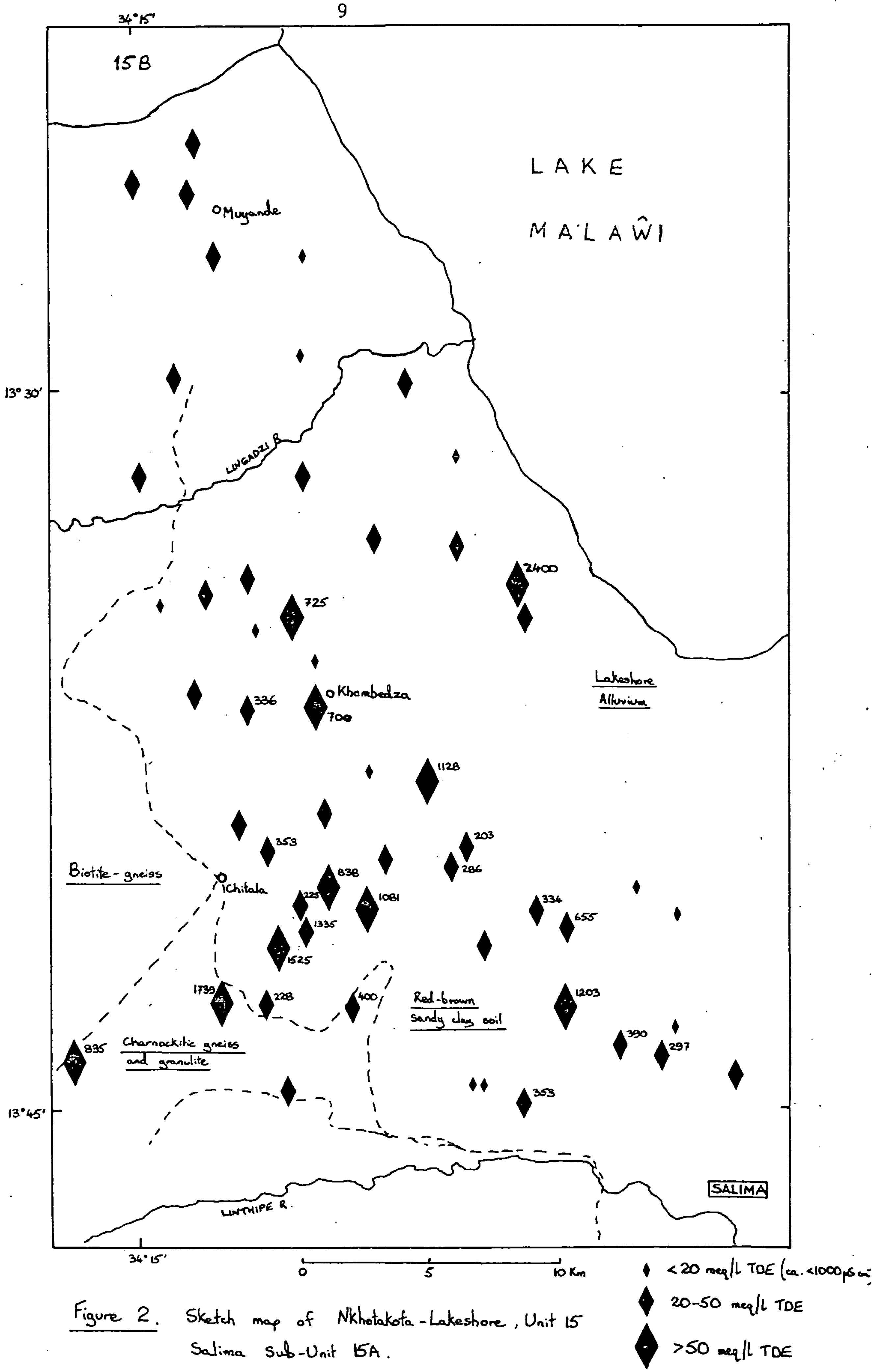


Figure 2. Sketch map of Nkhotakota-Lakeshore, Unit 15
Salima Sub-Unit 15A.
Geological boundaries (---) according to Walter (1972)
Groundwater quality represented by total equivalents (TDE)
Sulphate concentrations >200 mg/L are shown.

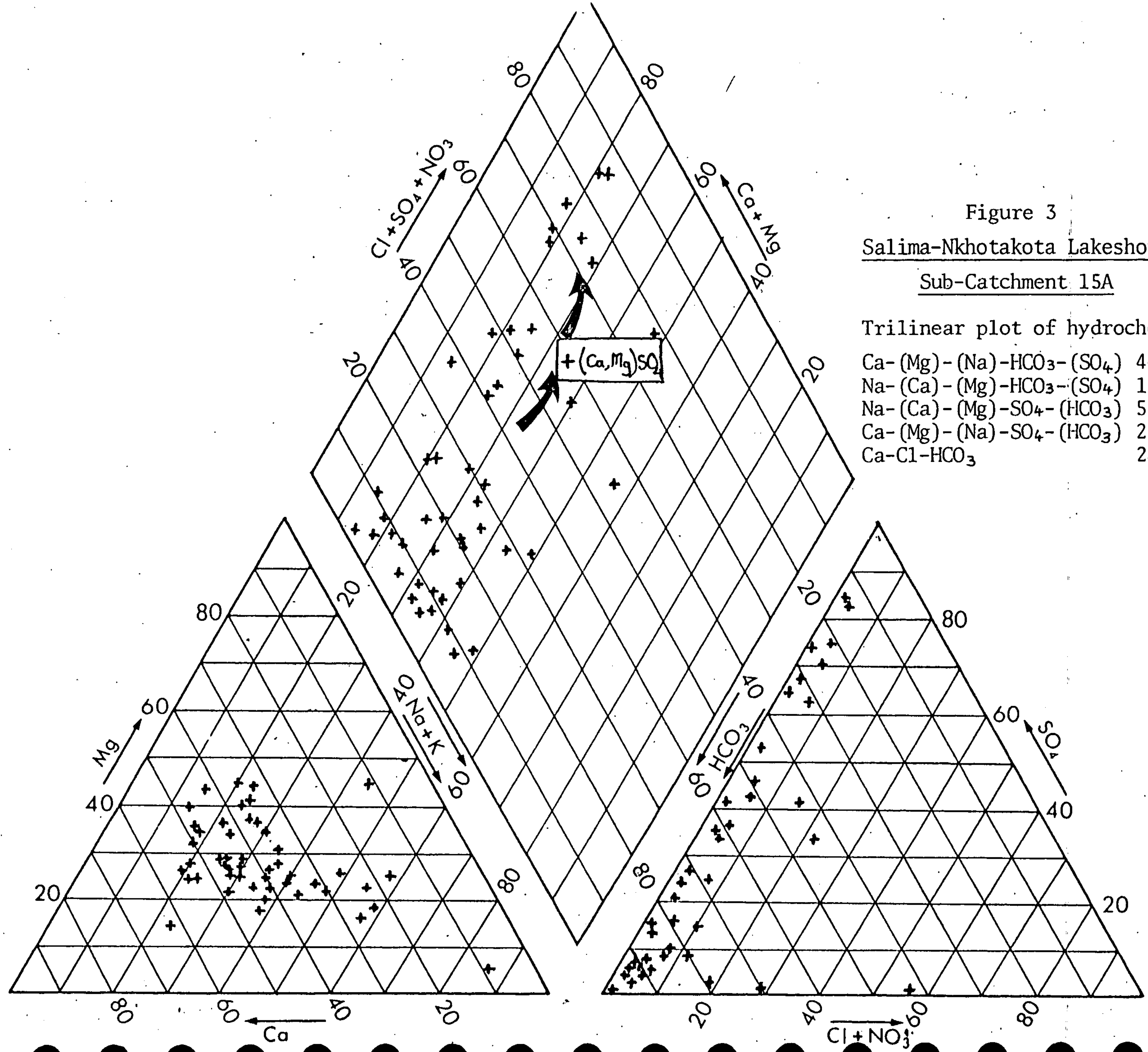


Figure 3

Salima-Nkhotakota Lakeshore

Sub-Catchment 15A

Trilinear plot of hydrochemistry

Ca-(Mg)-(Na)-HCO_3-(SO_4)	4-40 meq/1 TDE
Na-(Ca)-(Mg)-HCO_3-(SO_4)	12-34 meq/1
Na-(Ca)-(Mg)-SO_4-(HCO_3)	52 & 132 meq/1
Ca-(Mg)-(Na)-SO_4-(HCO_3)	25-96 meq/1
Ca-Cl-HCO_3	28 meq/1

Saturation Index (SI):

Borehole no.	Ca^{2+} mg/l	SO_4^{2-} mg/l	SI (gypsum)
15A/1	87	40	-1.69
9	378	1203	-0.07
18	340	1739	-0.04
26	104	700	-0.67
63	392	2400	-0.07
65	332	1525	-0.08
68	230	655	-0.39
97	278	1128	-0.15
100	241	1081	-0.24
101	132	140	-1.08
166	243	838	-0.30

(SI + indicates oversaturation, - undersaturation, zero indicates equilibrium)

It can be seen that the waters tend towards gypsum saturation as Ca^{2+} and SO_4^{2-} increase, with the four highest SO_4^{2-} and Ca^{2+} combinations representing equilibrium within error limits.

3.2.6 The increases in Ca^{2+} concentrations are, however, insufficient to represent full chemical equivalence with the high SO_4^{2-} values (100 mg/l Ca^{2+} is equivalent to 240 mg/l SO_4^{2-}) as the slope in Figure 4 demonstrates. The apparent loss of Ca^{2+} is an extreme case of the process of ion exchange which dominates cation chemistry in these groundwaters.

3.2.7 The cation exchange takes place between solution and clay minerals which are the products of alteration reactions on silicate minerals:

$$\underset{\text{sodic plagioclase}}{2NaAlSi_3O_8} + H_2O + 2H^+ \longrightarrow \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_4} + 4SiO_2 + 2Na^+ \qquad (1)$$

The clays produced may be kaolinite or montmorillonites, depending upon the local conditions, and the reactions release a range of cations into solution depending upon the primary mineral assemblage and relative alteration rates (usually ferromagnesian minerals > feldspars). Pyroxenes are a source of Ca^{2+} and Mg^{2+}, amphiboles Mg^{2+}, Ca^{2+} and Na^+, and biotite Mg^{2+}, K^+ and Na^+. Additionally, the mobilisation of iron in dissolved, colloidal or suspended precipitate form is an important aspect of pumped water quality (see section 4.2).

3.2.8 The equilibrium distribution of cations between solution and exchange sites on clays with which the solution is in contact is exemplified by:

$$Ca^{2+}(aq) + Na^+ - clay \rightleftharpoons Na^+ (aq) + Ca^{2+} - clay \qquad (2)$$

This exchange equilibrium may account for the rather small range of values of the ratio of Ca^{2+} : Mg^{2+} in solution. These two cations

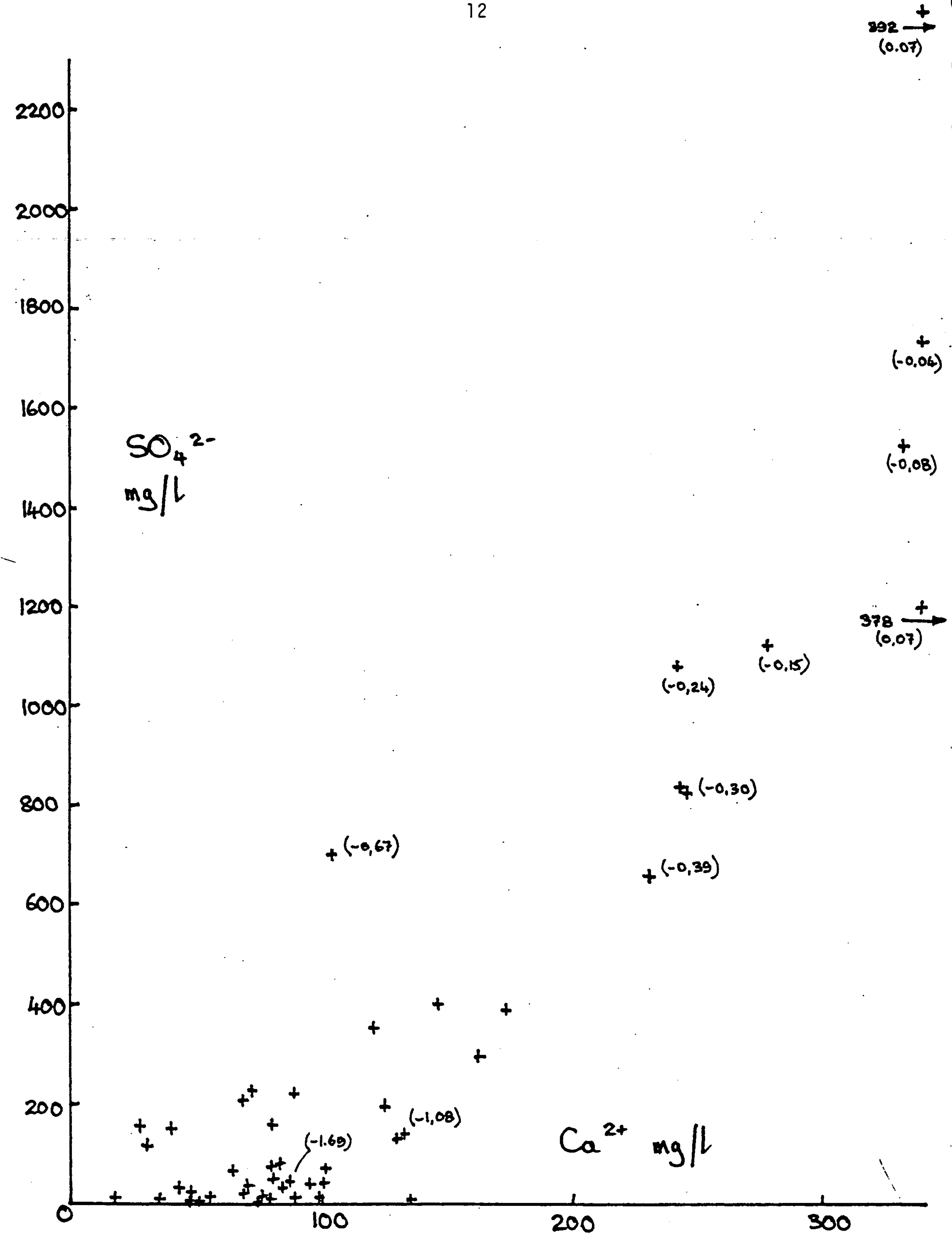


Figure 4. Ca^{2+} versus SO_4^{2-} in groundwater of sub-unit 15A

Figures in parentheses are saturation indices with respect to gypsum ($CaSO_4$). Refer to text.

have similar stabilities in the exchange sites of clays and therefore their proportions in solution will tend to be buffered by the much larger amounts attached to clays. The range of Ca^{2+} : Mg^{2+} in these groundwaters lies in the range 0.7-3.8 and is commonly between 1-2.

3.2.9 Concentrations of HCO_3^- (measured as total alkalinity) vary from 120 to 930 mg/l. This wide variation in HCO_3^- is typical of clay-rich weathering environments in which cation exchange becomes a major process. HCO_3^- is controlled in many mature groundwaters by an equilibrium with calcite, $CaCO_3$; Ca^{2+} and pH are therefore the other controlled or limiting parameters, according to the equilibria:

$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+ \qquad (3)$$

and

$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \qquad (4)$$

In the present case where dissolved Ca^{2+} is variable as a result of exchange with Na^+, the corresponding HCO_3^- concentration can vary inversely with Ca^{2+}. The reactions by which HCO_3^- enters solution are the calcite dissolution reaction which is probably rapid if there is any $CaCO_3$ present in the soil zone or weathered material:

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca^{2+} + 2HCO_3^- \qquad (5)$$

and hydrolysis of silicate minerals by 'carbonic acid' or dissolved CO_2:

e.g. $$NaAlSi_3O_8 + 2CO_2 + 3H_2O \longrightarrow 2Na^+ + 2HCO_3^- + 4SiO_2 + Al_2Si_2O_5(OH)_4 \qquad (6)$$

The latter reaction is a major process in the tropical weathering environment.

3.2.10 The chemical heterogeneity of groundwater over this region suggests that residence times are sufficient for localised processes to dominate the chemistry rather than regional flow. This is consistent with the very limited extent of identifiable aquifer zones within the weathered gneiss, colluvium or alluvium, in spite of the apparent widespread hydraulic continuity suggested by piezometric contouring. The variable but generally low Cl^- concentrations suggest local recharge with the moisture losses due to evapotranspiration determining the final concentration in infiltration; this may be enhanced by flushing of Cl^- from the aquifer matrix - although there is no obvious source. The semi-confined aquifer conditions may indicate that major recharge does not occur everywhere, but is restricted to particular topographic or hydrogeological features. Anomalously high Cl^- values are therefore not easily understood, and the possibility of unusual hydrogeological conditions or of contamination must be considered.

3.2.11 The source of gypsum, $CaSO_4$, which seems to be responsible for high concentrations of SO_4^{2-} (para. 3.2.5) is not known. The zone of high SO_4^{2-} groundwaters south and east of Chitala corresponds roughly with the outcrop and sub-crop of weathered charnockite of the basement complex (Walter, 1972). One possibility is that sulphate was produced by oxidation of sulphide (e.g. pyrite, FeS_2), although there are no reported anomalous occurrences. It should be noted, however, that the highest SO_4^{2-} and Ca^{2+} are found in a borehole (15A/63) in lakeshore alluvium.

3.2.12 The occurrence of boreholes with low SO_4^{2-} (e.g. 15A/1, 2, 83 and 94) in regions of generally high SO_4^{2-} suggests that there may be vertical zonation of water quality in the aquifer. There is no indication to prove or disprove this from the existing information.

3.3 Bua Catchment, Unit 5; Sub-units 5D to 5F.

3.3.1 These sub-units are situated on the upland plateau physiographic zone, although sub-unit 5D borders onto the fault scarp zone dissected by the Bua headwaters. The geology is entirely deeply weathered basement complex. A typical example of 'dambo' landform occurs over much of sub-unit 5F, south-west of Kasungu (only 2 analyses are available from this area).

3.3.2 Boreholes in this region are commonly drilled to depths of around 50 metres, most of which is recorded as weathered or fractured basement gneiss, with abundant clay material, and sometimes 'quartzites'.

3.3.3 TDS values only are recorded in most cases and it is not clear whether these are derived from EC or directly measured. The TDS values range from 205-744 mg/l in sub-unit 5D and from 45-654 mg/l in 5E. These correspond to range in TDE 7.8-26.4 meq/l and 2.4-20.9 meq/l respectively. The two samples from 5F have TDE 9.8 and 12.6 meq/l. Overall, these values represent low to very low mineralisation of groundwaters in the Bua catchment.

3.3.4 Most of the anion-cation charge balance calculations show an excess of anions in the analytical results; in most cases the % excess is acceptable in view of the low concentrations being analysed, but in some cases excessively negative balances (and also a few excessively positive) make the data unacceptable.

3.3.5 The range of Cl^- concentrations in sub-unit 5D, 9-40 mg/l (and one anomaly, Q87, with 74 mg/l) is larger than that in sub-unit 5E in which the highest recorded Cl^- is 12 mg/l. The exceptionally high Cl^- in borehole Q87 is coupled with a high NO_3^- concentration of 15 mg/l, which suggests the presence of contamination which elsewhere has been found to affect both NO_3^- and Cl^- (Lewis *et al.*, 1978). (However the analysis of Q87 must be treated with caution since the charge balance is -28%).

3.3.6 SO_4^{2-} data show considerably more variation in 5E than they do in 5D, in which all values except one (RB65, 15 mg/l SO_4^{2-}) are below 10 mg/l. SO_4^{2-} up to 375 mg/l is reported for 5E. However it is noted that the grouping of data according to sub-unit may be an artefact of the time and methods of analysis - for instance, a different detection limit for $SO_4{}^{2-}$ (10 mg/l) has been used for most of the data in 5E compared with that used for 5D. Additionally, the consistently negative charge balance for most 5E data casts some doubt on the anion analyses. The higher range of $HCO_3{}^-$, 218-940 mg/l in 5D, compared to that in 5E, 50-319 mg/l, is also distinctive.

3.3.7 The groundwater in sub-unit 5E is classified predominantly as Ca-(Mg)-(Na)-HCO_3-(SO_4), although there are cases where Mg^{2+} and/or Na^+ predominates over Ca^{2+}. There is no correlation between the occurrence of high $SO_4{}^{2-}$ and the predominance of a particular cation e.g. Ca^{2+} (cf. para. 3.2.5). The position is similar in 5D, with groundwater falling into the Ca-Na-(Mg)-HCO_3 classification (Figures 5 and 6).

3.3.8 The relatively low mineralisation and distinctive hydrochemical evolution of this groundwater is considered to typify the effects of silicate alteration reactions on the chemistry of water infiltrating the weathering profile. The cationic distribution trend shows large variation in Ca : Mg ratio (Figure 6), suggesting an early stage of weathering in which the relative contributions of soil carbonate and breakdown of silicates, particularly ferromagnesians, to the final solution compositions varies widely. Cation exchange involving Ca, Mg and Na also takes place on the clay products of alteration. The variable amounts of sulphate may arise from the oxidation of trace amounts of sulphide, e.g. pyrite:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2Fe^{2+} + 4SO_4{}^{2-} + 4H^+ \qquad (7)$$

which also produces acidic conditions to promote silicate breakdown (e.g. reaction 1) and releases Fe^{2+} into solution (note the high total Fe analysed in high $SO_4{}^{2-}$ samples e.g. RB36, RB5, FC90, FC80, DP125, etc.).

3.3.9 The occurrence of relatively $SO_4{}^{2-}$-rich groundwater is found to coincide approximately with the area reported to contain several sizeable deposits of pyrite-pyrrhotite (Thatcher & Wilderspin, 1968). This area lies east of the Bua River and extends from Chisepo in the north to Namitete Mission, and there may be additional sulphide occurrences so far undetected in outcrop but giving rise to enriched dissolved $SO_4{}^{2-}$.

3.3.10 In effect, the reactions represented by the water chemistry in the weathering zone of the upland plateau are the precursors for reactions inferred to be taking place in parts of the colluvium/alluvium at the base of the fault scarp zone. Thus the sulphate produced as a result of progressive sulphide oxidation may have accumulated as a secondary mineral precipitate of gypsum and been subsequently redissolved by groundwater such as that found in parts of sub-unit 15A (section 3.2).

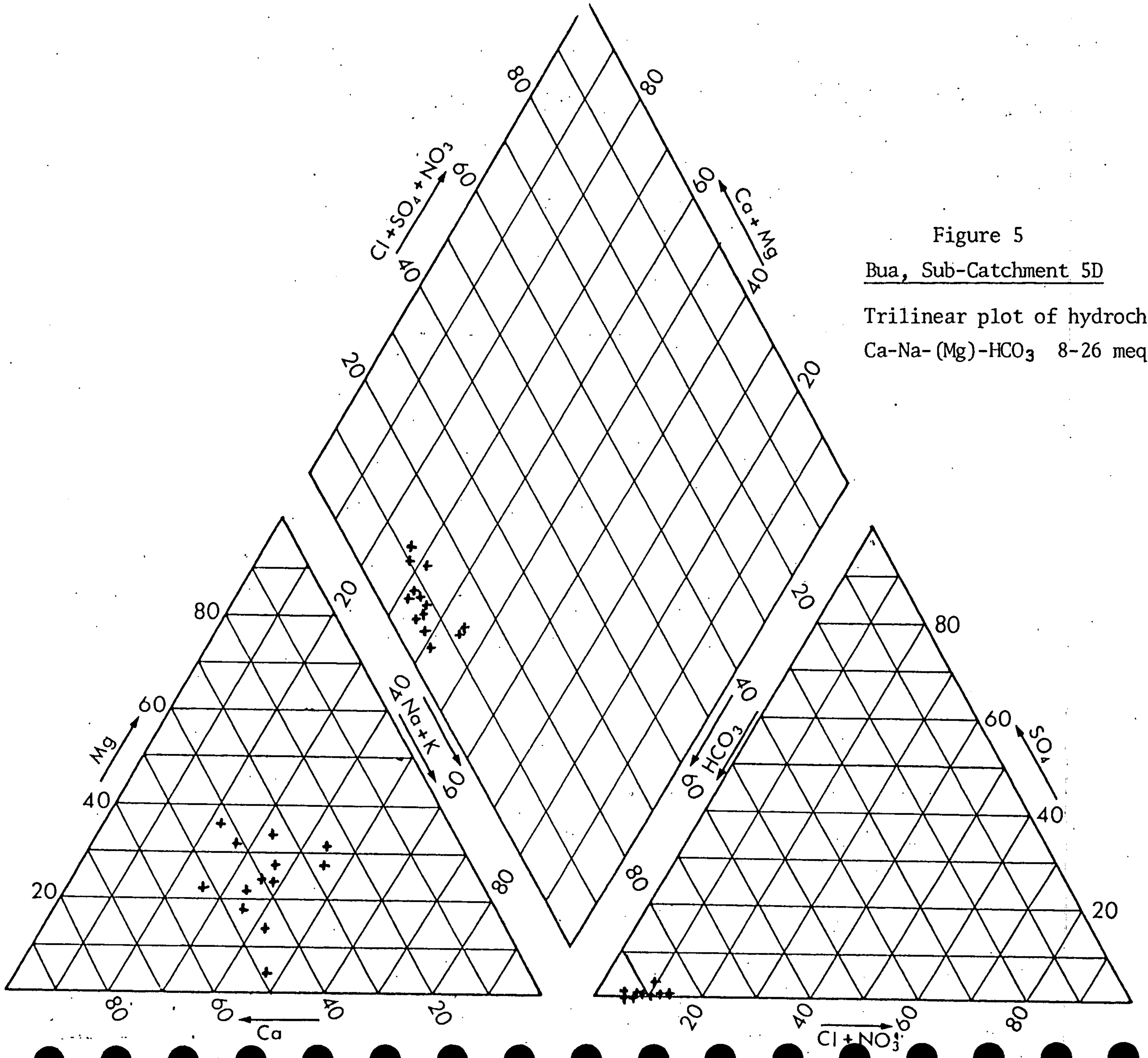


Figure 5

Bua, Sub-Catchment 5D

Trilinear plot of hydrochemistry

Ca-Na-(Mg)-HCO_3 8-26 meq/1 TDE

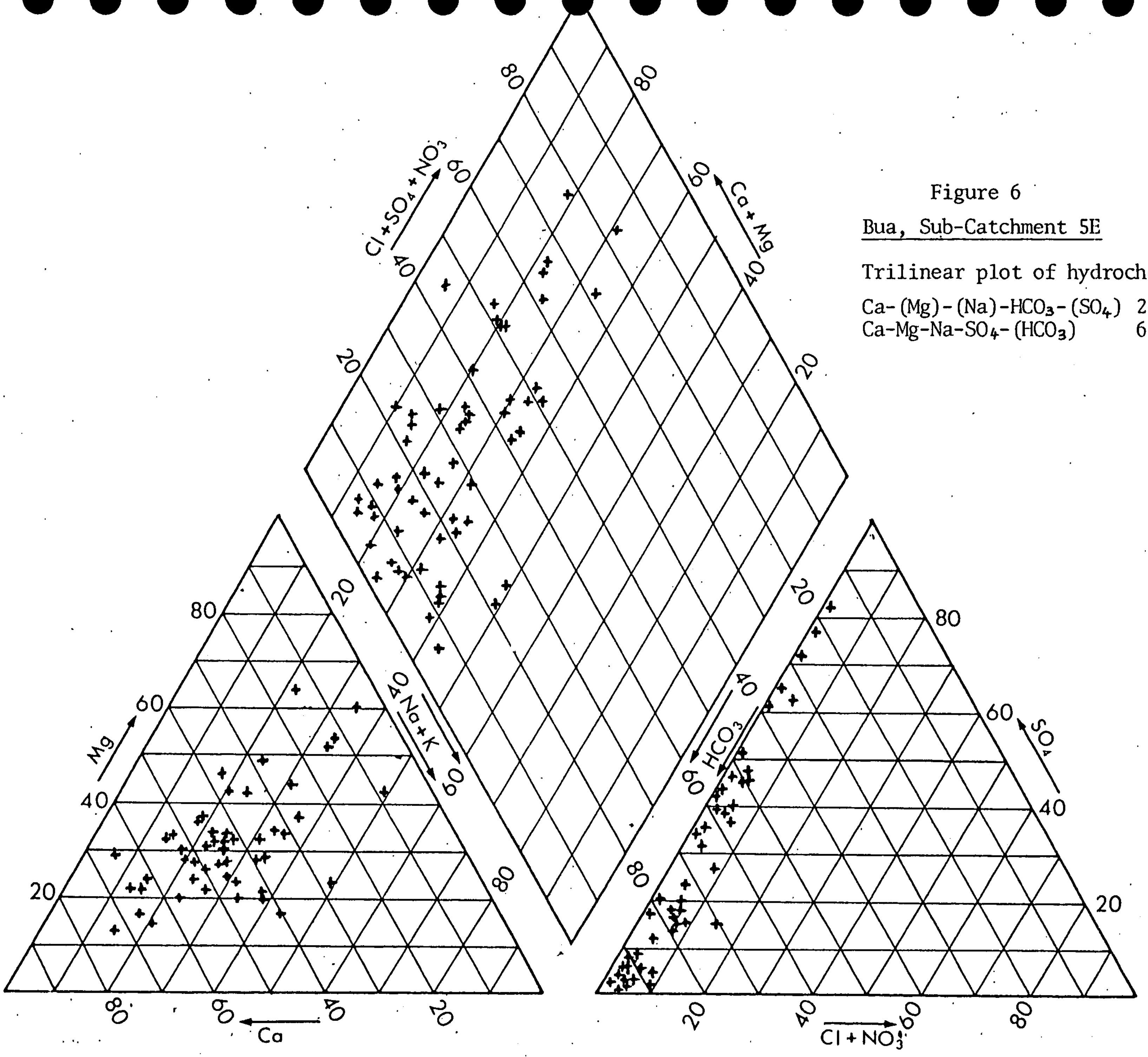


Figure 6

Bua, Sub-Catchment 5E

Trilinear plot of hydrochemistry

Ca-(Mg)-(Na)-HCO_3-(SO_4) 2-13 meq/l TDE
Ca-Mg-Na-SO_4-(HCO_3) 6-21 meq/l

3.4 Shire Catchment, Unit 1; Sub-units 1F, 1G, 1H, 1K.

3.4.1 The Lower Shire Valley is at the southern tip of Malawi, the Shire River accounting for the outflow from Lake Malawi eventually into the Zambezi. The valley is in many places bounded by faults representing extensions of the rift system, and the centre is infilled with superficial deposits with evidence of provenance from the rocks comprising the valley sides. The surrounding geology is principally Basement Complex, but on the western side of the valley outcrops of Karoo sediments and volcanics occur faulted against the Basement Complex. In addition a small but significant outcrop of Cretaceous desert sandstone (Lupata Series) occurs overlying unconformably the Karoo sediments. Sub-unit 1F lies on the eastern side of the Shire River and is situated in an area comprising Basement Complex and its derived alluvium/colluvium. The other sub-units (1G, 1H, 1K) lie on the western side, with 1H containing the Karoo outcrops mentioned above. Sub-unit 1K, the Mwanza Valley catchment, is bounded to the north by the Mwanza Fault escarpment which separates Basement Complex from the alluvial fill of the Mwanza Valley.

3.4.2 The hydrogeology and hydrochemistry of the Lower Shire Valley were reported on previously by Bradford (1973). In general, the piezometric contours indicate a regime of groundwater flow towards the central axis of the valley, i.e. towards the river, although the exact relationship between river and groundwater has not been established. As far as can be judged from present information, there is at least partial hydraulic continuity between groundwater in the weathered bedrock at the valley sides and water in the valley-fill alluvium. The total depth of alluvium lying on top of bedrock in the centre of the valley is not known.

3.4.3 Boreholes have been drilled to depths usually between 30 and 60 metres. It is probable that the water-producing zones intercepted have limited lateral extent due to the variable natures of both the weathering profiles and the alluvial profiles. Shallow wells, either properly constructed wells or dug water-holes, also demonstrate the existence of a relatively shallow aquifer in some places, particularly in the dry beds of ephemeral water-courses.

3.4.4 Sub-unit 1F lies on the eastern side of the Shire, with most boreholes being drilled into the superficial deposits below the Thyolo Fault escarpment. The groundwater here is characterised by relatively low mineralisation, measured EC values being between 80 and 1600 $\mu S\ cm^{-1}$ (TDE between 7-36 meq/l). Cl^- and SO_4^{2-} are both low, generally below 100 mg/l and 50 mg/l respectively. Most of the water is classified as Ca-Mg-Na-HCO_3 with very variable proportions of the cations (Figure 7). Borehole FP134 has high Cl^- (1630 mg/l) and SO_4^{2-} (440 mg/l) and is very anomalous, possibly representing evaporative concentration processes in operation very close to the river. The groundwater in this unit is typical of locally-recharged water, having initially been dominated by Ca-Mg-HCO_3 and subsequently undergone Ca-Mg-Na cation exchange among the abundant clays in the alluvium/colluvium profile.

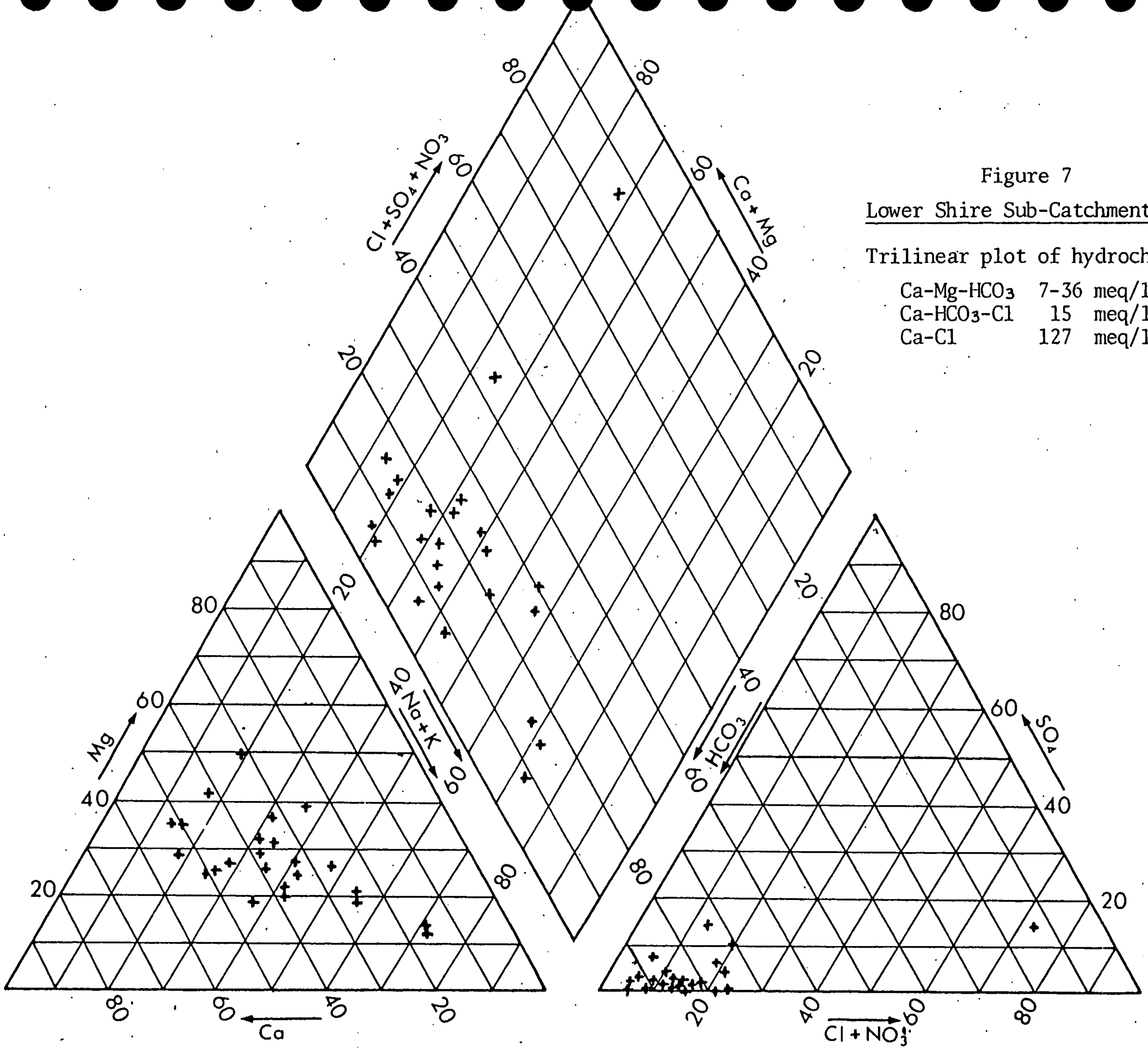


Figure 7

Lower Shire Sub-Catchment 1F

Trilinear plot of hydrochemistry

Ca-Mg-HCO_3	7-36	meq/1 TDE
Ca-HCO_3-Cl	15	meq/1
Ca-Cl	127	meq/1

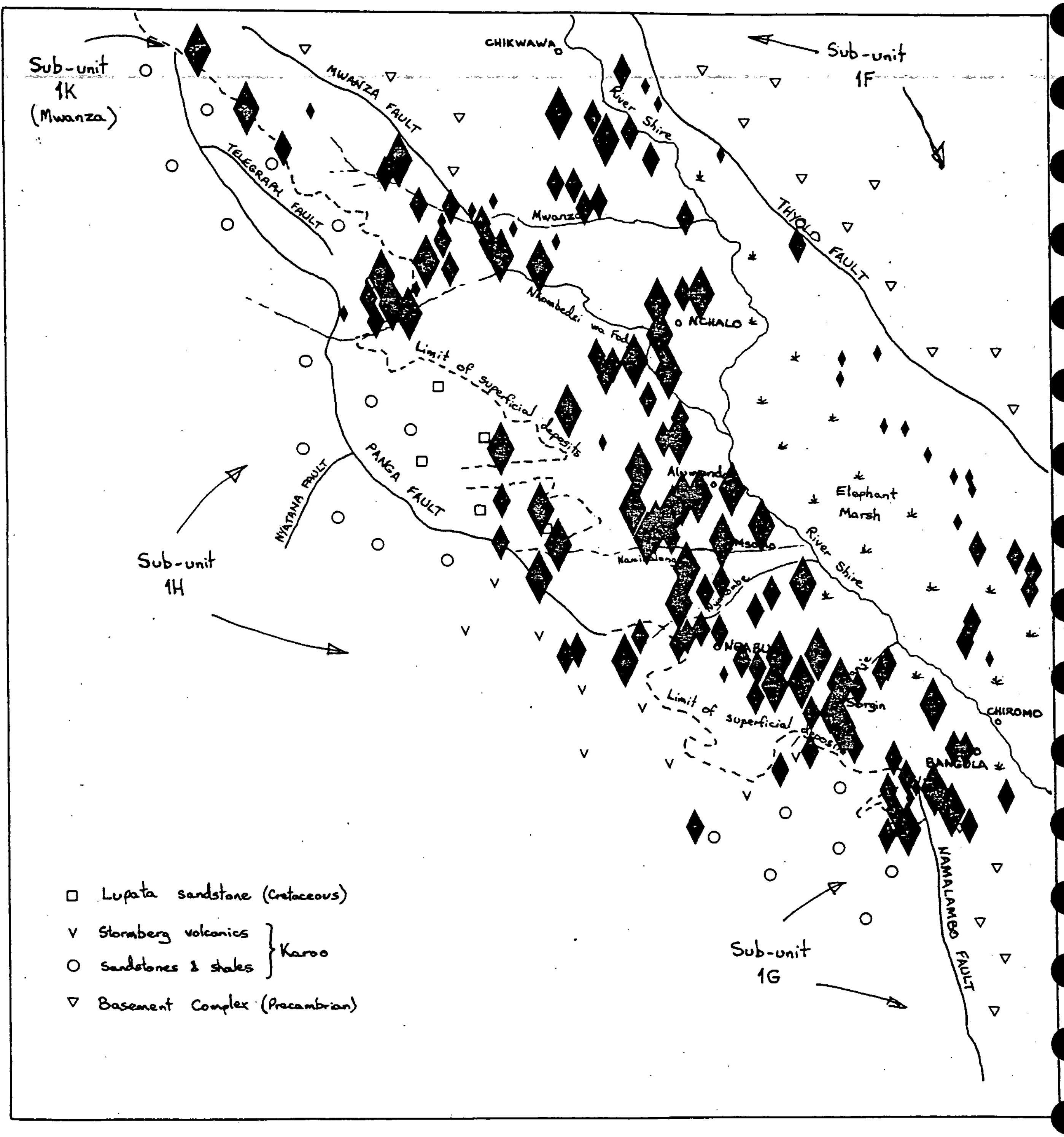


Figure 8 1:500,000 Sketch map of part of Lower Shire Valley showing solid geology and boundary of superficial deposits, and groundwater quality

◆ <20 meq/L TDE (ca. <1000 µS cm⁻¹ EC)

◆ 20-50 meq/L TDE

◆ >50 meq/L TDE

3.4.5. Sub-unit 1G (Figure 8) contains groundwater representing the progressive evolution from Ca-HCO_3 to strongly mineralised Na-Cl types (Figure 9). Measured EC values range from 510 to 16000 µS cm^{-1} (TDE between 10.7-440 meq/l). A large number of the analyses indicate the intermediate Na-HCO_3 classification (TDE between 14-133 meq/l). Cl^- and SO_4^{2-} both increase with mineralisation, reaching 4115 and 4400 mg/l respectively in FC122. High mineralisation is mostly associated with boreholes close to the river between Chiromo and Msanje and is associated with evaporative concentration from the shallow water-table. The high salinities suggest that the river is not significantly influent to the underlying water-table, but likewise that there is negligible, or very slow, movement of water from the aquifer to the river. South of Nsanje, groundwater west of the marsh within the colluvial aquifer of the weathered Basement Complex is of more dependable quality, varying from 510-1640 µS cm^{-1} EC (11-36 meq/l TDE), except for D32 which is reportedly 3070 µS cm^{-1}. Water classifications are Ca-Na-HCO_3 in this area, and probably represent local recharge and evolution as found in sub-unit 1F (para. 3.4.4). Saline groundwaters just south-west of Bangula at PM114 and PM366 (2730 and 2650 µS cm^{-1}) occur at or close to the Namalambo Fault and its associated hydrothermal 'siliceous fault-rock', from which groundwater mineralisation probably derives including anomalously high F^- concentrations (para. 4.5.4). Borehole FC122 (16000 µS cm^{-1}) apparently is situated west of this fault in Karoo Red Bed sediments, from which it may derive its mineralisation.

3.4.6 Sub-unit 1H (Figure 8) comprises predominantly Karoo sediments (shales and sandstones) and volcanics, the latter extending in a faulted block west of Ngabu, and derived alluvium and colluvium. Groundwater is of very variable quality with Ca-Mg-HCO_3 compositions in the range 590-1320 µS cm^{-1} EC (TDE 11-27 meq/l), Na-HCO_3 in the range 930-6050 µS cm^{-1} (TDE 25-110 meq/l), and Na-Cl 1830-17900 µS cm^{-1} (TDE 26-437 meq/l). SO_4^{2-} concentrations are also very variable, exceeding 2000 mg/l at Y64 and X83 and reaching 4900 mg/l at RB98; these three anomalies occur in different locations; Y64 at Ndakwera on the Nkombedzi Wa Fodya (in Karoo sediments and colluvium), X83 at Chidaya west of Ngabu where Karoo volcanics become overlain by superificial deposits (this site was visited by the author in November 1980, however the borehole had been out of service since August 1979), and RB98 at Bandewende northwest of Bangula at the edge of the Elephant Marsh (probably saline as a result of evaporation from the shallow water-table in the alluvial silt/sand).

3.4.7 A zone of consistently poor groundwater quality occurs down-gradient of the outcrop of Cretaceous Lupata Series desert sandstones, in sub-unit 1H (Figure 8). The influence of this mineralisation is apparent in the superficial deposits from adjacent to Alumenda northwards to Nchalo. Groundwater compositions are mainly Na-Cl or Na-HCO_3-Cl, with EC up to 6330 µS cm^{-1} (130 meq/l); some less saline groundwater analyses reported for this zone (e.g. Q296, Ca-HCO_3 and 710 µS cm^{-1}) probably represent anomalous circumstances where locally-recharged water dominates over the regional flows from the Lupata sandstone. The Lupata Series is reportedly calcareous, and abundant traces of evaporite minerals are probably contained within the calcareous matrix.

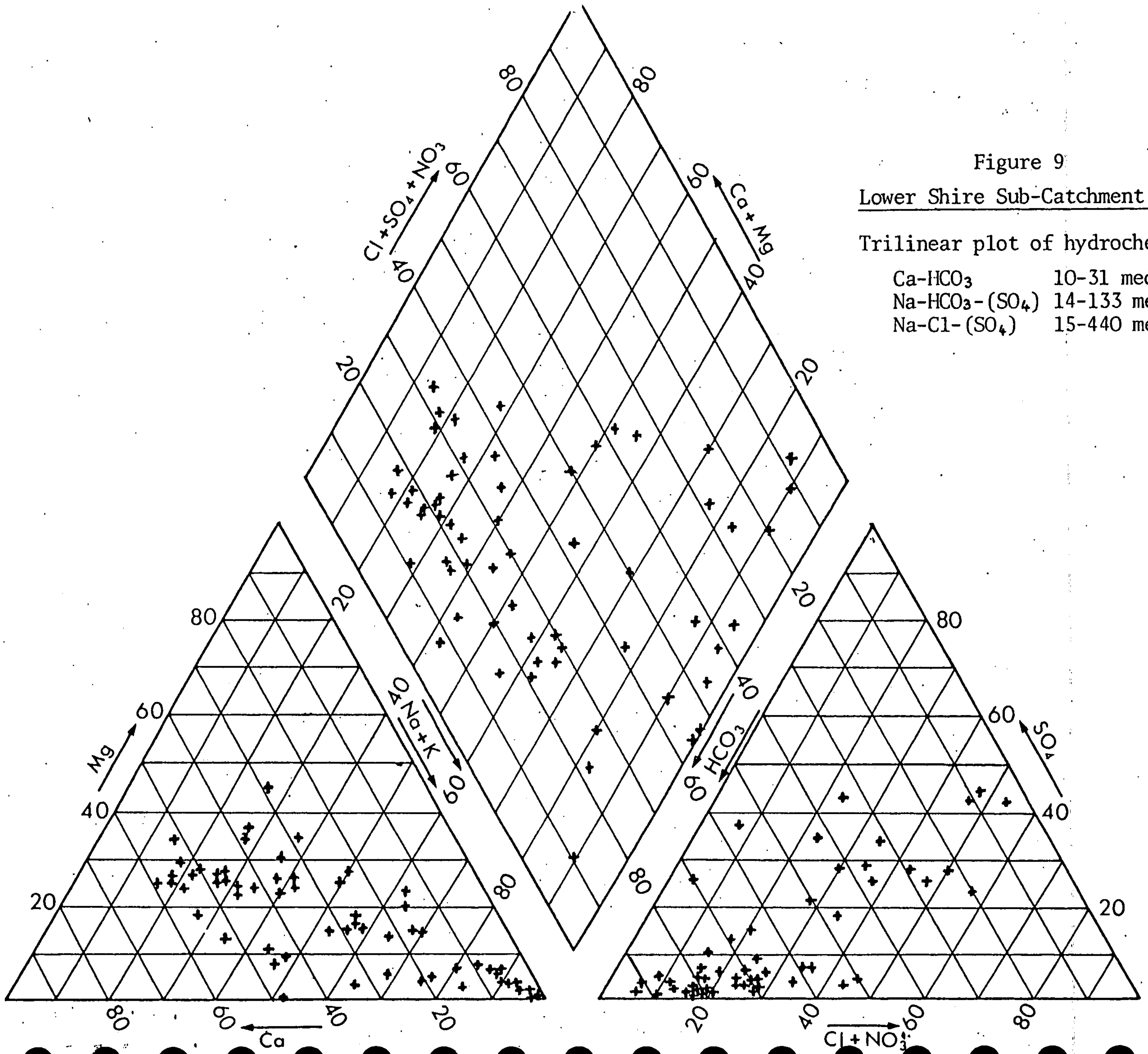


Figure 9

Lower Shire Sub-Catchment 1G

Trilinear plot of hydrochemistry

Ca-HCO_3	10-31 meq/1 TDE
Na-HCO_3-(SO_4)	14-133 meq/1
Na-Cl-(SO_4)	15-440 meq/1

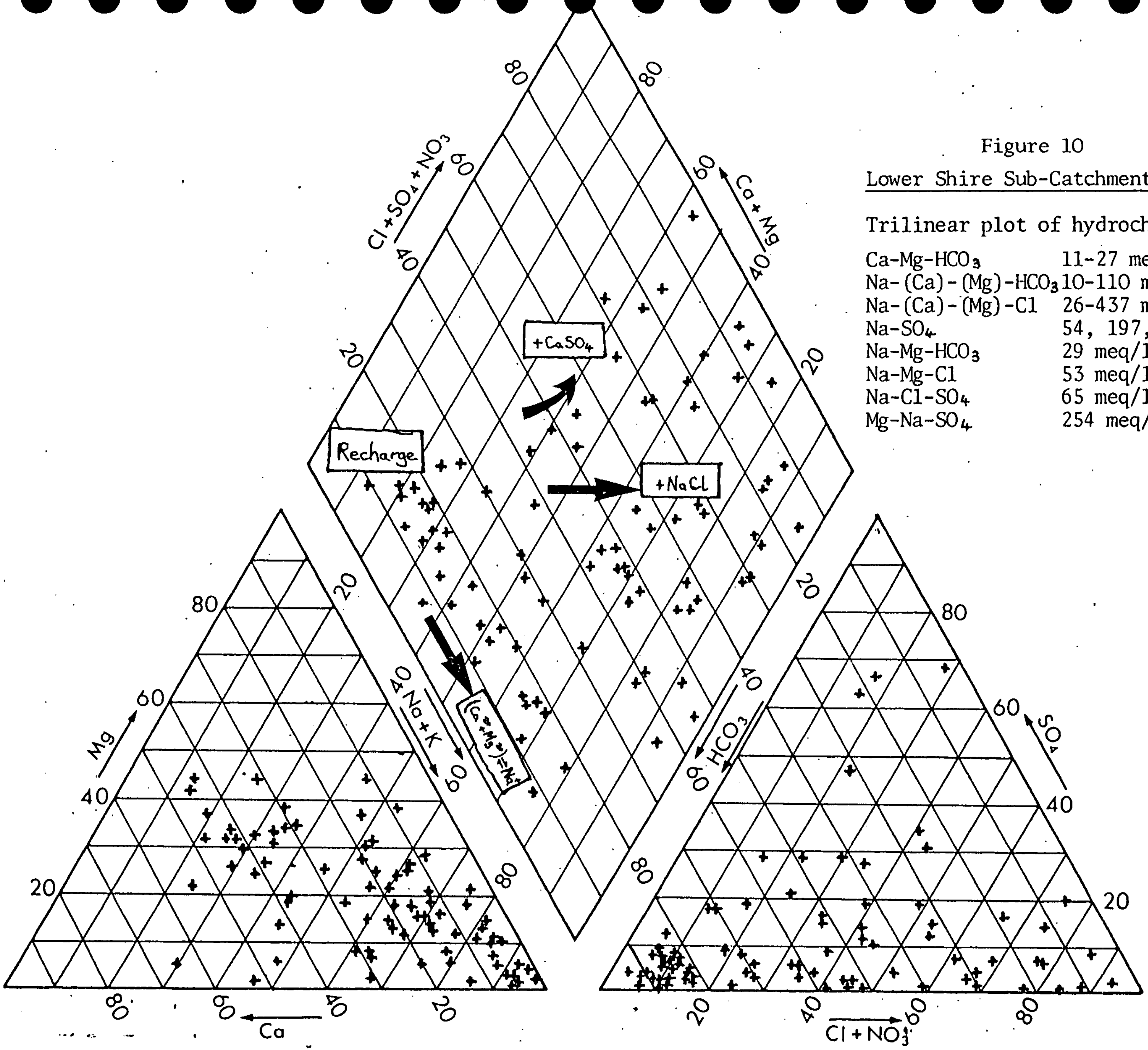


Figure 10

Lower Shire Sub-Catchment 1H

Trilinear plot of hydrochemistry

Ca-Mg-HCO$_3$	11-27 meq/1 TDE
Na-(Ca)-(Mg)-HCO$_3$	10-110 meq/1
Na-(Ca)-(Mg)-Cl	26-437 meq/1
Na-SO$_4$	54, 197, 456 meq/1
Na-Mg-HCO$_3$	29 meq/1
Na-Mg-Cl	53 meq/1
Na-Cl-SO$_4$	65 meq/1
Mg-Na-SO$_4$	254 meq/1

3.4.8 Localised occurrences of fresher groundwater with Ca-HCO_3 composition are frequently associated with ephemeral river courses from which direct recharge might be expected. It is known that shallow water tables often occur below these water courses from which hand-dug wells can collect water in the dry season. Examples of the Ca-HCO_3 groundwaters are found around Ngabu (Nyakambo River) and Sorgin (Mafume R.).

3.4.9 Sub-unit 1K contains groundwater ranging from Na-HCO_3 composition (430-1430 µS cm^{-1} EC; 9-33 meq/l) to Na-Cl composition (2000-4000 µS cm^{-1} EC; 37-69 meq/l TDE). SO_4^{2-} is relatively low, <500 mg/l. Two anomalous analyses are reported, indicating Mg-HCO_3-Cl for Y67 (61 meq/l TDE) and Mg-Ca-Cl for PM95 (166 meq/l). The latter, very highly mineralised, groundwater may originate in deep faults normal to the major Mwanza Fault; abnormal hydrogeological conditions are indicated by piezometric contours in this locality and the replacement of an identifiable water-course by marshy conditions. Most boreholes in this sub-unit extract water from superficial deposits derived from Karoo shales and sandstones; the evolution towards Na-HCO_3 and Na-Cl compositions with increasing mineralisation is associated with cation exchange and mixing with saline water trapped within lower permeability clays and silts. The lateral heterogeneity in water mineralisation and composition, even over short distances in apparently the same 'aquifer-unit' (e.g. at Ndakwera), is indicative of the heterogeneity and discontinuity in the water-bearing horizons in the superficial deposits.

3.4.10 The Lower Shire Valley was visited by the author in November 1980. Boreholes were sampled, mostly in sub-unit 1H, for field determinations and subsequent laboratory analyses in UK. Analytical results and comments are in Appendix 2.

3.5 South Rukuru Catchment, Unit 7.

3.5.1 The South Rukuru catchment is situated south of the Nyika Plateau and west of the Viphya Mountains (Figure 12). The geology in the catchment comprises predominantly thin colluvium overlying basement gneiss and granite gneiss, occasionally penetrated by 'pegmatites' (Gaskell, 1973). Dambos form an important feature of the drainage pattern within the catchment.

3.5.2 Chemical analyses available in the data files represent groundwater from three areas within the catchment: the area between the Mzimba and S. Rukuru Rivers (Sub-unit 7A), the area between the Kasitu and S. Rukuru Rivers around Emcisweni (Sub-units 7C and 7E), and along the S. Rukuru River northeast of Rumphi (Sub-unit 7G).

3.5.3 Groundwater in sub-unit 7A has low to very-low mineralisation (70-390 µS cm^{-1} EC; 2-19 meq/l TDE with one exception - see below). Compositions are mostly close to Na-HCO_3 (Figure 13). These chemistries must represent local recharge to the aquifer and chemical evolution by silicate weathering reactions (para. 3.2.9) in the shallow subsurface environment. Cl^- concentrations do not exceed 119 mg/l (H35) except apparently at borehole E189 where the 1978 analysis reports 560 mg/l although a 1972 analysis reports only 6 mg/l. The apparent shift from a dilute Na-HCO_3 composition (110 µS cm^{-1} EC) to a slightly saline Ca-Cl-HCO_3 composition (2550 µS cm^{-1}) over the 6-year period has no immediately obvious explanation. The increase in Cl^- is not accompanied by a similar

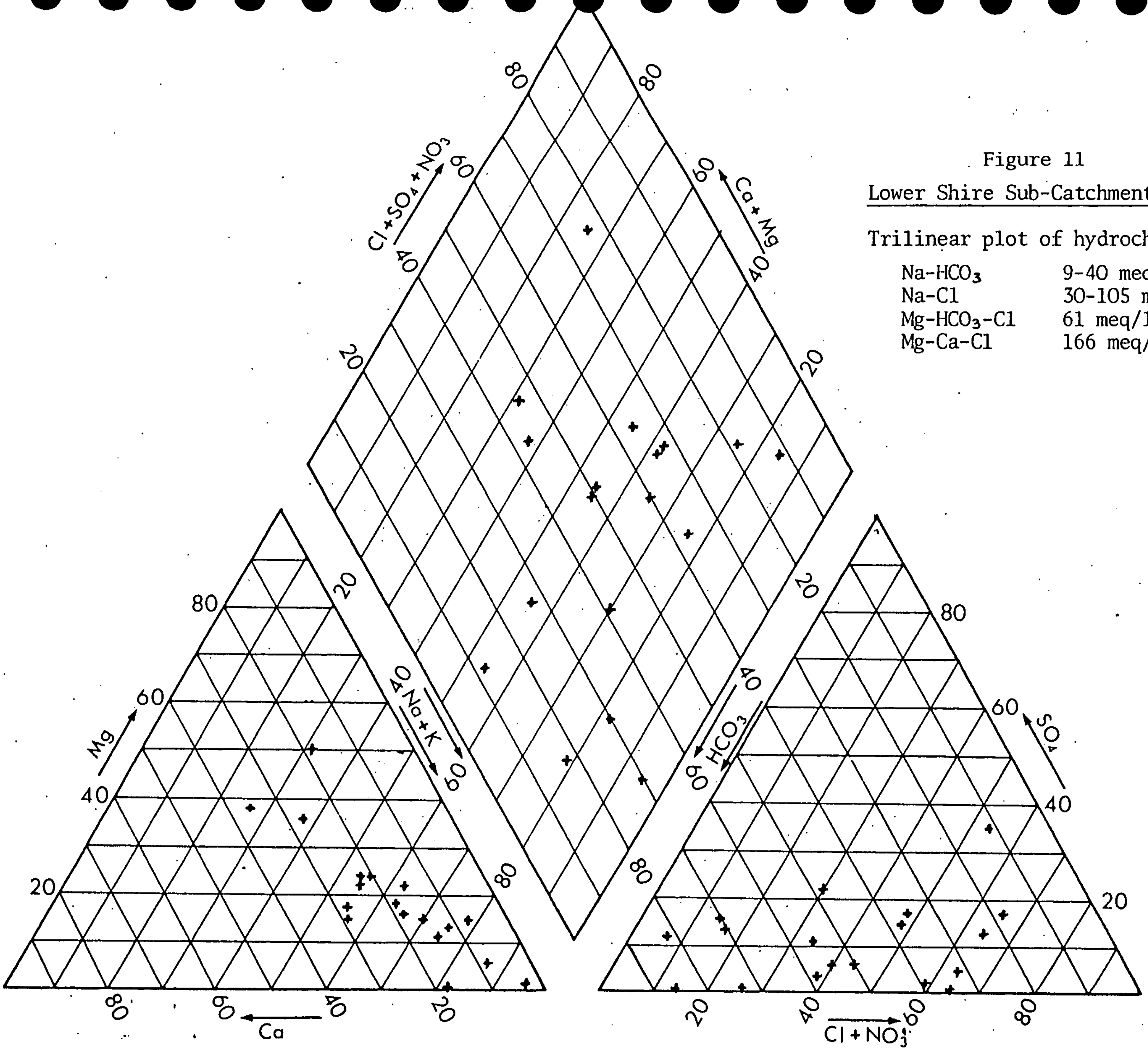


Figure 11

Lower Shire Sub-Catchment 1K

Trilinear plot of hydrochemistry

Na-HCO_3	9-40 meq/l TDE
Na-Cl	30-105 meq/l
Mg-HCO_3-Cl	61 meq/l
Mg-Ca-Cl	166 meq/l

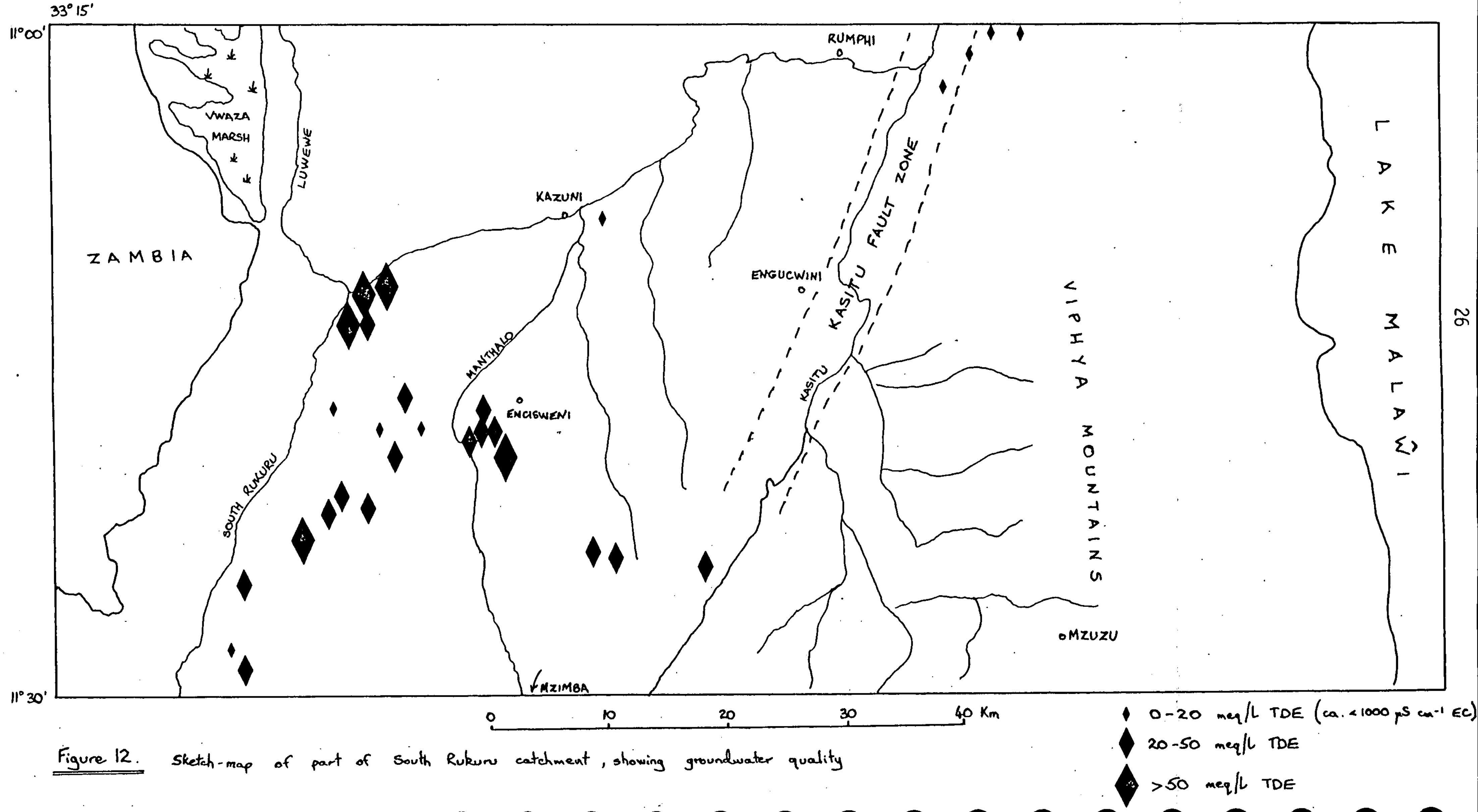


Figure 12. Sketch-map of part of South Rukuru catchment, showing groundwater quality

increase in SO_4^{2-}, so a simple concentration process by e.g. evaporation is not operating. This rather unusual shift in composition towards Ca-Cl type is also found in sub-units 7C and 7E (see below), and gives rise to quite widespread salinity problems.

3.5.4 Groundwater analyses for sub-units 7C and 7E exhibit mineralisation ranging up to 171 meq/l TDE (7650 µS cm^{-1} EC) in X167. The general compositional trend is towards Ca-Cl with increasing mineralisation (Figure 13). In most cases, SO_4^{2-} remains low as Cl^- increases, although in two cases high SO_4^{2-} are also reported (X165 and X167). X167 has the highest reported Cl^- at 1520 mg/l. Within the area represented by available analyses, there is no apparent geographical grouping of high salinities; some relatively fresh groundwaters (PM21, R183, X169) are found south-west of Emcisweni in an area otherwise dominated by more mineralised groundwater. No source of this groundwater mineralisation is immediately obvious. Ca-Cl mineralisation is rare in shallow groundwaters, and possible origins include the influence of deep-seated groundwater discharging into colluvium fault lines in the basement (cf. para. 3.4.9), or shallow exchange of Ca^{2+} for Na^+ in weathered profile combined with enrichment of Cl^- by e.g. evaporation. The frequently low SO_4^{2-} concentrations tend to argue against the latter process. Further geological and hydrogeochemical work is required to delineate the extent of the Ca-Cl mineralisation and identify its origin.

3.5.5 Analyses from sub-unit 7G represent good quality groundwater, up to 1600 µS cm^{-1} EC (33 meq/l TDE) and ranging between Ca-HCO_3 and Na-HCO_3 compositions. Cl^- concentrations up to 117 mg/l are reported, and SO_4^{2-} up to 95 mg/l. Na/Cl ratios are generally >1 and Ca/HCO_3 ratios <1, suggesting enrichment of Na^+ in solution by Na Ca ion exchange, unlike the case in 7C/E where Na/Cl frequently <1 and Ca/HCO_3 >1 suggests the reverse process.

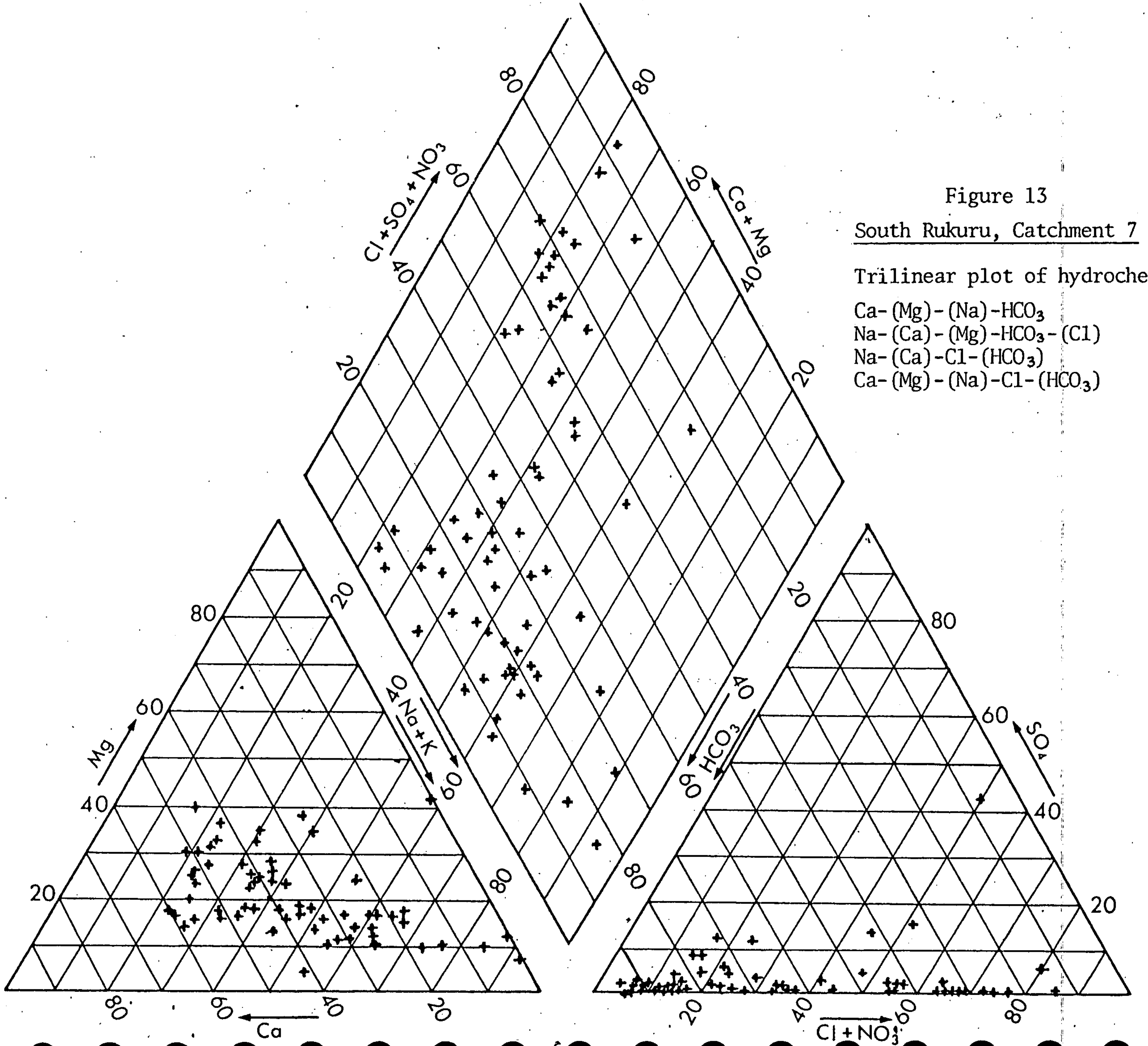


Figure 13

South Rukuru, Catchment 7

Trilinear plot of hydrochemistry

Ca-(Mg)-(Na)-HCO$_3$	3-43 meq/1 TDE
Na-(Ca)-(Mg)-HCO$_3$-(Cl)	2-33 meq/1
Na-(Ca)-Cl-(HCO$_3$)	4-46 meq/1
Ca-(Mg)-(Na)-Cl-(HCO$_3$)	12-138 meq/1

4. GROUNDWATER QUALITY

4.1 Salinity.

4.1.1 The most commonly used parameter for describing salinity of groundwater is the electrical conductivity (EC; para. 3.1.4), which is a function of the total ionic species in solution. Conductivity values up to about 2000 µS cm^{-1} can occur for groundwaters whose mineralisation is Na-HCO_3 type and have evolved by the normal reaction pathways of silicate weathering, carbonate dissolution and ion exchange (paras. 3.2.7 to 3.2.9). Higher EC values are connected with increasing mineralisation due to Cl^- and/or $SO_4{}^{2-}$, since $HCO_3{}^-$ is usually limited by $CaCO_3$ solubility and only infrequently exceeds 1000 mg/l. In this context, salinity gives rise to unacceptable taste or, in extreme cases, total rejection except for washing and perhaps consumption by animals. Maximum permissible concentrations advised by the World Health Organisation (1971) for drinking water are 600 mg/l Cl^- and 400 mg/l $SO_4{}^{2-}$, although it is clear that these limits are exceeded in some rural supplies in areas where no alternative supply is available at an acceptable distance.

4.1.2 The two dominant causes of high salinity in Malawi groundwaters are evaporative concentration and dissolution of evaporite minerals from sedimentary-facies lithologies. Evaporative concentration occurs where the water-table is close to ground surface, and where the rate of potential evapotranspiration greatly exceeds the rate of infiltration. Depths to which evaporative concentration at the water table operates can probably extend to several metres, depending on the depth of the rooting zone of vegetation; a residual effect may also be found in zones where the rate of flushing is too slow to remove the salinity derived from evaporation at a previously higher water table. Evaporative concentration will result in ionic proportions unaltered from the original groundwater, except possibly for modification due to $CaCO_3$ and/or $CaSO_4$ precipitation. Dissolution of evaporite minerals from the aquifer matrix will cause enrichments in specific ionic species derived from these minerals e.g. $CaSO_4$, NaCl. In normal sediments the evaporite minerals are often disseminated through shaly or marly strata, and any originally deposited in more permeable strata would have been rapidly removed by flushing. Thus this source of salinity is most important in water from low-yielding formations.

4.1.3 High chloride salinity in Lower Shire groundwaters occurs as a result of both of the above processes (Section 3.4). Virtually all boreholes located adjacent to the river channel and having reported water table depths only a few metres below ground level are saline to varying degrees. For example, Q360 at Alumenda had a reported 4000 mg/l Cl^- and RWL at 5.8 metres bgl (this borehole was found to be abandoned when visited Nov. 1980); X197 at Mwana Na Njovu had 2920 mg/l Cl^- and RWL at 3.4 mbgl (also found to be abandoned in Nov. 1980 and replaced by a water-hole - see Appendix 2); PM109 at Mkotamu (N of Msanje) had 2960 mg/l Cl^- and RWL at 2.9 mbgl, whilst nearby PM365 had only 148 mg/l Cl^- and RWL at 4.6 mbgl. It is clear that the generally poor salinity of groundwater in these locations frequently leads to abandonment of boreholes in favour of water taken direct from the river or marsh or from water-holes in dry river beds.

There are many examples of high salinity (chloride and/or sulphate) as a result of the dissolution of evaporite minerals in the less permeable horizons. Boreholes drilled into alluvium and colluvium adjacent to the Karoo sandstones and shales and also the Lupata sandstone particularly show this (3.4.6), with reported Cl^- up to 2140 mg/l (X207) and SO_4^{2-} up to 2430 mg/l (X83). High Cl^- is not associated necessarily with high SO_4^{2-}, for example SO_4^{2-} in X207 is only 250 mg/l. Poor salinity in these areas presents a greater problem than adjacent to the river, because of both the greater population density and also the absence of any alternative supplies. For example, borehole Y58 (N of Gome) is saline (1100 mg/l Cl^- and 570 mg/l SO_4^{2-} reported in the archive and approx. 820 mg/l Cl^- measured in Nov. 1980 - see Appendix 2) but remains an important source of water for washing and for drinking "when thirsty"; the nearest alternative borehole supply is 2½ kms away at Malikapo (60-80 mg/l Cl^- - Appendix 2). Similarly, X57 (S. of Msomo) was in use in Nov. 1980 in spite of 480-500 mg/l Cl^- (Appendix 2), and was described by users as 'slightly saline'. Although shallow wells frequently can provide a water supply with lower salinity than deeper groundwater in such circumstances (e.g. at Mwana Na Njovu - see Appendix 2), this is not always the case, e.g. at the shallow well constructed in Aug. 1980 at Chimpambana near Ngabu, where Cl^- is 400-600 mg/l (see Appendix 2).

4.1.4 High chloride salinity in the South Rukuru catchment is confined to the area around Emcisweni (3.5.4), where Cl^- is reported up to 2090 mg/l, and is frequently around 200-500 mg/l. The source of the high Cl^- is not identified (3.5.4) and the local tolerances to high Cl^- are not known, although the salinity is understood to give rise to concern since the area is delineated as a tobacco development project.

4.1.5 Further investigation is required in the Lower Shire of the variation of salinity with depth in the formations where saline groundwater is found to be a problem. This information is necessary since some improvement may be possible by modifying present construction methods, i.e. depth and slotted lining interval, in saline areas. It is understood that one of of the aims of the hydrogeological input to the S.V.A.C.P. is to evaluate the deep hydrogeological regime in the Lower Shire Valley. In addition, more information is required on the shallow groundwater regime which can provide fresh water in dug wells in some areas, where salinity affects boreholes. Although there is a large archive of information on borehole water, there is no parallel compilation of information on wells although this information is potentially of similar importance. Any future sampling programme should include shallow wells; the appointment of a water quality chemist to the S.V.A.C.P. at Ngabu would enable this to be carried out in the Lower Shire Valley.

Preliminary proposals for investigations of water quality variations in shallow wells and boreholes were outlined during the author's visit, and are attached here as Appendix 8.

4.1.6 Very little is known about the tolerance of people to saline (high chloride) drinking water and its effect on health. There are obviously areas in Malawi where water is consumed in spite of Cl^- concentrations above those which are 'advised' by WHO, for the simple reason that no alternative source is available. The indirect effect on health - that of reduced water consumption when the water is unpalatable - must also be considered. A first step in this direction is the forthcoming report of a survey by CSC on perception and acceptability of rural water supply, the questionnaire for which is included here as Appendix 6. This report should be considered jointly by CSC and DLVW since it should provide indications of where the priorities in water quality improvement should be.

4.2 Iron.

4.2.1 The widespread but apparently random presence of high iron concentrations in borehole water is one of the most serious barriers to acceptability of this water. High concentrations of iron lead to discolouration of food during cooking and laundry as well as giving a bitter taste to the water. Concentrations of iron far in excess of the limits advised by WHO (0.1 mg/l highest desirable and 1 mg/l maximum permissible) appear in the archived data, and reports of water acceptability (e.g. the CSC report - para. 4.1.6) confirm the problem in Malawi. The existing analytical information applies to unfiltered samples and therefore represents total iron - dissolved and colloidal. However results from measurements on filtered and unfiltered samples at Timadzi (near Lilongwe) suggest that initially the iron is present as soluble complexes and subsequently precipitates out as a result of oxidation either on prolonged standing in contact with atmosphere or after boiling. The problem of high iron levels is one of acceptability and potability rather than any direct toxic effects, but the indirect effect on health of water rejection, possibly in favour of an unsafe and potentially contaminated source, make it important that ways of minimising iron in borehole water are investigated.

4.2.2 There are two possible sources of iron in borehole water: the aquifer matrix itself, and corrosion of steel borehole construction materials. Ferromagnesian minerals in the aquifer matrix include pyroxenes, amphiboles and biotite in order of their stability towards weathering by reactions analogous to that shown in (1) (para. 3.2.7). The fate of iron removed from these minerals during weathering may be secondary phases - e.g. hydrous iron oxides, chlorite or vermiculite - as well as dissolved iron and iron complexes. The sequence of mobilisation and precipitation reactions in which iron may be involved under various tropical weathering environments accounts for the familiar latosol or lateritic profile development. In addition to the important parameters of acidity (pH) and oxidising-reducing potential (Eh) in the microenvironment of the weathering profile, the presence of complexing (or 'chelating') ligands is an important factor in the mobilisation of iron. The formation of low-molecular weight and high-molecular weight ('fulvic') organic acids is encouraged in particular tropical soil environments, and complexation of iron (especially Fe) with these acid anions may increase the total 'dissolved' load of iron by up to several orders of magnitude over that predicted for simple iron species alone (Bolt and Bruggenwert, 1976; p. 155). Corrosion of steel borehole casing, pump or rising main by aggressive groundwater may also result in raised concentrations of iron, dissolved and/or suspended. The corrosion reactions are encouraged by low (reducing) Eh, low (acidic) pH, and the presence of complexing agents. These assist in removing iron from the reaction sites on the metal surface where a protective precipitate might otherwise form. In the absence of chelating ligands, iron solubility in natural waters is limited by the precipitation reactions of pyrite, FeS_2, ferric hydroxide, $Fe(OH)_3$, and to a lesser extent siderite $FeCO_3$. An average composition groundwater with pH in the maximum range of 4 to 9 will sustain dissolved Fe^{2+} in excess of 0.5 mg/l only under strongly reducing conditions, i.e. Eh < 200 mV. It is therefore extremely likely that organic ligands play an important role in the iron chemistry of these groundwaters from the tropical weathering profile regime.

4.2.3 The extent of the iron problem in groundwater of the Weathered Basement Complex is represented by the Bua Catchment data (Unit 5). Reported total iron determinations range from sub-detection limit (< 0.1 mg/l) to 59 mg/l. It must be remembered that these values are for total iron in unfiltered samples. Filtration of samples through 0.45 µm causes separation of dissolved from suspended particulate material, although the criterion is arbitrary and permits the passage through the filter of some colloidal material. The higher values of iron are clearly far in excess of predicted values. There is no direct redox information on these groundwaters, but an indirect inference drawn from the presence of abundant SO_4^{2-} in many cases suggests that redox conditions are not severely reducing. Qualitative or semi-qualitative information (e.g. from smell) on the presence or absence of H_2S would be useful in this respect. Presence of high Fe concentration in Bua Catchment appears to be a random occurrence, and in some (e.g. RB36, RB5) but not all (e.g. W190, W26, DP120) cases correlates with relatively high SO_4^{2-} concentrations. It is suggested that the high iron concentrations are a result of the tropical weathering processes as described in 4.2.2 which sometimes are also a source of SO_4^{2-} by pyrite oxidation (3.3.8). It seems that there are certain environments in which Fe remains in chelated form in solution through to the watertable rather than precipitating in the unsaturated profile as is tupical in the lateritic environment.

4.2.4 A brief investigation during this visit of groundwater chemistry at the Timadzi camp-site outside Lilongwe illustrates the problem of high Fe concentrations in weathered basement groundwaters. The results of field and laboratory analyses on groundwater samples from the 2 boreholes at Timadzi are shown in Appendix 7. Water from the relatively shallow plastic-lined borehole (IR22) contains about 0.7 mg/l Fe whether filtered or unfiltered, whereas water from the main deep borehole (steel lined) contains about 7 mg/l Fe whether filtered or unfiltered. Neither water sample has the smell of H_2S; the latter sample has the bitter taste typical of high Fe content, and is consequently very unpopular for consumption. The analyses also show a distinct difference in overall mineralisation, mainly as a result of enhanced SO_4^{2-}, HCO_3^-, Ca^{2+} and Mg^{2+} (and NO_3^-) in the more shallow borehole. If a significant part of the total iron load originated from corrosion reactions this would represent the removal of several kilograms of steel per year from the casing and pump:

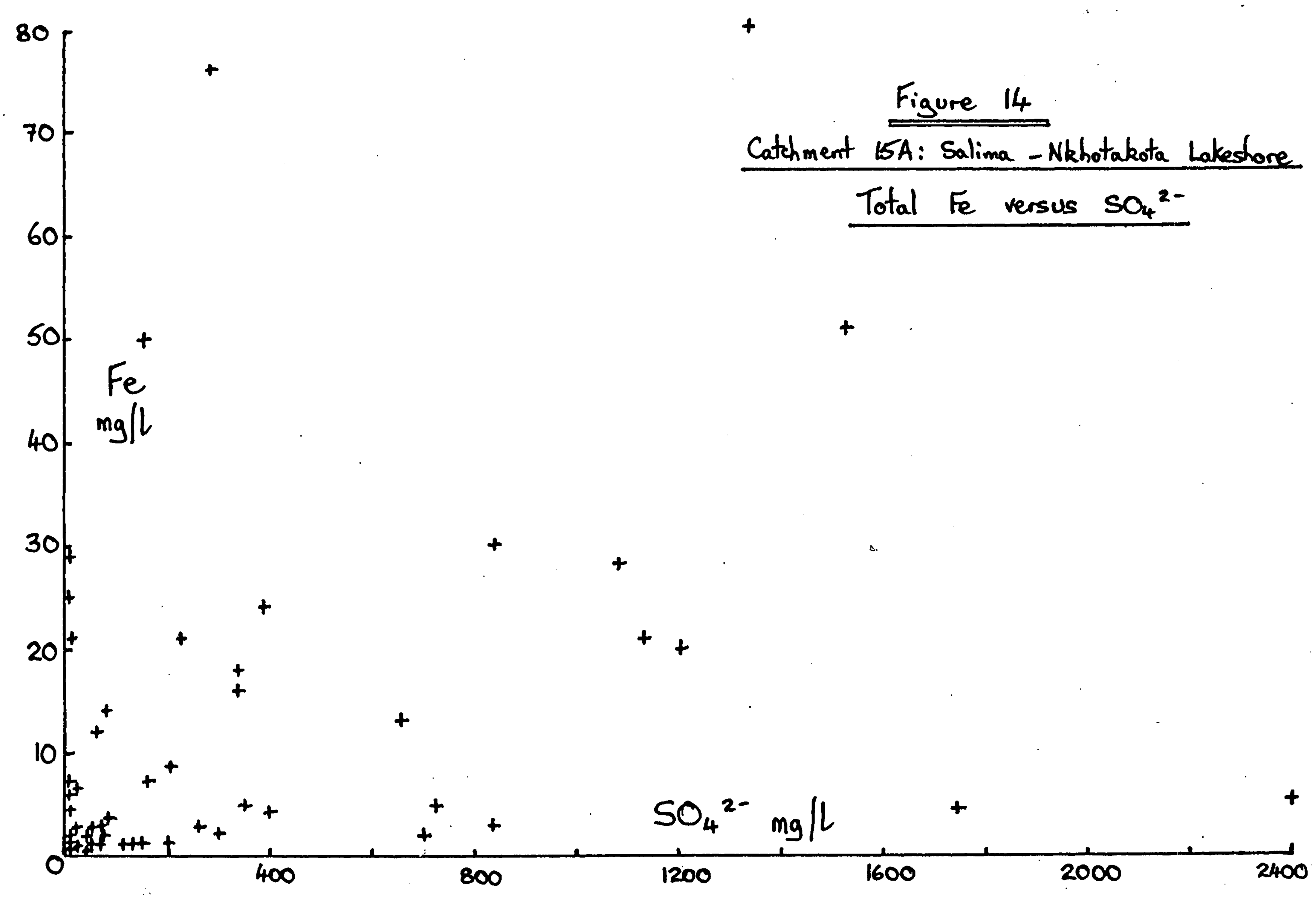


Figure 14

Catchment 15A: Salima - Nkhotakota Lakeshore

Total Fe versus SO_4^{2-}

> for example, a handpumped well producing 1 m^3/hr would represent about 3000 m^3 per year abstraction; if this contained 7 mg/l Fe, a total of 20 Kg Fe would be removed each year.

As stated above, it seems more probable on the basis of existing evidence that the greater part of these high Fe concentrations originate in the weathering reactions on ferromagnesian minerals.

4.2.5 Randomly high Fe concentrations are also found in groundwater in the colluvium/alluvium of the Scarp Foot zone, illustrated by the data for Salima-Nkhotakota Lakeshore (Unit 15). Fe analyses up to 80 mg/l are reported, although there is a strong possibility that at least some particulate material contributes to these amazingly high values. Again there is a partial correlation with the incidence of high SO_4^{2-} (Fig.14). There is insufficient lithological information to assess whether there is a relationship with geological details, although the apparently random incidence argues against this being a major factor on its own.

4.2.6 Reported iron concentrations in Lower Shire Valley groundwater have a very wide range. with some values > 100 mg/l (but these values are treated with caution since it is clear that some Shire Valley data had lost decimal points in being copied from X-files to Cardex). Most of the severely high Fe values are confined to sub-units 1F, 1G, 1K and 1L, whilst 1H contains relatively few anomalous Fe concentrations (i.e. > 20 mg/l). This suggests once again that the high Fe levels are associated with weathered basement and its derived colluvium and alluvium, which are the source of groundwater in 1F and most of 1G and also may constitute much of the alluvium in the Mwanza Valley (1K). The generally low Fe in 1H with reported anomalies only around 10-20 mg/l must reflect the predominance of sedimentary facies source rocks with only the Karoo volcanics providing ferromagnesian minerals. The extremely high Fe concentrations found around Ndakwera in 1K are associated with high mineralisation due to Cl^- and SO_4^{2-} which, as suggested previously (3.4.9) might be associated with deep faulting.

4.2.7 Since iron is one of the most widespread causes of borehole water rejection, a considerable effort is warranted to establish exact causes and possible remedial measures if they exist. Identification of organic chelating compounds in the weathering process is not feasible, but it is important to establish the hydrogeological and geomorphological conditions under which these complexes may be formed and under which they persist and therefore mobilise large concentrations of iron. The data collected at Timadzi (Appendix 7) show that dramatically different Fe concentrations can occur at adjacent boreholes, for which reasons should be sought. It is possible that in specific geomorphological environments the Fe-complexes do not persist but breakdown - this presumably is the formative process for laterites - whereas under other conditions the complexes remain stable to the water table. Identification of conditions under which the complexes remain stable might assist in the siting and construction of boreholes so as to minimise the iron problem. It is also important to establish the redox conditions in groundwater so as to assess the significance of corrosion as a source of dissolved iron, as well as to assess the potential technical problems caused by corrosion of pump parts etc. The accurate measurement of Eh is possible only under anaerobic conditions of pumping and is therefore restricted to the few mechanically-pumped boreholes. However measurement of H_2S is a useful indicator of redox conditions. In all sampling and analytical work it is essential that filtered and unfiltered samples are collected in the field and suitably preserved by acidification if possible prior to analysis (refer to Cook *et al.*, 1979; Cook & Miles, 1980; Walton, 1980).

4.2.8 If it is not possible to reduce the concentrations of iron being pumped by modification of borehole siting and/or construction, it will become necessary to evaluate the possibility of simple treatment to remove iron before consumption. Iron removal is usually effected by aeration followed by settling or filtration of the resulting precipitate (Mann & Williamson, 1976). The success of this method may be affected by the presence of chelate complexes - the slow rate of breakdown of the complexes is demonstrated by their persistence during filtration and standing (e.g. during sampling at Timadzi).

4.3 Sulphate.

4.3.1 Excessive concentrations of sulphate are considered to cause gastro-intestinal irritation. The maximum desirable concentration recommended by WHO (1971) is 400 mg/l, although it seems that higher concentrations can be tolerated without harmful effect by regular consumers who have become accustomed to the dosage. Concentrations above the WHO limit occur in several areas in Malawi in water which is consumed because there is no alternative supply. The CSC report on water acceptability (4.1.5) should provide some initial information on whether there is a problem associated specifically with sulphate, although in many cases high sulphate is associated with excessive overall (i.e. chloride + sulphate) salinity (4.1.1) and a specific effect related to sulphate alone may not be apparent.

4.3.2 Sulphate concentrations are theoretically limited by equilibrium with gypsum, $CaSO_4$, and therefore the ability of a water to sustain high SO_4^{2-} is inversely proportional to its Ca^{2+} concentration at gypsum saturation. A trend towards gypsum saturation is shown by high SO_4^{2-} groundwater in the Salima sub-catchment (3.2.5). The Salima data demonstrate that providing Ca^{2+} remains relatively low - up to several hundred milligrams per litre - then up to several thousand mg/l SO_4^{2-} can be sustained in solution before $CaSO_4$ precipitation is predicted. The more saline groundwaters can sustain high Ca^{2+} and SO_4^{2-} levels at equilibrium because of the effects of complex formation and ion activity coefficient reduction (Bath, 1980).

4.3.3 It has been noted that the occurrences of moderate to high concentrations of SO_4^{2-} in groundwater in the upland plateau and scarp foot zones of the weathered Basement Complex are restricted to specific areas (3.3.9 and 3.2.2). This has been interpreted as suggesting a strong lithological control on sulphate sources - iron sulphides in the former case (3.3.8) and possibly secondary gypsum or sulphides again in the latter case (3.2.11). Excessive SO_4^{2-} is reported in the Salima sub-catchment where concentrations up to 2400 mg/l have been measured (3.2.5).

4.3.4 High SO_4^{2-} concentrations are quite common in Lower Shire Valley groundwater (3.4), but are mostly associated with high $Cl^- + SO_4^{2-}$ mineralisation, and have been discussed already in the context of general salinity (4.1.3).

4.3.5 Detailed information on the lithology and mineralogy of drilling cuttings from areas on the weathered Basement Complex where SO_4^{2-} anomalies occur might assist in identifying positively the sources of SO_4^{2-} which are discussed above. Conversely, SO_4^{2-} anomalies are indicators of possible ore mineralisation along groundwater flow paths. The possibility of vertical water quality zonation has already been mentioned (3.2.12); the possibility of vertical and lateral heterogeneity of SO_4^{2-} concentrations in these restricted areas of high SO_4^{2-} should be considered if possible during borehole construction in order to optimise pumped water quality.

4.4 Nitrate and Possible Pollution by Waste.

4.4.1 The significance of nitrate in groundwater, both as a harmful contaminant in its own right and, more importantly, as an indicator of potentially harmful contamination by animal or human waste, is the subject of investigation and debate (e.g. Lewis et al., 1978; Cook, 1979). Nitrate itself can be harmful to infants, causing methaemoglobinaemia, and the WHO (1971) has advised a maximum accpetable limit of 45 mg/l NO_3^- for drinking water. Nitrate is a product of the breakdown of animal excreta, and therefore its occurrence at higher-than-natural-background concentrations in groundwater implies the possible presence of harmful bacteria and viruses derived from the excreta.

Anomalous nitrate concentrations provide evidence for frequent contamination of unprotected or poorly constructed sources of rural water supply in developing countries (Cook, 1979). The potential magnitude of the groundwater pollution problem in Malawi was discussed briefly in Chilton's project appraisal (Chilton, 1979), in which the results of in-situ NO_3^- determinations at 22 wells and boreholes were tabulated. Although significant NO_3^- was found in about half of the sources, the 45 mg/l limit was exceeded in only 2 cases - one an unprotected well. However, as Chilton points out, the common occurrence of significant NO_3^- prompts the need for further investigation of the extent of bacteriological pollution. There has been no systematic investigation of the extent of bacteriological contamination in rural water supply in Malawi, although a few spot checks of total coliform counts in wells and boreholes have been carried out by the Shallow Wells Programme and CSC in their evaluation survey using Millipore kits (but see 5.2.2.4); bacteriological tests of suspect water supply are also carried out for the Ministry of Health (5.1.5.3).

4.4.2 The existing data archive is far from complete with NO_3^- analyses, and moreover the method of analysis employed (3.1.3) may not have been totally reliable. Also, since the occurrence and magnitude of pollution may vary with time, historical data is of restricted value in assessing current problems. However this data suggests, in agreement with Chilton's report, that anomalous NO_3^- concentrations are found in a significant number of borehole supplies in all the hydrogeological environments. Depending on individual circumstances, these may be associated with movement of waste from nearby sanitation and/or with leakage of animal waste in particular at the wellhead due to poor construction or maintenance (see discussion in Chilton, 1979).

4.4.3 The field determinations of NO_3^- carried out in the Lower Shire during the author's visit in November 1980 (Appendix 2) confirm the above. Only one of the sites visited gives rise to severe concern: the new well at Chimpambana gave 194 mg/l NO_3^- but has already been rejected for consumption due to its salinity and the proximity of an alternative source. Two boreholes have sizeable NO_3^- concentrations: Y58 and X199, whilst remaining below 45 mg/l. It is worth noting that the field determinations of NO_3^- are of similar magnitude to archived data, with anomalies being confirmed except in the case of Q417 where a previous value of 82 mg/l NO_3^- is apparently reduced to 7 mg/l, this being accompanied by a fall in overall mineralisation from 7270 $\mu S\ cm^{-1}$ EC to 4460 $\mu S\ cm^{-1}$. The occurrence of low NO_3^- concentrations at some boreholes where wellhead conditions (i.e. crowding of animals in muddy conditions) might give rise to pollution is encouraging and demonstrates that boreholes can give good water even under adverse conditions, bearing in mind that bacteriological tests should be the conclusive test for purity.

4.4.4 Further investigations of the sources of pollution giving rise to anomalous NO_3^- concentrations (and unacceptable faecal coliform counts) are required, in order that remedial measures may be taken in the guidelines for borehole siting, construction and maintenance. Virtually no data exists for water quality (NO_3^- and bacteriological) of unprotected and protected shallow wells except the data in Appendix 2 and in Chilton's report, and a few inconclusive total coliform measurements by Shallow Wells Programme and CSC. More reliable data is urgently required to judge the effectiveness of shallow well construction methods in safeguarding against pollution of these particularly vulnerable sources.

4.4.5 The data collected at the Timadzi boreholes (Appendix 7) show an interesting contrast in NO_3^- concentrations which is opposed to the contrast in Fe already discussed (4.2.4). The higher NO_3^- in the less deep borehole accompanies generally higher salinity.

The borehole is sited on a dambo margin with no obvious source of pollution from nearby habitation. It is thought that the high NO_3^- and mineralisation might originate from fertilisers applied to the area which had been used for growing maize. The possibility of fertiliser application causing deterioration of groundwater quality in unconfined aquifers tapped by shallow wells and some boreholes deserves some consideration in the future.

4.5 Fluoride.

4.5.1 Ingestion of excessive amounts of F^- can cause dental fluorosis and in severe cases skeletal damage. Children are particularly at risk. WHO (1971) has advised maximum limits for drinking water based on estimated total intakes of water and food; for the temperatures prevailing in Malawi the recommended limit is 1.0 mg/l F^-. Fluoride analyses in the existing data are not comprehensive, and older analyses particularly might be unreliable, but there are instances where the advised limit is exceeded significantly. Groundwater in the Lower Shire seems to be particularly prone to excessive F^-. Analytical data on thermal springs in Malawi also show excessive F^- content in many cases (Kirkpatrick, 1969); this is of particular concern at Nkhotakota where the spring has been in use for urban supply and where cases of dental fluorosis have been identified.

4.5.2 Maximum fluoride concentrations sustainable in natural waters are limited by fluorite (CaF_2) solubility analagously to the control of SO_4^{2-} by gypsum (4.3.2). For example, a solution with 40 mg/l Ca^{2+} could sustain a maximum concentration of about 3 mg/l F^- above which fluorite precipitation is predicted. Complexing of F^- becomes important in saline solutions and consequently the effective solubility of CaF_2 increases with salinity.

4.5.3 High concentrations of F^-, many greater than 2 mg/l and a few in the order of 10 mg/l, are reported both from 'clay-sand' alluvial and weathered gneiss aquifers in the Lower Shire. The reliability of values reported for F^- are somewhat suspect, in part due to the omission of some decimal points in copying data onto the Cardex system, and also due to the absence of an inverse correlation between high F^- values and low Ca^{2+} concentrations which would be the result of equilibrium control by CaF_2. However the possibility of high F^- values requires confirmation by new measurements using the specific ion electrode method recommended (Appendix 3). A possible natural source of F^- in the groundwaters is the breakdown of hornblende amphibole and biotite which are constituent phases of the gneisses and which may contain significant amounts of F as replacement for OH groups in the crystal lattice. Another possible source is that responsible for high salinity in groundwaters associated with Karoo and Lupata sediments. However there is insufficient F^- data on these groundwaters to judge whether there is a problem and whether F^- correlates with Cl^-.

4.5.4 Some anomalous F^- concentrations in borehole water around Nantana Village (1G/X62, PM114, PM366), up to 8 mg/l is reported, may be attributed to the presence of hydrothermal mineralisation in the Namalambo Fault system (3.4.5).

4.5.5 No F^- data exists for Bua Catchment groundwater. Data for the Salima-Nkhotakota and South Rukuru catchments suggests that most groundwater is < 1 mg/l F^-. This observation for these weathered gneiss aquifers is in contrast to the situation found in the Lower Shire, and prompts further questioning of the Shire data which if correct might be accounted for by different precursor lithologies for the gneisses in the different locations.

4.5.6 Hydrothermal activity is often accompanied by elevated F^- concentrations due to the concentration of F^- in late-stage hydrothermal fluids and pegmatitic mineralisation. This feature is demonstrated by the analyses for Malawian thermal springs reported by Kirkpatrick (1969), and may also account for high F^- in some cases where a deep-seated groundwater component has not been identified (e.g. along fault-lines, see 4.5.4). The spring at Nkhotakota is reported to contain 17 mg/l F^- which, in common with the other springs, is compatible with its low Ca^{2+} concentration, 4 mg/l (though the reported analyses have extremely poor cation-anion charge balances around +60%, and doubt is cast on all of these figures). The deep-seated thermal groundwater is probably at equilibrium with fluorite but suffers dilution by shallow cooler groundwater. Cases of fluorosis are reported in Nkhotakota, and consumption of the spring water and any related groundwaters without treatment should be ceased if not already stopped.

4.5.7 Further investigations of the magnitude of the fluoride problem are obviously required in view of the paucity of reliable data presently available. The analytical equipment, recommended in Appendix 3, should be obtained as soon as possible and measurements commenced in the Shire Valley. The prime target for suspecting anomalous F^- concentrations are those groundwaters with low Ca^{2+} i.e. the $Na-HCO_3$ and Na-Cl compositional types. In areas where excessive F^- is confirmed, health staff should investigate the incidence of dental fluorosis in relation to water consumption. The main concern must be the possibility of skeletal damage in children as a result of advanced fluorosis.

4.6 Irrigation.

4.6.1 It is understood that areas considered for irrigation by groundwater are those in the 'lakeshore' zone but distant from the lake itself and areas of the Shire Valley alluvium distant from the river. Initial criteria for irrigation-suitability of groundwater are total salinity and sodium (alkali) content. Subsequently, boron content and potential crop application might also require consideration. The U.S. Salinity Laboratory (1954) guidelines for suitability are commonly used, although tolerances in specific cases depend on soil types, crop types, rainfall amount and distribution, and so on. The Sodium Adsorption Ratio (SAR) is defined by:

$$\text{SAR} = \frac{(\text{Na}^+)}{\left[\frac{(\text{Ca}^{2+}) + (\text{Mg}^{2+})}{2}\right]^{\frac{1}{2}}}$$

where concentrations (X) are in milliequivalents per litre. This ratio is an expression of the dissolved ionic component of the cation exchange equilibrium (3.2.8) and represents the tendency of the water to displace Ca^{2+} and Mg^{2+} from soil clays producing deflocculation and loss of permeability. $Na-HCO_3$ type waters tend to have poor SAR values, and high SAR is also associated with the general problem of salinity which usually results in Na-Cl compositions. The South Rukuru aquifer is an exception, exhibiting Ca-Cl compositions with low SAR values but a high salinity hazard.

4.6.2 SAR values in the Lower Shire groundwaters rise with salinity, so that values above 30 are found for the most saline Na-Cl groundwaters in 1G and 1H. In the low and moderately saline groundwaters the SAR values are acceptable (<10) and the criterion of salinity is probably sufficient for initial consideration. The patchy salinity in most of 1G, 1H and 1K (4.1.3) suggests that only detailed investigation will confirm the extent and suitability of the occurrences of fresher groundwater, say < 1000 μS cm^{-1} EC (Fig. 8) Sub-catchment 1F and the southern part of 1G have consistently acceptable, or at worst marginal, groundwater quality for irrigation with EC values mostly around and below 1000 μS cm^{-1}. Some caution is suggested, however, in connection with the predominance of $Na-HCO_3$ compositions with relatively high HCO_3^- concentrations; the US Salinity Lab (1954) report suggests that there might be an additional hazard connected with high "Residual Sodium Carbonate" (i.e. dissolved carbonate not balanced by Ca^{2+} and Mg^{2+}), although this concept is debatable. RSC values in excess of 2.5 meq/l, the limit set by US Salinity Lab, occur in some of the $Na-HCO_3$ waters.

4.6.3 Calculated SAR values for groundwater in the Salima-Nkhotakota catchment are not excessive and are mostly below 6. A problem is caused by overall salinity of those groundwaters which have high SO_4^{2-} content (4.3.3) for which EC values up to 4000 μS cm^{-1} are reported. EC values around 1000 μS cm^{-1} are reported outside these zones of anomalous SO_4^{2-}.

5. ANALYTICAL FACILITIES FOR WATER QUALITY MONITORING IN MALAWI

5.1 Existing Facilities and Practice.

5.1.1 Water Resources Branch.

5.1.1.1 The Water Resources Section presently maintains a small laboratory still housed in the Section's previous accomodation at Capital Hill, Lilongwe. The laboratory is supervised by a professional officer with 2 staff and has concerned itself solely with monitoring the quality of surface water at a series of points mostly within the Lilongwe Basin. Equipment comprises a Lovibond comparator (formerly used to measure pH), pHOX 42 pH meter and electrode (on loan from Groundwater Project), pHOX 52 conductivity meter and probe, EIL 1520 dissolved oxygen meter and electrode, Carbolite muffle furnace, ovens, Termak cooling incubator (for BOD incubation at 20°C), refrigerator, water bath, B&T 3-place 2-pan balance, water still, Elgastat B114 deioniser, and a very limited range of assorted glassware etc. The chemicals available are mostly restricted to those necessary for the routine work carried out by the laboratory. Monthly or weekly stream samples are analysed for dissolved oxygen, pH, conductivity volatile solids, suspended solids, total dissolved solids, COD, BOD, chloride (by silver nitrate titration), and total hardness (by EDTA titration). Several other parameters can be measured semi-quantitatively, including NH_3-N and phosphate.

5.1.1.2 It is planned to expand the activities of the Water Resources Section as part of the 2nd phase of the National Water Resources Master Plan. A project entitled 'Water Quality and Sediment Monitoring' is proposed (1981-84), and will include the establishment of a water quality monitoring network. It is hoped to appoint an expatriate to a new post of Senior Water Chemist, who would be responsible to the Chief Water Resources Officer for advising on the various aspects of water quality monitoring. In the longer term it is intended that a comprehensive water quality department will serve all areas of water supply, involving the establishment of regional laboratories in addition to a central facility. The Water Resources Master Plan project (phase 1, 1979-80) brief includes consultation with Ministry of Health (see 5.1.5.4) in the design of a water quality monitoring system. It will be the duty of the Senior Water Chemist to advise the statutory Water Resources Board on questions of water quality, with regard to both natural variations and the effects of effluent pollution on both surface and groundwater resources. A draft recommendation of standards for surface water quality has been submitted to WRB by R Drayton (26.7.79), with the proviso that a degree of flexibility should be applied.

5.1.1.3 As part of Phase 1 of the Water Resources Master Plan, a request has been submitted to the UN for a 2 month visit by a water quality expert during 1981. He would advise on desirable standards for surface water quality, design laboratories, and plan a network for monitoring quality of surface and groundwater and eventually of effluent quality. The activities of such an advisory visit would obviously overlap very strongly in some areas with the present author's visit and also with the activities of the Senior Water Chemist assuming him to be in post by that time; it is to be hoped that full liaison will enable maximum benefit to be gained with minimised duplication of effort.

5.1.1.4 The hydrogeologist working with the Shire Valley Agricultural Consolidation Project, based in Ngabu, is attached to Water Resources Branch. At present this post is supplemented by the Netherlands Government. It is hoped that it will be possible to appoint a water quality engineer or chemist to work alongside the hydrogeologist for a limited period. The purpose of this post would be to provide basic and relevant analytical facilities locally, in order to support the varied activities of groundwater development in the Lower Shire. Duties would also include tasks in surface water monitoring, and training of local staff. However no positive action on this post has yet been taken by the DLVW (refer to 5.2.3.2).

5.1.2 Water Supplies Branch.

5.1.2.1 The Urban Supplies Section carries out analyses of its water sources on an *ad hoc* basis. It has no laboratory facilities of its own, although it has 3 portable Millipore bacteriological test kits, and has recently obtained a portable Hach water engineers chemistry kit with a range of tests. Water samples have been sent to the Agricultural research Station at Chitedze for chemical analysis (including HPO_4^{2-}, NO_3, Fe, Mn, Cu, Zn) with F^- being measured at the Geological Survey lab in Zomba. Bacteriological tests with the Millipore filter kits are carried out in order to check on the quality of supply, after treatment where applicable. Total coliform determinations only are made, and the water quality categorised (for instance: 0 coliforms per 100 ml = excellent, 1-3 = satisfactory, 4-10 = suspicious, and >10 = unsatisfactory).

5.1.2.2 It is understood that Rural Supplies Section carries out Millipore determinations of bacteriological water quality in its gravity-fed piped water schemes. A proposal by USAID to assist the development of these self-help schemes incorporates the expansion of present monitoring to cover all the rural supplies, with a Public Health Coordinator providing liaison between Rural Water Supplies Section and Ministry of Health. The Shallow Wells Programme has also carried out a limited number of bacteriological tests on water from dug wells, as an aid when considering chlorination of the wells. The Millipore kits in these cases have been donated by CSC (Christian Service Committee of the Churches in Malawi) through whom many of the funds for water supply programmes are channelled. CSC themselves have carried out some tests as part of a wide-ranging evaluation of the programmes with which they are associated (see 5.2.2.4).

5.1.3 Geological Survey Department, Zomba.

5.1.3.1 The existing archive of groundwater chemistry, over a thousand analyses (3.1.1), originated from the Geological Survey laboratory. Since the transfer of groundwater responsibility to Lilongwe the laboratory has virtually ceased to carry out water analyses. The new emphasis of Geological Survey on development of industrial mineral resources has shifted the capability of the laboratory towards industrial minerals testing. A proposal has been submitted to the UN for a visit by a chemist in 1981 to advise on the re-equipping of the laboratory towards industrial and energy-related minerals analysis.

5.1.3.2 The laboratory is staffed by laboratory technologists and the analytical methods employed are principally those described in method sheets written by expatriate staff in the early-to-mid 1970's. A senior chemist has not been in post for five years or so.

5.1.3.3 Equipment relevant to water analysis includes a Pye-Unicam SP90 atomic absorption spectrophotometer (with hollow cathode lamps for Ca, Mg, Zn, Cu, Fe, Ni, Co, Cr, Mn, Pb), EEL flame photometer (for Na, K and Li), a fairly new CECIL CE404 colorimeter with automatic sampler (for complexometric determinations of e.g. SiO_2, Al, Fe) and an Orion 407A specific ion meter with electrodes for pH and F^-. A comprehensive stock of reagents (some rather old) and glassware is held.

5.1.4 Lilongwe and Blantyre Water Boards.

5.1.4.1 The two city Water Boards are statutory bodies under the control of Department of Lands, Valuation and Water. They supply treated piped water in the two centres.

5.1.4.2 The Lilongwe Water Board has set up a small laboratory for water quality control at its treatment works and pumping station. The laboratory is staffed by a trainee chemist (graduate from University of Malawi) and assistant, and has been assisted by the services on a volunteer basis of an expatriate microbiologist. Daily bacteriological tests are carried out on treated water and also spot samples from supply points. Plate counts for "total viable organisms" and multiple tube tests for total coliforms and *E. coli* are feasible. Other equipment includes a Corning-EEL 109 pH meter, a Hach 2100A turbidimeter, and a dissolved O_2 meter.

5.1.4.3 Blantyre Water Board has laboratory facilities at its works at Mudi. Bacteriological monitoring is carried out by multiple tube tests. In addition, several inorganic parameters are monitored in its intake, including Mn, Fe, Cl, HPO_4 and NO_3. Staff comprises a Senior Chemist, a Senior Technical Officer, 2 lab assistants and 1 trainee. The Senior Chemist is presently attending a training course in U.K. Equipment includes a new Perkin-Elmer 550 spectrophotometer; it is hoped to purchase further equipment, including an atomic absorption spectrophotometer, in the future.

5.1.5 Ministry of Health.

5.1.5.1 In terms of its statutory responsibility for health, the Ministry has a responsibility to ensure that water supply meets acceptable quality standards. In the two cities this is accomplished via the routine monitoring work of the Water Boards. In rural areas this becomes more difficult due to the logistics of preservation and transport of samples, and also due to the inability to define 'acceptable standards' for a wide range of supply conditions.

5.1.5.2 Such sampling as is carried out in rural areas is either 'random' or 'incidental' in nature, the latter in response to a particular problem. Regional Health Inspectors and their staff are responsible for carrying this out and for sending samples for analysis.

5.1.5.3 The MoH has no analytical facilities specifically dedicated to environmental monitoring. Samples are send for bacteriological examination to the Central Pathology Laboratory at Queen Elizabeth Central Hospital in Blantyre, or occasionally to the Central Veterinary Laboratory in Lilongwe. In practice, the number of samples reported upon is low (e.g. 8 reports only are on file for the first 6 months of 1980). It has been agreed that copies of reports should be forwarded to the Controller, Department of Lands, Valuation and Water.

5.1.5.4 The WHO report entitled "Water Supply, ~~and~~ Sewerage Sector Study: Community Water Supply and Sanitation" (WHO/WBCP/Govt. of Malawi, 1978) proposed that, as part of the National Water Resources Master Plan, the position of MoH in water quality monitoring should be strengthened in regard to piped water supplies. International cooperation was called for in the training of health inspectors and the development of a national programme for water quality surveillance. A short term consultancy by a water quality expert was proposed (refer to 5.1.1.3). It was recommended that a water quality control laboratory (presumably under MoH) should be established in Lilongwe, either in the new Kamuzu Central Hospital or by extending the existing Veterinary Laboratory. A cost of K50,000 was estimated. Subsequently, plans have been drawn up and costed for a Public Health Laboratory in accomodation at the old hospital buildings in Lilongwe. It is understood that no further action has been taken on the grounds of lack of adequate finance and suitably trained staff.

5.1.5.5 According to information available at the time of the WHO report, the major part of water-related deaths are by enteritis and diarrhoeal diseases (ca. 500 per year). However schistosomiasis is endemic particularly in the irrigated agricultural areas.

5.1.6 Other Analytical Facilities in Malawi.

5.1.6.1 The Central Veterinary Laboratory in Lilongwe in the past has provided bacteriological examination facilities to MoH. The laboratory was not visited by the author.

5.1.6.2 The Central Pathology lab of QECH in Blantyre carries out routine bacteriological examinations for MoH (5.1.5.3), and also is responsible for determinations of pathogenic organisms in environmental samples. In discussions with the Senior Pathologist it was stated that there would be capacity for more bacteriological samples, probably over 100 samples per year, in spite of the shortage of trained bacteriologists and laboratory technicians. There is some concern over the manner in which samples are collected and transported to the laboratory. It was felt that the establishment of a Public Health Laboratory would require expatriate input for setting-up and training. (The present Senior Pathologist, a VSO volunteer, returns home in January 1981 and apparently will not be replaced; consequently the capacity of the laboratory might suffer).

5.1.6.3 The Malawi Bureau of Standards in Blantyre is a statutory body controlled by the Ministry of Trade. It maintains laboratories for a wide range of analytical problems. Equipment relevant to present purposes include a Varian 175 atomic absorption spectrophotometer (lamps for Fe, As, K, Mn, Cu, Ca, Zn, Hg, Pb) and a Zeiss spectrophotometer PM6. Although they have no microbiological facilities themselves, a microbiologist is employed who has access to the lab. at QECH. An unofficial but apparently widely used and appreciated service of minor repairs of scientific equipment is provided by the Senior Analyst in the absence of regular service facilities in the country.

5.1.6.4 The Agricultural Research Station at Chitedze (near Lilongwe) provides water analyses for the Urban Supplies Section of the Water Resources Branch (5.1.2.1); its equipment includes a Southern A3000 atomic absorption spectrophotometer.

5.1.6.5 Some other institutions with chemical analytical facilities are Bunda College of Agriculture, Malawi Polytechnic and Chancellor College (University of Malawi). Chancellor College provides a degree course in chemistry whilst Malawi Polytechnic has in the past run a course for a Diploma in Laboratory Technology.

5.2 Recommended Facilities for Water Quality Monitoring.

5.2.1 Introduction.

5.2.1.1 It is clear from the previous section that there are already a number of laboratories in Malawi equipped for water analyses, chemical or bacteriological, to varying degrees of completeness and reliability. However it is not satisfactory that water analyses, particularly those for drinking supply, should be carried out on an *ad hoc* basis and it is therefore logical that a central laboratory and relevant expertise should form part of the National Water Resources Strategy.

5.2.1.2 The laboratory should be a natural expansion of the existing laboratory in Water Resources Branch, as has been proposed previously (5.1.1.2). The laboratory would be responsible for both surface water and groundwater work; this is particularly desirable in view of the close association between them in many cases.

5.2.1.3 The role of the laboratory should be two-fold in order of priority:

(i) to identify and investigate particular water quality problems;

(ii) to carry out routine monitoring of quality of surface water and groundwater resources.

The laboratory would support hydrological and hydrogeological projects. An area requiring urgent attention is that of water quality and pollution of rural groundwater resources and the influence on this of borehole or shallow well design, construction and maintenance. Additionally the laboratory should provide a service to Urban Supplies Branch; in some cases where urban supply projects utilise groundwater the water quality problems are similar to those experienced in rural supply.

5.2.1.4 It is considered to be of paramount importance that lines of communication between the Department and the Ministry of Health should be established in order that water quality problems can be identified, investigated and remedial measures formulated. This is particularly important with regard to bacteriological investigations in which it is logical that the already-proposed Public Health Laboratory (5.1.5.4) should have responsibility for detailed laboratory examination of suspected pollution cases. Regional Health Inspectors and their staff at district level are usually in a position to identify problems, and should be trained and equipped for simple sampling of water for microbiological or chemical examination. Millipore kits for preliminary bacteriological tests should be used by staff trained wherever possible in field investigations.

5.2.1.5 The establishment of regional laboratories with trained personnel is seen as an important factor in ensuring adequate coverage of areas remote from the central laboratory. The regional laboratories would be responsible for proper sample collection and preliminary bacteriological (Millipore) and chemical tests, but would be dependent on the central laboratory for a comprehensive analytical service. It is logical that regional facilities, which will be limited in scope, should not be set up until the central laboratory has been satisfactorily established.

5.2.2 Water Resources Laboratory, Lilongwe.

5.2.2.1 The present laboratory is to be expanded to provide analytical facilities for all relevant chemical species in surface waters and groundwater. The species considered relevant to groundwater investigations are Na, K, Ca, Mg, Cl, SO_4, HCO_3, Fe, Mn, H_2S, F, NO_3 and pH. Future interest in development for irrigation purposes in particular areas might add B to this list. A list of equipment for laboratory determination of these species is included in Appendix 3. Improvement of methods for surface water quality measurements would be largely encompassed by this list, and are also included in the brief of the proposed advisory visit by a UN expert (5.1.1.3).

5.2.2.2 The expanded laboratory would require suitable accommodation. This is not available in the present location at Capital Hill or at DLVW office (Tikwere House). Estimates of reasonable working area for the laboratory are in Appendix 3. A site close to the old hospital buildings in Lilongwe, in which it is proposed to establish the urgently needed Public Health Laboratory, would encourage close liaison. Apparently a possible site for laboratory accommodation is the Functional Buildings at Chilambula Road, Lilongwe. Conversion and fitting out of laboratories would require sizeable expenditure; no attempt is made here to give an estimate of the cost.

5.2.2.3 Some equipment for field measurements of chemical water quality is already held by the Groundwater Section, having been provided by the UK consultant hydrogeologists. This comprises pHOX 52 conductivity meters, pHOX 42 pH and Eh (oxidation-reduction potential) meters and electrodes, flow-through anaerobic cells for Eh measurement, filter units, and a Bausch and Lomb Minispec 20 spectrophotometer with kits for NO_3, Fe, SO_4, Cl, alkalinity and hardness. The Minispec kits are of widely varying sensitivity and reliability, and results should be interpreted in consultation with an experienced chemist (similar considerations apply to the Hach test kits held by Urban Supplies Branch). It is considered that although the field chemical tests are invaluable in providing an immediate 'feedback' they must be regarded as semi-quantitative only and therefore, should be used with the support of subsequent laboratory analyses. There are, however, unstable parameters which require measurement *in situ* - these are pH, Eh, dissolved oxygen and preferably alkalinity. NO_3 also is changeable and requires special storage conditions and rapid analysis.

5.2.2.4 Field bacteriological determinations using Millipore filter kits should be an integral part of water quality testing of rural groundwater sources. An alternative to immediate incubation under field conditions is the preservation of samples on transport medium prior to laboratory incubation. Careful consideration is required of the problems which might arise as a result of the frequently high ambient temperatures to which samples might be subjected in the field. Total coliform analyses only are of little use with regard to detecting faecal pollution of rural water supplies (Feachem *et al.*, 1978), and it is essential that determinations are made of faecal coliforms (*E. coli*) and also where feasible faecal streptococci. This important point concerning the inapplicability of total coliform examination should be noted by those already testing some rural supplies by this method - namely the Shallow Wells Programme and CSC. Millipore kits and suitable culture media are included in the equipment list (Appendix 1), although it might be possible to arrange loans of kits already in Malawi but which are under-used at present.

5.2.3 Regional Laboratories.

5.2.3.1 The establishment of regional laboratories to serve Northern and Southern Regions is part of the Water Resources Master Plan (5.1.1.2). These laboratories should provide liaison with, for example, Regional Health Inspectors and should be responsible for assessment of water quality parameters (surface and groundwater) prior to submission of samples to the central laboratory if necessary. It is suggested that they should be equipped to carry out routine field monitoring of water quality, including bacteriological determinations with Millipore kits. Equipment should be as simple as possible whilst providing for measurement of unstable parameters. The staffing of regional laboratories with personnel already trained and experienced in the activities of the central laboratory is recommended.

5.2.3.2. A proposal is about to be submitted for aid-funded basic laboratory facilities in the Lower Shire Valley (5.1.1.4). These would be set up by a limited-duration input of expatriate assistance. Initially the restricted facilities in Ngabu would support the hydrogeological and hydrological work of the Shire Valley Agricultural Consolidation Project, but it has been suggested that they might subsequently form the basis of the Southern Region Laboratory (possibly in Blantyre). Support from the central laboratory will be important, particularly in investigations of groundwater quality problems.

5.2.4 Staffing and Training.

5.2.4.1 It seems probable that an expatriate chemist will undertake the task of expanding the central laboratory for surface and groundwater work. Similarly, temporary expatriate assistance will be available to S.V.A.C.P. in Ngabu.

5.2.4.2 The Water Resources Technical Officer in charge of the present hydrological laboratory has undertaken training in the UK (3 month course sponsored by National Water Council, UK) and has experience which is not being fully exploited. This should be valuable in speeding up the routine functioning of the laboratory.

At least one further technical officer should be recruited and trained in field sampling and analytical work. This will ensure the availability of trained and experienced personnel for the long-term aim of providing a regional service.

6. SUMMARY

6.1 Conclusions.

6.1.1 The existing archive of hydrochemical data forms a valuable and mostly reliable background to groundwater quality investigation. However caution should be exercised on the quantitative significance of some analyses of minor components, namely NO_3, Fe and F, particularly since numerous errors in transferring these data onto the Cardex system have been identified. Similarly, some errors obviously exist in reported EC data which should also be used with caution.

6.1.2 Groundwater of acceptable quality can be found in all of the areas studied in this report, with the possible exception of some parts of the Lower Shire. The problems of poor water quality, both overall salinity and specific minor components, occur sporadically and are evidence for the extreme lateral (and probably also vertical) heterogeneity in water quality. This must be a reflection of the lithological heterogeneity of the colluvial weathering profiles and derived alluvial sequences. The very low mineralisation of groundwater underlying the dambo topography of the Upland Plateau zone, e.g. in Bua Catchment, is evidence for the very local nature of the groundwater regime with direct recharge and only small scale lateral movement.

6.1.3 The major problems of groundwater acceptability are geochemical in origin. In the Weathered Basement Complex aquifers, which constitute the major groundwater resource, the water quality problems are associated with the alteration reactions upon the metamorphic lithology due to groundwater circulation. Examples of these reactions are believed to account for high SO_4^{2-} concentrations in pockets of the Nkhotakota-Lakeshore Catchment and for sporadic occurrence of unacceptable total iron concentrations in groundwater in all of the areas studied. The iron problem originates from the importance of organic complexing agents (ligands) in the tropical weathering process and subsequent mobilisation of iron and other solutes. It is suggested that the sporadic nature of these anomalies may be indicative of fluctuating geochemical and hydrogeological conditions under which the mobility of the problem species may vary considerably.

6.1.4 The major influence of the argillaceous end-products of the weathering reactions, to which the lithological and hydrochemical heterogeneities are attributed, is further demonstrated by the advanced state of base-exchange reactions achieved in many groundwaters. Whilst the exchange of Na^+ for Ca^{2+} and Mg^{2+} does not directly affect water quality other than hardness, an indirect result may be the increased capacity of the groundwater for species such as SO_4^{2-} and F^- which are otherwise limited by phase equilibria involving Ca^{2+}.

6.1.5 Anomalous F^- concentrations may also have their origin in the weathering reactions, specifically on hydroxyl-bearing minerals such as hornblende amphibole. However it seems on the scant data available (including one anomaly confirmed during this study) that the highest concentrations, far above acceptable limits, are associated with active or relict hydrothermal activity. Thus the present thermal spring activity, specifically that at Nkhotakota, contains very high concentrations, as does groundwater apparently derived from fault zones infilled with late hydrothermal mineralisation, mostly silica. These zones, although potentially attractive for their yield, should be developed cautiously with respect to water quality.

6.1.6 The Lower Shire Valley aquifers within the Karoo and Lupata formations present perhaps the most difficult groundwater quality problems, as well as urgent and basic problems of borehole and well construction and maintenance. Salinity originates from the less permeable strata, and also possibly from evapotranspiration from a near-surface water table in areas close to the river. The best prospects for fresher groundwater in these areas seem to be in shallow aquifer zones, sometimes associated with direct recharge from ephemeral river flow, and overlying the older, slower-mvoing, and more mineralised groundwater at depth.

6.1.7 Insufficient information exists for any conclusive statement to be made about the magnitude of the pollution hazard posed by sanitation close to boreholes and wells. The incidence of significant amounts of NO_3^- in some sources, and unacceptable amounts in a few, suggest that further work is required. This is particularly relevant to considerations of the pros and cons of shallow well and deeper borehole construction. The ability of the colluvial and alluvial sequences to attenuate the harmful constituents of human and animal waste in the unsaturated zone before reaching the water table should be determined. This may assist in formulating guidelines for use in borehole siting and construction.

6.1.8 It is possible that the application of fertilisers in the more heavily cultivated areas may be affecting groundwater quality. A possible occurrence at Timadzi is described in an appendix to this report. No direct evidence exists for such pollution, but the possibility should be explored in areas where NO_3^- and SO_4^{2-} anomalies are found. For example, this source of high SO_4^{2-} has not yet been positively ruled out for the area around Chitala in the Nkhotakota Catchment, although a lithological source is preferred on the existing evidence.

6.1.9 The source of moderately high Cl^- concentrations in part of the South Rukuru Catchment has not been identified. Artificial sources such as fertilisers should be eliminated before concluding that a natural source is responsible. This type of groundwater mineralisation, Ca-Cl, is unusual and is explained elsewhere by a process of evaporative concentration accompanied by dolomitisation of calcite in which Ca and Cl become enriched in solution.

6.2 Recommendations.

6.2.1 The data transferred to the Cardex system must be checked thoroughly for transfer errors before this file can be referred to with confidence.

6.2.2 Laboratory facilities in Lilongwe should be improved to permit full inorganic analysis of ground- and surface-water samples, and also simple bacteriological testing. A programme of water quality investigations linked to borehole and well construction programmes should be implemented as soon as possible.

6.2.3 Close liaison with Ministry of Health is required over questions of water quality and acceptability. Much will depend on whether a Public Health laboratory is established as proposed. The Water Resources Branch requires expertise in the interpretation of the significance of water quality measurements, and in the formulation of remedial measures where possible in collaboration with other technical staff in DLVW. The proposed appointment of a Senior Water Quality Chemist should fill this requirement and will provide for training of junior staff in analytical methods, data collection and interpretation.

6.2.4 Regional laboratories, supported by the central laboratory, should ensure coverage of remote areas of the country. Facilities and staff should be adequate to ensure proper sample collection and measurement of unstable parameters prior to submission to the central laboratory.

6.2.5 Three priorities are identified for further investigation. The occurrence of iron in groundwater is a major barrier to acceptability, in spite of its harmless nature. The possibility of minimising this problem by borehole siting and construction should be explored. The occurrence of high mineralisation in groundwater in the lower Shire is a major problem - variation with depth should be investigated. The investigation of water quality variation and particularly the susceptibility to pollution from wastes should form a major part of the effort to make groundwater development, by wells or boreholes, more cost effective in the various and different hydrogeological environments in Malawi.

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APPENDIX 1

Summary of Archived Hydrochemical Data for Groundwater Quality in

Sub-unit 15A (Nkhotakota - Lakeshore)
Sub-units 5D, 5E, 5F (Bua)
Sub-units 1F, 1G, 1H, 1K (Lower Shire)
Unit 7 (South Rukuru)

		milligrams per litre							%	mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
15A/Z60	87	25	72	26	537	40	9	<2,2	+1,4	0,8	1,2	680	20,1	12	2,1	5				
Z63	86	47	95	3	692	48	10	<1	-1,1	1,2		1000	25,0	15	1,1	54				
Z64	80	23	34	3	326	53	25	<1	+1,9	3,5		640	14,6	2,1	2,1	19				
Z66	89	63	67	6	458	225	19		-0,1	21	<0,4	1060	25,4	5,4	0,9	19				
Z71	378	150	153	5	508	1203	16	<1	+5,8	20		2900	71,9	15	1,5	52				
Z87	101	35	70	2	536	48	42	2	+0,1	0,9		900	22,0	3	1,8	60				
Z90	340	194	311	8	776	1739	11	4	-2,7	4,3		3350	96,0	44	1,1	66				
L340	242	101	195	10	542	835	7		+4,8	2,9	0,9	2080	55,6	43	1,5	33				
L342	104	68	308	2	749	700	27	<2,2	-6,6	1,8	0,6	2200	51,9	18	0,9	262	0,4			
L332	125	44	128	1	768	199	10	<1	-4,8	1,2		1330	32,5	20	1,7	218	0,5			
W98	162	53	62	7	462	297	38		+1,7	2	<0,4	1410	30,1	2,5	1,9	15	1,1			
W282	87	31	69	4	576	14	21	1	-1,7	0,8		840	20,4	5,1	1,7	29	0,5			
A269	113	78	23	13	652	336	11	<2,2	-14,7	16	1	1440	31,4	3,2	0,8	3	0,5			
Q23	50	8	19	<1	234	<10	6		-2,5	0,7	0,4	360	8,2	4,9	3,8	32	0,7			
Q25	50	8	19	<1	338	1335	25		-78,9	82	<0,4	2440	38,1	1,2	3,8	32	0,5			
Q32	130	62	140	9	776	130	21	<0,4	+5,6	1,1		1290	34,0	10	1,3	26	0,5			
H143	55	18	48	5	313	12	40	<1	-0,6	2		570	13,0	1,9	1,9	16	0,5			
Q171	392	176	720	5	844	2400	73	27	-0,6	5,2		4570	132	15	1,4	245	1,4			
Q165	332	179	190	8	354	1525	34		+1,6	51	<0,4	2980	78	8,6	1,1	40	2,9			
Q174	230	97	104	5	434	655	57		+3,8	13		1920	47	2,8	1,4	35	1,6			
Q243	80	51	28	6	353	160	9		+1,0	7,2	0,5	890	18,9	4,8	1,0	8	0,7			
Q250	68	25	163	5	384	203	107	<1	-3,4	8,6		1240	26	2,4	1,7	55	0,6			
Q251	198	133	200	9	433	286	58		+33,9	76	0,7	2240	44	5,4	0,9	38				
Q176	69	22	17	2	390	24	10	<2,2	-8,7	1,8	0,2	550	13	2,6	1,9	14				
Q178	74	39	22	3	464	<10	<1		+1,3	25	0,7	710	16	34	1,1	12				
Q254	80	31	54	1	515	77	4	<1	-6,6	1,8		740	19	21	1,6	92				
Q323	157	87	57	4	350	334	60		+10,0	18		1270	32	1,5	1,1	24	1,4			
Q327	103	84	77	6	864	71	6		-0,8	2,1		1210	31	20	0,7	22	0,4			
Q336	278	81	131	6	249	1128	24		-3,4	21		2210	55	8,4	2,1	37	3,4			

	milligrams per litre									mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
15A/Q335	241	118	153	7	482	1081	9		-5,5	28		2360	42	4,5	1,2	37	1,5			
Q340	132	35	95	2	530	140	10		-3,2			1060	48	1,4	2,3	81	0,8			
Q338	75	29	28	6	445	14	25		-1,6	6,5		620	50	8,6	1,6	8	0,5			
Q339	222	106	46	3	437	725	19		-20	4,8		2300	51	0,2	1,3	26	1,6			
Q341	68	24	44	3	447	14	16		-2,9	21		620	46	11	1,7	25	0,5			
Q345	115	47	85	7	541	70	42	18	+10			940	43	11	1,5	21	0,7			
Q351	39	20	88	3	313	10	11		+14	1,4		470	26	14	1,2	50	0,4			
Q346	135	51	78	6	340	10	7		+5,0	1,6		1180	47	0,5	1,6	22	1,2			
Q348	77	46	65	8	477	15	27		-2,5			780	36	0,9	1,0	14	0,5			
Q442	36	13	36	<1	259	11	10		-1,6	4,3		370	40	14	1,7	61	0,4			
Q337	64	19	26	3	300	63	38		-3,2	2,8		520	54	10	2,1	15	0,7			
R92	83	37	130	6	599	85	21		-2,5			1060	37	30	1,5	41	0,4			
R93	84	33	97	4	786	36	11		-3,4	1,0		860	32	18	1,4	37	0,3			
R91	99	41	94	7	778	15	6	22	-3,8	1,2	0.4	790	26	24	1,5	23	0,4			
R100	31	11	323	1	932	115	25		-4,0	1,2	7.6	1440	34	71	1,7	549	0,1			
Q333	70	51	38	4	586	37	21		-6,3	0,3	1.4	740	20	5,3	0,8	16	0,4			
R95	46	16	59	2	352	20	40		-1,4	2,8		520	13	11	1,8	50	0,4			
Y79	28	69	124	<1	504	152	73		+3,5	50		1070	24	27	0,3	211	0,2			
X104	351	111	180	12	327	64	34	11	+67	1,4	0,2	470	42	70	1,9	26	3,3			
X100	138	52	120	2	276(?)	5			+55	1,4	0,3	1210	21	31	1,6	102	1,5			
X101	47	12	34	0,4	276	5			-0,1	1,4	0,3	380	10	8,8	2,4	145	0,5			
Y87	95	24	91	7	540	40		18	+1,0	0,8	0,6	860	22	5,9	2,4	22	0,5			
Y90	40	36	157	1	495	150			-0,6	1,4	0,3	990	24	10	0,7	267	0,3			
DP81	243	108	98	9	475	838			-0,6	30		1890	51	7,2	1,4	19	1,6			
DP73	99	30	205	8	369	155			+26		<0,4	810	26	23	2,0	44	0,8			
DP67	173	66	103	4	513	390			+4,0	24		1450	36	6,6	1,6	44	1,0			
DP82	18	7	13	2	123	9			-6,0	22		180	5	4,0	1,6	11	0,5			
DP71	71	64	95	5	510	228			-1,6	2,9	0,3	950	27	11.	0,7	32	0,4			
DP84	120	50	151	4	463	353			-1,8	4,8		1420	34	2,7	1,5	64	0,8			

			milligrams per litre							mg l⁻¹		µS cm⁻¹	meq l⁻¹		equivalent ratios					
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
15A/DP69	146	83	113	5	700	400	10		-0,3	4,1		1450	40	17	1,0	38	0,6			
RB138	43	26	88	3	463	30	10		-2,0	12	0,2	610	17	14	1,0	50	0,3			
15B/E57			0,7	1,2		15		<2,2		2,7	<0,1									
E55			0,7	0,1		33		22		1,8	<0,1	20								
E56			0,4			5		<2,2		7,4	<0,1	20								
Y111	7	5	12	2	91	0	6	<2,2	-1,9	29	0,2	120	3	3,1	0,9	10	0,2			
Y112	21	12	14	5	175	5	11	<2,2	-8,9	6,6	0,2	230	6	2,0	1,1	5	0,4			
X112	30	13	16	4	218	0	5	<2,2	-5,4	1,4	0,7	270	7	5,0	1,4	6	0,4			
Y100	45	19	223	1	951	85	14	4,4	-14	3,7	1,4	1060	31	25	1,4	379	0,1			
Y84	27	11	31	3	216	10	3	<2,2	-2,5	1,6	0,3	300	8	16	1,5	18	0,4			
FC151	43	24	16	2	215	80	6	<2,2	-5,1	14	0,4	420	10	4,1	1,1	14	0,6			

	milligrams per litre									mg l⁻¹		μS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
5D/P89	48				413	3	17	<1	-2,2	3,5			14	4,5	1,0		0,4	0,01	2,3	
SM49	41				461	5	38	0,3	-0,9	5,4	0,2		17	3,5	0,8		0,3	0,01	1,3	
SM179	42				383	1	10		-7,4		0,2		12	6,8	1,3		0,3		1,9	
Q310	99				461	4	23	<1	+0,7	0,2		630	17	4,5	12		0,7	0,01	1,8	
Q369	31				218	2	9	<1	+0,5	4,8		320	8	5,0	1,6		0,4	0,01	2,0	
Q87	74				520	4	74	15	-28	0,6		920								
Q92	48				782	9	21	<1	-32	<0,2		930								
SM32	74				490	5	24	0,6	-6,1	<0,1	0,5		17	3,7	2,5		0,5	0,01	2,1	
W126	131				658	<2	26	<1	+12,1	1,7			26	6,3	1,9		0,6		2,2	
X194	81				520	<2	9	11	+1,1	0,2			18	14,4	2,9		0,5		1,5	
A119	81				538	<2	32	<1	+0,7	5,1			20	2,9	1,3		0,5		2,8	
E116	105				940	4	11	<1	-26	2,2										
PM190	30				353	0	28	0,1	-8,0	9	0,4	580	12	3,0	1,0		0,3		1,3	
K127	59				322	4	18	3	-0,9	0,6			12	2,7	2,2		0,6	0,02	3,1	
K56	64				525	5	11	2,8	-4,8	<0,1	0,3		17	9,5	1,7		0,4	0,01	1,7	
RB65	79				510	15	28	<1	+0,2	11			19	2,3	1,1		0,5	0,04	4,1	
5E/Y223	50				195	140	4	<1	-7,7	4,1			12	15	2,3		0,8	0,9	2,2	
W188	25				135	104	6,4		+0,6	0,2			9	8,9	0,7		0,6	1,0	1,9	
RB36	3				61	121	1	<1	-13	25			6	29	0,1		0,2	2,5	2,2	
RB5	96				135	375	3	<1	+2,9	39			21	22	1,2		2,2	3,5	4,8	
RB19	32				59	3	7	16	+5,3	7,1										
FC109	27				127	15	7	28	-8,3	1,4			6	2,2	1,8		0,7	0,2	4,8	
FC105	36				163	140		<1	-4,5	7,1			11		0,9		0,7	1,1	4,3	
FC103	42				230	50	1	<1	-5,3	5,4			9	29	1,6		0,6	0,3	4,1	
FC86	5				79	41	2	<1	-12	33			4	10	0,3		0,2	0,7	2,0	
FC89	30				78	112	2	11	-6,2	0,8			7	12	1,3		1,2	1,8	3,8	
FC90	8				90	70	4		-10	28			6	3,9	0,3		0,3	1,0	4,5	
FC91	74				310	73	2	8	-6,8	1,4			13	15	2,8		0,7	0,3	6,1	

	milligrams per litre									mg l⁻¹		μS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg/Na	Notes
5E/FC19	25				168	3		<1	-1,3	0,4			6		1,5		7,9	0,02	3,4	
FC18	56				264	78	5	3	-6,6	0,6			12	9,6	2,4		18	0,4	2,9	
FC17	39				133	20	9	<1	+14	1,8			7	1,4	1,3		14	0,2	9,9	
FC80	21				47	185	1	<1	-4,5	23			9	42	0,6		7,7	5,0	2,5	
E257	26				121	100	0		-2,1	2,2			8		1,0		7,4	1,1	2,3	
DP124	8				59	20	2	4	-12	1,4			3	4,6	0,8		10	0,4	3,4	
DP125	18				16	186	7	<1	+64	27										
DP121	58				253	<10	4		-1,2	3,3			9	4,2	3,2		6,2	0,05	8,0	
R175	76				160	135	<1		+6,8	1,6			12	34	2,7		13	1,1	5,4	
R142	32				145	73	9		-9,4	1,6			8	3,6	1,9		8,9	0,6	2,7	
R63	57				182	93	4		-6,9	11			9	7,3	4,3		16	0,7	4,3	
R61	34				155	68	<1		-7,8	3			7	23	1,9		4,3	0,6	4,0	
Y193	29				170	<10	2		-4,6	2,7			6	7,7	1,8		5,7	0,07	5,2	
Y192	26				125	<10	2		+2,8	2,5			5	9,3	2,3		10	0,1	3,6	
Y191	54				222	<10	2		-2,6	2,9			8	7,7	5,5		5,7	0,06	7,4	
W323	4				45	<10	2		-17	0,8			2	3,8	1,2		1,7	0,3	1,7	
W190	2				76	<10	4		-15	59			3	4,6	0,2		10	0,2	1,1	
W154	7				57	<10	2		-15	2,5			2	3,9	1,4		2,8	0,2	2,8	
W136	20				113	<10	8		-2,9	0,8			5	2,5	2,0		5,5	0,1	2,6	
W92	17				128	<10	2		-7,7	0,3			4	13	2,1		29	0,1	1,7	
W26	5				60	<10	2		-16	33			2	30	0,6		6,8	0,2	3,8	
W25	13				65	<10	5		-6,5	1			3	0,9	1,6		2,6	0,2	8,1	
W24	14				70	<10	3			2,3										
W18	21				120	<10	1			0,6										
W17	2				36	<10	6			1,2										
FP11	20				155	<10	2		-6,6	1,2			5	16	2,0		18	0,08	1,6	
A74	16				136	<10	<1		-6,6	12			5	12	0,8		14	0,09	5,1	
DP130	2				53	130	<1		-19	23										
DP133	3				75	15	<1		-13	6,8			3	14	0,2		7,7	0,3	2,1	

	milligrams per litre								%	mg l⁻¹		µS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg/Na	Notes
5E/DP111	30				152	70	1	<1	-22	1,8										
W122	38				222	2	3	1	-27	0,3										
W41	33				161	90	2	12	-7,6	2,5			9	20	1,3		0,6	0,7	2,6	
E317	79				319	53	12	<1	-6,6	1,6			13	2,4	4,0		0,8	0,2	6	
R141	28				151	<10	4		-3,7	1,0			5	3,1	1,7		0,6	0,08	6,4	
Q21	13				78	<10	2		-5,4	4,4			3	3,9	1,3		0,5	0,2	5,3	
A71	8				62	<10	3		-10	2,3			2	3,1	1,2		0,4	0,2	2,8	
DP120	4				57	<10	8		-22	46										
W15	10				54	<10	6		-7,7	0,8			2	1,5	2,0		0,6	0,2	2,9	
Z11	5				44	<10	2		-20	8										
DP137	60				153	225	3	<1	-6,0				14	15	1,5		1,2	1,9	4,0	
DP136	60				223	139	1	<1	-18	5,4			11	4,5	2,3		0,8	0,8	34	
DP135	20				129	13	6	<1	-6,6	5,4			5	2,3	1,2		0,5	0,1	4,7	
DP117	29				162	31	5	5	-5,9	1,8			7	5,3	1,8		0,6	0,2	3,1	
DP113	19				127	22	1	1	-5,8	2			5	40	1,3		0,5	0,2	3,2	
DP65	23				150	88	1	<1	-8,8	8			8	42	0,9		0,5	0,8	2,0	
FC27	43				129	158		<1	-4,9	9,5			10		1,4		1,0	1,6	3,3	
W27	13				92	4	1	2	-5,5	1			3	14	1,6		0,4	0,06	2,7	
W266	110				174	35	2,5		+30	3,6										
HD7	38				147	65		5	-7,5	2,8			7		2,9		0,2	0,6	3,7	
A72	21				179	3	5	<1	-11	1,8			6	4,0	1,3		0,4	0,02	3,3	
G96	16				119	6	5	<1	-6,6	1,8			4	4,9	1,9		0,4	0,06	1,7	
RB16	21				161	3	9		-5,8				6	2,9	1,4		0,4	0,02	2,4	
DP60	48				289	<2	6	<1	-2,2	2,3			10	4,9	1,7		0,5	0,01	4,6	
5F/FC50	49				366	<10	8		-1,8	8,7			13	12	2,3		0,4	0,03	2,4	
DP194	46				273	<10	8		+0,1	0,6			10	6,2	2,0		0,5	0,05	1,2	

			milligrams per litre							mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg / Na	Notes
1E/PM87	42	30	215	14?	697	39	36	<22	+2,4	36	0,9	700	28	9,2	0,9		0,2	0,1	0,5	
1F/ M160	98	57	191	1	896	13	116	14	-1,5	0,3		1640	36	2,5	1,0		0,3	0,02	1,2	
M110	123	41	47	3	640	12	59	<1	-3,2	14		990	24	1,2	1,8		0,6	0,02	4,7	
K173	78	32	25	0,9	405	5	24	0,7	+1,7	0,9	0,5		15	1,6	1,5		0,6	0,02	6,0	
D24	58	19	73	<1	426	5	19	<1	+0,2	0,7		620	15	5,9	1,9		0,4	0,01	1,4	
D25	57	28	75	<1	397	24	60	2	-1,7	0,6		720	17	1,9	1,2		0,4	0,08	1,6	
X51	73	43	34	0,2	491	12	13	<1	+0,2	13		700	17	4,0	1,0		0,5	0,03	4,9	
X58	68	37	180	1	552	61	92	<1	+5,0	12		1130	27	3,0	1,1		0,4	0,1	0,8	
X279	27	12	16	16?	173	8	15	<2,2	-4,7	0,2	0,4	200	7	1,7	1,4		0,5	0,06	3,4	
RB202	91	43	220	22?	767	122	65	<2,2	+2,6	26	0,3		35	5,2	1,3		0,4	0,2	0,9	
FP105	94	88	60	14?	762	0	13	<2,2	+6,0	0,5	0,8	1300	28	7,1	0,7		0,4		4,6	
FP82	46	13	16	20?	267	6	17	<2,2	-8,2	30	0,5	400	10	1,5	2,1		0,5	0,03	4,8	
FP85	54	15	33	0,4	309	4	15	<2,2	-4,0	70	0,8	500	11	3,4	2,2		0,5	0,02	2,7	
FP84	39	16	34	0,8	282	8	8	<2,2	-4,1	<0,2	0,7	600	10	6,6	1,5		0,4	0,04	2,2	
FP86	32	11	30	18?	191	0	22	<2,2	+2,0	0,9	0,3	300	8	2,1	1,8		0,5		1,9	
FP87	80	34	16	14?	426	0	33	<2,2	-2,6	24	0,4	700	16	0,8	1,4		0,6		9,8	
FP134	576	209	390	38?	506	440	1629	0,4	+0,4	30	0,2	6760	127	0,4	1,7		3,5	1,1	2,7	
FP89	47	23	193	91?	659	48	14	<2,2	+8,8	<0,2	0,5	1200	28	21	1,2		0,2	0,1	0,5	
FP88	71	71	115	20?	856	18	36	<2,2	-2,8	17	10	1300	31	4,9	0,6		0,3	0,03	1,9	
PM106	29	15	158	0,6	560	18	7	<2,2	-2,0	0,9	14	900	20	35	1,2		0,2	0,04	0,4	
PM105	28	15	18	16?	175	0	3	4,4	+2,2	11	0,3	300	8	9,3	1,1		0,5		3,4	
PM104	38	21	41	0,4	273	0	1	<2,2	+6,3	<0,2	0,6	500	10	63	1,1		0,4		2,0	
DM52	65	25	32	0,8	275	0	116	<2,2	-8,2	0,3	0,4		15	0,4	1,6		0,7		3,8	
DM54	29	20	17	26?	230	6	11	<2,2	-0,7	11	0,6	600	9	2,4	0,9		0,4	0,03	4,2	
DM63	31	20	22	28?	215	8	35	<2,2	-1,7	0,5	0,6		10	1,0	0,9		0,4	0,05	3,3	
1G/ K14	67	61	77	1,4	615	7	36	5	+1,9	24	0,9	990	23	3,3	0,7		0,3	0,01	2,5	
K13	88	65	140	4,6	740	19	101	4,8	+1,6	<0,2	1,1	1026	31	2,1	0,8		0,4	0,03	1,6	
M96	48	8	32	0,9	300	8	21	22	-12,6	123	0,8	510	11	2,4	3,7		0,5	0,03	2,2	

	milligrams per litre								Balance %	mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3		Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
G/M101	64	25	165		706	54	36	115	-9,6	<0,1	24	1230	28	7,1	1,6		0,3	0,1	0,7	
M102	66	17	18	0,5	313	12	21	23	-6,1	0,5	0,6	550	12	1,3	2,4		0,6	0,05	6,0	
M104	75	16	36		284	33	56	80	-8,0	115	11	840	15	1,0	2,9		0,8	0,15	3,2	
M105	98	45	144	0,9	634	45	67	5,5	+3,4	0,6	1,7	1180	29	3,3	1,3		0,5	0,09	1,4	
M103	66	22	30	0,2	382	8	21	32	-7,6	<0,1	0,9	630	14	2,2	1,8		0,5	0,03	3,9	
K11	80	12	59		406	17	23		+5,4	14	0,7	700	16	4,0	4,1		0,6	0,05	1,9	
HD142	100	78	190		1032	15	78	10	+3,8	0,9	2,6	2030	44	3,8	0,8		0,3	0,02	1,4	
HD149	135	13	278		1026	80	70	89	-3,4	0,4	15	1870	42	6,1	6,3		0,4	0,1	0,7	
HD154	108	46	343		1124	48	206	0,4	+0,8	35	31	2490	51	2,6	1,4		0,3	0,05	0,6	
K169	130	1,5?	150		664	75	50	37	-3,2	<0,2	2,6	950	28	4,6	53		0,6	0,1	1,0	
D28	79	17	180		583	42	112		+2,2	0,7	0,7	1320	28	2,5	2,8		0,4	0,1	0,7	
D31	32	29	123		498	10	33	67	+0,6	<0,2	14	1350	21	5,8	0,7		0,2	0,03	0,8	
D32	163	77	415		697	685	276		-1,0	27	17	3070	66	2,3	1,3		0,7	1,3	0,8	
Q404	47	36	210		728	54	95,5	82	-6,8	0,6	24	1520	32	3,4	0,8		0,2	0,1	0,6	
X60	0	2	440	0,2	656	38	277	50	-2,1	0,7	47	2030	40	2,5				0,07	0,01	
X62	43	14	77	3,0	357	12	19	18	+3,4	0,5	6,9	610	14	6,3	1,9		0,4	0,04	1,0	
X59	7	1	450	2,2	697	44	287	4,7	-1,5	0,3		2220	42	2,4	4,3		0,03	0,08	0,02	
X276	110	37	203	1,1	414	223	220	4,7	-0,9	0,4	1,2	2030	35	1,4	1,8		0,8	0,7	1,0	
X277	98	39	30	1,1	354	28	40	75	+4,0	0,3	1,5	1050	18	1,2	1,5		0,8	0,1	6,2	
X278	32	13	240	0,3	614	40	108	0,6	-3,1	0,3	2,0	1440	27	3,4	1,5		0,2	0,08	0,3	
X275	73	39	62	2,2	490	14	60	7,4	-2,6	0,7	1,4	940	20	1,6	1,1		0,5	0,04	2,5	
FC122	661	400	3450	180	690	4400	4115	0,4	+0,4	42	0,7	16200	440	1,3	1,0		2,9	8,1	0,4	
RB128	85	23	35	0,4	406	12	23	4,3	-3,0	<0,1	0,9	650	16	2,4	2,3		0,6	0,04	4,0	
RB97	67	41	320		659	58	269	13	-0,4	<0,1	1,4	1880	43	1,8	1,0		0,3	0,1	0,5	
RB127	58	21	36	0,5	330	17	33	8	-3,8	<0,1	6,9	580	13	1,7	1,7		0,5	0,07	3,0	
RB126	102	15	130	0,5	372	128	90	5,6	-0,4	2,5	0,9	1320	24	2,2	4,1		0,8	0,4	1,1	
FP125	114	66	145	0,5	693	133	127	0,5	-0,9	1,6	1,4	1640	36	1,8	1,1		0,5	0,2	1,8	
FP126	99	35	115	0,6	634	90	62	6	-7,2	15	0,6	1250	28	2,9	1,7		0,5	0,2	1,6	
FP127	58	21	36	0,5	330	17	33	8	-12	<0,1	0,9	580	14	1,7	1,7		0,5	0,07	3,0	

	milligrams per litre									mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg / Na	Notes
1G/FP128	72	25	38	0,9	406	12	23	4,3	-4,5	<0,1	0,9	650	16	2,6	1,8		0,5	0,04	3,4	
FP123	64	37	50	0,5	434	26	32	3,8	-3,5	12	1,1	1010	18	2,4	1,1		0,5	0,08	2,9	
FP129	105	29	34	1,1	477	140	8	0,9	-8,3	72		890	21	6,6	2,2		0,7	0,4	5,2	
FP122	80	24	26	0,6	391	12	25	0,9	-1,7	<0,1	1,0	670	15	1,6	2,0		0,6	0,04	5,3	
FP130	147	100	345		820	540	259	0,7	-1,9	0,4	1,5	2370	63	2,1	0,9		0,6	0,8	1,0	
FP120	88	31	39	0,5	435	50	41	80	-9,5	<0,1	1,2	840	19	1,5	1,7		0,6	0,2	4,1	
FP119	78	28	1260	0,5	762	685	1234	43	-0,9	<0,1	2,6	6320	123	1,6	1,7		0,3	1,1	0,1	
FP118	16	18	400	0,4	1044	33	37	17	+1,7	0,7	2,9	1880	39	17	0,5		0,05	0,04	0,1	
FP116	18	15	770	1,2	832	500	435	18	-0,9	0,9	6,3	3760	73	2,7	0,7		0,07	0,8	0,06	
FP117	9	7	350	0,5	444	245	192		-4,2	<0,1	2,0	1880	34	2,8	0,8		0,06	0,7	0,07	
FP115	22	16	420	0,9	401	330	254		+0,7	<0,1	1,2	2220	42	2,6	0,8		0,2	1,1	0,1	
FP114	81	14	495		433	335	442	10	+7,5	<0,1	8,1	2730	58	1,7	35		0,6	1,0	0,2	
PM112	24	16	1500	0,9	1876	610	678	180	+1,9	1,8	4,0	6760	133	3,4	0,9		0,04	0,4	0,04	
PM109	171	168	3550		1052	3750	2957	27	-1,7	2,0	2,8	11610	360	1,9	0,6		0,5	4,5	0,1	
PM111	68	23	38	0,9	317	15	31	5,2	-0,3	18	1,2	740	14	1,9	1,8		0,7	0,06	3,2	
FP95	41	6	185	2,0	401	44	123	0,8	+0,1	24	1,0	1110	22	2,3	4,2		0,3	0,1	0,3	
DM61	96	85	2650	10	838	2600	2049	18	-0,5	0,4	9,4	11960	256	2,0	0,7		0,4	3,9	0,1	
PM360	77	28	63		402	20	31	3,8	+5,4	11	13	860	18	3,1	1,7		0,6	0,06	2,3	
PM365	92	34	190		612	67	148	11,8	-2,0	0,2	1,0	1720	34	2,0	1,6		0,5	0,1	0,9	
PM366	132	19	348		318	320	410	3	+6,7	12,8	4,9	2650	50	1,3	4,2		1,3	1,3	0,5	
PM518	65	20	47	0,6	390	5	18	7,1	-6,9	0,5	0,9	760	15	4,0	2,0		0,5	0,02	2,4	
PM519	41	18	41	0,7	306	5	23	2,4	-5,7	27	1,1	610	12	2,8	1,4		0,4	0,02	2,0	
PM523	58	6	61		307	10	36	6	-6,6	0,8	1,5	590	14	2,6	5,9		0,6	0,04	1,3	
PM520	42	25	420	0,5	1240	25	80	19,5	-7,6	11	1,7	2030	49	8,1	1,0		0,1	0,03	0,2	
PM515	111	39	39	0,9	546	22	31	16,8	-9,7	0,6	1,8	1090	24	1,9	1,7		0,6	0,05	5,2	
PM521	34	21	708		1128	615	67	1,2	+1,7	15	17?	4520	68	16	1,0		0,09	0,7	0,1	
PM516	90	43	119		747	17	23	13	+1,0	84	0,8	1270	27	8	1,3		0,4	0,03	1,6	
PM522	84	9	370		295	225	244	0,5	+13	0,7	25?	2180	38	2,3	5,7		0,9	1,0	0,3	
PM517	46	15	27		228	15	27	7,4	-7,5	0,9	0,5	560	11	1,5	1,9		0,6	0,08	3,0	

	milligrams per litre									mg l⁻¹		µS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
H/HD103	82	36	61	<1	465	92	31	19	-4,8	13		820	21	3,0	1,4		0,5	0,3	2,7	
K12	35	31	200	11	613	40	55	13,5	-4,8	<0,1	0,7	1180	28	5,6	0,7		0,2	0,08	0,5	
K97	71	43	24	<1	348	22	27	8	+7,3	22		800	15	1,4	1,0		0,6	0,08	6,8	
K99	81	24	214	<1	770	62	40	1	+1,0	0,9		1220	30	8,3	2,1		0,3	0,1	0,7	
K114	218	67	287	1	834	108	432	11	-2,1	14		2660	69	1,0	2,0		0,8	0,3	1,3	
K98	58	45	154	1	660	23	24	4	+5,1	0,9		930	25	9,9	0,8		0,3	0,04	1,0	
K141	292	56	690	2	1096	<2	444	<1	+24	16		4750	80	2,4	3,2		0,8		0,6	
L206	59	40	320	0,9	796	172	136	28	-10	<0,2	0,8	2370	45	3,6	0,9		0,2	0,3	0,5	
L324	107	19	280	1	622	7	346	<1	-2,5	12		1890	39	1,3	3,4		0,5	0,01	0,6	
E142	117	52	78	<1	680	48	40	<1	-0,2	12		1050	27	3,0	1,4		0,5	0,1	3,0	
E314	130	10	978	1	520	338	1033	<1	+5,5	20		4360	95	1,5	7,9		0,8	0,8	0,2	
E345	80	7	203	<1	682	7	346	<1	-22	0,5		1050	35	0,9	6,9		0,4	0,01	0,5	
E343	61	73	1110	<1	768	145	457	<1	+34	12		6380	86	3,8	0,5		0,2	0,2	0,2	
H129	84	31	1226	2	466	458	451	<1	+34	16		6970	90	4,2	1,7		0,6	1,3	0,1	
H137	65	14	27	4	298	5	17	<1	+1,7	0,8		590	11	2,5	2,8		0,7	0,02	3,8	
D29	125	31	57		537	8	50	7,8	-0,3	<1		1080	23	1,8	2,5		0,7	0,02	3,6	
D30	105	41	49	0,5	592	7	26	8,2	-4,5	0,5	0,4	940	23	2,9	1,6		0,5	0,02	4,1	
Q185	101	8	120	1	452	16	98	<1	+2,0	0,7		920	22	1,9	7,7		0,7	0,04	1,1	
Q187	51	16	916	1	1460	234	596	4	-2,0	27		4870	89	2,4	1,9		0,1	0,2	0,1	
Q190	54	46	155	0,5	684	33	34	18	-8,3	13	0,9	1350	29	7,0	0,7		0,2	0,06	1,0	
Q191	114	14	104	<1	628	15	35	6	-1,3	3		950	23	4,6	5,0		0,6	0,03	1,5	
Q194	56	37	45	6	494	7	28	<1		10		760	34	2,5	0,9		0,4	0,02	3,0	
Q237	90	46	78	<1	654	73	88	15	-12	20		1320	27	1,4	1,2		0,4	0,1	2,4	
Q234	39	118	307	3	532	98	607	<1	-5,3	4,6		2480	53	0,8	0,2		0,2	0,2	0,9	
Q235	39	12	254	1	624	123	61	<1	-1,8	0,8		1190	29	6,4	2,0		0,2	0,3	0,3	
Q275	28	53	1318		1760	644	956	<1	-26	12		6050	110		0,3		0,05	0,5		
Q299	154	78	289	1	824	389	208	<1	-1,6	3,2		2320	54	2,1	1,2		0,6	0,6	1,1	
Q297	435	324	2240	2	634	463	4520	<1	-0,5	11		13100	293	0,8	0,8		2,1	0,9	0,5	
Q296	111	6	57	4	470	<2	13	1,8	+1,3	2,9		710	17	6,8	11		0,7	0,01	2,4	

	milligrams per litre									mg l⁻¹		µS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
1H/Q302	90	44	65	<1	568	41	35	11	-1,8	11		890	22	2,9	1,2		0,5	0,09	2,9	
Q280	100	73	680	0,4	836	576	369	14	+2,8	14	1,4	4390	75	2,6	0,8		0,4	0,9	0,4	
Q281	394	730	3110	3	754	2169	5840	16	-1,6	16		17900	437	0,8	0,3		1,6	3,7	0,6	
Q276	56	53	166	<1	740	64	26	0,6	+0,7	0,6		1180	29	9,9	0,6		0,2	0,1	1,0	
Q294	34	77	852	6	1496	117	448	0,9	+6,6	0,9		3740	85	2,9	0,3		0,07	0,1	0,2	
Q360	75	190	2850	4	1150	1119	4000	22	-3,8	22		13200	298	1,1	0,2		0,2	1,2	0,2	
Q363	59	44	125	0,1	514	27	72	0,7	-6,1	0,7	0,8	1250	26	2,7	0,8		0,4	0,07	1,2	
Q303	86	50	139	1	724	20	72	0,5		0,5		1190	29	3,0	1,0		0,4	0,04	1,4	
Q427	275	97	279		606	78	794	5		5		3630	68	0,5	1,7		1,4	0,2	1,8	
Q129	80	36	54	0,7	640	15	46	4	-14,6	0,6	0,6	1180	22	1,8	1,4		0,4	0,03	3,0	
Q417	69	26	1330		1509	540	955	82	-8,8	<0,2	2,4	7270	140	2,2	1,6		0,1	0,5	0,1	
Q425	47	62	168	<1	700	50	38	2	+0,1	<0,2		1186	28	6,8	0,6		0,2	0,1	0,9	
X70	71	54	85	<1	552	22	58	<1	+2,4	18		1000	23	2,3	0,8		0,4	0,05	2,2	
X63	88	44	43	<1	510	22	33	8	+0,2	0,5		800	20	2,0	1,2		0,5	0,05	4,3	
X73	84	46	24	0,4	681	0	34	<2,2	-16	4,4	0,4	1100	22	1,1	1,1		0,4		7,7	
X61	82	50	80		584	20	50	0,4	+2,5	1,8	0,5	1020	24	2,5	1,0		0,4	0,04	2,4	
X76	150	28	54	<1	656	13	30	3	-0,7	0,5		980	25	2,8	3,3		0,7	0,03	4,2	
Y72	78	33	78		530	23	28	<1	+0,7	0,8		790	20	4,3	1,4		0,5	0,06	2,0	
Y70	73	25	50		402	28	27	<1	+0,4	0,6		640	16	2,9	1,8		0,6	0,09	2,6	
X94	74	13	325	<1	734	12	26	<1	+18,5	0,7		1010	32	19	3,5		0,3	0,02	0,3	
Y69	49	55	323		660	30	323	<1	+1,4	4,6		1870	42	1,5	0,5		0,2	0,06	0,5	
Y60	20	9	153	1		41	40		+62	1,0		830	10							
X83	284	396	1584	0,3	1044	2435	454	0,8	+18	<0,2		10500	197	5,4	0,4		0,8	3,0	0,7	
Y124	55	20	1034	<1	241	254	230	<1	+52	1,7		4020	65							
Y42	37	51	606	2	740	398	308	<1	+5,4	0,7		2760	62	3,0	0,4		0,2	0,7	0,2	
Y55	273	190	420	3	518	198	80	<1	+52	16		4440	63							
Y58	41	166	1040	<1	1260	568	1102	14	-2,3	0,6		5340	125	1,5	0,2		0,1	0,6	0,4	
FC9	24	21	295	2	440	86	229	<1	+1,1	0,2		1570	31	2,0	0,7		0,2	0,3	0,2	
X199	78	38	413	1,6	818	25	330	7,5	+1,2	1,3	1,2	2800	50	1,9	1,3		0,3	0,04	0,4	

			milligrams	per litre						mg l^{-1}		µS cm^{-1}	meq l^{-1}		equivalent	ratios				
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
1H/X196	119	54	380	0,5	918	266	200	5,7	-0,2	<0,2	0,8	2650	54	2,9	1,3		0,4	0,4	0,6	
X197	147	106	2100	4,6	1112	290	2024	<0,2	+0,4	9	1,5	11830	214	1,1	0,8		0,4	0,3	0,2	
X267	92	64	700	3	168?	108	449	<1		<1		3950								
X204	52	41	242	<1	864	60	56	<1	-0,8	31		1340	33	6,7	0,8		0,2	0,1	0,6	
X208	93	37	90	<1	1248	275	152	3	-45	0,2		2670								
X255	504	273	3035	2	704	192	5960	<1	-1,0	12		17500	363	0,8	1,1		2,2	0,4	0,4	
X218	72	26	256	<1	870	95	38	<1	-1,3	1,6		2960	34	10	1,7		0,3	0,1	0,5	
X227	64	124	968	3,5	1081	358	1019	<2,2	+1,2	3,2	0,4	6100	110	1,5	0,3		0,2	0,4	0,3	
X252	561	20	585	4	580	8	1680	<1	-1,6	11		5600	112	0,5	17		3,0	0,02	1,2	
X246	358	64	912	1	920	272	1620	<1	-3,3	2,2		6330	130	0,9	3,4		1,2	0,4	0,6	
X207	374	131	998	5	752	253	2138	<1	-3,2	3,8		6680	151	0,7	1,7		1,5	0,4	0,7	
X237	112	35	150	<1	218	6	73	34	+15	1,2		1830	26	3,2	1,9		1,6	0,03	1,3	
X242	80	66	84	<1	736	29	38	5	-2,6	1,1		1120	27	3,4	0,7		0,3	0,05	2,6	
FC5	51	20	350	2	936	5	108	<1	+2,5	0,8		1630	38	5,0	1,6		0,2	0,01	0,3	
RB99	37	2	570	0,7	497	610	208		+0,5	0,5	3,0	2730	54	4,2	11		0,2	1,6	0,08	
RB98	232	586	1080		239	4900	1448		-15	282?	0,5		254	1,2	0,2		3,0	26	1,3	
FP80	85	50	200		338	13	429	<2,2	+1,9	3,0	0,7	1700	37	0,7	1,0		0,8	0,05	1,0	
PM103	44	66	158	0,8	754	71	16	<2,2	+0,2	<0,2	0,5	1300	29	15	0,4		0,2	0,1	1,1	
PM99	149	56	574		255	18	1152	<2,2	-0,1	0,7	0,3	3400	75	0,8	1,6		1,8	0,1	0,5	
PM100	109	60	44	0,4	640	4	36	<2,2	+15	1,2	0,3	1000	28	6,2	1,3		0,5	0,01	1,5	
FP93	45	31	160	0,4	644	30	40	25	-3,5	0,7	0,5	1200	25	6,2	0,9		0,2	0,06	0,7	
Q462	62	35	288		950	53	57	4,4	-0,2	<0,2	3,0	1400	38	7,8	1,1		0,2	0,07	0,5	
DM56	310	64	335		461	17	966	<2,2	+2,1	0,5	0,1	3400	73	0,5	2,9		2,1	0,05	1,4	
DM58	14	13	1060		1646	34	737	4,4	-0,4	12	1,4	5600	98	2,2	0,7		0,03	0,03	0,04	
PM370	103	54	203		704	18	6	<2,2	+8,3	<0,2	0,3	1200	27	28	1,2		0,5	0,03	2,0	
DM59	70	65	510		964	234	355	<2.2	+0,8	5,8	0,4	3300	63	2,2	0,7		0,2	0,3	0,4	
SM152	75	61	248		919	8	119	<2,2	+4,0	14	12		40	3,2	0,8		0,3	0,01	0,8	
FP94	102	28	135		640	7	90		+1.7	62	0,7	1210	27	2,3	2,2		0,5	0,01	1,3	

	milligrams per litre									mg l⁻¹		µS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg/Na	Notes
1K/M12	135	112	600	2	557	213	461	<1	+23	25		4000	69	2,0	0,7		0,7	0,5	0,6	
HD109	26	19	77		288	95	102	<1	-20	<2			16	1,2	0,8		0,3	0,4	0,9	
H138	48	0	255	2	716	109	102	<1	-11	0,8		1170	30	3,9			0,2	0,2	0,2	
D37	9	4	368	<1	708	119	88	<1	+0,7	0,4		1430	33	6,5	1,4		0,04	0,2	0,05	
Q198	27	21	41		260	41	83	<1	-20	11		610	12	0,8	0,8		0,3	0,2	1,7	
Y65	208	260	2160	2	744	318	448	<1	+68	147?										
Y66	148	128	1120	7	832	271	446	<1	+35	112?		5840								
Y67	112	185	213		1014	90	428	<1	-1,0	242?			61	0,8	0,4		0,3	0,1	2,2	
Y62	67	156	1200	1	730	270	445	<1	+39	86?		6410								
X262	50	36	394		510	164	384	<1	+0,2	11		2740	45	1,6	0,8		0,3	0,4	0,3	
X264	19	11	14	<1	404	13	24	<1	-51	1,4		690								
X259	25	10	55	2	248	0,4	20	<1	-1,5	1,1		430	9	4,2	1,5		0,3		0,9	
X256	88	62	265	<1	464		460		+1,2				42	0,9	0,9		0,6		0,8	
RB115A	28	12	288	1	100	256	292	<1	-0,9	84?		1780	30	1,5	1,4		0,9	3,3	0,2	
PM97	48	29	230		510	23	180	<2,2	+5,0	0,9	13	1700	30	2,0	1,0		0,3	0,06	0,5	
PM90	116	58	455		755	13	637	<2,2	-0,3	0,4	2,0	3400	62	1,1	1,2		0,5	0,02	0,5	
PM95	610	386	478		1218	510	1834	<2,2	+0,7	16	0,4	13600	166	0,4	1,0		1,5	0,5	3,0	
SM153	23	21	240		668	80	20	<2,2	+0,8	17	0,9	1800	27	19	0,7		0,1	0,2	0,3	
DM77	37	12	44		212	0	34	<2,2	+14	30	0,5	500	11	2,0	1,9		0,5		1,5	
SM148	72	43	253		346	43	385	<2,2	+3,2	12	0,3	2000	37	1,0	1,0		0,6	0,2	0,7	
DM74	141	60	980	10	619	432	1218	<2,2	-2,4	40	0,6	5500	105	1,1	1,2		0,7	0,9	0,3	
FP81	62	40	155		404	39	197	<2,2	+2,5	<0,2	0,6	1300	27	1,2	0,9		0,5	0,1	1,0	
1L/RB176	96	61	270		690	122	140	<2,2	+10	17	0,7	2100	41	3,0	1,0		0,4	0,2	0,8	
RB183B	70	37	81		469	39	32	<2,2	+9,9	119?	0,7		22	3,9	1,2		0,5	0,1	1,9	
FC13	288	224	690	<1	553		458	<2,2	+48	2,4		6700	85							
FP77	35	28	425		856	53	296	<2,2	-0,9	0,9	2,6	2200	47	2,2	0,8		0,1	0,08	0,2	
FP78	54	33	410		583	6	485	<2,2	+6,4	13	15	2300	51	1,3	1,0		0,3	0,01	0,3	
PM89	93	50	258		852	85	140	<2,2	+0,8	53?	10	1900	40	2,8	1,1		0,3	0,1	0,8	

	milligrams per litre									mg l^{-1}		μS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
L/PM98	7	10	300		552	128	71	<2,2	+1,8	0,7	9	1400	29	6,5	0,4		0,04	0,3	0,09	
DM55	48	27	166		331	26	198	44	+1,2	<0,2	0,3	1300	25	1,3	1,1		0,4	0,1	0,6	

	milligrams per litre									mg l⁻¹		μS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
7/X170	110	33	116	22	501	1	227	2,5	−3,0	2,4	0,6		29	0,8	2,0	9	0,7		1,6	
X167	867	277	380	65	433	1750	1520	20	−1,4	9,1	0,2	7650	171	0,4	1,9	9,9	6,1	5,1	4,0	
Z133	16	4	41	4	143	3	8	14	+2,7	0,4		250	6	7,9	2,4	17	0,3	0,03	0,6	
H21	67	14	70	10	382	2	69	6	−3,4	18		690	16	1,6	2,9	12	0,5	0,01	1,5	
RK3	30	10,7	60	8,8	207	0	69	0,1	−1,1	0,2	0,4		11	1,3	1,7	12	0,4		0,9	
RK2	8,2	3,3	26	9,2	110	2	14	0,5	−4,7	1,0	0,1		4	2,9	1,5	4,8	0,2	0,02	0,6	
E95	2,7	0,6	6	2,2	54	17	5,6	0,7	−48	3,9	<0,1									
RK1	22	4,3	19	5	181	35	31	0,3	−32	1,0	0,2									
Q395	2	1	16	4	35	17	20	9	−25	0,9	0,2	130								
A85	73	17	32	7	370	2	11	2,5	+1,2	0,9	0,6	600	13	4,5	2,6	8	0,6	0,01	3,6	
X164	276	49	108	18	480	28	502	15	+0,3	4,3	0,3	2550	46	0,3	3,4	10	1,8	0,07	3,8	
X165	208	117	116	20	538	210	478	2,5	−2,1	28	0,2	2700	52	0,4	1,1	10	1,2	0,5	4,0	
X166	631	148	500	72	592	10	2085	2,5	−1,0	18	0,2	7050	136	0,4	2,6	12	3,3	0,02	2,0	
Q131	28	13	83	3	332	2	18	2,5	+1,0	7	0,5	600	12	7,1	1,3	47	0,3	0,01	0,7	
E181	100	23	200	2	690	40	103	<2,5	+0,6	<0,2	1,8	1500	31	3,0	2,6	170	0,4	0,07	0,8	
Q132	55	16	145	3	485	44	45	2,5	+1,3	<0,2	0,3	1300	21	6,0	2,1	82	0,4	0,1	0,7	
R192	29	7	62	6	241	2	28	2,5	+0,6	4	0,6	600	10	3,4	2,5	18	0,4	0,01	0,8	
R199	69	20	80	3	476	8	34	2,5	−1,8	4	0,9	900	18	3,6	2,1	45	0,4	0,02	1,5	
W162	87	22	76	5	466	2	77	2,5	−1,5	<0,2	0,6	1000	20	1,5	2,4	26	0,6	0,01	1,9	
E274	26	13	172	2	416	1	117	2,5	−1,4	6	3,3	1200	20	2,3	1,2	146	0,2		0,3	
Q390	124	47	149	6,5	710	95	96	2,5	+1,1	13	1,2	1600	33	2,4	1,6	39	0,5	0,2	1,6	
Q392	4,4	12	73	3	372	8	36	2,5	−24	0,2	1,2	900								
E180	86	22	135	5	615	2	76	2,5	−0,8	<0,2	0,4	1500	24	2,7	2,4	46	0,4		1,0	
E138	4	2	24	6	48	11	10	57	−17	0,8	0,6	190								
L406	107	19	54	11	224	2,5	250	5,8	−6,8	1,0	0,2		20	0,3	3,5	8,4	1,5	0,01	2,9	
RK5	65	25	58	12	211	55	130	0,7	−1,2		0,5		16	0,7	1,6	8,6	0,9	0,3	2,1	
W85	1	1	10	2	23	30	8	16	−41	0,4	0,2									
PM341	244	85	108	32	472	2	624	2,5	−1,4	64	0,4	2850	50	0,3	1,7	5,7	1,6	0,01	4,1	
R182	37	19	122	32	166	2	315	2,5	−10	46	<2,5	1320	21	0,6	1,2	6,5	0,7	0,02	0,6	

	milligrams per litre									mg l⁻¹		µS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
7/R183	35	13	37	8	169	2	35	24	+5,1	1	0,4	500	9	1,6	1,6	7,9	0,6	0,02	1,8	
RK6	10	5	9	3	88	2	8	0,5	-12		<0,1		3	1,8	1,3	5,3	0,4	0,03	2,3	
H3	9	3	18	5	83	2	10	2	-3,3	35		150	3	2,8	1,8	6,1	0,3	0,03	0,9	
H2	13	4	36	3	144	2	4	3	+0,3	38		240	5	14	2,0	20	0,3	0,02	0,6	
H7	15	3	25	4	119	2	7	2	-0,8	5		180	4	5,5	3,0	11	0,4	0,02	0,9	
L413	44	38	62	4	492	2	112	6	-16	28		990	19							
Q95	41	35	75	5	369	2	80	2,5	-0,4	<0,2	0,4	900	17	1,5	0,7	26	0,3	0,01	1,5	
DP45	41	21	32	9	278	2	27	2,5	+0,1	0,2	0,3	600	11	1,8	1,2	5,9	0,5	0,01	2,7	
Q96	41	17	44	3	307	5	5	2,5	+1,1		0,6	500	11	14	1,5	25	0,4	0,02	1,8	
W78	34	10	46	4	202	18	21	2,5	+3,4	<0,2	0,5	600	9	3,4	2,1	20	0,5	0,1	1,3	
W161	58	8	63	4	296	2	83	2,5	-6,3		0,5	700	14	1,2	4,4	27	0,6	0,01	1,3	
GK38	152	55	136		370	1	458	4	-0,9	0,8	0,2	2100	38	0,5	1,7		1,3		2,1	
GK247	208	114	70		460	6	608	2,5	-2,8	1	0,4	2700	48	0,2	1,1		1,4	0,02	6,5	
GK246	126	39	144		481	2	345	2,5	-1,8	14	0,2	2100	35	0,6	2,0		0,8	0,01	1,5	
GK244	122	73	103		391	1	429	2,5	-3,2	24	0,2	2110	36	0,4	1,0		1,0		2,7	
Q394	191	36	67		464	13	314	3,9	-2,4	0,8	0,2	1800	33	0,3	3,2		1,3	0,04	4,3	
X169	89	32	38		489	2	34	2,5	-0,6	4	0,2	870	18	1,7	1,7		0,6	0,01	4,3	
X168	180	48	205		617	27	452	2,5	-1,5	28	0,3	2550	46	0,7	2,3		0,9	0,06	1,5	
X163	284	83	119		475	10	688	2,5	-1,3	1,4	0,2	2850	54	0,3	2,1		1,8	0,03	4,1	
R184	94	18	90		364	13	145	12	+0,7	8	0,2	2250	21	1,0	3,2		0,8	0,05	1,6	
PM21	63	28	30		420	2	16	2,5	+3,5	18	0,2	640	14	2,9	1,4		0,5	0,01	4,2	
A185	168	65	136		866	125	191	3	-3,5	17	0,4	2100	43	1,1	1,6		0,6	0,2	2,3	
DP44	103	22	64		487	1	82	2,5	-1,6	5	0,1	1000	20	1,2	2,8		0,7		2,5	
L404	160	43	72		256	7	406	7,6	-2,2	0,6	0,2	1950	31	0,3	2,3		1,9	0,03	3,7	
KK192	151	63	73		485	28	259	41	-1,0	0	<0,1		33	0,4	1,5		1,0	0,07	4,0	
RK16	166	24	79		344	1	334	0,3	-3,7	1,6	<0,1		29	0,4	4,2		1,5		3,0	
H34	7	5	15		71	2	12	9	-3,7	34		140	3	1,9	0,9		0,3	0,04	1,2	
H33	4	4	40		163	2	12	5	-4,2	1,2		270	6	5,1	0,6		0,07	0,02	0,3	
Q148	8	3	39		57	2	6	3	-8,9	8		220	5	10	1,6		0,2	0,02	0,4	

	milligrams per litre									mg l⁻¹		µS cm⁻¹	meq l⁻¹	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca+Mg / Na	Notes
7/W84	10	5	34		134	6	14	7	-6,3	2,3		210	5	3,8	1,2		0,2	0,06	0,6	
Q137	0	6	11		62	2	4	4	-2,4	65		110	2	4,2				0,04	1,0	
H35	48	16	39		164	2	119	2	-4,0	9		580	12	0,5	1,8		0,9	0,02	2,2	
H30	0	1	9		42	2	5	6	-25	23		70								
H32	20	13	71		229	2	74	7	-1,7	<0,2		540	12	1,5	0,9		0,3	0,01	0,7	
H26	29	3	39		189	2	23	6	-4,2	1,4		330	8	2,6	5,9		0,5	0,01	1,0	
H25	31	7	17		177	2	10	5	-4,1	4,2		280	6	2,6	2,7		0,5	0,01	2,9	
H13	39	13	68		360	2	15	5	-2,1	27		520	13	7,0	1,8		0,3	0,01	1,0	
H17	10	5	25		51	2	36	6	+7,9	65		250	4	1,1	1,2		0,6	0,05	0,8	
H16	24	8	35		199	8	16	3	-5,3	31		320	8	3,4	1,8		0,4	0,05	1,2	
H14	0	1	12		43	3	3	7	-15	38		70	2	6,2				0,09	0,2	
E189	0	1	21		68	0	6	4	-6,9	0,4		110	3	5,4					0,09	(?) 1972 analysis
E189	231	83	86		487	2	560	2,5	-2,3	35	0,3	2550	47	0,2	1,7		1,5	0,01	4,9	1978 analysis

APPENDIX 2

Report on a Visit to the Lower Shire Valley, including field determinations and laboratory analyses of water samples.

(Laboratory analyses by Miss J M Cook, Institute of Geological Sciences, Wallingford UK)

1. Introduction.

1.1 The author accompanied by Mr S M N Mainala, Senior Hydrogeologist in the Groundwater Project, visited the Lower Shire Valley between 3rd-6th November 1980. The visit was arranged in cooperation with Mr H Staal, Hydrogeologist to the Shire Valley Agricultural Consolidation Project at Ngabu. Boreholes and wells on the west side of the Shire Valley between Nchalo and Bangula were visited (Figure A-1). Samples were taken for field measurements of chemical parameters and in some cases samples were retained for subsequent chemical and isotopic analysis in the laboratories of the Hydrogeology Unit, Institute of Geological Sciences at Wallingford, UK.

1.2 There seems little doubt that, although groundwater quality is a problem in this region, the predominant problem of rural water supply is the maintenance of borehole equipment. Many of the boreholes which appear in the records as yielding saline water were found to be long-since abandoned - maintenance probably being neglected due to the low demand for the water. In many such areas the traditional, often-unprotected, water sources remain the only local water supply if such exists. A similarly high proportion of pump breakdowns was noted amongst boreholes yielding 'acceptable' or 'marginal' quality water (these descriptive terms reflect local acceptability of water quality rather than any definitive classification). A figure of around 30% is estimated for breakdowns currently awaiting maintenance (H Staal, personal communication). Thus a heavy demand is placed upon those boreholes which are operating acceptably, with women and children frequently walking several kilometres to draw water. The traditional water sources obviously still fulfill a large part of the demand for water in these areas where the effective operating borehole distribution is so sparse. The Lower Shire Valley is an area where insufficient quantity of water, particularly of 'acceptable' quality, operates against the health of the population both directly through poor hygiene and indirectly through the deterioration in quality of traditional unprotected water sources as a result of the heavy demand upon them.

1.3 The Lower Shire Valley hydrochemistry is discussed in section 3.4 of the main report, using available data from the analytical files. The geochemical sources of water quality problems are discussed there and also in section 4. The aims of the short visit in Nov. 1980 were to demonstrate and evaluate field sampling and analytical methods, and also to collect samples for subsequent analysis and comparison with archived analytical data.

2. Analytical Methods.

2.1 Field analytical methods and measurements were as follows:

Temperature	mercury thermometer
Conductivity	pHOX 52 meter and cell (see Appendix 4)
pH	pHOX 42 meter and electrode (calibrated with pH4, 7 and 9 buffers)
HCO_3^- (total alkalinity)	titration with Hach 1.589N H_2SO_4 cartridge and Hach digital titrator; 50 ml sample + bromophenol blue indicator.
Cl^-	Bausch & Lomb kit based on HgCNS titration and colour change.
SO_4^{2-}	Bausch & Lomb kit based on $BaSO_4$ turbidimetric determination used Minispec 20.
Fe	Bausch & Lomb kit based on $2,2^1$-bipyridyl complex formation and spectrophotometric measurement using Minispec 20.
NO_3^-	Bausch & Lomb kit based on diazotisation (hydroxylamine and sodium azide reagents) and spectrophotometric measurement using Minispec 20.

The calibration curves supplied with the Minispec 20 were used for the spectrophotometric measurements. Standards were prepared in the Water Resources Section laboratory in Lilongwe and analysed by the Bausch & Lomb kits to give a measure of the reliability of these calibration curves:

Cl^- standard 178 mg/l measured as 160 mg/l

SO_4^{2-} standard 50 mg/l measured as 40 mg/l

Fe standard 1.0 mg/l measured as 1.0 mg/l

NO_3^- standard 2.0 mg/l measured as 2.37 mg/l

Filtered (0.45 µm) and unfiltered samples were taken. No samples were acidified. Field measurements were mostly on unfiltered samples, i.e. on the water as it is drawn for use. Filtered samples were returned to UK for full analysis. In future, samples should be acidified after filtration, as described in Cook et al., 1979.

2.2 Chemical analyses at the Wallingford (UK) laboratory were by the following methods (see Cook & Miles, 1980) under the supervision of Miss J M Cook:

Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe, Mn, SO_4^{2-}	inductively coupled plasma spectrophotometry
Cl^{-}, NO_3^{-}	Technicon Auto-Analyser colourimetric methods
HCO_3^{-}	acid titration
F^{-}	Orion specific ion electrode using TISAB buffer

Stable isotope analyses of $^{18}O/^{16}O$ and $^{2}H/^{1}H$ were also carried out at Wallingford by mass spectrometry.

3. RESULTS

3.1 The field and laboratory analytical data are listed in Table A-1, and in Table A-2 for those sites at which limited data was collected and no samples retained; pH data are listed in Table A-3. The distribution of the sample locations is shown in Figure A-1. Table A-1 is constructed to allow comparison of field and lab data for each sample. The cation-anion charge balances for the UK lab analyses are excellent except for two samples (Mwana Na Njovu well and D30) for which there is no obvious explanation. In many cases the present set of data can be compared with existing analyses (up to 8-10 years old) from the files which are to be found in Appendix 1 of this report.

4. DISCUSSION

4.1 Comparison of the field and lab analytical data shows that the field methods provide a fairly good approximation for Cl, HCO_3, NO_3 and SO_4 in most cases. Serious deviation in HCO_3^{-} values occur for the most saline samples - Chimpambana well, X215, Y58, Q417 and Z201 - with field values being much higher than lab values. No obvious explanation can be offered, although it is possible that some HCO_3^{-} was lost from solution during storage due to $CaCO_3$ precipitation; it is also possible that some undetermined contribution to total alkalinity was present in these saline samples or that the salinity somehow had a strong influence on the end-point behaviour of the indicator. Further investigation of this discrepancy is required. Fe analyses in the field (only 3 determinations) are higher than lab values; this may be due to the breakdown of Fe-complexes (4.2.2) and subsequent 'plating-out' of Fe precipitate on the bottle during storage.

4.2 The large discrepancy between field and lab pH values (Table A-3) demonstrates the inherent instability of the pH buffering of these groundwaters, which might also lead to the $CaCO_3$ precipitation already suggested to be a cause of HCO_3^{-} discrepancy. Table A-4 lists saturation (equilibrium) indices for the groundwater samples with respect to calcite, dolomite and gypsum (Bath, 1980). These calculations show that most of the samples are in equilibrium with calcite under the pH conditions measured in the field, and therefore indicate that the upwards drift of pH during storage must result in a tendency towards oversaturation and precipitation. The saline samples tend to be those showing the most positive SI values with field pH values, and which would therefore have the greater probability of precipitation and loss of HCO_3^{-} from solution.

4.3 Sixteen samples were taken from boreholes for which chemical data already exist in the files: Q299, Q235, Q191, X218, PM103, Y58, Q185, FC9, Q303, K12, PM114, X62, X199, D30 and RB99. In general, the agreement between old and new analyses is reassuring with regard to the reliability of archived data with the exception that in virtually all cases the Ca and Mg values are different although the total equivalents (Ca + Mg) is often similar. This is attributed to the EDTA titration method used for the archived data, whereby separation of Ca and Mg may be unreliable. Great caution should be used in interpreting Ca and Mg data (e.g. as Ca/Mg ratios) in Appendix 1. The apparent stability of hydrochemistry with time at many boreholes (e.g. Q235, Q191, X218, Y58, FC9, PM114, X62, RB99) demonstrates the lack of 'stress' placed on the aquifer by the small abstraction caused by hand-pumping. Q299 is slightly less mineralised than previously - this borehole has a motorised pump and is reported to be only about 100 m away from a previous borehole which was 'saline'. The NO_3^- concentration in Y58 has apparently risen from 14 to about 50 mg/ - this borehole water is 'saline' and used mainly for washing, and is drunk 'only when thirsty'; the borehole surround is in poor condition and has much cattle activity. The old and new analyses for Q417 are very different, the recent sample being less mineralised in all respects including lower NO_3^-. X199 is situated at Ngulwe on an outcrop of Karoo sediments and therefore provides a good example of groundwater located in a solid rock aquifer rather than in unconsolidated alluvium. This groundwater sample show slightly elevated mineralisation (Na, HCO_3, SO_4, Cl) compared with the old analyses, and it again shows a high NO_3^- concentration (45 mg/l) though not as high as the previous analysis (75 mg/l). Pollution in this case is possibly from sanitation of surrounding habitation, though there are no houses within about 100 metres. This illustrates the potentially greater pollution threat from sanitation directly into a solid, possibly fissured, rock matrix compared with alluvial sequences in which clay-rich strata help to attenuate movement of waste products. Borehole L206 (marked 'L200'?) at Mbenje is less than 30 metres from a pit latrine, and consequently it is no surprise to find about 20 mg/l NO_3^- in this groundwater which is in use for consumption despite its poor mineralisation (2600 $\mu S\ cm^{-1}$ EC). These latter two polluted groundwaters, as suggested by their NO_3^- content, are good examples of sources which should be investigated further by bacteriological examination to determine the magnitude of any health risk. The F^- analyses are also in fairly good agreement with the previous analyses where data is available, with the exception of X62 where the reported previous value of 6.9 mg/l again casts doubt on the accuracy of the transfer of data to the Cardex files. The present analyses confirm the seriously high F^- at PM114 (7.6 mg/l) which is attributed to the presence of localised hydrothermal mineralisation in a fault-zone (para 3.4.5 in the main report).

TABLE A-1

No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg / Na	Notes
	milligrams per litre									mg l^{-1}		$\mu S\ cm^{-1}$	meq l^{-1}	equivalent ratios						
1H/SM 262					560	<5	<20	19		<0,2		869								Field measurements
	89	49	39	0,7	550	6,9	15	12	+2.1	<0.015	0,44		20	4.0	1.1	95	0,5	0,02	5,0	UK lab analysis
1H/Q299					760	~500	120	1,5		0,1		1980								Field
	65	107	227	0,9	750	252	127	<2	+1,9	<0.015	0,90		43	2,8	0,4	429	0,3	0,4	1,2	Lab
1H/Q235					650	~100	60-80	2,6		0,3		1470								Field
	20	27	270	0,8	630	118	69	<2	+0,8	<0.015	1,1		30	6,0	0,5	574	0,1	0,2	0,3	Lab
1H/Well					3470	320	400-600	190				4890								Village well at
	10	27	1250	3,1	2320	352	315	205	-0,4	<0.015	5,2		115	6,1	0,2	685	0,01	0,2	0,05	Chimpambana (Grid 033789)
1H/Q191					620	~50	40-60	17		0,2		1200								Field
	51	62	106	<0.6	640	11,5	40	16.8	+0.61	<0.015	0,85		24	4,1	0,5	>300	0,2	0,02	1.7	Lab
1H/X218					860	~200	60-80	1,7		0,3		1570								Field
	31	75	217	<0.6	800	105	53	<2	+1,1	<0.015	1,1		34	6,3	0,3	>615	0,1	0,2	0,8	Lab
1H/X215					1880	~1600	~520	2,6		0,5		4650								Field
	39	123	1010	2	1330	770	635	<2	+0,3	<0.015	0,83		112	2.5	0,2	859	0,09	0,7	0,3	Lab
1H/PM108					860		80-100	2,4		0,35		1470								Field
	31	71	202	0,8	810	84	30	<2	+1.0	<0.015	0,66		32	10,4	0,3	429	0,1	0,1	0,8	Lab
1H/M21					870	~110	160-180	0,4		0,25		2410								Field
	16	40	453	0,8	840	197	248	<2	-2,2	<0.015	1,5		49	2,8	0,2	963	0,06	0,3	0,2	Lab
1H/Y58					1260	420	820	43		0,55		5250								Field
	43	182	1020	<0.6	1120	628	1000	49.6	+0,9	<0.015	1,9		122	1,6	0,1	>2890	0,1	0,7	0,4	Lab

TABLE A-1 cont'd

	milligrams per litre									mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca•Mg / Na	Notes
1H/Q185					540	13	100-120	5,6		0,15		1180								Field
	75	30	124	1,2	450	18	134	<2	+0,4	<0.015	0,4		23	1,4	1,5	176	0,5	0,05	1,2	Lab
1H/FC9					530	~80	200-220	3,0		0,1		1640								Field
	19	22	291	1,3	460	89	220	<2	-0,5	<0.015	1,6		31	2,0	0,5	381	0,1	0,3	0,2	Lab
1H/RB150 & RB151					410	>80	220-240	0,4		0,15		1780								Field
	34	23	295	5	400	95	290	<2	-0,5	<0.015	2,9		33	1,6	0,9	100	0,3	0,3	0,3	Lab
1H/Q417					1350	~300	660-680	7,0				4460								Field
	34	56	979	1,7	1160	351	790	14,6	+0,1	<0.015	1,3		98	1,9	0,4	979	0,09	0,4	0,2	Lab
1H/Q364					880	12	20-40	6,6				1130								Field
	63	56	83	0,6	590	22	33	11	+0,6	<0.015	0,53		23	3,9	0,7	235	0,3	0,05	2,2	Lab
1H/Q303					870	12	40-60	2,6				1240								Field
	60	59	106	1,3	640	24	52	<2	+0,1	<0.015	0,38		25	3,2	0,6	139	0,3	0,05	1,7	Lab
1H/K12					1190	40	40-60	6,0				1240								Field
	19	40	190	<0,6	600	43	98	8	-4,2	<0.015	0,72		26	3,0	0,3	>538	0,1	0,09	0,5	Lab
1H/Well					510	11	20-40	7,7				900								Water-hole at Mwar
	40	48	28	5,1	490	22	22	8.4	-11.8	<0.015	0,13		17	2,0	0,5	9,3	0,3	0,06	4,9	Na Njovu (Grid 1857
14/Z201					2360	250	60-80	1,3				2340								Field
	57	30	462	2,4	1010	290	82	<2	+1,1	<0,015	0,47		50	8,7	1,2	327	0,2	0,4	0,3	Lab
1G/PM114					390	300	160-180	1,1				2740								Field
	71	17	484	21	420	335	432	<2	+0,9	<0,01	7,6		53	1,7	2,5	39	0,5	1,0	0,2	Lab

TABLE A-1 cont'd

	milligrams per litre								Balance %	$mg\ l^{-1}$		$\mu S\ cm^{-1}$	$meq\ l^{-1}$	equivalent ratios						
No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3		Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg / Na	Notes
G/X62					375	~7	40-60	6,9				610								Field
	40	14	70	4	320	15	20	16	-0,7	0,028	0,82		13	5,4	1,7	30	0,4	0,06	1,0	Lab
H/X199					1010	16	280-300	26				2655								Field
	65	55	464	1,7	960	37	385	45	-0,2	<0,015	1,1		56	1,9	0,7	464	0,2	0,05	0,4	Lab
H/D30					610	<5	40-60	3,9				1070								Field
	33	52	58	0,7	600	9	25	<2	-11.8	<0,015	0,34		19	3,6	0,4	141	0,2	0,02	2,4	Lab (Ca^{2+} erroneous?)
H/RB99					510	460	160-180	0,4				2660								Field
	20	16	557	1,4	500	578	225	<2	-0,04	<0,015	2,8		53	3,8	0,8	676	0,1	1.5	0,1	Lab
H/L206					920	210	180-200	15				2600								Field
	18	45	506	1,3	880	247	250	21,2	-0,6	<0,015	1,1		54	3,1	0,2	662	0,06	0,4	0,2	Lab.

TABLE A-2

No	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Balance %	Fe	F	EC	TDE	Na/Cl	Ca/Mg	Na/K	Ca/HCO_3	SO_4/HCO_3	Ca·Mg / Na	Notes
	milligrams per litre									mg l^{-1}		µS cm^{-1}	meq l^{-1}	equivalent ratios						
Namsato R. water-hole					~690	~10	20-40	1,7				1120								Grid Ref. 897816
1H/Q271					~740	~50	40-60	4,5		0,55		1315								
1H/X57					~1270	~360	480-500	0,4		0,6		4050								
1H/Y42												3170								
1H/X225												3380								
River Shire					~145	<10	20-40	3,2				285								at Sucoma Irrigation intake
1H/X63								1,7				1120								
Mbenje well								4,7				2970								Grid Ref 183739
1G/D91								1,3				1500								
Mbobo well								3,9				990								

TABLE A-3. Source details and comparison of field and lab. pH values for samples taken in Lower Shire, Nov. 1980.

Sample number & location	Water temp, °C	Field pH	Lab. pH
SM262 Maluwa village	29.5	6.7	8.05
Q299 Mikalango	30	6.8	8.1
Q235 Malikapo	29.5	7.25	8.35
Chimpambana well, Grid 033789	26.5	7.85	8.35
Q191 Chimpambana	29	7.05	8.05
X218 Balala	28	7.2	8.2
X215 Ubala	28.5	7.35	8.25
PM103 Khozo	29.5	7.1	8.2
Q271 (?X217) Chamboko	29	7.05	
X57 (?X57) S. of Msomo	29	7.2	
Y42 S. Of Msomo	29	7.3	
M21 Centre of Msomo	29	7.5	8.2
X225 Kumwembe	30	7.45	
Y58 N. of Gome	29.5	7.2	8.15
Q185 Jombo 1	29.8	7.0	8.0
River Shire at Sucomo irrigation intake	28	8.05	
FC9 Sucomo Estate, 'D' township	30.5	7.8	8.1
RB150/151 Nchalo urban supply boreholes	31	7.5	8.25
Q364 Rabu, Sorgin	29.5	6.9	8.3
Q303 Sorgin dispensary	29.5	7.0	8.15
X63 (?X70) Sorgin market place	29.8	7.1	
K12 Jowaki	29.5	7.6	8.2
Shallow well at Mbenje, Grid 183739	30	7.8	
L206 Mbenje	30	7.55	
Water-hole in Lalanje R., Mwana Na Njovu Grid 185743	29.5	7.2	8.2
Z201 Chiromo	29	6.95	8.2
PM114 Lino	29.5	7.1	8.1
X62 Nanthana	30	7.3	8.05
D91 (?D28) Dande	28	7.05	
X199 Ngulwe	30	6.9	8.1
Shallow well at Mbobo, Grid 160678	28	7.4	
D30 Mbobo	29.5	7.0	8.1
RB99 S. of Sorgin	30	7.7	8.25
Q417 Kanzere	31	7.4	8.2

Table A-4. Carbonate equilibrium calculations (Bath, 1980).

Saturation index (SI) <0 indicates undersaturation >0 oversaturation and

0 = equilibrium

Sample No.	SI(calcite)	SI(dolomite)	SI(gypsum)	Log P(CO_2)
SM262	+0.003	+0.07	-2.46	-0.94
Q299	-0.03	+0.48	-1.23	-0.92
Q235	-0.10	+0.25	-1.88	-1.43
Chimpambana well	+0.49	+1.72	-2.01	-1.52
Q191	+0.15	+0.71	-2.49	-1.23
X218	+0.095	+0.90	-1.82	-1.30
X215	+0.34	+1.49	-1.17	-1.26
PM103	+0.04	+0.78	-1.90	-1.18
M21	+0.09	+0.90	-1.87	-1.58
Y58	+0.18	+1.31	-1.25	-1.18
Q185	+0.14	+0.21	-2.11	-1.32
FC9	+0.31	+1.02	-2.02	-2.12
RB150/151	+0.21	+0.58	-1.76	-1.88
Q417	+0.38	+1.32	-1.47	-1.34
Q364	+0.07	+0.41	-2.11	-1.11
Q303	+0.17	+0.66	-2.11	-1.18
K12	+0.24	+1.13	-2.32	-1.80
Water-hole, Mwana Na Njovu	+0.11	+0.64	-2.26	-1.48
Z201	+0.15	+0.35	-1.17	-0.95
PM114	+0.02	-0.26	-1.02	-1.48
X62	+0.08	+0.04	-2.32	-1.76
X199	+0.21	+0.67	-2.01	-0.91
D30	-0.08	+0.36	-2.74	-1.20
RB99	+0.10	+0.43	-1.37	-2.00
L206	+0.21	+1.14	-1.76	-1.60

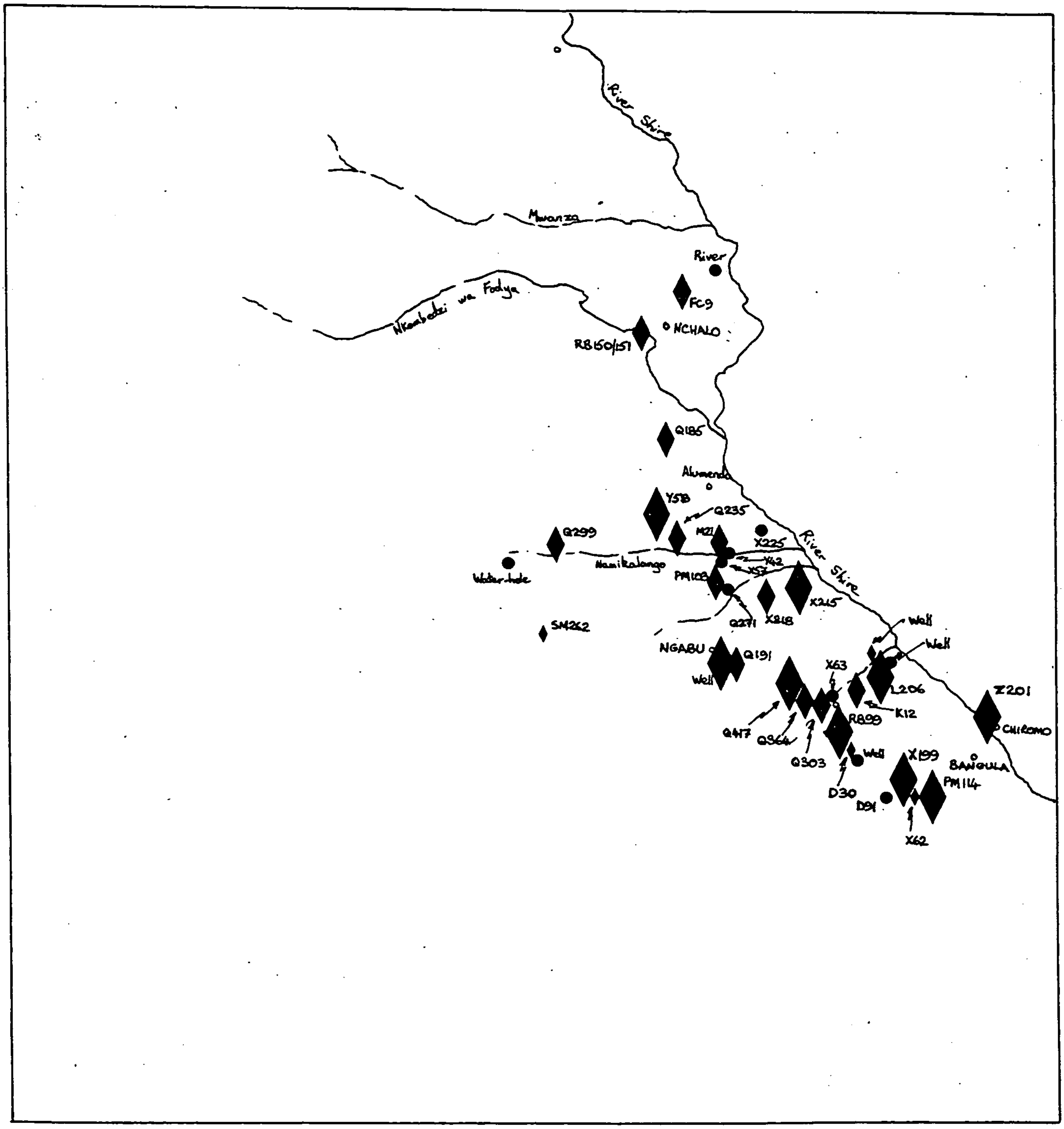


Figure A-1 1:500,000 Sketch map of part of Lower Shire Valley showing sites visited during November 1980.
Compare with Fig. 8 in text of main report.

♦ <20 meq/l
♦ 20-50 meq/l
♦ >50 meq/l
} Samples taken for analysis

● Field measurements only

APPENDIX 3

Central Water Laboratory (Lilongwe)

Recommended Minimum Specification.

Accommodation: At least 5 rooms are required, suitably fitted out:

Instrument Lab (at least 25 m^2) : housing atomic absorption, flame photometry, spectrophotometer. Ample bench space and cupboard space. Adequate electrical supplies for instruments. Preferably air-conditioned to a suitable standard.

General Lab (at least 50 m^2) (or several smaller labs) : for wet chemical work, sample preparation, etc. Housing ovens, refrigerator, water bath, pH and specific ion meter, water still and deioniser. Fitted with fume cupboard, ample bench space, sinks, and storage space for reagents and analytical glassware.

Bacteriological Lab (at least 20 m^2): for Millipore filter tests, incubation and examination. Housing incubating oven and water bath.

Store Room : for storage of samples, stocks of equipment, etc.

Office : for Senior Chemist.

Equipment:

Atomic absorption spectrophotometer with selection of lamps (Na, K, Ca, Mg, Fe, Mn). A straightforward instrument is recommended, preferably with parts in common with instruments in other establishments in Malawi so that loans of e.g. lamps are possible when breakdowns occur. No routine service facilties are yet provided in Malawi by any manufacturer. Acetylene and nitrous oxide gases are available from Industrial Gases Ltd., in Lilongwe.

Flame Photometer: to provide analysis for Na, K and Li.

Spectrophotometer (UV/Visible): for example, Pye-Unicam SP600.

Specific ion meter and electrodes: for pH measurement, F^-, Cl^- titration (Ag/AgCl electrode), S^{2-} (Ag/AgS electrode).

Water still and deionising equipment.

Water-bath (12-place).

Weighing balance (single-pan digital readout torsion balance).

Oven (up to 300°C).

Refrigerator.

Millipore filter test kits (2) for bacteriological examination with culture media for faecal coliforms and faecal streptococci.

Incubating oven and water-bath.

Adjustable autopipettes and tips (e.g. 1, 5, 10 ml).

Polythene sample bottles, screw top, 500 ml/1000 ml.

Glassware (burettes, pipettes, volumetric flasks, beakers, graduated cylinders, etc.) - some more resilient plasticware is now available. Also evaporating dishes.

Filtration equipment for chemical purposes, e.g. Millipore set.

Stock of consumables - chemicals, etc.

An approximate estimate of the capital cost of the above equipment is K50,000.

APPENDIX 4

Calibration and Use of pHOX 52 Conductivity Meters.

The meters and cells have been calibrated using 0.05M KCl solution (theoretical EC = 6670 μS cm^{-1} at 25°C) and the Wayne-Kerr M101 Bridge with Mullard conductivity cell (cell constant K = 1.89).

It has been found that (i) a cell constant (K) must be applied to readings to obtain a calibrated value in μS cm^{-1}, i.e. corrected EC at T°C = Measured EC at T°C x K and (ii) the temperature compensation circuit (T "IN") which supposedly re-adjust EC readings to a 25°C value is unreliable at the ambient temperatures experienced.

Therefore the proposed measurement procedure is as follows:

(i) Measure EC (T°C) with temperature compensation "OUT";

(ii) Measure T if possible otherwise assume a value (29-30°C seems common in the Lower Shire groundwaters, for example);

(iii) Corrected EC (T°C) = Measured EC (T°C) x K (K values are marked on probes and listed below)

(iv) $$\text{EC } (25^{\circ}\text{C}) = \text{EC } (\text{T}^{\circ}\text{C}) \quad 1 - \frac{(\text{T}-25)}{50} \quad \mu\text{S cm}^{-1}$$

(this assumes a temperatures coefficient on EC values of 2% per °C).

Conductivity Probe Number	Used with Meter No.	K Value	Location
EC 1	1	1.14	Lilongwe
EC 2 (short lead)	Spare (1)	1.13	
EC 3	2	1.28	Lilongwe
EC 4	3	1.18	Ngabu
EC 5	Spare (1)	1.48	
EC 6	4	1.11	Borehole siting (C.Carr)

Calibrations may change with time and use, and should be checked periodically (say, every 6-12 months) against the M101.

APPENDIX 5

TI-59 Programmable Calculator Program for Processing Chemical Data.

A program has been written and recorded on magnetic card for the TI-59 calculator. Analytical results (in mg/l) for the major species are keyed in and the output to the PC-100 printer comprises:

(i) cation-anion charge balance, %;

(ii) equivalent percentages of Ca, Mg, Na + K

and HCO_3, SO_4, Cl + NO_3

for plotting trilinear diagrams;

(iii) total determined equivalent, TDE

$$TDE = \Sigma\ (Ca + Mg + Na + K + HCO_3 + SO_4 + Cl + NO_3) \text{ in meq/l.}$$

(iv) equivalent ratios Na/Cl, Ca/Mg, Na/K, Ca/HCO_3, SO_4/HCO_3 and (Ca + Mg)/Na;

(v) 'excess Na' defined as (Na - Cl) in meq/l;

(vi) Sodium Adsorption Ratio, SAR, and Residual Sodium Carbonate, RSC, defined by:

$$SAR = \frac{(Na^+)}{\left[\dfrac{(Ca^{2+}) + (Mg^{2+})}{2}\right]^{\frac{1}{2}}}$$

$$RSC = (HCO_3^-) - (Ca^{2+}) + (Mg^{2+})$$

where concentrations (X) are in meq/l.

Instructions for use of the program are as follows:

1. Load the program (sides 1 and 2 of the magnetic card) into the TI-59.

2. Initiate by pressing 'CLR' and 'RST'.

3. Key in the analytical data in mg/l:

	Key
Ca	A
Mg	B
Na	C
K	D
HCO_3 (tot. alkalinity)	E
SO_4	2nd A
Cl	2nd B
NO_3	2nd C

After each key the calculator and printer will show the relevant data as entered.

4. The charge balance in +/- % will be printed.

5. Press R/S- the equivalent % of Ca will be printed.

6. Repeat R/S for % of each of Mg, Na + K, HCO_3, SO_4, Cl + NO_3.

7. Press R/S; TDE in meq/l will be printed.

8. Press R/S; Na/Cl will be printed.

9. Repeat R/S for each of Ca/Mg, Na/K, Ca/HCO_3, SO_4/HCO_3, and (Ca + Mg)/Na.

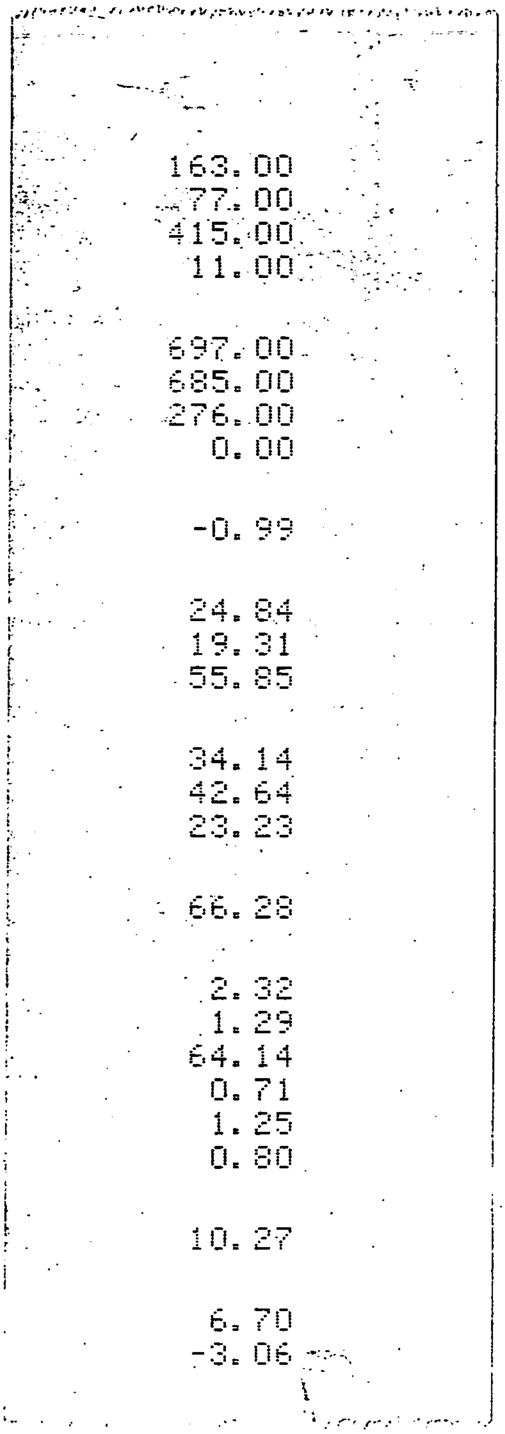
10. Press R/S; 'excess Na' will be printed.

11. Press R/S; SAR will be printed.

12. Press R/S; RSC will be printed.

13. Return to (2) to enter new set of data.

PC-100 Printer Output:



```
163.00    Ca
 77.00    Mg          mg/l
415.00    Na
 11.00    K

697.00    HCO3
685.00    SO4         mg/l
276.00    Cl
  0.00    NO3

 -0.99    Balance, %

 24.84    Ca
 19.31    Mg          %  meq
 55.85    Na + K

 34.14    HCO3
 42.64    SO4                % meq
 23.23    Cl + NO3

 66.28    Total meq/l

  2.32    Na/Cl
  1.29    Ca/Mg
 64.14    Na/K                 equivalent ratios
  0.71    Ca/HCO3
  1.25    SO4/HCO3
  0.80    (Ca + Mg)/Na

 10.27    (Na - Cl)  meq/l

  6.70    SAR
 -3.06    RSC
```

Program Listing:

```
000  76  LBL
001  11   A
002  47  CMS
003  58  FIX
004  02   02
005  99  PRT
006  55   ÷
007  02   2
008  00   0
009  95   =
010  42  STD
011  01   01
012  91  R/S
013  76  LBL
014  12   B
015  99  PRT
016  55   ÷
017  01   1
018  02   2
019  93   .
020  01   1
021  05   5
022  95   =
023  42  STD
024  02   02
025  91  R/S
026  76  LBL
027  13   C
028  99  PRT
029  55   ÷
030  02   2
031  03   3
032  95   =
033  42  STD
034  03   03
035  91  R/S
036  76  LBL
037  14   D
038  99  PRT
039  98  ADV
040  55   ÷
041  03   3
042  09   9
043  93   .
044  01   1
045  95   =
046  42  STD
047  09   09
048  91  R/S
049  76  LBL
050  15   E
051  99  PRT
052  55   ÷
053  06   6
054  01   1
055  95   =
056  42  STD
057  04   04
058  91  R/S
059  76  LBL
060  16  A'
061  99  PRT
062  55  ÷
063  04  4
064  08  8
065  95  =
066  42  STD
067  05   05
068  91  R/S
069  76  LBL
070  17  B'
071  99  PRT
072  55  ÷
073  03  3
074  05  5
075  93  .
076  05  5
077  95  =
078  42  STD
079  06   06
080  91  R/S
081  76  LBL
082  18  C'
083  99  PRT
084  55  ÷
085  06  6
086  02  2
087  95  =
088  42  STD
089  10   10
090  43  RCL
091  01   01
092  85  +
093  43  RCL
094  02   02
095  85  +
096  43  RCL
097  03   03
098  85  +
099  43  RCL
100  09   09
101  95  =
102  42  STD
103  07   07
104  43  RCL
105  04   04
106  85  +
107  43  RCL
108  05   05
109  85  +
110  43  RCL
111  06   06
112  85  +
113  43  RCL
114  10   10
115  95  =
116  42  STD
117  08   08
```

```
118  53  (
119  43  RCL
120  07   07
121  75   -
122  43  RCL
123  08   08
124  54   )
125  55   ÷
126  53   (
127  43  RCL
128  07   07
129  85   +
130  43  RCL
131  08   08
132  54   )
133  65   ×
134  01   1
135  00   0
136  00   0
137  95   =
138  98  ADV
139  99  PRT
140  91  R/S
141  43  RCL
142  01   01
143  55   ÷
144  43  RCL
145  07   07
146  65   ×
147  01   1
148  00   0
149  00   0
150  95   =
151  98  ADV
152  99  PRT
153  91  R/S
154  43  RCL
155  02   02
156  55   ÷
157  43  RCL
158  07   07
159  65   ×
160  01   1
161  00   0
162  00   0
163  95   =
164  99  PRT
165  91  R/S
166  53   (
167  43  RCL
168  03   03
169  85   +
170  43  RCL
171  09   09
172  54   )
173  55   ÷
174  43  RCL
175  07   07
176  65   ×
177  01   1
```

```
178  00   0
179  00   0
180  95   =
181  99  PRT
182  91  R/S
183  43  RCL
184  04   04
185  55   ÷
186  43  RCL
187  08   08
188  65   ×
189  01   1
190  00   0
191  00   0
192  95   =
193  98  ADV
194  99  PRT
195  91  R/S
196  43  RCL
197  05   05
198  55   ÷
199  43  RCL
200  08   08
201  65   ×
202  01   1
203  00   0
204  00   0
205  95   =
206  99  PRT
207  91  R/S
208  53   (
209  43  RCL
210  06   06
211  85   +
212  43  RCL
213  10   10
214  54   )
215  55   ÷
216  43  RCL
217  08   08
218  65   ×
219  01   1
220  00   0
221  00   0
222  95   =
223  99  PRT
224  91  R/S
225  43  RCL
226  07   07
227  85   +
228  43  RCL
229  08   08
230  95   =
231  98  ADV
232  99  PRT
233  91  R/S
234  43  RCL
235  03   03
236  55   ÷
237  43  RCL
```

```
238  06   06
239  95   =
240  98  ADV
241  99  PRT
242  91  R/S
243  43  RCL
244  01   01
245  55   ÷
246  43  RCL
247  02   02
248  95   =
249  99  PRT
250  91  R/S
251  43  RCL
252  03   03
253  55   ÷
254  43  RCL
255  09   09
256  95   =
257  99  PRT
258  91  R/S
259  43  RCL
260  01   01
261  55   ÷
262  43  RCL
263  04   04
264  95   =
265  99  PRT
266  91  R/S
267  43  RCL
268  05   05
269  55   ÷
270  43  RCL
271  04   04
272  95   =
273  99  PRT
274  91  R/S
275  53   (
276  43  RCL
277  01   01
278  85   +
279  43  RCL
280  02   02
281  54   )
282  55   ÷
283  43  RCL
284  03   03
285  95   =
286  99  PRT
287  91  R/S
288  43  RCL
289  03   03
290  75   -
291  43  RCL
292  06   06
293  95   =
294  98  ADV
295  99  PRT
296  91  R/S
297  43  RCL
298  03   03
```

```
299  55   ÷
300  53   (
301  53   (
302  43  RCL
303  01   01
304  85   +
305  43  RCL
306  02   02
307  54   )
308  55   ÷
309  02   2
310  54   )
311  34  ΓX
312  54   )
313  95   =
314  98  ADV
315  99  PRT
316  91  R/S
317  43  RCL
318  04   04
319  75   -
320  53   (
321  43  RCL
322  01   01
323  85   +
324  43  RCL
325  02   02
326  54   )
327  95   =
328  99  PRT
329  98  ADV
330  98  ADV
331  98  ADV
332  98  ADV
333  91  R/S
334  00   0
335  00   0
```

APPENDIX 6

EVALUATION OF CSC FUNDED WATER PROJECTS QUESTIONNAIRE

N.B. Questions marked (I) are to be answered by the interviewer.

A. General Information:

(I) 1.Name of Interviewer ....

2.Name of Interviewee ....

Sex Male/Female

Function:

(I)B. Details of Visit:

1. Date of Visit ....
2. Time of Visit ....
3. Date of last visit (where applicable) ....

(I)C. Type of Project

1. Name ....(Site).........

2. Type of Project:

Borehole ☐ G. S. Number ....

Well ☐ L.D.C. Well ☐

Protected Spring ☐ Government Well ☐

Piped Water ☐

3. Year of Installation ....

(I)D. Location

1. Church Land ☐ Leased/freehold land

(Delete what is not applicable)

Denomination ....

Customary Land ☐

Public Land ☐

2.(a)Are there any difficulties of access? (for users) YES/NO

(b)If Yes, what are the difficulties?

Too far from the user ☐

Too high so that children can't reach ☐

River in way ☐

[illegible] path to climb (elderly) ☐

Other (specify) ☐

(I) 3. General Description of situation including difficulties of access ....

....

....

E.. <u>Description of Surrounding:</u>

(I)1.

(a) Is there provision of an Apron YES/NO

(b) If Yes, what is its condition?

Good ☐ Fair ☐ Poor ☐

(I)2.

(a) Is there a soakaway YES/NO

(b) If Yes, what is its condition?

Good ☐ Fair ☐ Poor ☐

3. By whom were the apron and soakaway constructed?

Local people ☐

D.D.C. ☐

Geological Survey ☐

Other Government Official (Specify) ☐

Mission ☐

4. If there is no apron or soakaway are there any plans to provide these? ....

....

5. Any posible sources of pollution nearby?

(Not relevant for Piped Water Scheme)

		<u>Distance (Estimated)</u>
Pit latrines	☐	.... Feet
Open Wells	☐	.... Feet
Sewage Disposal	☐	.... Feet
Animal	☐	.... Feet
Grave-yard	☐	.... Feet
Pools of Stagnant Waste Water	☐	.... Feet
Other (Specify)	☐	.... Feet

6. Is washing done nearby? YES/NO

at distance of .... feet

7. What happens to waste water?

Vegetable garden ☐

Runs off ☐

Other use (Specify) ☐

(QUESTIONS 8 TO 11 REFER TO WELLS ONLY)

8. By whom was the well constructed?

(I)9. Is the Well open ☐ Covered ☐

(I)10. How high is the well above ground level. (Measure)

(I)11. Any other comments on the state of the well?

F. <u>Pump/Tap</u>

(I)1. Is there a pump YES/NO or Tap YES/NO

(I)2. Is the pump or tap working? YES/NO

3. If No, for how long has it been out of action?

4. Is it easy to operate? YES/NO

5. Does Water flow easily? YES/NO

6. Does it need repairs? YES/NO

7. If so what? ....

8.(a)Is it maintained regularly? YES/NO

(b)If Yes, by whom ? ....

(I)9. If there is a pump, what type of pump is it?

Hand pump: Wheel ☐ Climax ☐

Handle ☐ National ☐

G.S. Bush ☐

C.S.C. ☐ B. & C. ☐

Community Develop. ☐

Motor Driven ☐

(I)10. WELLS ONLY:

If no pump, how is water drawn?

G. <u>USERS</u>

(I)1. How many people were at the water supply at the time of the visit? ....

(I)2. How many of these came to the water supply for the purpose of drawing water? ....

3. How many of the people at the water supply were Male?....... Female ....

4. Indicate predominant age distribution of those at the water supply

(I) Under 15 years old ☐

15-30 years old ☐

Over 30 years old ☐

(I)5. Apart from home domestic use, is the water supply used b

School ☐ School population ....

Health Centre ☐ Health Centre population ......

Mission ☐ How many people ....

Other Institution (Specify) ☐ How many people ....

6. What are the villages using the water supply? (give names of villages)

1........................... 2................ 3 ....

4........................... 5................ 6 ....

7........................... 8................ 9 ....

FOR PIPED WATER, STATE NUMBER OF FAMILIES

7. Can you estimate the total number of people using the wa supply? ....

8. What is the approximate maximum distance travelled?..... miles.

9. What is the distance between the water supply and the ne house .... yards (estimate)

10. Is the water supply also used by animals? YES/NO

YES : Cattle ☐ How many? ....

Goats ☐ " ....

Sheep ☐ " ....

Pigs ☐ " ....

Others(which) ☐ ....

11. Give distance in yards between the water supply tap/pump or well and the point from which animals drink .... yards

H. QUANTITY AND QUALITY OF WATER

1. Is the amount of water:

	in rain season	in dry season
More than enough	☐	☐
Enough	☐	☐

	in rainy season	in dry season
Some but not enough	☐	☐
None at all	☐	☐

2. How does the volume of water compare with that when the water supply was first installed?

More ☐ Less ☐ The same ☐ n't know ☐

(I) 3. How many minutes does it take to fill a four gallon pail? .... Minutes

(N.B. For this question you have actually got to fill the pail and check time it takes)

4. Do you consider the water good with ragards to (delete whatever is not applicable)

Colour	YES/NO
Clearness	YES/NO
Taste	YES/NO
Washing	YES/NO
Cooking	YES/NO
Safety (absence of pollution)	YES/NO

5. Does it change its colour when boiled? YES/NO

6. Are there any seasonal variations in the quality of water YES/NO

If Yes, Specify ....
....
....

I. ALTERNATIVE SOURCES OF WATER:

1. Where did you get your water from before this supply was installed? (Tick what is applicable)

borehole	☐
dug well	☐
river/stream	☐
spring	☐
Lake	☐
Other (Specify)	☐

2. Did you think it was good water? YES/NO

3. How far away was this water?

From present supply .... miles

From the users .... miles

4. Is the old source of water still used? YES/NO

~~5. If Yes, what are the reasons?~~

....

....

J. POLLUTION

1. How can you tell whether water is polluted or not?

Appearance ☐
Taste/Smell ☐
Affects cooking ☐
Recognise source of pollution nearby ☐
Information from health worker etc. ☐
Other (Specify) ☐

2. Is it possible that the present supply could be polluted? YES/NO

3. Do people take steps to make the water safer if it is polluted? YES/NO

4. If so, what? ....

....

....

(QUESTION 5 TO BE COMPLETED IN THE OFFICE)

5. Results of bacteriological water test:

Excellent ☐
Satisfactory ☐
Suspicious ☐
Polluted ☐
Heavily polluted ☐

K. COMMUNITY ATTITUDES

1. Who initiated the project? (Tick what is applicable)

Government ☐
Mission ☐
Village headman ☐
Councillor ☐
Area/Village Action Committee ☐
An Individual (Who?) .... ☐

9. If it is the Committee, how often does it meet? ....

10. How often are the [illegible] inspected. ....

11. Are you happy with the quality of service the water supply is giving? YES/NO

12. If No what is lacking? ....

....

....

....

L. FAMILY USE

1. How many times a day does the family draw water? ....
2. What size is the container you use for drawing water? ....
3. How many are you in your family? ....
4. What do you use this water for

Drinking ☐

Cooking ☐

Bathing ☐

Washing pots, plates etc. ☐

Washing clothes ☐

Giving to animals ☐

Watering Garden ☐

Other (Specify) .... ☐

5. Do you use more water than you used to before the present water supply was installed? YES/NO

6. Has using this water made any difference to the health of your family? YES/NO

If so, What? ....

....

....

....

APPENDIX 7

Timadzi Camp Water Chemistry.

Two boreholes located at Timadzi, near Lilongwe, were sampled and analysed in the field and laboratory (methods as in Appendix 2). The boreholes are sited about 1 km apart on the side of a dambo and penetrate weathered Basement Complex. One borehole (IR22) is recently constructed with plastic lining and about 18-21 metres deep; it is equipped with a hand-pump of local design utilising a perspex plunger. The other borehole is mild steel lined and is about 60 metres deep; it is equipped with a standard hand pump and was in frequent use at the Timadzi Camp.

The analytical results are shown in Table A-5 from which it is apparent that there are marked differences between the chemistries of water pumped at the two sites. Groundwater in the more shallow borehole is considerably more saline than that at the deeper borehole; the increased mineralisation occurs in Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-} and SO_4^{2-} but not in K^{+} or Cl^{-}. NO_3^{-} is also significantly high in the shallow borehole but negligible in the deeper borehole. The higher NO_3^{-} is tentatively attributed to fertiliser pollution of groundwater (4.4.5) although this should be backed up by further investigation of possible sources (including ascertaining fertiliser chemistry) and bacteriological analysis. The increase in mineralisation occurs whilst retaining the remarkably low Cl^{-} concentration (3-4 mg/1) which must be close to that of water recharging the aquifer. It is puzzling that no Cl^{-} increase accompanies the source of NO_3^{-}, since both waste pollution and fertilisers might be expected to contribute some additional Cl^{-}. The possibility of geochemical sources of SO_4^{2-} (3.2.11 and 3.3.8) must be considered for the enhanced SO_4^{2-}.

The contrast in total Fe concentrations has already been mentioned in the main report (4.2.1). It is noteworthy that the filtered sample from the main borehole, in spite of giving the surprisingly high analysis of 7 mg/l Fe consistent with the unfiltered sample, gave only <0.015 mg/l Fe when analysed after storage. The iron has obviously 'plated out' on the bottle walls, presumably due to breakdown of chelate complex similar to the breakdown and 'scum' formation observed on standing overnight or boiling the water.

In summary, the contrasting hydrochemistries at the two boreholes demonstrate the requirement for detailed investigations of the factors and processes controlling pumped groundwater chemistry in this environment. The same conclusion has been made from consideration of regional hydrochemistries in Nkhotakota and Bua catchments (3.2 and 3.3). The influence of borehole location with respect to geomorphological and hydrogeological features of dambos on the chemistry of pumped water requires investigation, and also the influence of methods of construction particularly screened intervals. Measurements of redox conditions are required, as outlined in 4.2.7, in order to assess the significance of corrosion reactions on steel components to the overall dissolved iron load of pumped water. Outline proposals for investigations of the influence of such factors on the chemistry of water from shallow boreholes and wells are attached as Appendix 8.

TABLE A-5. Chemical analyses of pumped groundwater at Timadzi.

(Field determinations in parenthese, except pH)

		Plastic-lined b/h (IR22)	Main b/h, steel lined
Depth, metres		18-20	$\sim$60
Conductivity, μS cm^{-1}		2440	520
pH (lab. values)		7.05 (8.0)	6.65 (7.95)
Ca^{2+}		124	44
Mg^{2+}		105	17
Na^+		309	28
K^+	mg/l	5.6	5.7
HCO_3^-		510 (460)	250 (240)
SO_4^{2-}		812 (750)	33 (22)
Cl^-		4 (<20)	3 (<20)
NO_3^-		48.3 (34)	<2 (2.2)
F^-		1.3	0.4
Fe (filtered)	mg/l	<0.015 (0.85)	<0.015 (7)
Fe (unfiltered)		(0.7)	(6.5)
Mn (filtered)		0.012	0.29
		Some Fe deposit on filter No smell of H_2S	Bitter taste No smell of H_2S No Fe deposit on filter

APPENDIX 8

Proposals for Investigations of Water Quality Variations in Shallow Wells and Boreholes.

Aims.

(i) To establish the magnitude of water quality problems in wells and boreholes in different physiographic and geological environments.

(ii) To investigate methods of construction (depth, casing material, screened interval) and operation (low yield, high yield) affect water quality.

Immediate Tasks.

(i) Identify representative areas where particular problems may be prevalent, and where it is observed that local variations in quality from different sources might offer some hope of finding ways of improving overall water supply quality. Some examples are to be found in my report: groundwater salinity in some areas of the Lower Shire Valley seems to fluctuate widely over short distances, unacceptable concentration of sulphate are found in some but not all of the boreholes in the scarp-foot area of the Salima catchment, iron occurs in unpleasant concentrations in an apparently random selection of boreholes particularly on the upland plateau basement complex areas. The CSC evaluation survey should help in a qualitative fashion to pinpoint the areas where unacceptability really is a problem to groundwater development.

(ii) Follow this up by confirmatory tests using the available field kits. Boreholes on which data already exists in the files should be re-tested to confirm the data. Borehole and wells in the representative areas, but on which data does not exist, should be sampled. It is important that sampling is carried out carefully and systematically, and that filtered samples are taken except for iron when both filtered and unfiltered samples should be analysed. Remember that the field test kits give only semi-quantitative 'estimates'. All field parameters should be collected where possible: temperature, pH, alkalinity. Eh measurements can only be made on non-aerated pumped sources, but every effort should be made to get these for sulphate and iron investigations particularly. Tabulate the maximum information obtainable on well or borehole depth, construction, yield, usage, etc. and also on geology and physiographic situation.

Detailed Studies.

(i) The dependence of groundwater quality with respect to pollution (principally from human/animal excreta) on the method of well or borehole construction needs to be assessed. This requires a careful study of faecal coliforms, nitrate, sulphate and chloride concentrations in existing wells and boreholes under similar conditions. This would require the use of Millipore bacteriological test kits (with appropriate culture media) and the support of reliable laboratory facilities. This work would be supervised by the Senior Water Chemist. In the absence of an appointment to this post, the investigation is of such importance to the future orientation of groundwater development that the visit of a hydrochemist for 2-3 months is suggested.

(ii) The programme for low-cost borehole development and also the Lower Shire Valley drilling project will provide opportunities for investigations of geochemical influences on groundwater quality. The Senior Water Chemist would carry out the study in close collaboration with the hydrogeologists, using if necessary special analytical support in the UK. Careful planning and sampling is required to get maximum information from the drilling operations, depth sampling and pump testing. Down-hole geophysical logging would also be valuable in interpreting chemistry. The timescale over which the drilling and testing programmes would take place would make it difficult for a geochemist on a short-term visit to collect the maximum information. It is suggested that the possibility of short-term geochemical support from the UK be considered by the Senior Water Chemist and hydrogeologists when more details of the proposed drilling programmes are available to them.