ABSTRACT

Borehole and river water samples were collected from the Upper Shire Valley between Lirangwe and Linthipe rivers to investigate the possibility of using collector wells along the Shire river and as a study of groundwater quality in the area.

The general groundwater composition and variation in chemical constituents is given. It is a mixed Na—Ca—Mg—HCO₃ water generally of good quality. Iron, bicarbonate and fluoride are the only excessive ions. Cationic exchange and variation in mineralogy are the main factors affecting quality.

The Shire River water has a Ca—Mg—Na HCO₃ water of a high chemical quality. Little contribution is thought to be made of groundwater to the Shire and flow by leakage may occur in the opposite direction.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Climate, Topography, Soils, Vegetation and Drainage</td>
<td>1</td>
</tr>
<tr>
<td>3. Summary of Geology</td>
<td>2</td>
</tr>
<tr>
<td>4. Hydrogeology</td>
<td>2</td>
</tr>
<tr>
<td>5. Hydrogeochemistry</td>
<td>3-8</td>
</tr>
<tr>
<td>5.1 General</td>
<td>3</td>
</tr>
<tr>
<td>5.2 Water Classes</td>
<td>3</td>
</tr>
<tr>
<td>5.3 S.E.C. and Total Solids</td>
<td>4</td>
</tr>
<tr>
<td>5.4 pH</td>
<td>5</td>
</tr>
<tr>
<td>5.5 Silica</td>
<td>5</td>
</tr>
<tr>
<td>5.6 Iron, Manganese and Zinc</td>
<td>5</td>
</tr>
<tr>
<td>5.7 Cations</td>
<td>5-6</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>5.8 Anions</td>
<td>7-8</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td></td>
</tr>
<tr>
<td>Sulphate</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td></td>
</tr>
<tr>
<td>5.9 Surface Water Analyses</td>
<td>8</td>
</tr>
<tr>
<td>6. Conclusions</td>
<td>8</td>
</tr>
</tbody>
</table>

References

Appendix: Analysis results
Figure

1. Location of Study Area in S. Malawi
2. Trilinear Diagram
3. Cross-Sections at Borehole G74 and B28
4. Geology
5. Hydrogeology
6. Stiff Pattern Diagrams and Ratio of Calcium and Magnesium to Sodium
7. Quality

Tables

1. Range and average ionic constituents
2. Analyses of River Shire samples
INTRODUCTION

To meet further water requirements in the Blantyre area the Geological Survey has suggested to the Blantyre Water Board that collector wells, installed alongside the Shire river between Murchison Falls and Shire Bridge Siding, could provide an alternative water supply.

A preliminary study of groundwater in the area was initiated by the Geological Survey and a hydrogeological map has already been prepared from available existing data. This report considers the groundwater quality.

Forty-four borehole samples and two river samples from the Shire river were collected during August 1972 to investigate the chemical quality, the processes that may be affecting it and on the basis of chemistry to assess the degree of interconnection between the groundwater and the Shire river. An extensive area was sampled to include as many aquifers as possible, and to define lateral changes.

The area lies some 30 miles north of Blantyre in the southernmost part of the Upper Shire valley. It covers 65 square miles forming a roughly triangular shape. The main Blantyre-Nchera road forms the southwest boundary; the Shire river forms the northwestern limit; and the eastern boundary is an escarpment of Basement Complex gneisses. The area location in S. Malawi is shown in Fig. 1.

CLIMATE, TOPOGRAPHY, SOILS, VEGETATION AND DRAINAGE

Climate. Within the valley temperatures are in excess of 75°F (24°C) and bordering the river it may be as high as 100°F (38°C) during part of the year. The highland to the east has a mean annual temperature of less than 75°F (24°C).

Mean annual rainfall along the Shire is less than 33 inches (84 cm); along the valley slopes 30-40 inches (76-102 cm); and on the highlands, in excess of 40 inches (102 cm). The area is considered as a semi-arid to arid climate (Pike and Rimmington 1965).

Topography. The Upper Shire valley is a flat wide valley trending S.S.W. There is a gradual rise of between 200 ft and 400 ft from the Shire, at about 1550 ft O.D., to the foot of the escarpment where a sharp rise to nearly 3000 ft occurs. The escarpment is absent to the southeast of the area and the valley floor rises beyond the main road to an area of more dissected relief.

Within the alluvial plain there are scattered hills rising some 200-500 ft above the valley.

Soils. Fertile, shallow alluvium of gray-brown pebbly sands to silty clays (often having a high mica content) cover most of the area. 'Mopane' soils, mainly sands to sandy-loams with calcium carbonate and iron-manganese concretions, occur on the higher parts of the plain (op. cit.).

Vegetation. The lower slopes are covered with alluvial parkland, lake and river plain vegetation which passes to 'escarpment and foothill woodlands' (op. cit.) to the east. The mopane soils have a distinctive vegetation. Due to heavy cultivation much of the natural vegetation has been altered.

Drainage. The only perennial river is the Shire which flows NE-SW across the western edge of the area in a series of meanders. There is a fall of some 50 ft in the twenty miles from Shire Bridge Siding to Murchison Falls.
The valley slopes are drained by intermittent streams, which usually flow from November to April as 'flash floods'. They form a dendritic pattern, mainly rising on the eastern highlands. The largest streams are the Linjizi, Fatudzi and Linthipe.

3. GEOLOGY

Malawi Basement Complex rocks underlie the area to the north-east, forming the scarp, and also north of the Blantyre-Noheu road are semi-pelitic hornblende biotite gneisses; to the south-east and south-west are kinematic perthitic gneiss and perthitic syenites; and to the south charnockitic gneiss and granulite.

Of more importance as aquifers are the unconsolidated to partly consolidated sediments of the valley floor. To the east and west of the valley these are separated from bedrock by terrace features, probably representing an ancient flood plain.

The oldest sediments are the Matope beds, thought to be late Tertiary in age. These are found, mainly from borehole evidence, west of N.A. Lundu. They are mainly arkosic sandstones (coarse grain to conglomerates) of cream to buff colour and often current bedded, reaching a thickness of over 100 ft. Their origin is probably deltaic, laid down at the edge of a lake or lagoon which is represented by lacustrine black sandy clays (giving 'mopanosols', above) which thicken towards the Shire.

Sheet erosion has resulted in thin spreads of red-brown sandy or gravelly colluvium over the area and they may also underlie the black clays at depth. These sands appear from under cover of the clays at the southern edge. They may become more sandy to the west.

Recently abandoned channels of the Shire can be seen as a braided pattern on aerial photographs. It is possible that older channels may exist further from the river.

The geology is summarized in Fig. 4. Further reference to the geology can be found in Bulletin 16 (Bloomfield 1965) and Bulletin 17 (Bloomfield and Garson 1965) of the Geological Survey.

4. HYDROGEOLOGY

The hydrogeology of the area has been prepared in map form (Fig. 5) by Wilderspin. Unfortunately, as many of the boreholes were drilled during the 1950's and early 1960's, little information is available on strata penetrated and aquifer parameters.

The principal aquifers are:

- Colluvial sands and sands within the black clay deposits;
- Weathered gneiss;
- Fractured gneiss;

Some older wells and boreholes are reported to tap perched aquifers. Aquicludes, which may give rise to more than one piezometric surface, are the clays and unfractured bedrock. The arenaceous Matope Beds appear to be dry (Bloomfield and Garson, 1965, p. 225), although the underlying gneiss contains water.

Yields are variable, ranging from 120 g.p.h. to 2,000 g.p.h., related mainly to availability of recharge and clay content. The best yields are obtained from around the Mafuzi stream. As shown in Fig. 5 boreholes in alluvium do not fully penetrate the aquifer. If an aquifer thickness of 40 ft was assumed, yields of up to 6,000 g.p.h. could be obtained - assuming constant vertical permeability and adequate recharge. Bloomfield and Garson (1965, p. 224) report that where 20 ft or even less of drift rests on weathered rock little difficulty was encountered in obtaining adequate water. The degree of weathering is very variable.
The water table and piezometric surface slope towards the river and strike N.E. parallel to the valley, the slope of both increasing rapidly towards the highlands. The shape of the contours suggests that recharge occurs, particularly along the Chia, Mafuzi and Linthipe streams. Intervening areas show mutually lower yields.

From driller's reports, the only confined conditions occur south-west of the Linjizi stream (Fig. 5). Elsewhere both a water table and piezometric surface occur giving 'leaky confined' conditions with downward leakage. All are sub-artesian. The only reported unconfined area is around borehole B133 by the Chia stream and this may be perched.

With the lack of data it is difficult to ascertain whether the Shire is effluent or influent. Fig. 3 shows the approximate levels of the piezometric surface and water table at the Shire river. The main aquifer is reported at approximately 100 ft below the river and is probably separated from it by clays. Estimating the height of the river in the area around the Matedmi and Linthipe there would appear to be a gradient from the river to the water table and piezometric surface. The contours should 'V' downstream if there is contribution from the river to groundwater. Further reference is made to the interaction of surface and groundwater along the Shire in section 5.9.

5. HYDROGEOCHEMISTRY

5.1 General. Samples were collected in plastic bottles from the outlet point of each borehole after pumping for five minutes to remove standing water. All boreholes were fitted with hand pumps. Sampling cover is not complete mainly due to faulty pumps or dry boreholes at the time of collection. Slotted casing often covers a large percentage of the total depth of the borehole and samples will therefore represent the groundwater composition throughout the aquifers penetrated.

Analysis was made in the Geological Survey laboratory, Zomba, for conductivity, total solids, pH, silica, the major cations and anions (including fluoride), iron, manganese and zinc. In addition the concentration of certain selected heavy metals was determined by spectrometer, although the results of these are not dealt with here.

The results were expressed in parts per million (p.p.m.) on G.S. file X-535 (Appendix). These were converted to equivalents per million (e.p.m.), as an expression of chemical equivalence, and then to percentage e.p.m. This then enabled a quick check on accuracy (by comparing the total e.p.m. cations to that of anions); the construction of a Paper Trilinear diagram (Fig. 2); the plotting of selected ions (summarised as Fig. 7); calculation of selected ratios (Fig. 6) and the plotting of modified Stiff pattern diagrams (Fig. 6).

The range and average ionic compositions for borehole samples are given in Table 1. An attempt is made to divide these into different aquifers, on the evidence available.

Different water types, based on the trilinear and modified Stiff pattern diagrams are first discussed than lateral variations, and their possible cause (s), in individual ionic content summarised.

5.2 Water Classes.

According to the trilinear diagram (Fig. 2) 75% of the samples are of a mixed Na-Mg-Ca-HCO₃ water. This water type is of a typical groundwater composition.

Much greater variation occurs in the cations than in the anions mainly towards sodium or magnesium. On this basis two dominant water types emerge: a NaHCO₃ water
and a NaHCO₃ water with a third water of a Ca-Na or Na-CaHCO₃ type. These waters show
other features for sub-division:
1. Na-HCO₃ with high Mg.
2. Na-HCO₃ with approximately equal Ca, Mg but low SO₄.
3. Na-Ca or Ca-Na HCO₃ with reduced Mg and approximately equal Ca, Na (and may have
   high SO₄).
4. Ca-Mg-(Na) HCO₃ with low Na, approximately equal Ca, Mg.
5. MgHCO₃ water probably represents the original groundwater compositions mainly
derived from the action of the water on mafic minerals. This water is probably modified
down-dip by cationic exchange to a NaHCO₃ water, which occurs in the northern part of area
around the Nafusi stream and at borehole B22. The NaHCO₃ at Q415 possibly reflects the
abundance of sodic feldspars rather than cationic exchange. South west of Malala stream
there occurs Na-Mg-HCO₃ water which is probably a mixed water. The MgHCO₃ water is the
most extensive type and is found in both alluvial and weathered gneiss aquifers, suggesting
hydraulic continuity between them.

Point river samples taken at Murchison Falls and Shire Bridge Siding show a similar
composition to that of a 'mixed' groundwater composition and is a Na-Ca-Mg-HCO₃ water
(see Fig. 6). Further reference to this is made in section 6.7.

5.3. Specific Electrical Conductance and Total Solids (TDS)

Conductivity (S.E.C.) in micromhos was measured in the laboratory. The range is
from 6.9 x 10⁻² to 27.4 x 10⁻² micromhos. Conversion to total dissolved solids can be
approximated by dividing by 1.56.

Total solids was measured by evaporation. The average for all borehole samples
is 676 ppm and ranges from 204-1558 ppm (Table 1). Only two samples, both on the east
bank, exceed 1000 ppm. These figures are very low for waters under semi-arid conditions.
The low values imply lack of mineralized leakage and a higher permeability than is usual
in Malawi.

Areas of less than 500 ppm occur near bedrock areas to the south of the main road
and as isolated areas north of the Linjizi stream, probably in areas of greater trans-
misivity and recharge. It is thought that the eastern bank adjacent to the river may
have a low total solids.

Values in excess of 1000 ppm (Fig. 7) occur in three small separate areas both in
weathered gneiss and colluvium. The two areas on the east bank have high sulphate
and high chloride which may be due to contribution from mineralized leakage. On the
west bank, borehole 153 has a dominant NaHCO₃ water, possibly the result of low permeability
allowing cationic exchange and (?) sulphate reduction to take place. Elsewhere total
solids range from 500-1000 ppm.

5.4. pH. Values of pH, measured to the nearest unit, were obtained in the laboratory
and may not be representative due to changes that may have occurred since sampling.

The pH of a solution is normally controlled by chemical reactions and equilibrium
between ions in solution, of which the most important is hydrolysis (predominantly that
of carbonate to bicarbonate). Of the samples collected the majority have a pH of 6 and
therefore carbonate ions have completely dissociated to bicarbonate ions.
Muir (1954) records an increase in pH with depth in the black lacustrine clays due to an increase in exchangeable sodium.

5.5. Silica (SiO₂)

Silica values range from 7 to more than 125 ppm. It is mainly derived from the decomposition of feldspars and ferromagnesiums, particularly the latter, as the highest values occur in the southern edge of the area around metapyroxenite and charnockitic gneiss and granulite. Values over the rest of the area are mainly less than 60 ppm.

5.6. Iron, Manganese, and Zinc

Iron ranges from 0.1 ppm to 14.5 ppm. Various factors, such as oxidation on sampling, or artificial additions from well pumps or screens, can affect the true determination of iron and no great reliance is put on the results.

The World Health Organisation limit to potability is 1.0 ppm and areas with less than this are found south of the Chia stream in weathered gneiss aquifers and also around the Nafusi stream (Fig. 7). Alluvial aquifers to the north of the Chia stream have values from 1-10 ppm and also west of Mirale siding in weathered gneiss—the latter is probably related to the same source as silica in this area (see above, section 5.5.), although iron oxide is reported as a cementing material in the overlying Matope Beds. The very high value of 14.5 ppm at borehole D76 may be due to standing water and therefore erroneous.

Iron is a common constituent of crystalline rocks, particularly in pyroxenes, amphiboles and the dark mica minerals. It is more abundant in clays than other sedimentary rocks, usually as iron sulphide. In the pH range 6-8 iron will occur in the ferrous state.

Manganese is less abundant than iron, occurring mainly in metamorphic rocks or sediments derived from them. It may be concentrated in sediments by the removal of more soluble minerals and may accumulate in soils as a result of rock weathering.

Concentration of manganese vary from less than 0.01 to 0.33 ppm. Only two samples, B26 and B133 are greater than the World Health Organisation potability limit of 0.3 ppm. Both are in oolitum near the R. Shire (although the river has less than 0.01 ppm) and the manganese may be derived from surface soil sources. Manganese is subject to the same factors that affect iron.

All samples record some component of zinc, except sample B28. The greatest value is 1.12 (sample B37). They are considerably less than both the 'general acceptability limit' of 5.0 ppm and the 'potability limit' of 15.0 ppm recommenced by the World Health Organisation. The main source is probably from well screens.

5.7. Cations

Calcium (Ca): Variation in calcium from 15 to 157 ppm was found over the area, well within the World Health Organisation limit of 200 ppm. Samples from boreholes in alluvium have calcium of two to three times the magnesium content, whereas those from weathered gneiss have magnesium in excess of calcium. To the west of Nemulule hill calcium comprises over 50% total cations, e.g. W230.

The major silicate sources of calcium is usually from feldspars but some contribution is made by pyroxenes and amphiboles. Carbon dioxide (CO₂) plays an important part in controlling the calcium solubility, but as CO₂ is thought to be low in these aquifers, the calcium content is most likely to be controlled by the amounts and distribution of calcium bearing minerals, and then modified by ionic exchange. Calcium may also, in part, be derived from downward leaching of CaCO₃ forming near the surface.
Magnesium (Mg): A similar range to calcium is found in magnesium, from 10–144 ppm, and also in percentage of total cations, 7.5–58%. This may imply a similar source or that the same process is affecting both ions. The World Health Organization limit is 150 ppm.

Samples from boreholes in alluvium have less magnesium on average than samples from weathered or fractured gneiss, 38 ppm compared to approximately 55 ppm (see Table 1). Those samples having more than 50% magnesium to total cations are MgHCO$_3$ waters and occur in weathered or fractured gneiss. The low sodium associated with these waters may imply a lack of cationic exchange or readily soluble sodium-bearing minerals. However, this may relate to the CO$_2$ content and the presence of magnesite (MgHCO$_3$) for without CO$_2$ magnesium carbonate is less soluble:

$$\text{MgCO}_3 + \text{CO}_2 + \text{H}_2\text{O} = \text{Mg(HCO}_3)_2$$

To the west of T.A. Lunde confined conditions exist and the partial pressure of CO$_2$ should be higher leading to increased solution of the magnesite that is found in the Metope Beds. But the Metope Beds are a low yielding aquifer and a more likely source of the MgHCO$_3$ water would therefore be magnesium bearing silicate minerals.

Sodium (Na): Concentrations of sodium ions range from 17–378 ppm representing 7.5–89% total cations. The highest sodium value lies to the west of the river in sample D53.

Average sodium contents in samples from alluvium and weathered gneiss aquifers are nearly equal, 109 ppm and 95 ppm respectively, but both have greater sodium than samples from fractured gneiss, 72 ppm. This may be the result of cationic exchange — a trend also apparent on the trilinear diagram (Fig. 2).

Cationic exchange takes place mainly in clay sequences, where there is a large substrate available for the exchange process and which commonly contains absorbed sodium. Usually, this is exchanged for calcium and magnesium ions in the water in contact with the clay. Changing equilibria cause a reverse in the reaction.

To illustrate the degree to which this has taken place the ratio of calcium and magnesium to sodium has been calculated and plotted on Fig. 6. If a ratio of less than one is taken to represent the stage where most of the calcium and/or magnesium has been replaced, two areas appear — along the Shire, and north of the Mafuzi stream. The ratio decreases in the direction of water movement so that areas with higher ratios indicate areas of recharge. Ratios are lowest in NaHCO$_3$ waters in the colluvium.

Potassium (K): Only small amounts of potassium have been found in the samples. The values range from less than 1 to 9 ppm and average 2.0 ppm. These are less than values found in the central and northern parts of Malawi but are very similar to results from the Lower Shire valley (range 1–8 ppm, average 2.0 ppm). This reflects the trend in the potassic content of the crystalline rocks, which is lower in the south of Malawi than in the north.

Potassium is more soluble and approximately equal to sodium in plagioclase feldspars and mica, but potassium is quickly adsorbed onto clays and hence potassium values are usually considerably less than those for sodium in natural waters. This is shown here by the higher potassium values occurring towards the edge of the valley.

5.8. Anions

Bicarbonate (HCO$_3$): Within the pH range 6–7 found in the samples any carbonate originally present has been changed to bicarbonate. Concentrations range from 196–972 ppm...
over the area with an average of 600 ppm (very similar to the Lower Shire valley average of 675 ppm). This represents a range of 43-96% of the total anions.

The NaHCO₃ waters are very hard but in changing to a NaHCO₃ water by cationic exchange there occurs a natural softening of the groundwater.

Average bicarbonate values for samples in alluvium, weathered gneiss and fractured gneiss are 545 ppm, 680 ppm, and 609 ppm respectively. The differences may relate to varying carbon dioxide content or in the abundance of minerals yielding bicarbonate.

The lower average found in alluvial aquifers also suggests a lack of sulphate reduction.

Fig. 8 illustrates areas with high bicarbonate values. Between the Chia and Linthipe streams and towards the edge of the valley, values are between 250 and 500 ppm but the two areas are separated by a zone of more than 500 ppm. Two boreholes along the Matadi, one of which, B19, has a yield of 2000 gph, have the lowest bicarbonate values, which may be due to recharge or low CO₂ content.

**Sulphate (SO₄):** A wide variation (commonly found in sulphate) occurs — from less than 2 ppm to 555 ppm, representing 1 to 46% total anions. However, the average value is low, 44 ppm. Only one sample (B37) exceeds the World Health Organization potability limit of 400 ppm and only one other sample (K4) is in excess of the limits of general acceptability of 200 ppm.

Groundwater in crystalline rocks or sediments derived from them are reported to contain up to 100 ppm sulphate (Hem, 1959). Sulphate may be derived from disseminated iron pyrite or sulphates in the soil, however, Muir (1954) reports less than 0.17% sulphate in the black clay soils.

Sulphate easily combines with cations and is readily soluble thus the low average would imply a lack of sulphate sources within the study area. In samples from alluvial sources there is greater sulphate than in samples from weathered or fractured gneiss, particularly west of Mwananyamula hill.

**Chloride (Cl):** There is a similarity between sulphate and chloride results. The range in chloride is from 4-460 ppm, averaging 47 ppm, which represents a percentage range of 1.5 to 56%. Generally, chloride values are lower than sulphate in alluvial aquifers but greater in weathered gneiss.

The unusual composition of Ca-C1-HCO₃ water in samples L214 and N131, which both have similar sulphate, may reflect mineralised leakage in the former and surface source from the nearby dambo in the latter. These are the only samples having chloride in excess of the World Health Organization limits of 200 ppm.

Crystalline rocks form a minor source of chloride and most chloride comes from sedimentary sources. There are no excessively high chlorides, suggesting that there is little contribution from within the aquifers.

**Nitrate (NO₃):** Nitrate values are low, less than 6.5 ppm (the value of 14 ppm in 02 samples may be erroneous), which is well within the World Health Organization limit of 45 ppm. With these low values there appears to be little polluted water from around the borehole entering through loose casing, which is the normal source of nitrate in Melaka.

**Fluoride (F):** Average fluoride values are given below. Sub-division is made into two areas, north and south of the Chia stream, and into aquifers:

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>North of Chia (average fluoride for samples from alluvium)</th>
<th>South of Chia (average fluoride for samples from weathered gneiss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chia Stream</td>
<td>1.9 ppm</td>
<td>1.0 ppm (1 sample)</td>
</tr>
<tr>
<td>Weathered gneiss</td>
<td>1.0 ppm</td>
<td></td>
</tr>
<tr>
<td>Fractured gneiss</td>
<td>1.2 ppm</td>
<td></td>
</tr>
</tbody>
</table>
There is little difference between values for samples from weathered or fractured gneiss in the two areas but a significant difference in values for samples from alluvium. There appears to be greater concentrations in waters with higher sodium.

Areas with fluoride in excess of 1.5 ppm are shown in Fig. 7. Most of the area has values of less than 1.5 ppm. Intermediate values occur along the Shire river and around the valley sides. Small areas having excess of 3.0 ppm are restricted to the north of the Chia stream and Mwananyamula hill.

Fluoride is commonly found in hornblende and micas or as calcium fluoride (fluorite). The solubility of calcium fluoride is low and both sodium fluoride and magnesium fluoride are far more soluble and probably form the main sources.

The question of fluoridation and the presence of fluoride in water has led to much controversy. The World Health Organisation (1963) do not give maximum limits but the European World Health Organisation (1961) give 1.5 ppm as the maximum. The United States Public Health Service, however, give values of 1.4–2.4 ppm as grounds for the rejection of a supply. If 2.4 ppm is used as a maximum, only four samples have in excess of this figure (B22, B37, Q105 and Q82). Over the area generally values are not excessive but it should be noted that the method for the determination of fluoride at the Geological Survey has not yet been perfected and results are therefore tentative.

5.9. Surface Water Analyses

The results of analyses on two point samples (unmixed) taken from the R. Shire at Shire Bridge Siding (153543 Y0235076) and Murchison Falls (153443 Y43981) to represent river water composition entering and leaving the area are given in Table 2.

The chemical quality of both samples is very good. They have low conductivity and total solids and are Na-Mg-Ca-HCO₃ waters (Fig. 2). Silica is very low but potassium is fairly high, as is iron. The slightly higher sulphate and chloride recorded in the downstream sample is probably derived from water with a higher content of these two anions occurring in the marsh areas along the river source. Nitrate is very low and fluoride is comparatively high (but well within maximum limits).

Both samples are of a similar, but more dilute, water type to that from the nearest borehole B28. However, there is little agreement in ratios between the river samples and that from the borehole. Hence it is more likely that water is moving (by leakage?) from the river to groundwater and this would explain the higher T.S. and increased sodium (due to cationic exchange) in B28.

6. CONCLUSIONS

The Na-Mg-Ca-HCO₃ water found in the Mirale area is of a typical groundwater composition, and can be divided into two main areas. Towards recharge areas there is a MgHCO₃ water with low Na and towards the river a Na-HCO₃ water with low Mg and, in some samples, increased sulphate and chloride. Groundwater of mixed composition exists between the two areas. Cationic exchange is the main factor influencing composition.

Differences in certain ions occur between samples from alluvium and those from weathered or fractured gneiss. Except for scattered individual samples, most of the
area has ionic values of less than those limits recommended by the World Health Organization. Similarity exists in values of bicarbonate and potassium with samples from sediments in the Lower Shire Valley. Both nitrate and sulphate indicate pollution to be negligible. There is little contribution from mineralized leakage.

The overall chemical quality of the groundwater is good, and of river water particularly so.

Contribution from groundwater to the river or vice versa is on the basis of chemistry, inconclusive but there is thought to be leakage from the river to the groundwater
REFERENCES


APPENDIX

ANALYSES OF BOREHOLE WATER SAMPLES

This appendix gives the results in ppm of the 44 samples collected from boreholes, together with relevant details of each borehole. These are assigned according to aquifer into 'colluvium' (lacraintrine/deltaic deposits) (A), 'weathered gneiss' (WG) and 'fractured gneiss' (FG). For the most part this is based on original drilling data and also data published in Bulletins 16 and 17, but some amendments have been made based on chemical composition. Further division is made within each aquifer by grid reference, working east to west and south to north.

The symbols M and m refer to maximum and minimum values over the study area respectively and ions are referred to by their chemical symbol.
### Table I Range and average ionic constituents

<table>
<thead>
<tr>
<th></th>
<th>TS+</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K+</th>
<th>HCO₃⁻</th>
<th>SO₄²⁻</th>
<th>Cl⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE ppm</td>
<td>204-1558</td>
<td>15-157</td>
<td>10-144</td>
<td>17-378</td>
<td>1-9</td>
<td>196-972</td>
<td>2-555</td>
<td>4-460</td>
</tr>
<tr>
<td>% tot. cats./an.</td>
<td></td>
<td>4-53</td>
<td>6-58</td>
<td>8-89</td>
<td></td>
<td>43-96</td>
<td>1-46</td>
<td>2-56</td>
</tr>
<tr>
<td>AVERAGE FOR WHOLE AREA</td>
<td>676</td>
<td>77</td>
<td>47</td>
<td>97</td>
<td>600</td>
<td>609</td>
<td>44</td>
<td>47</td>
</tr>
<tr>
<td><strong>ALLUVIUM</strong></td>
<td>690</td>
<td>77</td>
<td>38</td>
<td>109</td>
<td>680</td>
<td>545</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WEATHERED GNEISS</strong></td>
<td>495</td>
<td>83</td>
<td>55</td>
<td>95</td>
<td>534</td>
<td>469</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FRACTURED GNEISS</strong></td>
<td>534</td>
<td>69</td>
<td>56</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table II Analyses of 10 Shire samples

<table>
<thead>
<tr>
<th>Site</th>
<th>Cons.</th>
<th>pH</th>
<th>Ca</th>
<th>SiO₂</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>HCO₃⁻</th>
<th>SO₄²⁻</th>
<th>Cl⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shire Bridge Siding 153543 YD25076(8/72)</td>
<td>2.5</td>
<td>6</td>
<td>3</td>
<td>12</td>
<td>9</td>
<td>22</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>40</td>
<td>5</td>
<td>18</td>
<td>1</td>
<td>0.5</td>
<td>1.8</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Marchison Falls 153404 YD043981(8/72)</td>
<td>2.4</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>9</td>
<td>21</td>
<td>6</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>40</td>
<td>5</td>
<td>18</td>
<td>1</td>
<td>0.5</td>
<td>1.8</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Geol. Surv. Ref. No.</td>
<td>DD3</td>
<td>084</td>
<td>081</td>
<td>043</td>
<td>074</td>
<td>076</td>
<td>L213</td>
<td>L230</td>
<td>L212</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Sheet No.</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
<td>1534</td>
</tr>
<tr>
<td>Grid Reference</td>
<td>10000</td>
<td>229270</td>
<td>078941</td>
<td>0299270</td>
<td>071947</td>
<td>078941</td>
<td>0399270</td>
<td>071947</td>
<td>071947</td>
</tr>
<tr>
<td>Aquifer</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Datum (A.O.D.)</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
<td>1543</td>
</tr>
<tr>
<td>Depth Water Sought</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
</tr>
<tr>
<td>Depth to main supply</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Conductivity</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
<td>14,6</td>
</tr>
<tr>
<td>Total Solids</td>
<td>1065</td>
<td>736</td>
<td>736</td>
<td>736</td>
<td>736</td>
<td>736</td>
<td>736</td>
<td>736</td>
<td>736</td>
</tr>
<tr>
<td>pH</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Silica</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>CAUSTIC</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>CaO</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Mg</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>H</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>AIRION</td>
<td>792</td>
<td>792</td>
<td>792</td>
<td>792</td>
<td>792</td>
<td>792</td>
<td>792</td>
<td>792</td>
<td>792</td>
</tr>
<tr>
<td>HCl</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Na</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>KO</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>NITRATES</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Ca</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
</tr>
<tr>
<td>Mg</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>K</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
</tr>
</tbody>
</table>

**APPENDIX**

**ANALYSIS RESULTS**

**PAGE 2**