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BASEMENT AQUIFER PROJECT
Report on June-July 1987 Field Investigations in Masvingo Project Area

E P WRIGHT

SUMMARY

During June-July 1987, studies have been carried out at a number of locations which require a water supply (List A). It is planned to drill these sites in September-November 1987 using the BGS Drill Rig and a Zimbabwe Government Rig. List B is of locations which have also been visited during the same period but for reasons given in the report, no additional drilling is recommended. At several of the locations in List B, the handpumps installed require servicing.

List A

Locations where drilling is recommended

		Map	Grid Reference
AREA C			
1.	Chikofa Primary School	2030 D1	2446/77216
2.	Chikore School	2030 D1	2543/77296
3.	Chirogwe School	2030 D1	2465/77298
4.	Rungai B.C.	2030 D1	
AREA E			
1.	Madangombe School	2030 A2	2193/77788
2.	Maramba School	2030 A2	22270/776820
AREA F			
1.	Chibi B.C.	2030 B3	2392/77535
2.	Chinambiri School	2030 B3	2458/77552
3.	Mhatiwa School	2030 B3	24875/774730
AREA G			
1.	Matatire School	1930 D4	2775/78023
2.	Nanwi School	1930 D4	2819/77968
3.	Nemarandwe School	1930 D4	2828/78015
4.	Zimuto Mission	1930 D4	27402/77935
AREA J			
1.	Sarahura B.C.	2030 D3	2448/76775
2.	Chikadze School	2030 D3	2538/76778

List B

Locations visited but not recommended for drilling

AREA C

1.	Chikofa Secondary School	2030 D1	2447/77252
2.	Chikofa New School	2030 D1	244-/77840

AREA E

1.	Mukotosi School	2030 A2	2165/77840
2.	Madangombe B.C.	2030 A2	2199/77812
3.	Bvutu School	2030 A2	2143/77773
4.	Chigwike B.C.	2030 A1	2045/77725
5.	Chigwike School	2030 A1	2063/77715

AREA F

1.	Mazorodze School	2030 B3	2430/77534
2.	Masunda South School	2030 B3	2536/77432

AREA G

Zimuto Siding	1930 D4	2759/78031

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1. Programme Planning.

The work during the 1986 field season was concerned with evaluating the structural geology (Greenbaum, 1986), the groundwater occurrence by borehole data (Lewis and Orzel, 1986) and by site observations, and by geophysical responses using a range of surface and borehole geophysical techniques (Smith, 1987; Shedlock, 1987).

During the 1987 and final field season, it is planned to evaluate the significance of improved background knowledge of the areas of detailed study in terms of borehole 'success' rate, whether minimum yields or statistically higher yields that heretofore. The areas of detailed study (Figures 1 and 2) have been selected in a range of the main basement rock types and where a significant concentration of dry or low yielding boreholes occurs.

There are various ways in which the result of this evaluation might be expressed.

(a) An increased 'success' rate for the same amount of time spent on siting (3/4 hours per site) and with the standard techniques (resistivity profiling and soundings).

(b) As above but with different methodology (e.g. electromagnetics or seismic) but no increase in exploration costs.

(c) An increased 'sucess' rate but with higher exploration costs in consequence of longer time inputs and/or different exploration methodology. Cost-benefit comparisons would need to be made to demonstrate comparative effectiveness.

(d) Establishing in difficult/marginal areas of a better appreciation of the constraints to water supply and the criteria of development feasibility which may be different from those which are applicable more generally.

Methods (a) to (c) can be demonstrated most clearly and unambiguously in a development programme in which a substantial number of boreholes are to be drilled. Method (d) applies more appropriately to the studies being carried out in the Masvingo project area although the results can, it is hoped, be extrapolated more generally.

2. Borehole Siting in Zimbabwe in Basement Rocks.

The Zimbabwe Master Plan identifies calculated electrical resistivity (from vertical electrical soundings) as the single most important guideline in optimising borehole siting procedures. The following correlations are stated to exist for resistivity values in the weathered overburden aquifers with basement rocks.

< 20 ohm m	Clays with limited groundwater potential
20-100 " "	Optimum weathering and optimum groundwater potential
100-150 " "	Medium conditions and medium potential
150-250 " "	Little weathering and poor potential
>250 " "	Negligible potential

The Master Plan quotes Astier (UN Report) that the following relationship has been demonstrated by extensive research.

Thickness of Overburden	Success Rate
<10 metres	0%
10-20 metres	25%
20-25 metres	45%
>25 metres	70%

These two criteria, appropriate resistivity and thickness of overburden, in combination with an available drawdown (saturated thickness of weathered overburden) of at least 20 m constitute the essential siting criteria for borehole sites to provide a minimum handpump yield (10 m^3/d) and an acceptable (70%+) 'success' rate. In the recent Interconsult Mashonaland Crach Programme in which several hundred boreholes were sited using these criteria, some 52% of all sites investigated by VES soundings were rejected as not meeting the basic criteria. Although the implications in terms of the supply programme were not detailed, it is implied that many locations could not be provided with a borehole supply since the conditions could not be identified. Dug wells were usually suggested as an alternative source although without particular sites being identified.

3. Borehole Success: Yield Criteria.

The Master Plan quotes a minimum requirement for 250 people as 10 m^3/day. On the assumption of a 10 hour pumping day, the corresponding rate required is 0.28 l/sec. Typically an acceptable yield of at least 0.25 l/sec is quoted for boreholes fitted with hand pumps. In the Mashonaland Crash Programme, safe yield figures are quoted on the assumption of a pumping duration of 8-10 hours separated into two periods with a 2-3 hour intervening recovery. Even allowing for a doubling of the drawdown and hence doubling in effect the safe yield, some 20% of all the boreholes would be considered low yielding with sustained yields less than 0.25 l/sec. In the recent EEC Project in southern Zimbabwe, a substantial number of boreholes were completed with test yields between 0.1-0.25 l/s. The contention is that even the small yields are better than none at all. However, the BGS field investigations have demonstrated that many of the low yielding boreholes may become wholly ineffective in use during the dry season. Evidently such boreholes are very sensitive to a seasonal or drought controlled change of water level.

The studies which have been carried out in the Masvingo project area have resulted in the following preliminary conclusions.

(a) Many successful boreholes are drilled on sites which would not meet the Master Plan siting criteria.

(b) Most dry/low yielding boreholes would probably be rejected by the same criteria. These two observations demonstrate the limitations of the present siting criteria.

(c) Many low yielding boreholes are effective for only a few months of the year.

(d) Successful borehole sites for many localities in which dry or low yielding boreholes have been drilled, may not exist. To provide a water supply for such localities, consideration of a range of possible designs may need to be considered, as per the list below:-

1. Combined borehole and dug well. When water levels are shallow, preferably less than 7 metres and occurring within the weathered overburden, a dug well constructed on top of a low yielding borehole can increase the effectiveness by adding the manipulation of larger storage.

2. Collector well/dug well. A saturated weathered overburden of 5-10 m will be generally inadequate for a borehole but could be effective for a dug well or a collector well. If the permeability is too low for a dug well, a collector well would almost certainly provide an acceptable yield. The key constraint of a collector well is the higher cost.

3. Combination of dry season and wet season boreholes or wells. Many low yielding boreholes or wells are effective in the wet season only. In such circumstances, a more distant borehole or well to provide supplies in the dry season may be considered acceptable.

4. Rainwater catchments. These can often be installed at comparatively low cost and constitute a very effective supplementary supply. Favourable circumstances include the occurrence of large roof areas of suitable materials, such as in schools, or the presence of rock outcrops which can be adapted as natural catchments. Many schools appear to be located on the high ground in the vicinity of rock outcrops but only one example of rainwater catchment utilisation has been observed. Rainwater storage tanks constructed from ferrocement are fairly cheap and can be made in-situ using self-help or local labour. Details of modern tanks suitable for rainwater storage are included in Annex I. In many cases tanks can be constructed on sites suitable for the natural catchment and for gravity supply to the school.

4. Borehole Sites Investigated.

A number of sites in four of the detailed study areas are currently being investigated with a view to drilling boreholes. The majority of the sites are on a list provided by the Provincial Water Engineer, Masvingo and the District Administrators of Chibi and Neshoro which require a groundwater supply either because none exists or because the existing borehole has dried up or is drying up. Such sites are likely to be difficult to provide water for since the most obvious borehole locations will have been investigated in the initial drilling programme. The sites are listed below and discussions on the site with target objectives in the geophysical survey identified. These surveys are underway at present and where deemed feasible drill sites will be identified and marked. Drilling will be carried out in the period September-November 1987, using the BGS Experimental Rig and a Government Drill Rig.

List of Sites being Investigated

		Map	Grid Reference
AREA C			
1.	Chikofa Primary School	2030 D1	2446/77216
2.	Chikore School	2030 D1	2543/77296
3.	Chirogwe School	2030 D1	2465/77298
4.	Rungai B.C.	2030 D1	
AREA E			
1.	Madangombe School	2030 A2	2193/77788
2.	Maramba School	2030 A2	22270/776820
AREA F			
1.	Chibi* B.C.	2030 B3	2392/77535
2.	Chinambiri School	2030 B3	2458/77552
3.	Mhatiwa School	2030 B3	24875/774730
AREA G			
1.	Matatire School	1930 D4	2775/78023
2.	Nanwi+ School	1930 D4	2819/77968
3.	Nemarandwe School	1930 D4	2828/78015
4.	Zimuto Mission	1930 D4	27402/77935
AREA J			
1.	Sarahura B.C.	2030 D3	2448/76775
2.	Chikadze School	2030 D3	2538/76778

5. Other Sites Visited.

Other locations were in the lists provided by the PWE/District Administrators. A number of these were visited but for reasons given below, additional borehole sites are not recommended at present.

AREA C

1. Chikofa Secondary School 2030 D1 2447/77252.

Borehole sites are generally unfavourable in this location. The Lutheran Dug Well is the present source of supply but yield is apparently reducing. The well might be improved by deepening. A supplementary supply to the school by rain water catchments is also recommended.

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* *Chibi B.C. was not on the lists provided, but it is known to have a water supply problem. Its current supply is piped but ?untreated from a surface reservoir.*

\+ *This site has been selected for the experimental drilling of an inclined hole for more scientific purposes.*

2. Chikofa New School to the northwest of the Business Centre 244-/77840.

A borehole has recently been drilled close to an EEC borehole site which had been vandalised. The yield appears adequate.

AREA E

1. Mukotosi School 2030 A2 2165/77840.

There are two boreholes in the vicinity of the school, both functioning reasonably well.

2. Madangombe B.C. 2030 A2 2199/77812.

This Centre has a piped supply from a storage tank on high ground to the west of the Centre and supplied by a surface reservoir.

3. Bvutu School 2030 A2 2143/77773.

There is already a borehole at the school which has been tentatively identified at UV11407 which had a very good yield on completion (c. 4 l/sec). The yield is now low but this is probably due to reduction in pump efficiency which needs to be checked. The school would like to obtain a motor pump/tank and considers that the community would pay for the recurrent costs of pumping.

4. Chigwike B.C. 2030 A1 2045/77725.

A new borehole was drilled on the 27th April 1987. The yield is good but slightly saline.

5. Chigwike School 2030 A1 2063/77715.

The borehole near the school is not functioning due to breakdown of the handpump.

AREA F

1. Mazorodze School 2030 B3 2430/77534.

The school borehole has not been functioning for perhaps a year or more due to breakdown of the handpump (no handle exists). The school does receive a supply from a standpipe from the Chibi reservoir.

2. Masunda South School 2030 B3 2536/77432.

The school borehole produces poorly. However 2 new boreholes have been drilled recently funded by private donation (AfriCare). Neither has yet been completed with a pump but one is said to have a good yield.

AREA G

Zimuto Siding 1930 D4 2759/78031.

There is a disused railway borehole which is connected to a storage tank and is surplus to requirements but otherwise functioning. In addition two boreholes have been drilled close by, perhaps by the DDF, both of which are capped. These may not have been required in the circumstances.

6. Borehole Design.

Since the collapsing weathered overburden in the Masvingo Project Area is generally thin, commonly less than 10 metres, borehole Design A (Master Plan) will be utilised in most cases. With this design, 6 inch ID steel casing is cemented into an 8 inch hole with backfilling and a sanitary seal above. Open hole drilling will be continued through into the fractured non-collapsing formation. If the handpump cylinder is set within the open hole section, some protection may be needed. For the circumstances with a thick overburden in which completion will be wholly within the collapsing zone, Design B will be utilised which requires the use of 110 mm class 10 flush-jointed PVC casing and screen to total depth and a gravel pack opposite the productive aquifer.

7. Drilling Programme: Timing and Procedures

The drilling will be carried out by the BGS experimental rig and by one Zimbabwe Government rig. BGS hydrogeological staff will supervise drilling and sampling. The Zimbabwe Government will provide fuel and all essential drilling and borehole completion materials. Production holes will be capped after testing to await subsequent installation of a handpump.

The BGS experimental rig will be mobilised to commence drilling in mid-September. It would be helpful if the Zimbabwe Government rig could be on site by the end of September. Drilling will probably continue to the end of November.

8. Borehole Siting Details.

AREA C

Chikofa School 2030 D1 (Figure 3)+

1. Existing borehole: EEC 86 [2446/77216)
   Total depth: 30.5 m
   Saprolite*: 1.8 m
   Rest water level: 7.9 m below ground level
   Test yield: 0.28 l/sec

2. Current situation: Borehole now extremely low yielding. Intermittent pumping demonstrates that problem relates to borehole and not to handpump. No other feasible borehole sites in area which would justify geophysical survey. The thin regolith probably makes the borehole yield very sensitive to season water level changes.

Rocky outcrops have a widespread occurrence. The rock consists of a hard, weakly-fractured gneissose granite.

\+ *Figure 3 etc. have been drawn by Dr D Greenbaum.*

* *From drilling logs, the saprolite is assumed to constitute the collapsing material; if no lithological log is available, the depth of the casing is used and bracketed.*

Potential sites for dug wells or possibly a combination of borehole and well occur in watershed area to north of school between the two inselbergs or along the valley which trends to the SE and E of the school. The existing dug well on watershed has 1-2 m of dark clay (dambo clay) with at least 2 m of saprolite below. The saprolite is brown-stained, indicative of fluid movement. Rock outcrop are rare in the vicinity of well and in the tributary valley which joins from the NE and along which there are tall trees clearly drawing on shallow groundwater. Below the intersection, rock outcrops become more common and may constitute a barrier across the main valley.

Recommend EM traverses as shown and selected VES as appropriate to determine thickness of saprolite and saprock.

Chikore School   2030 D1   (Figure 4)

1. Existing borehole: JP 5458 [2543/77296]
   Total depth: 65 m
   Saprolite: [11.5 m]
   Rest water level: 6 m
   Yield: 0.89 l/sec

2. The existing borehole is on a watershed between two parallel valleys and at the foot of an ironstone ridge. The test yield after drilling was high but the apparent current yield is negligible. The DDF have visited the borehole 3 times in the last few years and have pulled the pump on at least one occasion. The Headmaster was informed verbally that there was 'no water'. The school community now obtains water from a very polluted reservoir close by. There have been various attempts to dig wells, both by the local people and the World Lutheran Digging Team but without success.

3. A few other possible borehole sites exist in the area but are not too favourable, mainly because shallow bedrock would be suspected and there are no strong lineaments. It is difficult to suggest an order of priority. The possible sites occur above and below the dam and in the valley to the east.

Site 1: In valley above the dam. There appears to be a rock barrier which extends below the dam and a short distance upstream as indicated by the stream gradient which flattens out in this location. A lineament may exist parallel to the stream. There are calcrete nodules in the stream alluvium which may indicate rising water tables.

Site 2: The site below the dam could aim to intersect the junction of a possible lineament with the main stream valley. Both sites 1 and 2 could possibly induce recharge from the surface storage above the dam.

Site 3: This occurs in valley to east and once again saprolite could be thicker above a rock barrier.

Chirogwe School   2030 D1   (Figure 5)

1. Existing borehole: JP 5419 [2465/77298]
   Total depth: 50 m
   Saprolite: [22.5 m]
   Rest water level: 16 m
   Test yield: 2.557 l/sec

2. The current borehole yield by handpump is very low but it is unclear whether the fault is that of the borehole or of the pump. The main likelihood is that the pump is faulty but it needs to be checked. According to the records there appears to be another borehole in the near vicinity (VO 954: 2466/77303) which had a good test yield but cannot be identified.

3. An additional site for possible survey is to the north of the school along a small valley which trends east-west.

<u>Rungai B.C. and Rungai School</u> (Figure 6)

1. This area has been intensively investigated. The EEC drilled three dry holes. There is a private operating borehole with handpump at the B.C. and a Lutheran well close by although at the time of our recent visit (3/7/87), the pump was broken down. The static water level at the same time was 8.60 m below the parapet and with a total depth in excess of 10 m.

2. Recommended site for another water supply point - borehole, dug well or collector well - is along the same valley on which the Lutheran well is sited and near the junction of a tributary valley which is along the line of a lineament. If yield is high, could provide water for both B.C. and school, preferably by pumping to storage.

3. Rungai School is also ideally placed to supplement its water supplies by rainwater catchments, both artificial (roofs) and natural (rock outcrops).

4. If a collector well is to be given consideration, the use of seismic data to indicate 'diggability' would be of interest.

<u>AREA E</u>

<u>Maramba School</u> 2030 A2 (Figure 7)

1. Existing borehole: V 2667 [2220/77680]
Total depth: 42 m
Saprolite: [20.6 m]
Rest water level: 8.0 m
Yield: 3.41 l/sec

2. The water quality was said in the drilling report to be fresh but is currently quite saline with an electrical conductivity of c. 4000 μS/cm which is equivalent to about 3000 ppm total dissolved solids. The yield is adequate for a handpump. Both quantity and quality of output is said to be constant throughout the year.

3. There are two pegged sites quite close to the school and almost at the same elevation. The locations do not appear to have been geophysically surveyed. A Lutheran well is in course of construction in the same area as one of the pegs. It is currently at c. 10 m depth without reaching water and is in fresh granite. The second peg has a bearing of 165^{0} magnetic from the school and about 150 m away from the edge of the school building.

4. The problem appears to be one of both quantity and quality and hence the need to seek sites with good localised recharge. Fresh water could overlie saline water and may constitute difficulties in the use of a deep borehole. In such circumstances, a well which 'skims' the surface aquifer might be more

effective. The recommended site for investigation is on the edge of an incised valley upstream of a quartzite dyke (2/3 metres) which is orthogonal to the stream and could act either as a barrier which will build up the water levels or as a good fracture zone. A borehole/well site on the school side of the stream would be more convenient. The investigation should seek to ascertain deep saprock or saprolite with good recharge.

5. If this site proves unacceptable, a feasible location for a protected dug well occurs close to the main river valley about 2.0 km from the school. There are tall phreatophyte trees in the area and an existing dug well apparently never dries. Although the site is too far from the school for general use, it might be considered as a supplementary supply for better quality drinking use to augment the saline water from the borehole. Roof catchments could also be added.

Madangombe School 2030 A2 (Figure 8)

1. Existing borehole: EEC 77 [2193/77788]
   Total depth: 61.0 m
   Saprolite: 45.0 m
   Rest water level: 10 m
   Yield: 0.270 l/sec

2. The existing borehole is on a watershed surrounded by low koppies of equigranular granite (Younger Granite). The current yield is quite good although abstraction rates tend to drop off in the afternoon with intensive use. There is a substantial demand for the combined requirements of the school, a military post and the local community. This is the origin of a request for a second water point.

3. A recommended site for survey is in the valley to the north east of the school and in the vicinity of the contact of the granite with migmatic older gneiss. The gneissic foliation strikes about 2000 m which is orthogonal to the stream and harder bands could create a barrier which may backup the water level in the granite saprolite. The site could be feasible for a borehole and/or a protected dug well. The site should avoid the lowest part of the valley where periodic flooding and still stand occurs. A site in the central valley could also lie on a lineament parallel to the valley. A likely site is on the intersection of a tributary valley which seems to follow the contact of granite and gneiss and where there is a pool which remains wet for a lengthy period of the dry season. There could be constraints on a dug well if the main aquifer is in weathered saprock rather than saprolite. Wire fences might constrain use of EM. A VES over the borehole could help to calibrate.

AREA F

Chibi B.C. 2030 B3 (Figure 9)

1. There are no existing boreholes in the immediate area of the B.C. which receives a piped supply from a surface reservoir. The supply is said to be inadequate. There is the possibility of locating a high yielding borehole or collector well in the close vicinity.

2. The recommended site for survey is in a valley which emerges from an upland area to the south of Chibi and which occurs on a strong fissure system which appears to intersect upland flat valleys which might well provide sustained

storage. There is clear evidence of shallow groundwater from the occurrence of green grass and phreatophytic trees and reeds within the valley.

<u>Chinambiri School</u> (= Old Mazorodze School) 2030 B3 (Figure 10)

1. Existing borehole: GEMS 3084 [2458/77552]
Total depth: 45.0 m
Saprolite: 18.0 m
Rest water level: 20.0 m
Yield: 0.208 l/sec

2. The borehole site is on or near a lineament trending north-west but fairly close to the watershed. Water levels are deep and there appears to be no saturated saprolite. The key criteria is whether the site is on sufficiently high transmissivity to locate adequate storage in near vicinity.

3. Alternative sites: The first site could be close to the existing borehole but located more precisely on the lineament.

4. A second alternative site is further down the valley to the NW. Constraints on yield will be effected by the barrier boundaries of the rocky adjacent hills. A successful site for a borehole will require adequate thickness of saturated regolith and a significant lineament effect to counteract the barrier effects; for a protected dug well there must be an adequate thickness (c. 10 m) of diggable saturated saprolite. Valley floor has dark soils and no obvious outcrop which looks favourable.

5. The third site is to the east of the school on an intersection of fracture systems, some of which are occupied by dolerite dykes. There is much rock outcrop in the general vicinity which would indicate a paucity of groundwater storage and this could be a major constraint. This site is only feasible for a borehole.

<u>Mhatiwa School</u> 2030 B3 (Figure 11)

1. Existing borehole: JP 5849 [2489/77474]
Total depth: 40.0 m
Saprolite: [4.0 m]
Rest water level: 8.0 m
Yield: 0.44 l/sec

2. The borehole had a very poor yield on test and is generally a poor producer which deteriorates in the dry season.

3. An alternative site is close to the existing borehole but located more precisely on the lineament. An angled hole might be an interesting possibility.

4. A second location for a borehole and/or dug well is in the vicinity of the dug wells down the valley close to the intersection of two strong lineament systems.

5. A final site is in the valley which continues the same valley on which the borehole is located but downstream of the intersection above. The valley is floored by dark soils with green grass and phreatophytes apparent in the middle of the dry season.

AREA G

Nanwi School   1930 D4   (Figure 12)

1. Existing borehole: EEC 54B [2819/77968]
   Total depth: 30.2 m
   Saprolite: 7.3 m
   Rest water level: 4.4 m
   Yield: 0.270 l/sec

2. The borehole gives an adequate yield but is rather far from the school. It is nonetheless the most obvious site in the area and a nearer site on the watershed proved dry.

3. The purpose of any drilling here is to evaluate the significance of a clearly defined lineament. If a borehole is located more precisely on a lineament, it could overcome the constraints of more limited upstream storage. The site selected is to the west of the school where the position of the lineament can be previsely located. There is much rock outcrop and clearly rock barrier boundaries will also exercise a constraint. This is a borehole site only.

Nemarundwe School   1930 D4   (Figure 13)

1. Existing borehole: EEC 56
   Total depth: 30.3 m
   Saprolite: 6.1 m
   Rest water level: 4.0 m
   Yield: 0.32 l/sec

2. The borehole yield is adequate but the site is some distance away and beyond a flat valley which floods in the wet season. Both the Primary School and the Secondary School to the west of the road are largely dependent on this borehole.

3. An alternative site for a borehole/well is in the valley which trends south west from the school. The valley appears to follow a lineament. The catchment area is obviously smaller in sites closer to the school and a boreholes effectiveness would depend on the water level gradient and the transmissivity/storage of the aquifer and lineament system.

4. To the south of the Secondary School there is a dug well in a valley which trends due west to the deeply incised main north-south stream valley. It is surprising that shallow water levels exist at this site which has a high elevation not much lower than the watershed. The reason might relate to a rock barrier down valley. The dug well is not a high producer and the school is contemplating having it deepened. Information on the saprolite thickness would be valuable.

Matatire School   1930 D4   (Figure 14)

1. Existing boreholes: JP 5490 [2783/78023]
   Total depth: 55 m
   DRY

   : EEC 303 [2775/78023]
   Total depth: 32.0 m
   Saprolite: 0.9 m
   Rest water level: +0.6 m (positive head)
   Yield: 0.42 l/sec
   Lithology: granite

2. The main borehole supply at EEC 303 is some distance from the school and is well used by the community and the school. An additional borehole in another direction and possibly nearer the school would serve the general requirements of the school and the community.

3. The recommended site for survey is in the valley which tends to the south east. Locations further down the valley are likely to become increasingly favourable hydrogeologically since water levels will tend to be shallower and the effects of recharge more advantageous. Exploration should be designed to identify the position of the lineament an the thickness of the saprock since the saprolite it likely to be thin. Sites selected for drilling should preferably not be subject to flooding. The greeness of the grass, the large phreatophyte trees, including the Makuti tree, indicates the presence of shallow groundwater. The valley is marginally less favourable than that in which EEC 303 is located since the former has a steeper gradient to discharge locations in the main stream.

4. The dambo soils have significant clays and could be irrigated if the water supply was adequate. A collector well would be of interest. Remnants of the old rice paddies are apparent.

Zimuto Mission   1930 D4   (Figure 15)

1. Existing boreholes: Two occur fitted with motor pumps. General grid reference about 2743/77938. Additional boreholes are required for the School for the Blind and the nearby Railway Siding.

2. Two locations are recommended for survey: (a) The valley which trends SE from the School for the Blind. Extensive outcrops of granite gneiss occur near the junction with the main stream and this barrier might back up water levels. A possibly more favourable site could occur at the intersection of the main lineament with an orthogonal metadolerite dyke. (b) The second site is near the intersection of two valleys which together constitute the main stream and both appear to occur on lineament trends.

AREA J

Sarahuru Siding   2030 D3

1. Existing boreholes: (i) V 948 [2467/76780]; Tshumele
   Total depth: 29 m
   Saprolite: 23.2 m
   Rest water level: 7.6 m

Yield: 2.525 l/sec

(ii) V 2385 - cannot locate properly

2. The existing borehole is on a marked lineament and had a good yield on test. The borehole could be given a long term test to see if it is capable of being used with a motor pump. Abstraction could be pumped to a low hill close to the Neshoro Road which may have enough elevation to feed by gravity to Sarahuru.

3. An alternative borehole site could be placed on the same lineament where it crosses the Neshoro Road. This is closer to the proposed storage location.

Chikadze School 2030 D3

1. Existing borehole: JP 6260 [2527/76777]
   Total depth: 45.0 m
   Saprolite: [13.0 m]
   Rest water level: 15 m
   Yield: 0.278 l/sec

2. The test yield was quite high but the current yield is very low and the community have to wait lengthy periods between pumping to allow the water levels to recover. The trouble clearly lies with the aquifer water levels.

3. Alternative sites include one fairly close to the road and to the east-south-east from the existing well. It occurs on a possible junction of lineaments and the presence of grass which is green and phreatophyte trees suggest shallow groundwater.

4. A more reliable site is in the valley further to the east beyond the dry hole. There is a dug well which occurs close to an intersection of a tributary valley from the north east, which apparently never dries up. A second dug well occurs in the tributary valley and has a good sustained yield. A borehole or a protected dug well could be considered in this location although it is rather far from the school. It might be given consideration if the recommended borehole site proves to be poor on survey. A supplementary rainwater supply could also be constructed using artifical and natural catchments.

9. Collector Wells.

1. The GTZ have provisionally agreed to fund two collector wells in the Gutu District. Sites for survey have been identified and are described below. If the results of the preliminary geophysical survey appear favourable, test drilling and aquifer testing will be carried out with a view to confirming the suitability of the two sites. Construction will then commence. The following CARD officers in Gutu are available to be contacted on the logistics etc. These names have been provided by Mr Van der Haar of the GTZ attached to the Ministry of Energy and Water Office in Masvingo and Mr Kawodza accompanied us on an initial visit to the project area.

Mr Kawodza
Mr Muwira
Mr Zapola
Mr Tanjanjiwa

The proposals were also discussed with staff in AGRITEX, with the District Administrator in Gutu, and with Resettlement Officers (Mr Joro, District Resettlement Officer; Mr Manhovi, Soti Source Resettlement Officer).

2. The first possible location was provided by the Provincial Water Engineer, Masvingo. A piped supply is required for the Chinyika Clinic. There is one existing borehole. A site for another borehole has been pegged by a private consultant (SRK) who also suggested a dug well as an alternative. Potential sites for collector wells have been identified in valleys to the east and west of the Clinic and within ½ km in either direction.

3. A number of potential sites for collector wells have been identified in the Soti Source Resettlement Area and these are currently being surveyed. The Soti Source area has recently been acquired from a private owner and a limited degree of resettlement has occurred. The sites selected would be suitable for the settlements both in respect to domestic water supply and for irrigation on the marginal valley areas in which the top soils contain some clay and hence a probable degree of fertility not apparent in the more sandy soils of the watersheds.

ANNEX 1

A Preliminary Note on Rainwater Catchments

Rainwater collection is relatively costly compared with other sources of water supply but can have particular applicability where these other sources are not available or too costly to develop. School sites in Zimbabwe are typically located in upland watershed areas and when such areas are in rocky terrain, the problems of water supply from ground water sources are compounded. Rainwater catchments can be regarded as providing a supplementary supply of good quality water which might do much to reduce the time spent on collecting essential supplies from distant sources. The roofing of the school buildings can readily be adapted for this purpose and also rock outcrops, particularly in the relatively smooth bornhardt type topography. To date, an example of such a construction has been seen only at one location, at Makawire school to the west of Neshoro.

Fuller information can be provided but some literature is enclosed as follows:

(1) Design and Calculation of Rainwater Collection Systems. C L Pompe

(2) Annex 6 of a WHO publication relating to costs of Ferrocement tanks.

There are many different designs of water storage tanks made from a variety of materials - bamboo cement, ferrocement, curved cement blocks, corrugated steel and plastic membrane. In recent years, the use of modular tanks constructed of ferrocement has become increasingly popular because of their simplicity of design, ease of construction and relatively low cost (see Annex 6). The modular units can be assembled in various combinations to satisfy different requirements for function and capacity. The simplicity of construction allows the utilisation of unskilled and semi-skilled labour.

DESIGN AND CALCULATION OF RAINWATER COLLECTION SYSTEMS

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INTRODUCTION

Dry seasons occur even in monsoon areas. If there are no nearby wells or rivers, people will walk long distances to obtain water. A solution to this problem may be the catchment of rain water—an ancient custom still practiced in many countries in the world where rainfall is collected during the wet season to use in the dry season. The questions are (1) what should the volume be of such a rainwater collection system and (2) how should such a collector be designed?

This paper deals mainly with the first question: the calculation of the volume of the rainwater collector.

H.M.C. Satijn (1979), who was a former project participant, analyzed the problem and designed a computer simulation model of the rainwater collection system. Because computers are not widely available, I was asked to review Satijn's work and to develop a slide rule-calculation method that could be used by regional technicians. Thus, a step-by-step method was designed to enable technicians to calculate the volume of rainwater collectors by using available monthly rainfall data.

The results of the calculation are not sacrosanct because, first of all, the variables of themselves vary widely, such as consumption or the water demand. Thus, if 5 ℓ/person/day is the basis for calculating drinking water needs, there is no way of knowing the actual use and the variation in conservation and utilization. What must be borne in mind in the statistical calculation of rainwater catchment systems is that its accuracy will depend on correct input. It is also important to be realistic in using the statistical calculation method, rather than concentrating on complicated statistical computations.

The vital question is "Who pays?" If the farmer (user) pays, he will construct a 15-m^3 collector and in the dry season will be conservative in using his water while praying to Allah that rain will soon fall again. When the government or an international organization pays, the designer might think of future users and design a 20- or even 25-m^3 collector.

The basic principle of this method is the importance of calculating storage to provide enough water of the period of the year when there is no rainfall or when it is insufficient to meet water needs. In the following sections the step-by-step method and the theoretical background of the method are presented, and the last section includes some design criteria for the rainwater collection system.

CALCULATION OF RESERVOIR VOLUME

In this section, a step-by-step method is presented to calculate the volume of rainwater catchment reservoirs.

STEP 1. Daily consumption (liters/day × number of users)
- a. Drinking and cooking = ... × ...... = ...
- b. Washing and bathing = ... × ...... = ...
- c. Livestock water = ... × ...... = ...
- d. Irrigation = ... × ...... = ...

Total Daily Consumption = ...

STEP 2. Monthly consumption, MC (liters/month)
MC = total daily consumption × 30.5 days = ... × 30.5 = ...

STEP 3. Catchment area, A (m^2)
Determine available catchment area, A = ...

STEP 4. Runoff factor, ROF
Determine ROF: for vegetative cover ROF = 0.5; for hard paved areas ROF = 0.9
Runoff factor, ROF = ...

STEP 5. Critical rainfall, CRF (mm/month)
Calculate $CRF = \frac{MC}{ROF \times A} = \frac{.....}{..... \times .....} = ...$

STEP 6. Go to Rainfall data
Circle rainfall having more than critical rainfall with green; circle rainfall figures having less than critical rainfall with red, and the dry months with black

Calculate the total supply, TS, values (the length of storage periods that supply water)

YEAR	MONTHLY RAINFALL DATA OF														TS =
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TD	TI	TD+s.TI

Critical Rainfall, CRF = ... mm/mo (Stop 5)
Shortage factor, s = 0.6 (Indonesia)

STEP 7. Determine Time Storage, TmS (mo)
Determine the TmS value from the following:
a. Number of rainfall data, 10: T10S (storage not sufficient once in 10 years) is equal to the highest value of TS; T20S is equal to 1.1 × highest value of TS
b. Number of rainfall data, 15: T10S = next to highest TS; T20S = 1.1 × next to highest TS
c. Number of rainfall data, 20: T10S = 0.9 × highest value of TS; T20S = highest value of TS

STEP 8. Determine leakage, L
L = 0.1 puddled clay-line reservoir
L = 0.05 concrete-lined reservoir
L = 0.01 ferrocement or steel reservoir

STEP 9. Determine evaporation, E (m/mo)
E = 0.1 m/mo for open reservoir (Indonesian conditions)
E = 0.01 m/mo for ventilated, roofed reservoir
E = 0.0 m/mo for closed reservoir

STEP 10. Determine evaporation surface, S (m^2)
Calculate open water surface, S = ...

STEP 11. Calculate storage volume, SV (m^2)

$$SV = \frac{(MC \cdot 10^{-3} + S \cdot E) \cdot TmS}{(1 - 0.5 \cdot L \cdot TmS)} = \frac{......}{......} = ...$$

MC = STEP 2 (ℓ/mo); S = STEP 10 (m^2); E = STEP 9 (m/mo); L = STEP 8; and TmS = STEP 7 (mo).

THEORETICAL BACKGROUND OF THE METHOD

The roof or any surface area on which rainfall is collected is called the catchment area. From this catchment area, the water is conveyed into the collector (Fig. 1). A filter is mostly used to treat the incoming water before it enters the collector to prevent pollution, and its capacity should be large enough that the inflow is not obstructed. The disadvantage of an open collector is evaporation; and in closed collectors, a certain amount of leakage outflow. Thus, outflow can consist of leakage and withdrawal for consumption.

During the wet season, there is both inflow and outflow; in the wet dry season, there is only outflow. In Indonesia, a certain part of the wet season is characterized by less inflow than outflow. Therefore, it is for this particular period that rainwater collectors would provide storage for surplus rain water.

This period of insufficient rainfall is determined by the rain, R; the constant runoff factor, ROF; and the catchment area, A, for the flow of water into the storage which can be expressed as

$$IN = ROF \times R \times A .$$

If the inflow exceeds the outflow (consumption, leakage and evaporation), then

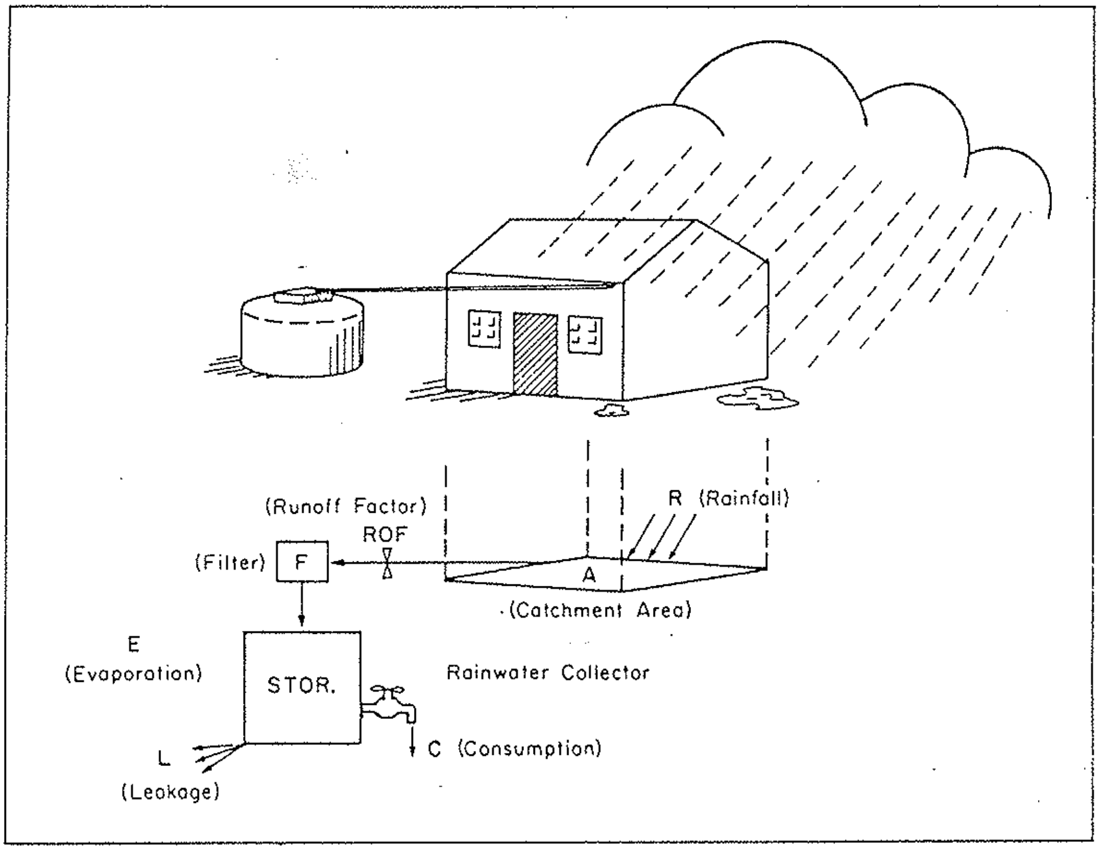


Figure 1. Rainwater collection system

the storage is charged or overflowing. When rainfall is insufficient, the inflow is less than the outflow. In the situation where the inflow equals the outflow, the critical rainfall, CRF, can be derived from

$$IN = ROF \cdot R \cdot A = ROF \cdot CRF \cdot A = OUT$$

which results in

$$CRF = \frac{OUT}{ROF \cdot A}$$

Thus, the year can be divided into periods with sufficient rainfall; the wet period, TW, ~~and periods with insufficient rainfall; and~~ the dry period, TD, and the insufficient rain period, TI. This division is schematically shown in Figure 2. It must be noted that this calculation method is based on the importance of the adequacy of storage to provide water in periods of insufficient and no rainfall.

THEORETICAL BACKGROUND. The length of the period in which the storage has to supply the outflow is determined by the rainfall data. These TS periods seem to follow cumulatively an exponential curve in the form, $a.e^{-bx}$ for the northern coastal plain of West Java, which is approximately $1.2 \cdot e^{-0.38 \times TS}$. However, to calculate the different parameters by local technicians will prove to be too difficult. Furthermore, it must be borne in mind that this calculation only results in an "estimation" of the needed storage capacity. Therefore, TS is exceeded once in 10 years, and T10S is directly derived from rain-

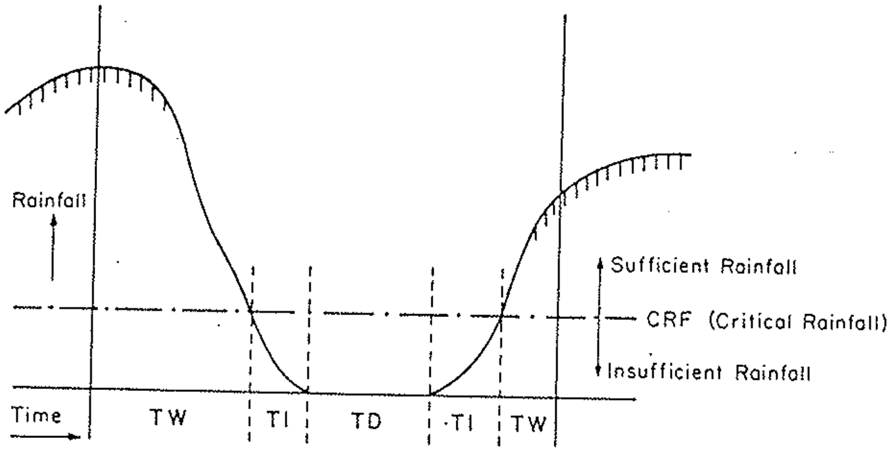


Figure 2. Annual rainfall in relation to water supply by rainwater catchment

fall data and not calculated with statistical parameters. Thus, if about ten years of rainfall data are available, the highest value for T10S is selected; and if the storage is insufficient only once in 20 years, then T20S = 1.1 × T10S. Although this is a rough calculation, it seems to work well in our case as shown in Figure 3.

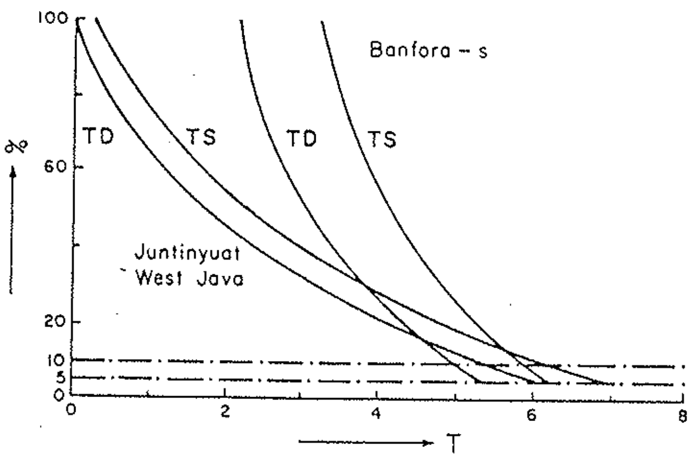


Figure 3. Cumulative frequency distribution length of dry TD periods and length of periods supplied by water tank

During TI, the period of insufficient rainfall, only part of the outflow is supplied by rain catchment; the rest should be provided from storage. To calculate this condition, the shortage factor, s, is used. Thus, in Figure 4, r = rain water supply and s = the storage addition. One should also take into consideration that during the first light shower, rainfall often evaporates

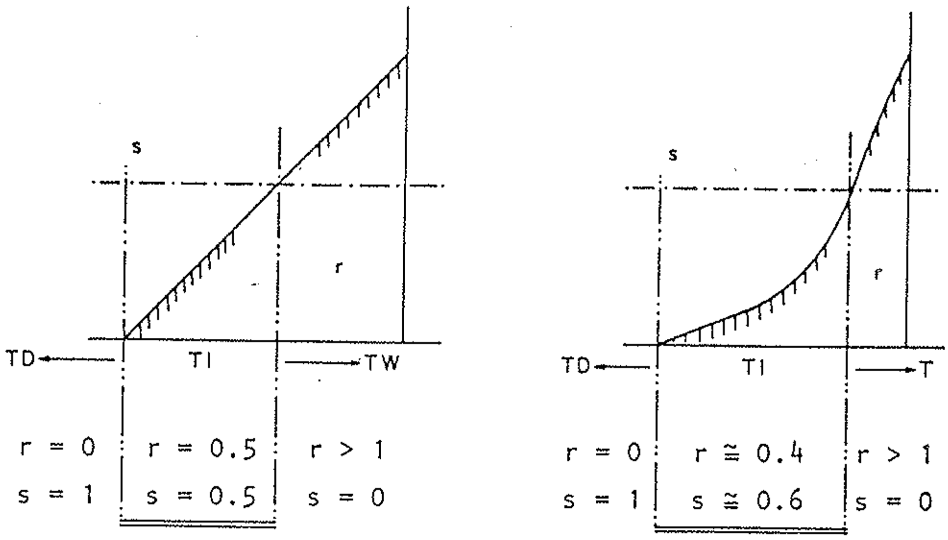


Figure 4. Section of graph showing period of insufficient rainfall

when it falls on hot surfaces, such as roofs. For example, when the s value is theoretically 0.5, use s = 0.55. Thus, TS = TD + s × TI. Because the value of s is difficult to determine for Indonesian conditions, the shortage factor, s, can be put at 0.6.

To obtain the TmS—such as the T10S, which is the storage-supply period, TS, that is exceeded once in ten years, the TD and TI is elaborated on the rainfall data sheet into TS by using the relation of TS = TD + s × TI. For the TS, the highest value for T10S is used if ten years of rainfall data are available. Then, if 20 years of rainfall data are available, we use T10S = 0.9 × the highest value or T10S = 0.0 × T20S.

Now that we know the TmS, we have to find an expression for the necessary volume of storage. To calculate this volume, VSTOR, the discharge, OUT, must be first determined. This discharge can be divided into consumption, leakage and evaporation. Consumption is difficult to determine exactly; and to do so, the following questions must be answered:

1. How (cooking, drinking, bathing, irrigation) will the water be used?
2. What quantities per month per use per family members per animals per hectares will be required?
3. How many family members, animals and hectares will require water?

Based on these consumption factors, the monthly consumption is expressed as MC. The leakage related to the volume of stored water which decreases over time is expressed as

$$OUT_{leakage} = \tfrac{1}{2} \cdot L \cdot VSTOR \cdot TmS.$$

Evaporation is proportional to the open water surface, temperature, wind conditions and time. To simplify this calculation, we used Penman's simple relation of

$$OUT_{evaporation} = A \cdot E \cdot Time.$$

Using Penman's constant, E, in this relation, E may amount to 0.1 m/mo for Indonesian conditions. To obtain the total outflow times the length of the period that the storage has to meet demand in the needed volume, let

$$VSTOR = \frac{(MC \cdot 10^{-3} + A \cdot E) \cdot TmS}{1 - 0.5 \cdot L \cdot TmS}$$

in which MC is expressed in ℓ, A in m^2, E in m/mo and TmS in mo.

Following the step-by-step method, the local technician should be able to easily calculate the VSTOR relation on his sliderule.

DESIGN CONSIDERATIONS. In closing, I would like to suggest the following design considerations:

1. Use as impervious as possible lining, such as plastic sheets or a thin lining of bamboo cement or ferrocement laid on the natural slope of the ground
2. Minimize evaporation by installing a roof or covering the cisterns with soil or concrete; wood should not be used
3. Filter the inflow at the entrace point of storage to eliminate dust and foreign matter
4. Guard against mosquitos or their larvae especially the species that are carriers of diseases.

In addition, users should be taught to boil water used for drinking purposes if the water quality is questionable. I do not pretend to have given a complete listing of all design considerations for rainwater cisterns. The viewpoints presented in this paper are the results of lessons experienced in our West Java Rural Watersupply Project.

REFERENCE

Satijn, H.M.C. 1979. *Hydrological investigation of rainwater collecting systems.* Internal Rep. IWACO, Rotterdam, The Netherlands.

COST ESTIMATE

(For Materials Only - 1982 Prices, Suva, Fiji)

1. Hints on Tank Selection

When the actual required capacity of the tanks is established from the cost comparison tables, select the tank with the lowest total cost figure.

It is always easier however, to construct single unit tanks on account of labour costs. The labour costs of multi-unit tanks are expected to be governed by the number of the units rather than the size of the tank components.

2. Modular Systems of As Standard Panels

2.1. Rectangular Modules

Modular System	Capacity Imp. Gal.	Est. Cost US$	Unit Cost ¢ Imp. Gal
As-1	450	82	18
As-2	900	148	16
As-3/11	1,350	220	16
As-3	1,350	212	16
As-4	1,800	271	15
As-6	2,700	389	14

2.2. Cross Shaped

Modular System	Capacity Imp. gal	Est. Cost US$	Unit Cost ¢ Imp Gal
As-5	2,250	300	13
As-9	4,050	510	12
As-13	5,850	614	10
As-25	11,250	1,057	9

COST ESTIMATE

(For Materials Only - 1982 Prices, Suva, Fiji)

3. Modular System of Al Standard Panels

3.1. Rectangular Modular System

Modular System	Capacity Imp. Gal	Est. Cost US$	Unit Cost ¢Imp. Gal.
Al-1	1,100	140	13
Al-1¼	1,370	202	15
Al-2	2,200	255	12
Al-3	3,300	350	11
Al-4	4,400	470	11
Al-6	6,600	676	10
Al-8	8,800	783	9
Al-9[a]	9,900	941	9.5

3.2. Cross Modular System

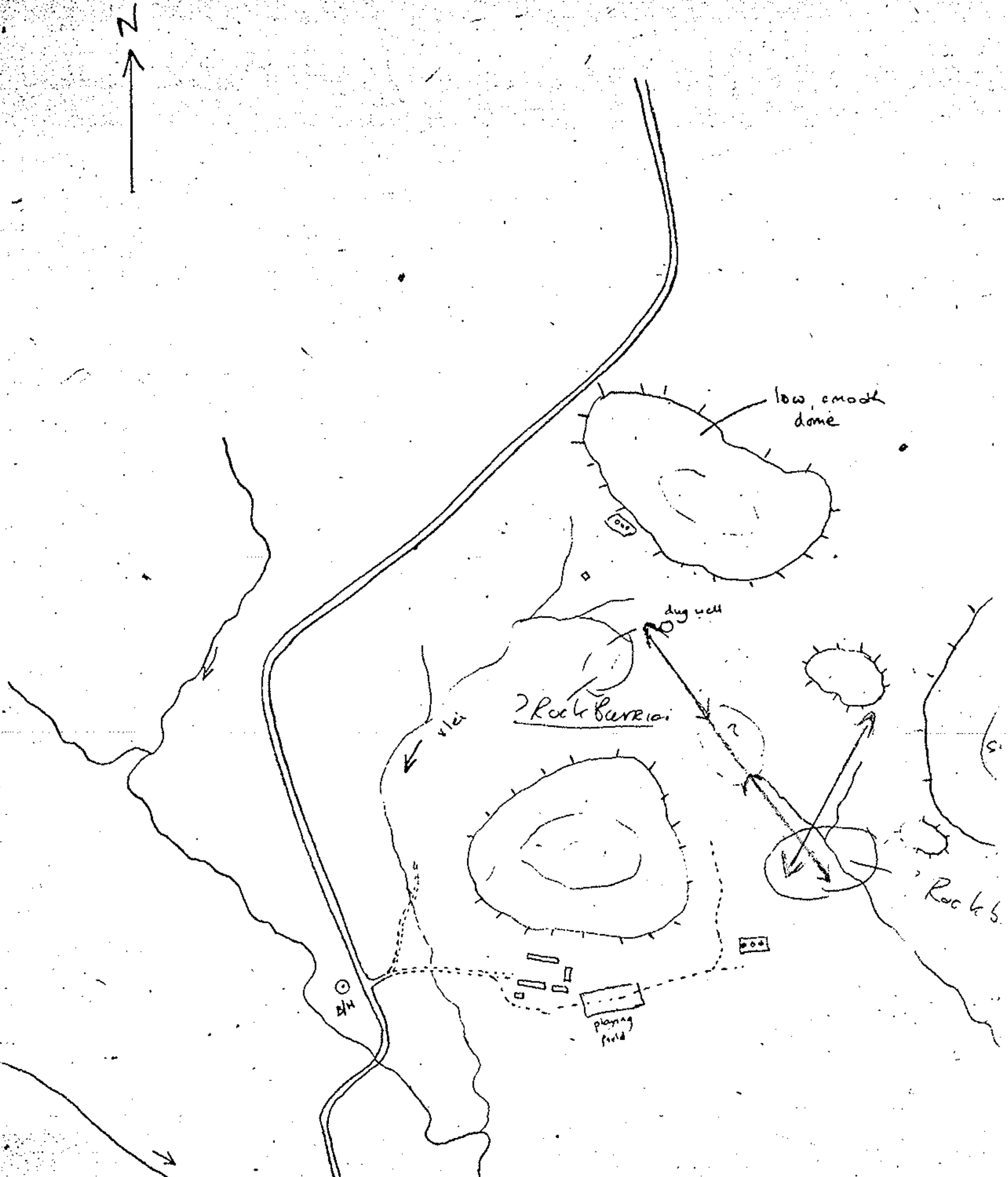
Modular System	Capacity Imp. Gal.	Est. Cost US$	Unit Cost ¢ Imp.Gal
Al-5	5,500	499	9
Al-9[b]	9,900	862	9
Al-13	14,300	1,016	7
Al-25	27,500	1,738	6

3.3. Open Rectangular System

Modular System	Capacity Imp. Gal	Est. Cost US$	Unit Cost ¢ Imp. Gal
Rl-4	4,000	407	10
Rl-6	6,000	463	8
Rl-9	9,000	575	6

FIGURE 3

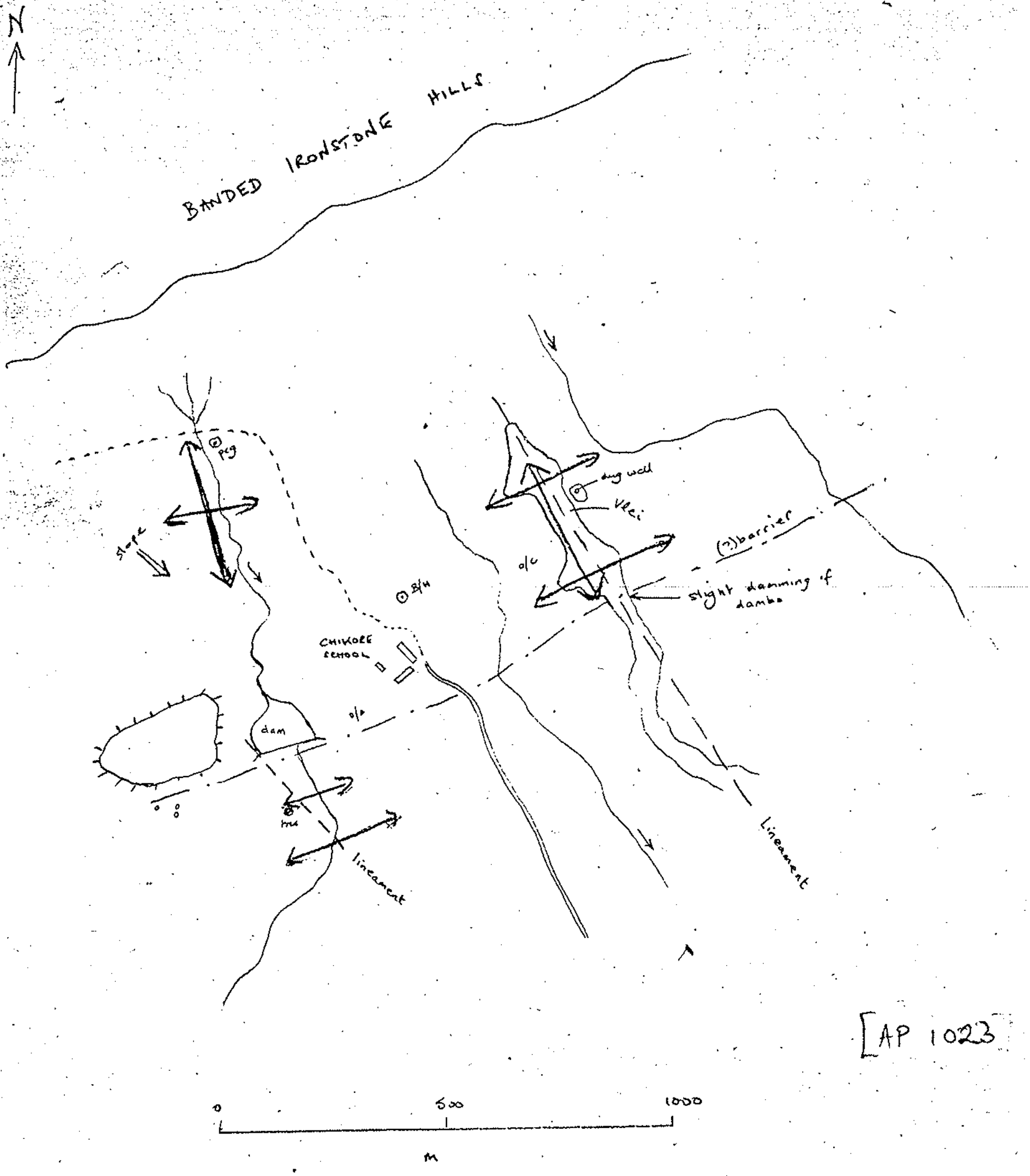
CHIKOFA SCHOOL : AREA C : MAP 2030D1



[AP 1172]

FIGURE 4

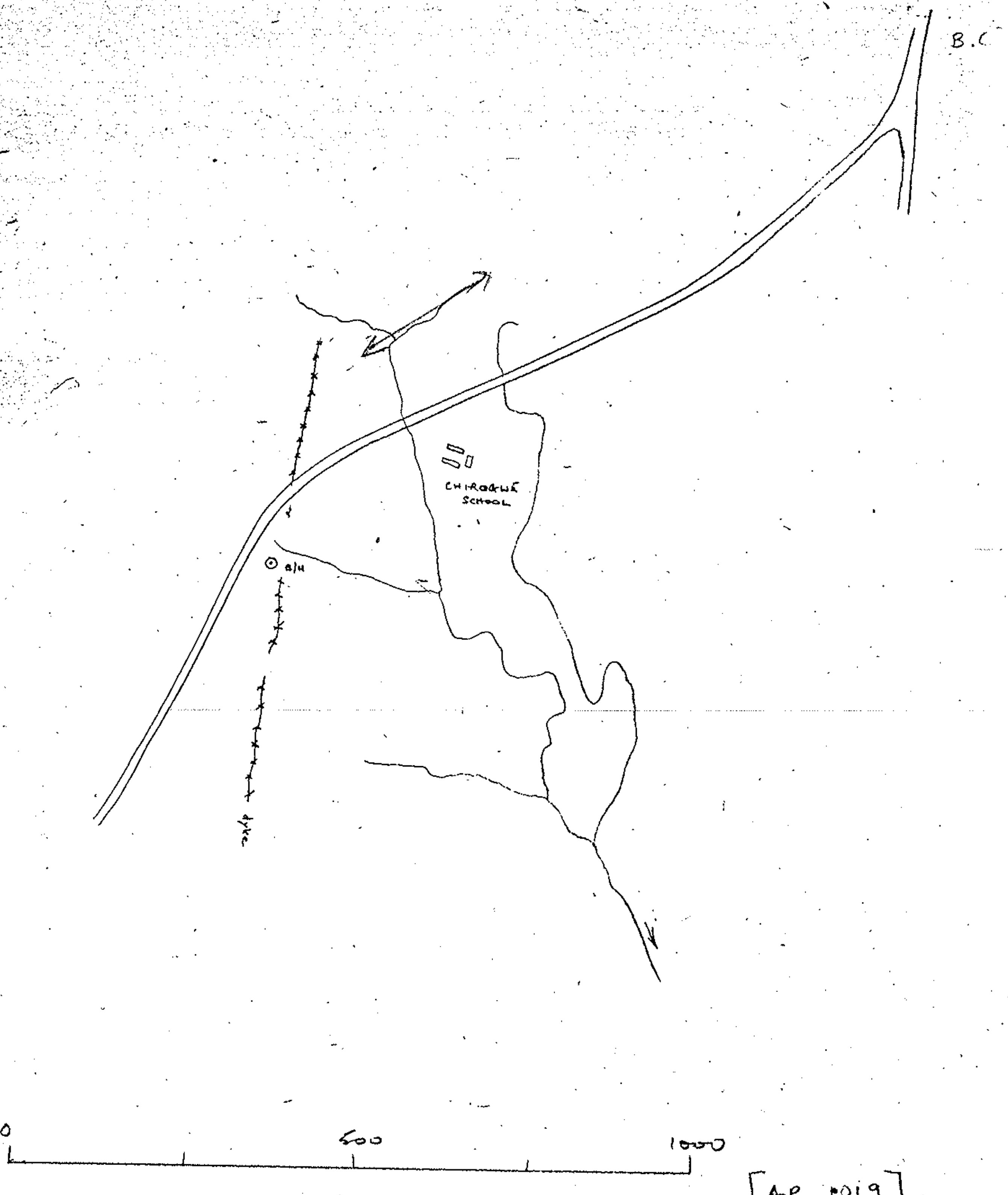
CHIKORE SCHOOL: MAP 2030 D1 AREA C.



[AP 1023

FIGURE 5

CHIROGWE SCHOOL : AREA C : MAP



[AP 1019]

FIGURE 6

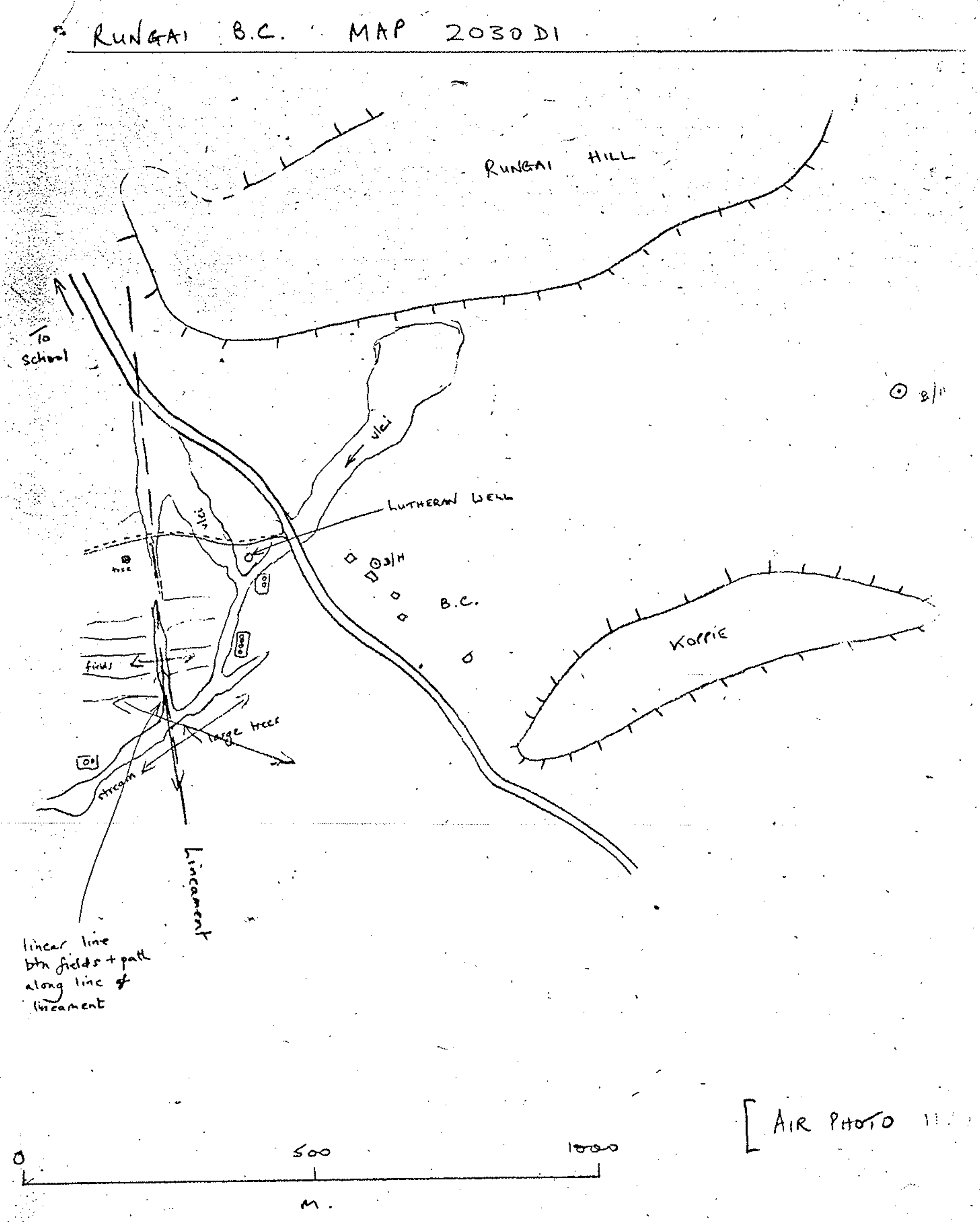
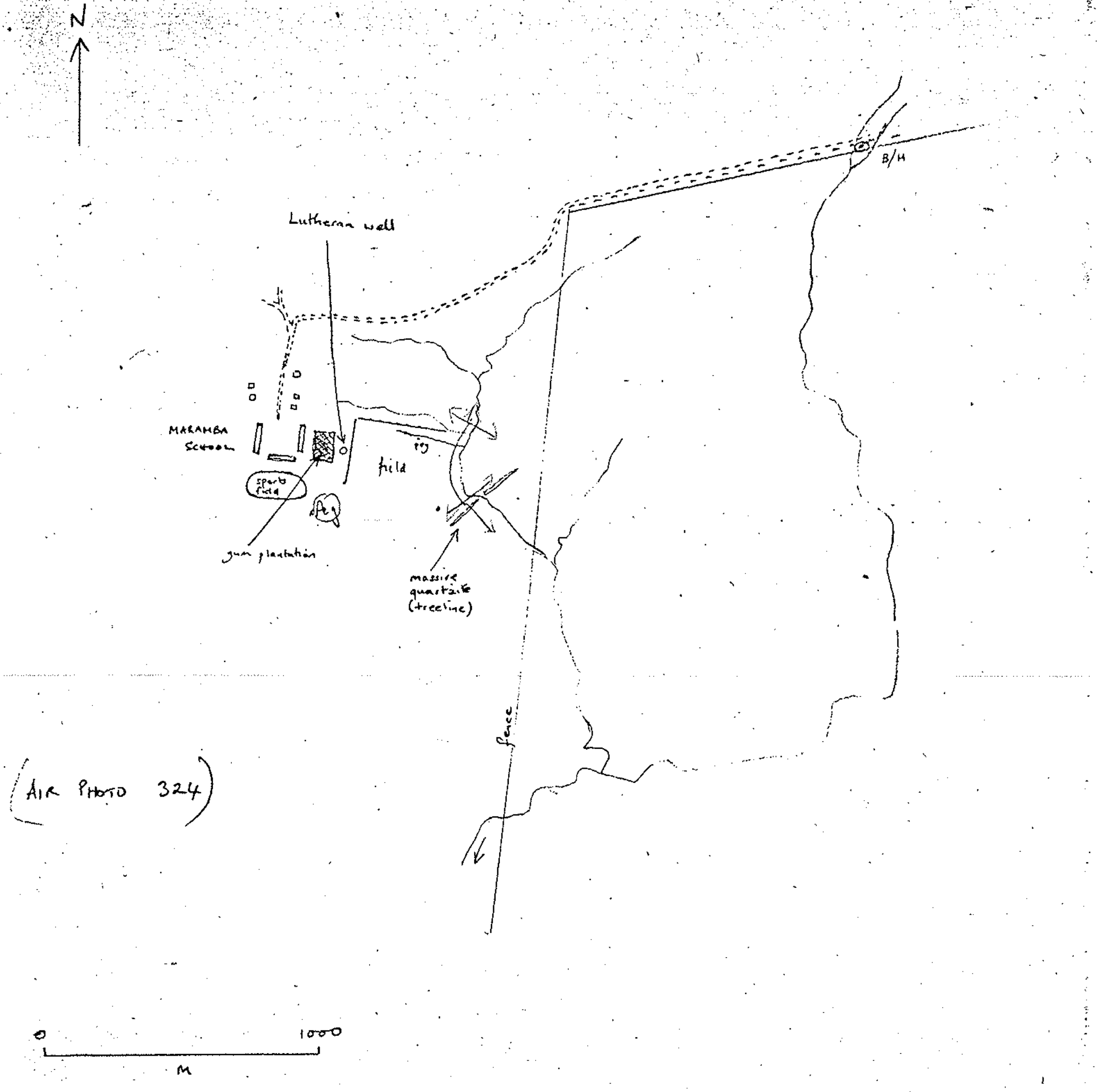

RUNGAI B.C. MAP 2030 D1
RUNGAI HILL
To school
vlei
LUTHERAN WELL
vlei
tree
B/H
B.C.
KOPPIE
B/H
fields
large trees
stream
Lineament
linear line
btn fields + path
along line of
lineament
0
500
1000
M.
[AIR PHOTO

FIGURE 7

MARAMBA SCHOOL (AREA E) : MAP 2030A2 GR. 22270/776820



MADANGOMBE SCHOOL (AREA E) : MAP 2030 A2 GR: 21900/777

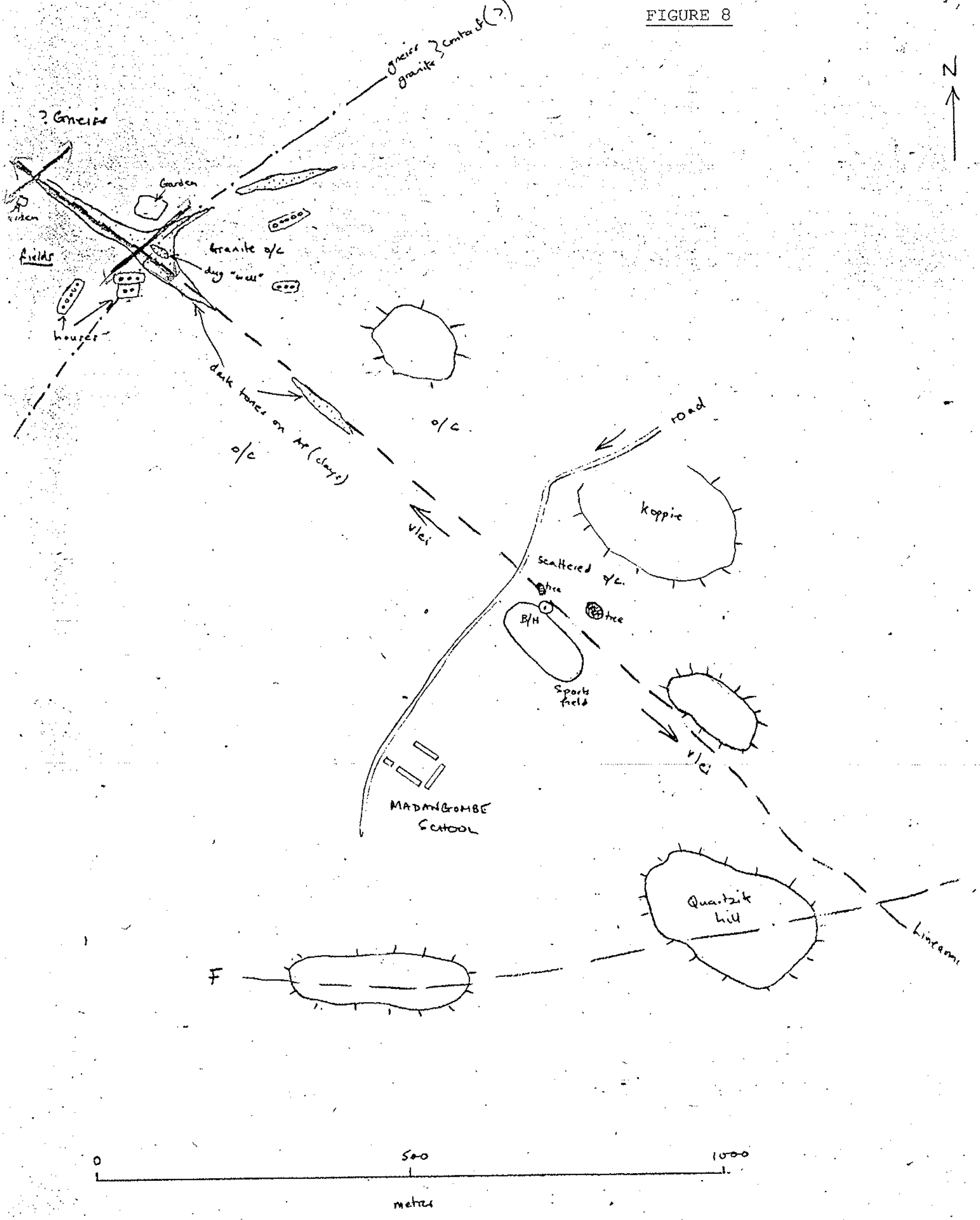
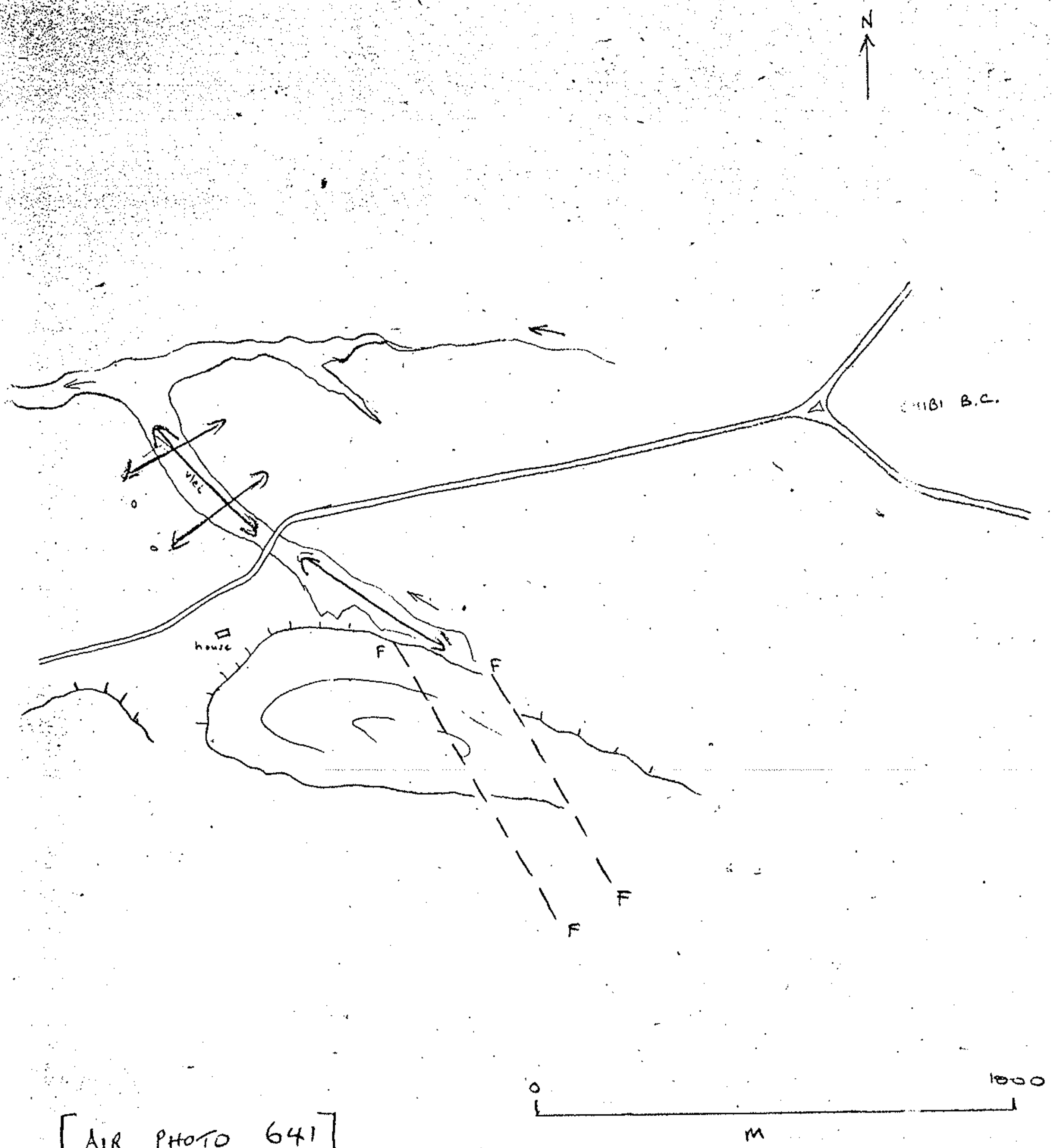


FIGURE 8

[AIR PHOTO 17

FIGURE 9

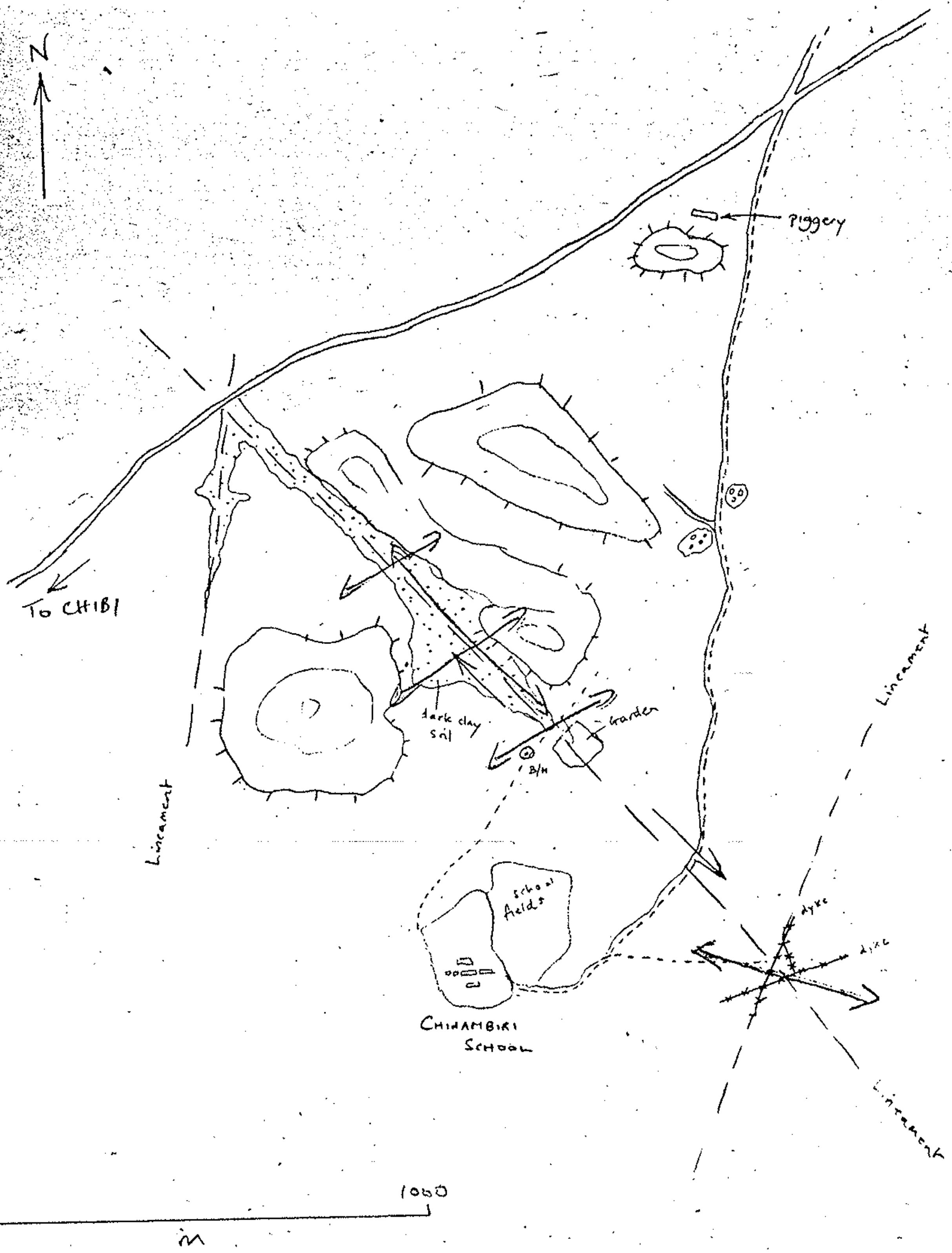
CHIBI B.C. AREA F



[AIR PHOTO 641]

FIGURE 10

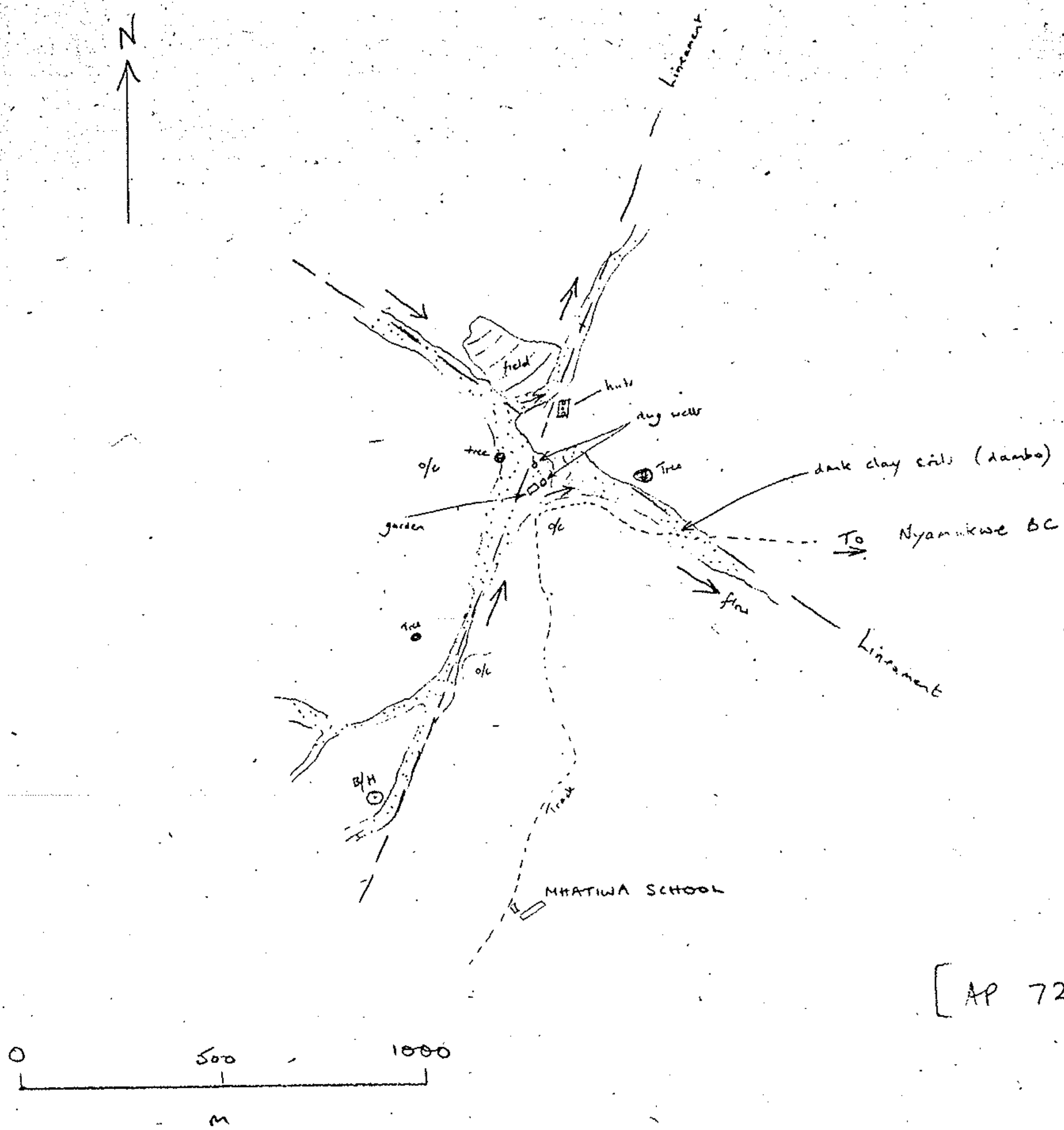
CHINAMBIRI SCHOOL : AREA F



[AP 56:

FIGURE 11

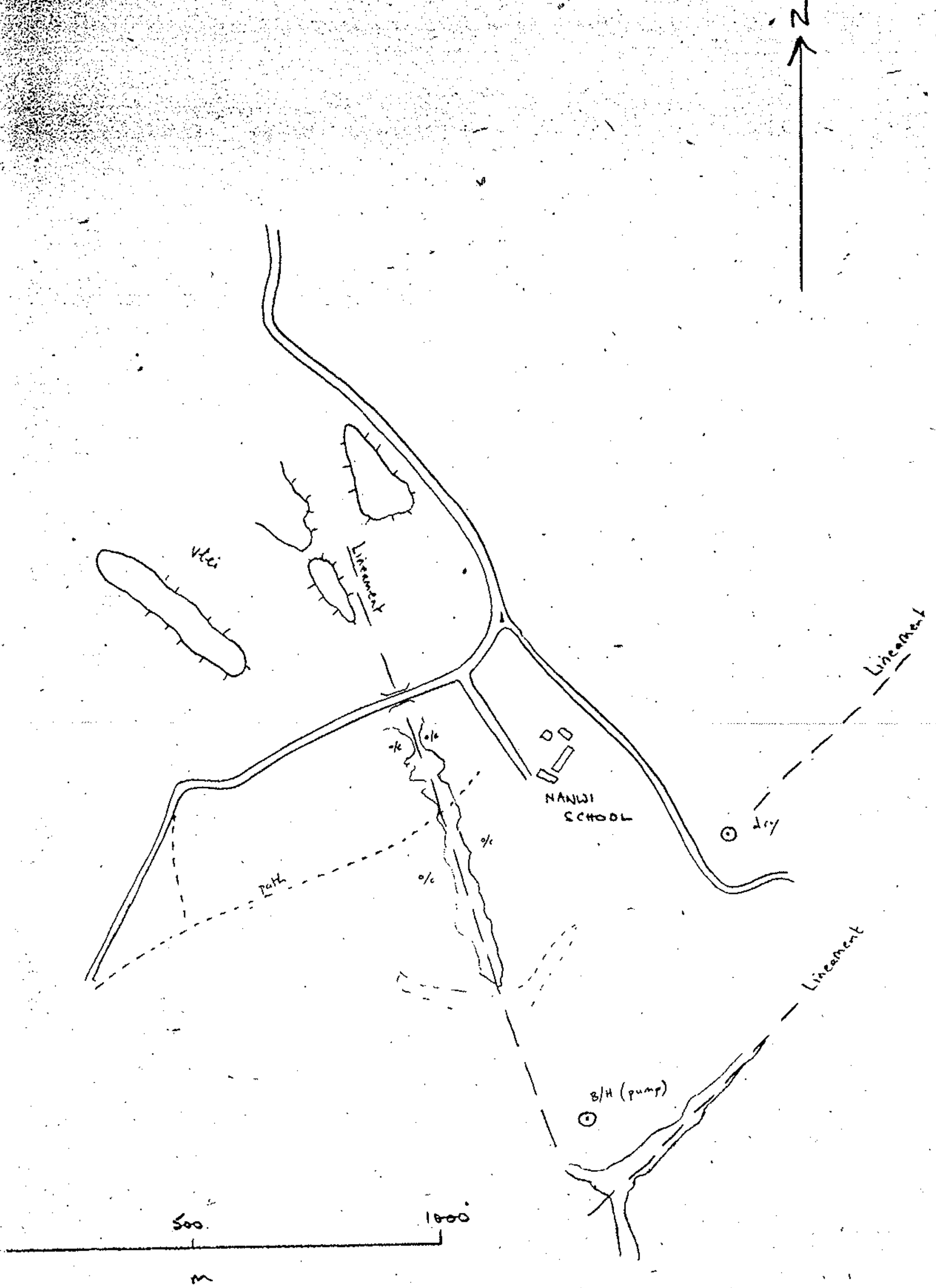
MHATIWA SCHOOL : AREA F : MAP 2030 B3



[AP 720]

FIGURE 12

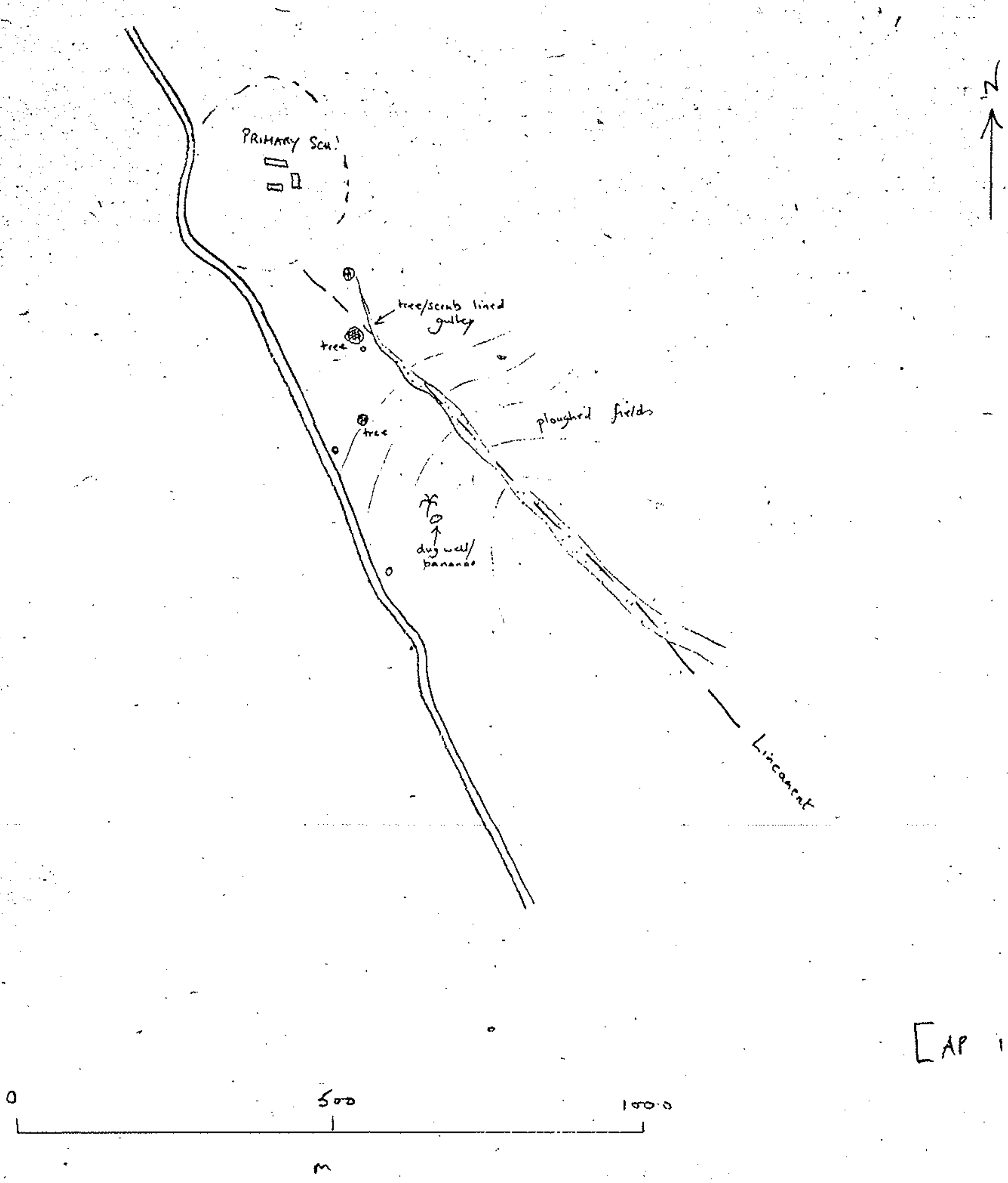
NANWI SCHOOL : AREA G : MAP 1930 D4



[AP 1899]

FIGURE 13

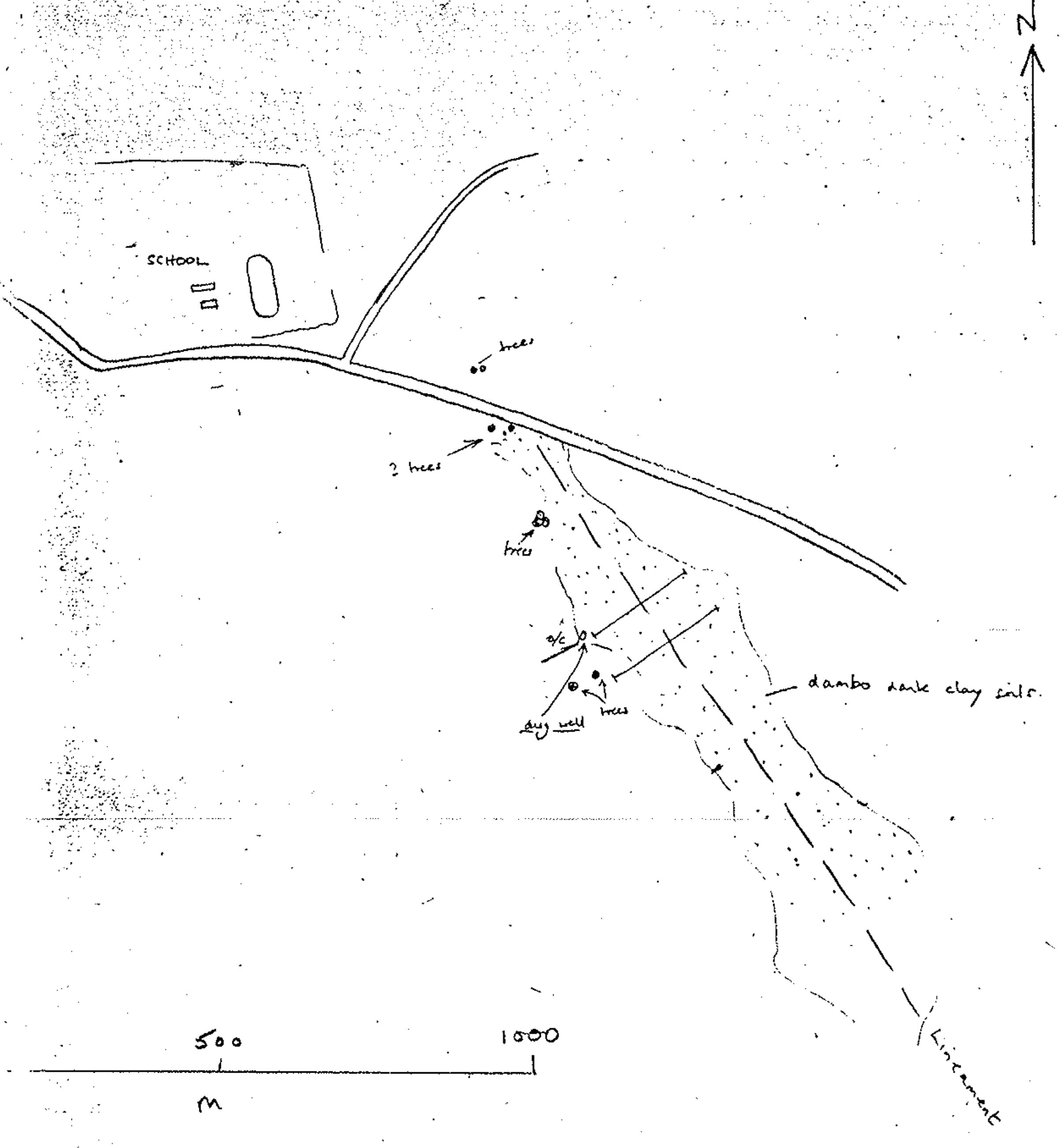
NEMARUNDWE SCHOOLS : AREA G : MAP 1930 D4



[AP 182

FIGURE 14

MATATIRE SCHOOL: AREA G: MAP 1930D4

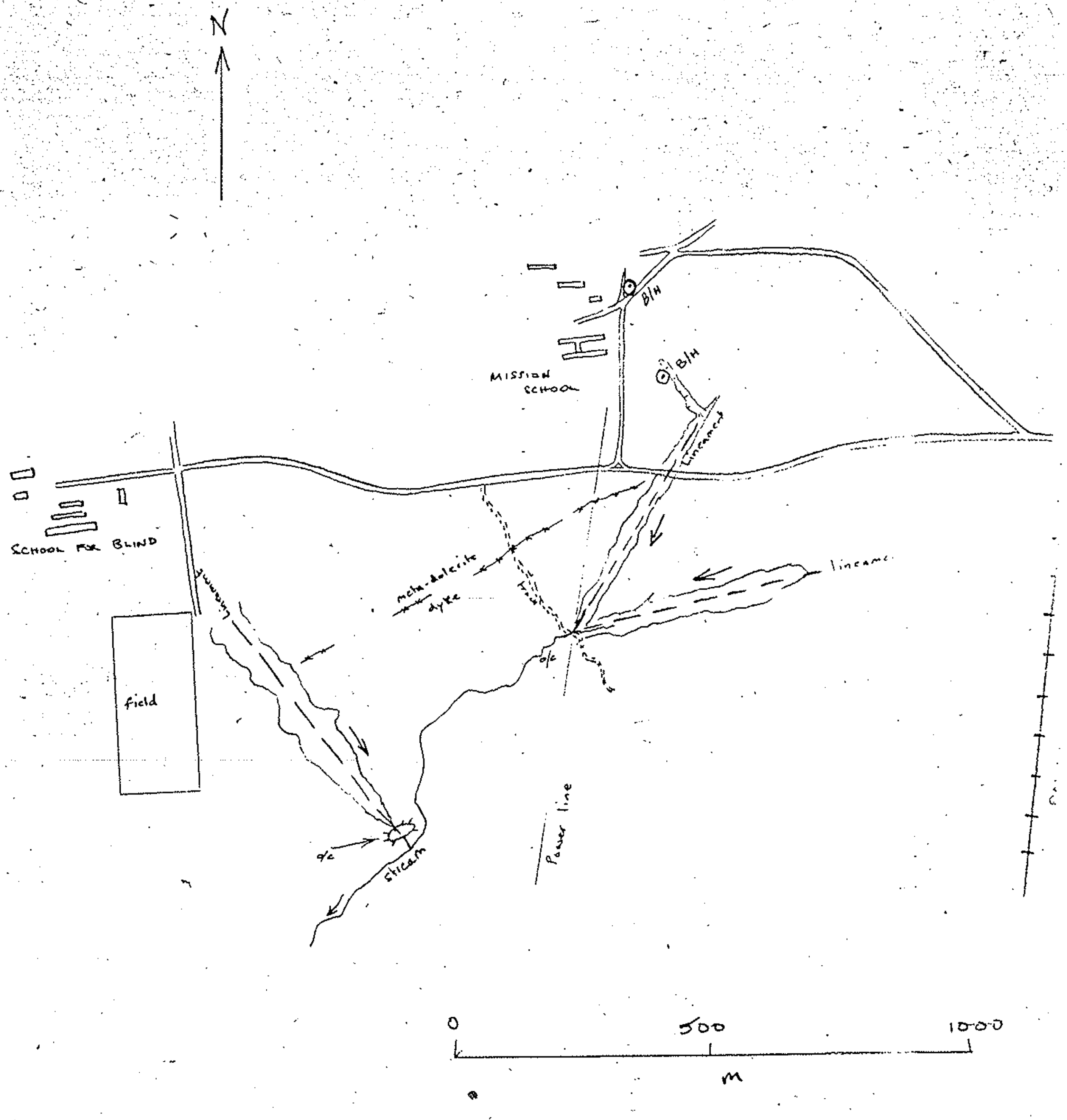


[AP.1823]

FIGURE 15

(15)

ZIMUTO MISSION : AREA G : MAP 1930 D4



[AP 1972